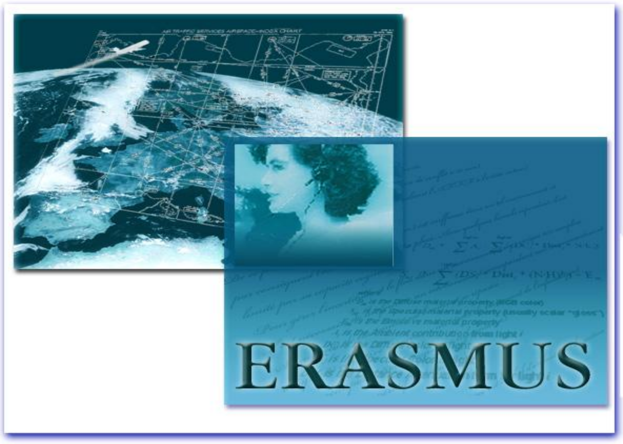
PRIORITY 4 - AERONAUTICS AND SPACE



ERASMUS
FINAL REPORT

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Project full title:	*En Route Air Traffic Soft Management Ultimate System*
Proposal/Contract no.:	*TREN/06/FP6AE/S07.58518/518276*
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Contents

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Executive summary

(1) The SESAR programme has identified new separation modes such as Trajectory Control by Speed Adjustment (TC-SA), which proposes trajectory control and airborne separation systems to minimize potential conflicts and hence reduce controllers' workload.

(2) The ERASMUS strategic de-conflicting service aims at adjusting the 4D Business Trajectory in order to minimise separation management. This service provides conflict free trajectory on a short segment of 15 minutes, reducing controllers' workload associated with routine monitoring and conflict detection. Furthermore, the number of ATC interventions to change flight profiles in order to resolve potential conflicts are reduces.

(3) To adjust the 4D Business Trajectory, the ERASMUS project validated:

- a high-precision Trajectory Prediction (TP) performance assessment, which will deliver more accurate and reliable information,
- Trajectory modification performed through minor speed adjustments, which aim at not being perceived by the controller in order to minimise interference with their actions.

(4) On the basis of fast-time simulations (FTS), it is estimated that with TC-SA the number of potential conflicts to be considered by controllers can be significantly reduced (i.e. up to 80%). With a time horizon of 15 minutes, this corresponds to a small speed change applied to pair of aircraft so as to increase their separation to above the established minimum of separation threshold (e.g. 7 Nm with a reference speed of 560kts). The resulting traffic to be managed by the tactical controller is characterised by fewer conflicts (e.g. 3 conflicts per hour/sector) and a significant decrease in complexity. This offers an important potential in saving controllers' mental resources and in allowing controllers to cope with a +70% traffic increase.

(5) In addition, the autonomous feature of the TC-SA approach was well accepted by controllers and pilots. The TC-SA works before the controller takes traffic into account, through minor speed adjustments that modify the longitudinal aircraft trajectory but are not perceptible by controllers, therefore not disturbing their cognitive activity. On the on-board side, pilots with respect to the concerns of their airlines at stake also accepted the idea because the speed changes:

- the objectives of the experiments,
- are more often than not acceptable,
- do not violate the aircraft speed envelope,
- have minimal impact on fuel consumption,
- do not impact the authority of the pilot.

(6) The effort required from the pilot to process a TC-SA clearance was perceived as relatively easy, demanding only a small additional workload. The time it took pilots to process TC-SA clearances demonstrated that this is not a limiting factor.

(7) The preliminary FHA, which aimed at identifying and evaluating potential hazards and their operational consequences, showed that the ATM system will not be impacted by hazardous situations and that the identified hazards will be easily managed to ensure "acceptably safe" operations. No class 1 and class 2 hazards were identified for any of the ERASMUS services defined.

(8) Moreover, the studies carried out demonstrated that the proposed automation (autonomous and support services) allows to achieve an important decrease of tactical intervention of the tactical controller to solve conflicts, consequently reducing the risk associated with a given procedure in terms of operational errors. In the real-time simulations (RTS), a traffic situation that was considered

highly dense was perceived to be less dense by controllers when ERASMUS was running. ERASMUS enabled the reduction of the peak in the traffic and a more organised flow of traffic, reducing the perceived level of complexity and difficulty for both reference traffic and increased traffic (i.e. +20%). This was achieved through a reduction of the number of potential conflict situations and of their complexity (in terms of geometry and severity), as well as a decrease in the total number of clearances given by the controller, for both lower and higher traffic loads.

(9) Definitely, the assessments carried out showed that not only the severity associated to potential hazards was low, meaning that ERASMUS operations will be acceptably safe, but also that the functionalities and performance of the system are sufficient to reduce the pre-existing risks (i.e. number of conflicts, complexity of traffic, average separation measures between aircraft, number of ATCO tactical intervention, delay between ATCO intervention and conflict time) to an acceptable level.

(10) The ERASMUS project has provided a set of arguments in order to ensure that the concept is environmentally compliant. The impact on the environment, and more specifically the atmospheric issues, such as gaseous emissions, were assessed during fast time simulations (FTS) and through a "case study". Although the FTS results showed that ERASMUS did not have a significant impact on fuel consumption per flight, the results of the experimentation demonstrated that ERASMUS would reduce the number of flight manoeuvres, preserving the executed trajectory as much as possible through minor trajectory modifications and smooth deviations to avoid tactical intervention. Any manoeuvre which had not been planned in the flight plan effectively degrades airline preferences represented by the cost index (time-related cost/cost of fuel), while an appropriate selection of manoeuvres for conflict resolution has a direct impact on flight efficiency and fuel burned. From test results it is evident that different manoeuvres to solve equivalent situations have different effects on fuel consumption. The test case, using an applied methodology to derive the manoeuvre cost in terms of fuel burned has also been used for a comparison analysis of the ERASMUS environment budget. It has determined that ERASMUS can significantly reduce the CO2 emission (i.e. the estimated CO2 reduction that has been calculated from sum of fuel saving per year), and consequently the impact of air traffic on the environment. The difference between fuel consumption due to ERASMUS driven manoeuvres, and standard trajectory changes to avoid potential conflicts, under selected conditions, can be considered as an advantage of the ERASMUS approach to ATM Conflict Detection & Resolution task. Although the effective CO2 savings are strongly dependant on the appropriate manoeuvre selected by the ERASMUS Solver, the direct connection between fuel consumption and CO2 emissions leads to positive and valuable conclusions about the impact of ERASMUS on the environment.

(11) The cost-benefit case study demonstrated the direct potential in terms of financial benefits for medium size airline in terms of millions of Euro per year. The return of investment has been estimated for the short-medium term (i.e. two-four years), in the case of appropriately selected manoeuvres for conflict resolution. Cost & benefit analysis of manoeuvres has demonstrated the need of such a function in the ERASMUS solver or algorithm. ERASMUS will allow potential benefits which will be evident for airlines and for the air navigation service providers (ANSP). The benefits for the ANSPs will be more easily seen taking into account that the controller will be supported by the new ERASMUS services. They will be able to have a clear vision of the management of flights and, at the same time, avoid further workload by the resolution of conflicts. This will allow controllers to manage more flights, avoiding the recruitment of additional staff.

(12) ERASMUS is thus considered to be directly beneficial for the controller's workload and, in terms of flight efficiency, it should be indirectly beneficial for the end users because these savings shall be passed to them reducing the unit rate.

(13) In the following paragraphs a number of recommendations are provided to be considered before the implementation of ERASMUS. They are based on the initial findings mentioned above and on the preliminary cost and benefit assessment.

1. Introduction

(14) The document provides a global overview of the work undertaken and achievements of the En route Air traffic Soft Management Ultimate System (ERASMUS) project ran in the period 2006-2009. In particular it encompasses a discussion of the ERASMUS results, a review of the validation steps undertaken and a set of recommendations for complementary work necessary to further develop the concept.

(15) This document is the final report of the ERASMUS project. It represents the **D4.6** delivery of the WP4 as defined in [2].

1.1. Background

(16) The ERASMUS project was funded partially by the European Commission (EC: 50% DG TREN funding under FP6). The partners of the project are EUROCONTROL (consortium leader), DSNA, HONEYWELL, SICTA, Universities of Zurich and Linkoping. Controllers from Aix en Provence en-route control centre participated in the studies and simulations carried out. ERASMUS is considered an important contribution to the validation and implementation of the SESAR WP4. The project finished at the end of March 2009.

(17) The main aims of the validation process were the following:

- To demonstrate the feasibility and potential benefits of a future air/ground integrated air traffic management system focusing on strategic de-conflicting and separation management functions in the en-route phases of a flight;
- To provide input to the definition of the SESAR concept implementation phase.

(18) The validation plan followed the European Operational Concept Validation Methodology (E-OCVM) methodology and proposed a stepped approach to validate the ERASMUS concept. Two operational scenarios were been explored:

- The **Baseline scenario** corresponding to the 2007 scenario (**reference scenario**);
- The **2020 scenario** corresponding to the IP2 SESAR scenario.

(19) A range of studies were carried, ranging from prototyping exercises, fast-time simulations, a gaming exercise, and real-time simulations. These studies aimed at demonstrating the potential of ERASMUS in terms of key performance areas (KPAs), in terms of the introduction of:

- the 4D Business Trajectory management modification and negotiation;
- multi-sector planning, to optimise on a larger scale the way the traffic is organised (i.e. larger than present day traditional sectors);
- advanced support tools and associated ground human machine interfaces (HMIs) assisting the controller in the organisation and planning of traffic.

(20) The project included eight major studies:

- an ATC prototyping simulation held in November 2006 at the Aix en Provence ACC, which investigated the effect of controllers' speed perception thresholds;
- 2 fast time simulations centred on the efficiency of ERASMUS and on the tuning of relevant parameters for an optimal strategic resolution;

- an ATC investigation simulation held in February and April 2007 at the Aix en Provence ACC and DTI in Toulouse, which investigated the graduation of the capacity thresholds according to the traffic partition;
- a real time ATC simulation held in May 2007 at the Aix en Provence ACC, which investigated the efficiency of the autonomous ERASMUS services;
- a real time ATC simulation held in February and March 2008 at the DTI in Toulouse that investigated the potential benefits in term of controller efficiency and sector capacity;
- a cockpit simulation held in June 2008 at the DTI in Toulouse, which addressed the pilots' working method and the effect of ERASMUS on the on-board component of the ATM system.
- an air-ground integrated gaming exercise held in October 2008 at the DTI in Toulouse which investigated how ERASMUS would work in a SESAR-compliant 2020 scenario.

1.2. Document structure

(21) The document is structured in 6 chapters:

- Chapter 1 introduces the document;
- Chapter 2 presents the validation strategy;
- Chapter 3 describes the validation methodology;
- Chapter 4 describes the research question assessment;
- Chapter 5 discussed the arguments;
- Chapter 6 presents the conclusions.

1.3. Document evolution & approval

(22) The production and review cycle as defined in [19] are applied to produce this ERASMUS final report.

1.4. Reference material

(23) The documents referenced in this document include:

[1] The EC ERASMUS contract TREN/06/FP6AE/S07.58518/518276;

[2] The ERASMUS Description Of Work (Released version – ERASMUS annex 1 – DOW – V2.0 ed 10 03 2008.doc);

[3] ERASMUS Document deliverable D1.2 "Ground-based Trajectory Prediction"

[4] SESAR Definition Phase, Task 2.1.2/D2 (2006), *Inventory of Existing Achievements and Ongoing Initiatives*, DLT-0607-212-ExecSum-00-04, SESAR Consortium, Toulouse.

[5] SESAR Airspace Users (2006), *Airspace User Operations, Vision Statements Document ATM 2020+,* AUO-VSD 1.0 (Mil Part 0.1), Version 1, Draft, SESAR Airspace Users Basic Consortium, Toulouse.

[6] SESAR Definition Phase, Task 2.2.2/D3 (November 2006), *SESAR Concept of Operations*, DLT0612-222-00-08, (Working draft), SESAR Consortium, Toulouse.

[7] SESAR Definition Phase (2006), Task 2.1.2 deliverable for SESAR D2 (17 November 2006), *Strategic Objectives Definition*, DLT-0607-212-01-02, SESAR Consortium, Toulouse.

[8] ERAMUS Web site, www.atm-eramus.com

[9] SESAR DEFINITION PHASE (2006), TASK 2.1.2 DELIVERABLE FOR SESAR D2 (17 NOVEMBER 2006), *STRATEGIC OBJECTIVES DEFINITION*, DLT-0607-212-01-02, SESAR CONSORTIUM, TOULOUSE.

[10] SESAR Definition Phase, Deliverable 3, The ATM Target Concept DLM-0612-001-02-00, V2.0

[11] SESAR Definition Phase, Deliverable 4, *ATM Deployment Sequence*, DLM-0706-001-00-08, (Working draft), SESAR Consortium, Toulouse.

[12] SESAR Master Plan, Deliverable 5, DLM-0710-001-02-00 April 2008

[13] Experiment 1 report DSNA/DTI/R&D, NT07-518 Public document

[14] Granger, Géraud, 2006, *Results of Fast Time Simulations for Erasmus*, SDER/Erasmus Internal note, 29th September.

[15] Experiment 2 report DSNA/DTI/R&D, NT07-150 Restricted document

[16] Experiment 3 report EUROCONTROL/EEC note 04/08 public document

[17] Experiment X report EUROCONTROL/EEC note 05/08 public document

[18] Experiment 4 report www.atm-erasmus.com/pagepublications.html/ HONEYWELL Public document

[19] ERASMUS Project Management Plan.

1.5. Definition, abbreviations and acronyms

4D Business Trajectory	A 4D trajectory which express the business intention of the user with or without constraints. It includes both ground and airborne segments of the aircraft operation and is built from, and updated with, the timeliest data available.
ACAS	Airborne collision avoidance system
ATCO	Air traffic controller officer
ATM	Air Traffic Management
CNS	Communication Navigation Surveillance
CPDLC	Controller-Pilot Data Link Communication
CTO / CTA	Controlled Time of Over-fly. An ATM imposed time constraint over a point.
E-OCVM	European Operational Concept Validation Methodology
ERASMUS	En-Route Air Traffic Soft Management Ultimate System
IP	Implementation Package
KPA	Key Performance Area
LoC	Line of Changes
MSP	Meta Sector Planner
OC	Operation Concept
OI	Operational Improvement
RBT	Reference Business Trajectory. The business trajectory which the airspace user agrees to fly and the ANSP and airports agree to facilitate (subject to separation provision). The times indicated in the RBT can be estimates, target times (TTA) to facilitate planning, or constraints (CTA, CTO) to assist in queue management when appropriate (e.g. with an arrival management tool).
SBT	Shared Business Trajectory. Published business trajectory that is available for collaborative ATM planning purposes. The refinement of the SBT will be an iterative process.
SESAR	Single European Sky ATM Research
SWIM	System Wide Information Management
TC-SA	Trajectory Control by minor Speed Adjustment

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2. THE VALIDATION STRATEGY

2.1. Strategy

(24) A validation strategy exists all along design process from the initial idea formulation until its implementation. Validation is about ensuring transition to the next stage of design. What is at stake is to ensure best fit for purpose, minimum risk and maximum chance of commissioning success. Validation ranges from technical aspect to functional aspect, it can be human factors and operational centred when dealing with service provision and activity of actors.

(25) In response to the European Commission and industry to clarify and improve the validation process, EUROCONTROL developed a method for operational concept validation (E-OCVM) [5]. This method was based on experience from MAEVA [4]. The E-OCVM is the reference used today in R&D to give evidence and information on the targeted and expected performance of new concepts and to help decision makers to identify the most appropriate solution. The underlying hypothesis is that information will be delivered by a design/validation method that is coherent and transparent. With the SESAR programme, this aspect is even more important as stakeholders take decisions for others, highlighting the importance of having a transparent and reliable decision making process.

(26) ERASMUS followed the E-OCVM approach for validation. The concept proposes several changes to the actual picture of ATM: some technological changes, some changes of responsibilities, some changes in traffic delivery, and some changes in working methods. The validation activity should cover all these aspects and relate them to the project goals.

(27) The ERASMUS project was led by the KPA/KPI defined in the SESAR programme. The aim was to make a clear and strong link between these KPA/KPI and ERASMUS project objectives.

(28) The KPA/KPI explored were safety, security, environment, cost-effectiveness, capacity, efficiency, predictability. The project objectives were to assess:

- Technical issues;
- Operational and human Factors issues;
- Efficiency, capacity and predictability issues;
- Cost-benefits issues;
- Safety issues;
- Security issues;
- Environmental issues.

(29) Iterative revisions to the operational concept had to be performed on the following topics:

- Safety assessment and mitigation: a specific assessment of ERASMUS' impact on safety;
- Human factors: once the ERASMUS concept was mature and stable, further analysis and studies were performed to understand how controllers and pilots interact with the concept. This was done by using prototypes, evaluations and simulations.

(30) Procedural aspect: a set of recommendations and instructions was developed for controllers as well as for pilots. These may be associated with automated tools or rely on information sources.

(31) Technical aspect/Operational systems: specific technical devices for ground and onboard support had to be developed and integrated into the project.

(32) The graph below represents this iterative process:

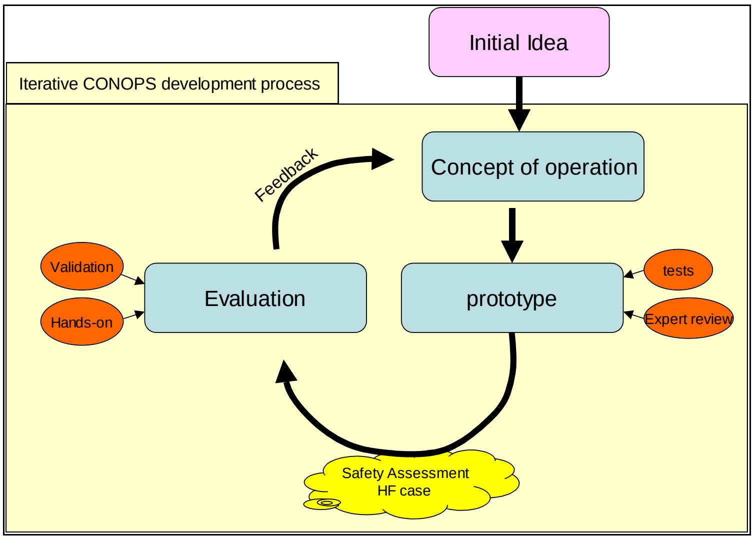

Figure 1: Operational concept iterative improvement process.

2.1. ATM needs being addressed

(33) ERASMUS has decided to focus on the management of traffic complexity, which is one of the ATM complexity components, in the future ATM environment, making the assumption that a part of complexity management should be transferred to automation in order to improve operational performances (capacity and efficiency).

(34) The objective of the ERASMUS project is twofold:

- To find an appropriate level of automation in order to reduce the traffic complexity and increase efficiency;
- To take into account the human and machine limitations, and to exploit their respective capabilities in the best possible way.

(35) The ERASMUS project identifies and deals with two main problems:

- Problem 1: The impact of the overall ATM system complexity on the controller:
- Problem 2: The Human – Machine interaction (ensuring that the impact on pilots is acceptable and that pilot interaction with enabling technology is operationally viable).

(36) These problems are addressed by exploring the following solutions:

- Solution 1: Acting on the traffic complexity delivered to the controller;
- Solution 2: Acting on the level of information exchanged between the human and the machine and on the level of autonomy / dependency of the agents.

(37) In order to develop the different services provided by the ERASMUS concept, the project proposes two applications :

- Strategic de-conflicting;
- Separation management.

(38) The Strategic de-confliction which will provide:

- Higher accuracy for Trajectory Prediction and potential conflict occurrences based on high-precision FMS TP Capabilities;
- Trajectory modification where the 4D Business trajectory is modified by minor speed adjustments (subliminal action).

(39) Concerning the separation management function, the ERASMUS project shall address the operational flexibility of the Strategic De-conflicting and its capability to be adapted to existing separation management process and controller's tools and working methods as well as its compatibility with airborne equipment and procedures. The ERASMUS concept uses TC-SA (Trajectory Control by minor Speed Adjustment) separation mode defined in the SESAR concept and documents. The ERASMUS elements are identified in the transition phase corresponding to the 2020 horizon (Intermediary Period 2).

(40) In consequence, it is proposed to identify the performance improvement of the ERASMUS Server within a 2007 baseline ATM environment and a defined SESAR 2020 ATM environment.

(41) The Strategic de-confliction: the machine will automatically resolve conflicts by minor alterations of the speeds with no controller intervention.

Comment [a1]: SICTA - I suggest to remove « rate of climb », due to the fact that we haven't taken into account this kind of adjustment during ERASMUS project.

Comment [g2R1]: OK

(42) In SESAR, the Strategic de-confliction function aims at adjusting the 4D Business Trajectory in order to optimise the separation management: the objective is to reduce the controller workload associated with routine monitoring and conflict detection and to moderate the interventions of ATC in changing flight profiles to resolve potential conflicts.

(43) To adjust the 4D Business Trajectory, two enablers are required:

- the trajectory prediction,
- the trajectory modification.

(44) In ERASMUS, the trajectory modification conforms to the SESAR definition, with the particularity that the 4D Business trajectory is modified by minor speed adjustments (subliminal action).

(45) A slight variation in an aircraft's speed may be imperceptible for the controller, and that this can be sufficient to prevent a latent conflict (15 minutes in advance a difference of some 2%, less than 10 knots, in the speeds of both aircrafts would change a "conflict" into a "non conflict"). Such accuracies are far out of reach of the controller's perception. Therefore, the machine's reasoning can solve conflicts by minor alterations of the vertical/horizontal speeds or rate of climb/descent for a given aircraft, so that it does not significantly modify the flight plan as they are fuzzily known by the controllers (human-like reasoning). The computer will have a "free zone" of autonomous initiative at the border of the "private zone" of responsibility of the controllers.

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Comment [g4R3]: OK

(46) Such actions can be qualified as subliminal, since they are not directly perceivable by controllers and not conflicting with their own action and responsibility. It can be expected that a very large number of conflicts could therefore be eradicated.

(47) This is the most powerful opportunity offered by the air/ground data-link for transforming the current "open loop" into a "closed loop" ATC.

(48) In summary, since it is not possible to free the controllers from the fuzziness of their perceived environment, the idea is to make profit of this fuzziness to allow the computer to navigate inside it, to resolve the conflict. The prediction is not used to inform the controller about conflicts but is exploited

in an air/ground closed-loop without interferences with the operator activity.

(49) It must be clearly recognised that neither the responsibility nor the freedom of both the controller and the pilot will be limited by the subliminal control. At any time, the controller remains able to issue any classical clearances and the pilot remains able to modify the flight plan after agreement with the controller.

(50) This application should be located at a strategic level in the Multi Sector Planning (MSP) function, which current envisaged role aims at "de-conflicting" the conflicting traffic. This de-conflicting by resolving the conflict is transparent as regards sector entity. The difference between the current MSP function and the subliminal application is the fact that the subliminal mechanism perform minor adjustment in full automated closed loop and not perceivable by the controller of the sector entity. It aims at resolving the barriers encounter in the current MSP approach.

(51) The Separation Management: to address the operational flexibility of the ERASMUS Server and their ability to be adapted to existing separation management process and controller's tools and working methods.

(52) ERASMUS will address two scenarios (defined by SESAR) regards to the separation management function:

- Baseline scenario (current ATC system)
  - Trajectory Prediction (with limited-accuracy)
  - CTA/CTO management (one constraint - FMS)
  - Strip-less environment
  - Safety nets (ACAS, STCA)
- SESAR 2020 scenario aiming to demonstrate the feasibility and efficiency of the ERASMUS in 2020. To define this 2020 scenario we need to take into account the SESAR 2020 ATM Capability Level, e.g. the ATM capability level 3. ATM capability level 3 corresponds to:
  - 4D Trajectory sharing A/G (with high-accuracy, high frequency D/L);
  - D/L capabilities;
  - CTA/CTO management (multiple constraints - FMS) ;
  - Cooperative separation functions (action delegation);
  - Conflict detection and resolutions applications;
  - Conformance monitoring;
  - Safety nets of potential future systems (ACAS, STCA);
  - ATCO side operational requirements and behaviour;
  - Pilot side operational requirements and behaviour.

2.2. Iterative Operational Concept Refinement

2.2.1. Human Factors Perspective

(53) From a human factors perspective, the design and implementation of ERASMUS needs to be addressed from the viewpoint of the change in and implications for the work of the operators (controllers and pilots) that are involved in handling the system operationally.

(54) The air traffic controller's global task is to manage the air traffic in order to avoid collisions between aircraft. With reference to a defined standard, he must ensure the separation between aircraft. To fulfil this task, the controller must:

- Integrate the flights: become aware of any new flight that is going to enter the sector he is controlling, based on the information contained in the radar label and the strip;
- Detect the conflictual situations between aircraft (situations for which the aircraft show separation values lower than the accepted minima at their closest point of approach (CPA);
- Resolve the conflicts detected, giving precise instructions that aim to modify the parameters of one or more flights (altitude, route/heading, rate of climb/descent, or speed);
- Monitor that the solutions put into effect to resolve the conflicts fulfil their objective;
- Establish the necessary coordination, in sufficient time, with the military and the adjacent sectors;
- Manage the radio frequency, giving each aircraft the necessary indications to continue its trajectory.

(55) Although the description of this task is sequential, the activity that underlies it is not. It corresponds more to a permanent cycle (see Figure 2).

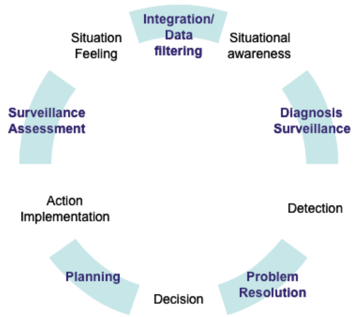

Figure 2 : ATCO resolution cycle

(56) It is commonly agreed that there is a great variability in conflict judgments by Air Traffic Control. [1] This is mainly the effect of the treatment of available data and the status they are given. The information in ATC is dynamic. The information on flight (parameters, data on paper strips) has a degree of uncertainty due to the level of accuracy of the technologies in the system.

(57) This uncertainty leads to a fuzziness reasoning of the controller. Experts take sufficient margins in the integration of data in their task as protection to the worst case scenario of inaccuracy. The fuzziness of data arises with time and accuracy increase with development of the situation. Then the cognitive process used is the "Doubt removal" in the fuzzy reasoning. This process is both deliberate and opportunistic. Monitoring of the relevant parameters in fuzziness and in a by-default reasoning consumes cognitive resources and forms a major part of the controller workload. Information management and data display are then core to the savings of the controllers workload.

(58) There are 3 kinds of data in the ATC environment: those which have to be remembered and updated, those which can be looked for when needed and which were forgotten, and those which can be ignored. Only the first ones are retained in the situation awareness.

- The aspect of timing is also of great importance when dealing with conflict management.
- The monitoring of traffic situation has its own pace which changes in time.

(59) From the controllers' point of view, doubt (Figure 3) concerns various objects: the problem-situation nature (whether there is a conflict or not), the solution to be achieved, the traffic load evolution, data (at the integration moment) and the lapse of memory concerning an action.

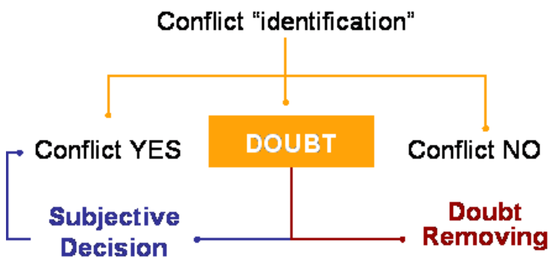

Figure 3 : the concept of doubt in conflict management

(60) In the case of traffic management, reducing uncertainty does not necessarily reduce workload. This is because uncertainty does not decrease uniformly across the separation spectrum. Therefore, it was useful to discuss ERASMUS only in terms of its ability to reduce the level of conflict risk associated with a particular traffic set (i.e., the controller's perceived risk assessment). This is because there looks to be a positive relationship between perceived risk and the workload associated with monitoring and/or intervention tasks.

(61) The Controller is involved in a never ending judgment revision process (see Figure 4) until doubt is removed.

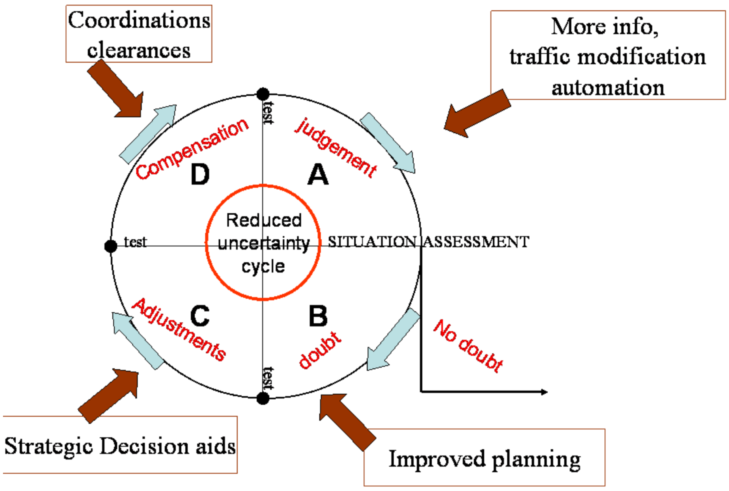

Figure 4 : controller revision process

(62) Time also impacts on action process (see Figure 5), as the available time period for implementing a resolution can show high variations in magnitude.

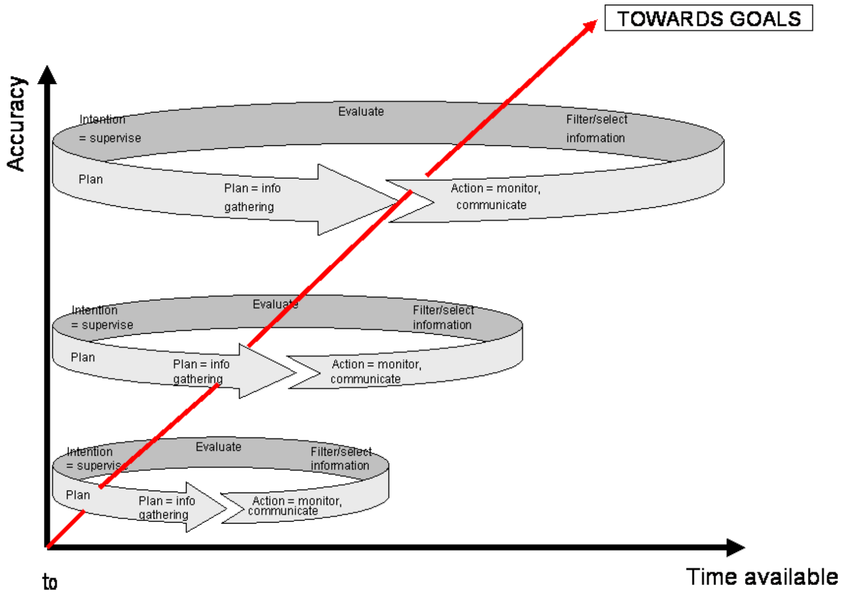

Figure 5 : relation between accuracy time and level of doubt

2.2.2. Impact on the validation of the concept

(63) ERASMUS initially proposed to reduce the number of controller tactical interventions by reducing the absolute number of potential conflicts and by acting on the aspect of doubt. Based on the assumption that the diagnosis of certain conflict is easier than detecting and acting upon uncertain conflict, ERASMUS proposes to decrease the number of doubtful situations in order to reduce the effort needed by controllers. Acting and removing doubtful situations before controllers are required to intervene could save resources and improve overall system performance.

(64) During the first part of the project, a phase of investigation of potential impact of the project has been realized to define a benefit mechanism for ERASMUS.

(65) When ERAMUS is subliminal, controllers can potentially act on an aircraft that is already considered by ERASMUS for a strategic de-confliction. Controllers also may potentially consider a conflict in a resolution process by ERASMUS if they still have doubt on the solution being implemented or if they consider it is a residual conflict. For the integration in an operational environment those aspects are essential and services are to be considered. The ERASMUS OC envisaged the need for information assurance, and for the display of relevant information about it. Those aspects of information management and information provision are the scope of the 2020 scenario and the ERASMUS services and ERASMUS integration with other controllers' tools (2020 scenario).

(66) The initial studies (Expe 2) couldn't demonstrate that doubt situations increase the demands to controllers' attention. However, the concept of doubt is not essential to the demonstration of the potential benefit of ERASMUS. What is important is to demonstrate reduced demands to cognitive resources, whether they come from doubt relief or not. Therefore the choice was made to measure the output of controllers' activities and perception to judge the ERASMUS impact. If we cannot measure the impact on the potential cause (doubt) the project could measure the impact of ERASMUS of the effect on controllers. At that time a major revision of the Validation strategy took place. The aim was to change the strategy to capture effects on external indicators of improvements

in ATC terms: Workload, traffic load, subjective comfort, safety margin, safety feeling…. Potential doubt reduction was measurable in terms of controller mental resources. It first aimed to establish that the demand to mental resources was reduced (Experiment 3). Then this reduced demand could be assessed with regard to the potential impacts on the controller in interactive environments to ensure generalisation of the findings (Experiment X).

(67) For Experiments 3 and X the demonstrations were centred on the assessment of reduced demand to cognitive resources from the ERASMUS action, coming not only from the reduction of doubt but also from the reduction of both conflicts and tactical interventions. They also showed acceptance of the controllers to work in parallel with an automatic system.

2.3. Assumptions

2.3.1. Solutions to the complexity problem

(68) In the ERASMUS project, the complexity is reduced through the reduction of the controller uncertainty using the following strategies:

- Change of the traffic distribution (transfer of aircraft from “conflicting” to “no conflicting” situations).
- Improvement of accuracy and information about the trajectory prediction (high-precision information provided to the controller).
- Improvement of the system automation tools enabling the shift from tactical intervention to strategic de-confliction

2.3.2. Solutions to the Human-Machine interaction problem

(69) ERASMUS investigates three solutions related to the Human – Interaction problem by:

- Acting on the levels of information and autonomy: ERASMUS assesses two combinations of information and autonomy parameters in order to find an optimum balance (in terms of tasks allocation) between the human and the machine.
- Assessing the impact on on-board side: ERASMUS requires specific onboard equipment and specific inputs and procedures for the pilots.
- Defining clear procedure to address the responsibility issue: ERASMUS must clearly define the extent to which the responsibility, and the related procedures, is shared between the actors.

2.4. Technical Requirements

(70) ERASMUS is built on a co-operation between air and ground systems. It takes full advantage of airborne flight management system and air/ground communication facilities.

(71) For the airborne part, the system architecture relies on two main functions:

- A Trajectory Prediction (TP) function that provides an estimated 4D trajectory computation for the next 20 to 30 minutes.
- A Trajectory Contracting function that allows the ATC ground system to set speed or time constraints on the 4D flight profile and a way to check that the proposed modification does not create a new conflict situation.

(72) On the ground side, the system is built on the following functions:

- A flight plan route consistency function that ensures that the airborne 4D trajectory is consistent with the ATC 4D-trajectory computed from flight plan and inter-centre coordination information.
- A Ground Trajectory Prediction function that computes the traffic around 20 to 30 minutes ahead of time. A Conflict Detection function that identifies the flights on which tactical controllers are likely to intervene if no strategic conflict resolution is performed.
- A Conflict Resolution function that implements whenever possible a strategic conflict resolution strategy based on minor speed alterations or RTA constraints in a transparent way for the controllers. The Conflict resolution function is also able to propose alternate resolution strategies based on route changes and/or level changes. These strategies can be assessed by the ATM operator via a set of ERASMUS User's services.
- The User's services may be used by an ATM actor to assess the ERASMUS proposed Route/Level change strategies as well as his self-made strategies.

2.5. ERASMUS concept overview

(73) SESAR Air Traffic Management (ATM) proposes a service-oriented approach based on a performance partnership amongst stakeholders, each single flight shall be performed according to the owner's request. This is the main driving principle for the ATM Target Concept, which is centred on the idea of the "business trajectory", which represents the airspace users' intention with respect to a given flight. Business trajectories are expressed in all 4 Dimensions (position and time) and will be flown with a much higher precision than nowadays, reducing uncertainty and allowing an increased reliance on airborne and ground based automation. This reduction of uncertainty opens innovative ways to address separation modes for increasing capacity. It is worth stressing that TC-SA (Trajectory Control by Speed Adjustment) which has been identified as a SESAR new separation mode it will use trajectory control and airborne separation systems to minimize potential conflicts and hence reduce controllers' interventions and workload.

(74) The ERASMUS Strategic de-confliction function aims at adjusting the 4D Business Trajectory in order to simplify separation management. This function provides a conflict free trajectory for the next 15 minutes of flight, and therefore reduces controllers workload related to routine monitoring and conflict detection together with the number of tactical interventions to resolve conflicts through flight profile modifications. To adjust the 4D Business Trajectory, the following points are investigated:

- A high-precision Trajectory Prediction performed by the airborne FMS;
- A Trajectory Modification function using minor aircraft speed adjustments that are "subliminal" in the sense that they are below the natural perception threshold of the controllers and that, consequently, they do not perturb the controllers. These speed modifications are calculated and executed as part of the 4D trajectory management of the aircraft and "transformed" into a RTA/CTO guidance that is firstly up-linked to the aircraft through air-ground data-link and secondly acknowledged and executed by the pilot.

(75) ERASMUS studies have indicated that the number of unresolved conflicts left to the controllers after minor-speed adjustment has been applied should significantly drop (up to 80%). Let's point out that given a sector the subliminal speed control must be initiated in the upstream sectors (15 min ahead) in order to get large enough separation modifications in the considered sector. As a rough guide, 5% speed change applied to a pair of aircraft during 15 minutes will increase their separation by 7 Nm.

(76) Some conflicts cannot be resolved by ERASMUS through strategic de-confliction. Thus, a number of residual conflicts will have to be solved through an active intervention of either the meta-sector planner (MSP) in the planning phase or the tactical controller (TC) in the tactical phase. In that case, ERASMUS provides support tools to the controllers for conflict detection and resolution.

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3. Validation Methodology

3.1. Methodology: Tools & Methods

(77) The ERASMUS project team recognised that it was not possible to use the same validation methodology approach to conduct a short-term scenario study (baseline environment) and a long-term scenario investigation (2020 SESAR environment). In particular, a distinction has been made regarding the technical system assessment and the human-machine interaction assessment.

(78) Considering the short-term scenario, the traditional methodology is based on an air traffic control real-time simulation environment. It aims at emulating today's environment, processes and functions related to human-machine interactions. In such a well-known environment the conditions to assess the performance of the human interacting with the technical system are met because:

- The technical system can be perfectly described and controlled: the technical behaviour performance is well known (qualification and quantification are possible);
- The human skill and training is very high: the human-technical interaction performance can be assessed (qualification and quantification are possible).

(79) The current air traffic control real-time simulation environment is very well adapted for short-term investigations. However, it is less suited to investigate innovative and long-term research issues because:

- The technical behaviour and performance are uncertain and unknown (quantification is not determined);
- The human skill developed in current conditions is too far away from envisioned future working conditions and skill demands: the human-technical interaction performance cannot be assessed (qualification and quantification not assessed).

(80) Consequently, in order to address the long-term 2020 scenario validation, a different methodology approach was deemed appropriate. This methodology is called Gaming.

- The first issue is to build capabilities to understand the behaviour and the order of magnitude of the technical system: mathematical modelling and fast-time simulation are very well adapted and allow both to qualify and to quantify the system's behaviour.
- The second issue is to build capability to understand and assess the human-machine interaction at a systemic level. It is recognized that it is only possible to qualify the system. It is not possible to quantify the human-machine system because the environment and job skill are too futurist.

Comment [a5]: SICTA - Is the future the right tense?

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(81) Our definition of the Gaming exercise combines aspects from the first and second issues:

- To qualify and to quantify the behaviour and the performance of the technical system using mathematical modelling (algorithms, functions, order of magnitude are identified and validated);
- To qualify the human-machine interaction behaviour and performance using expert judgement. The qualitative assessment will provide evaluation on the human-technical system consistency and robustness (while the qualitative assessment is related to performance).

(82) The peculiarity of gaming is also the fact that it is supported by a high-quality storyboard built allowing the exploration and playing of the system by experts oriented to capture qualitative assessment.

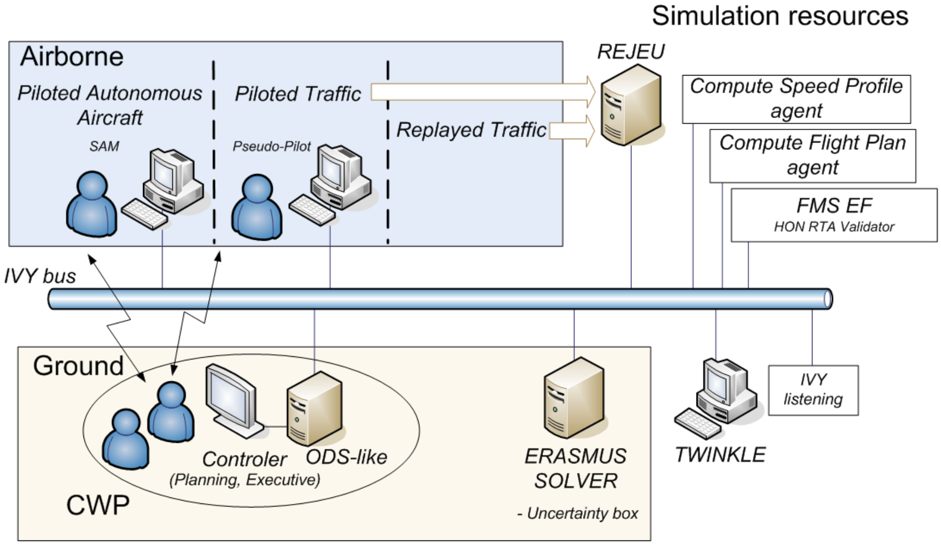
(83) The Gaming can support various objectives:

- Didactic and communication support;

- Discussion and decision-making support from subjective evaluation/judgement with experts in situation to explore benefits of a new system, as well as the possible risks associated with it.

3.2. Technical Air/ground Platform

(84) The prototype covers the ground and airborne domains, link together with a data link media.



3.2.1. Airborne traffic simulator and simulation resources

(85) **REJEU**: In order to have a realistic airborne context, a traffic simulator was used to replay flights from a real traffic situation. Moreover the simulator accepts trajectory modification (from pseudo-pilots commands) for any flight and maintains the new trajectory.

(86) **Compute Speed Profile agent**: This is the Ground Trajectory Prediction module used by the ERASMUS Solver to compute new trajectories constrained by speed adjustments. Updated trajectories are maintained in REJEU. Moreover the same algorithm is used by CATS (in ERASMUS Solver) during the conflict resolution process.

(87) **Compute Flight Plan agent**: This module is used by the FMS EF (see below) to translate ground flight plan (REJEU data structure) to board flight plan (FMS EF data structure) in order to compute a Board Trajectory Prediction.

(88) **FMS EF (HON RTA Validator)**: The Flight Management System Enhanced Functions checks if an RTA request is achievable according to the Board Trajectory Prediction and aircraft performance.

3.2.2. Airborne actors

(89) **Replayed Traffic:** REJEU is configured with a data file containing flight plans and associated trajectories. When running the simulator replays the flights, providing aircraft positions on a simulated

time base.

(90) **Piloted Autonomous Aircraft:** The cockpit simulator (SAM) is used to fly an autonomous flight in the traffic. It sends its position based on the REJEU clock. It has its own Board Trajectory Prediction module and provides updated trajectory on requested from the Solver. In order to have a realistic airborne context, a traffic simulator is used to replay flights from a real traffic situation.

(91) **Piloted Traffic:** The Pseudo-Pilot can manoeuvre any flight, sending guidance orders to REJEU. The simulator will compute a new realistic trajectory (though no performance model is used), update its database and maintain the trajectory along the test.

3.2.3. Ground actors

(92) **ODS-like:** A ground controller position (Planning and executive) is simulated; enabling to visualize the traffic (radar image) and to give clearances to aircrafts.

(93) **ERASMUS Solver:** The ERASMUS Solver is aware of the airborne traffic (board or ground estimated trajectories). It performs periodic potential aircraft conflicts detection and resolution, and sends speed or time constraints to concerned aircraft.

(94) **TWINKLE:** The light weight radar display simulator is used for development and integration purpose, to display the traffic (same as ODS Like) and to highlight (using colours) aircrafts involved by Solver time or speed constraints**.**

(95) **IVY Listening:** This application is used to monitor time or speed constraint messages sent by the solvers to concerned aircrafts.

3.2.4. Data link

(96) **IVY Bus:** A unified media link used to interconnect the airborne and ground simulated domains, as well as the airborne traffic simulator and monitoring applications.

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4. RESEARCH QUESTION ASSESSMENT

4.1. Strategic Deconflicting

(97) The 'TC-SA based Strategic De-conflicting' design and validation represents the major achievement of the ERASMUS project. Feasibility and benefits assessment clearly demonstrated the high added-value of this approach. During the Project Management Committee in Linköping (September 2007), it was decided to focus on the algorithms Solver (TC-SA) and the services provided to the strategic de-confliction activity of the controller. Little effort was then needed to make ERASMUS SESAR-compliant. Therefore, ERASMUS is a strategic and political success.

4.1.1. Operational and Human Factors Issues

4.1.1.1. Controllers Acceptability

(98) The innovative approach to propose an autonomous system (TC-SA) based on longitudinal trajectory variation for conflict resolution is by and large well accepted, in particular the idea of the TC-SA working in anticipation of the controller strategic tasks is well accepted and that a minor speed adjustment can take place in a sector to a potential conflict in another sector.

(99) The timing of ERASMUS process in strategic de-conflicting is also a key to controllers' acceptance, as a 20 minutes implementation still allows a lot of room for recovery or change if anything happens. Experts involved in the discussion have understood the complexity of applying a resolution strategy on a 2020 traffic level without support.

(100) The experiments concluded that speed variation could be applied within a range of 10% without being significantly noticed by the controllers. In addition controllers are not disturbed by such a trajectory longitudinal variation. It confirms that these adjustments will be so small that they will not disturb the cognitive activity of controllers. These actions are assumed not to require the controller's attention because they do not interfere with the controllers' activity, their decisions, or their responsibilities.

(101) In the ERASMUS solver, the magnitude of the speeds adjustments are tightly bounded and designed so as to not attract the attention of the controllers. In this way, ERASMUS will minimize any disruption to the tactical controller. Honeywell defined that the optimum speed variation range was within -6% and +3% and this value was used for the speed adjustments of the solver. This range also fits within the range of speed variation allowed to be applied on pilots' discretion by ICAO without noticing ATC.

4.1.1.2. Pilots Acceptability

(102) Pilots are informed of, and work with, the automatic clearances. The en-route phase of flight does not place a heavy task load upon the pilot as it is relatively free of activity. Therefore it is assumed that additional tasks can be allocated to the pilot with minimal negative impact upon their cognitive activities and task performance. Moreover the reduction in traffic complexity generated by ERASMUS (i.e. fewer conflicts and increased time for decision-making) should also serve to mitigate pilot workload by reducing the number of clearances issued by ATC and deviations from the planned routing.

(103) The pilots, with respects to their airlines concerns at stake also accepted the idea because:

- It demands speed changes (-6% to +3% of current airspeed) which are acceptable most of time;
- It will not violate the aircraft speed envelope;

- It will have minimal impact on arrival times;
- It will have minimal impact on fuel consumption, and
- it will not have an impact on the pilot's authority.

(104) The pilots were rather comfortable with the fact that the clearances address conflicts up to 20 minutes in the future, and (possibly because of this) they did not perceive ERASMUS clearances as time-critical. The pilots also reported that they believed that the computer was rather precise in the conflict detection and resolution even if the conflict is 20 minutes ahead.

(105) The tasks required to process the TC-SA clearance are perceived as rather easy. If the whole process and interface are more simplified and provide pilots immediately with required information, the implementation onboard will probably not increase pilots' workload.

(106) An order coming from a machine is rather acceptable to pilots as long as it behaves in line with the pilots' strategy. Pilots were rather comfortable with the concept of RTAs generated by automation. The most important factors for ERASMUS clearances acceptance/rejection were speed, fuel and time/ETA.

(107) It can be stated that the ERASMUS clearances were acceptable for the pilots from the perspective of the magnitude of speed change. It was not perceived as a problem if the speed change did not exceed 3% of the current speed. However, if the requested speed change exceeded this limit (up to 6% speed decrease), then 41% of these clearances were rejected (i.e. 9 out of 22), a number of them being identified as being out of the flight envelope by some pilots. In general, the pilots were neutral in the area of speed change. Pilots were comfortable with very low speed changes (not exceeding 0,03 Mach or 3% of the current speed), preferring a small speed decrease; i.e. the acceptability increases while the magnitude of speed change decreases.

4.1.1.3. Controllers Modus Operandi

(108) The controllers questioned the need to be able to access the TC-SA logic, e.g. to display or not the information on the controller working position of the aircraft under TC-SA constraints (i.e. which cluster is concerned and for what purpose). Approximately, 50% of controllers' preference is to get the information while 50% of controllers preferred not to have access to this information. Some pros and cons have been raised. In the baseline scenario, experiments demonstrated the risk for tactical intervention to go against the ERAMUS logic. In the gaming exercise controllers fears echoed the possibly excessive reduction of available tactical solutions. The latter is a consequence of the lower number of aircraft trajectories that could be modified i.e. the ones not already involved in an automatic resolution process. This question remains open and requires further investigation.

4.1.1.4. Pilots Modus Operandi

(109) It is demonstrated that programming the FMS to fly the RTA demands only small additional workload on the pilot. The tasks required to process the ERASMUS clearance are perceived as rather easy. Pilots were rather comfortable with the ERASMUS clearances, which resulted in the fact that most of the ERASMUS clearances were accepted (79%). However, differences were identified among the subcategories of comfort; two problematic areas were (a) not being able to negotiate an aspect of the clearance with ATCO and (b) the magnitude of speed change.

(110) The time it takes pilots to respond to CPDLC messages is directly linked to ERASMUS' ability to compute and resolve separation issues. Experiments demonstrated that the pilot response to RTA clearance is not a limiting factor. The mean airborne transaction time was 104s. Three distinct components of the airborne transaction time were identified: (a) notice time (~8s), (b) reading time (~15s) and (c) processing time (~83s). The 95th percentile of the airborne transaction time was 158s. The average processing time (i.e. the time the pilots required to make a decision about the

ERASMUS clearance) was ~83s. The ability of the flight crews to respond to and implement these clearances in a timely manner is compliant with the requirements.

4.1.2. Technical Issues

4.1.2.1. Air System Performance

(111) FMS TP performance was assessed in terms of the accuracy boundaries (D1.1). Essentially the same goal is addressed by the area navigation concepts introduced and mandated in recent years, and more advanced navigation concepts to be mandated in the future. They provide both the ground and airborne crews with a precise specification (95% of total flight time) of the boundaries which an aircraft must respect while using these navigation procedures.

(112) HONEYWELL used their in-house Aircraft Simulator (A380/A340) to study the impact of quality of TP input information, in particular wind forecast accuracy, to the precision of a FMS-generated trajectory for look-ahead time of 15 minutes (longer timeframe was also analysed).

(113) The cross-track errors reach very small values (i.e. less than 0.05NM) in all phases of flight. This proves that the guidance system is very effective in controlling lateral deviations.

(114) The along-track motion is less accurate. The ETA error was discussed in detail within the sensitivity analysis, and it shows that under modelled conditions (constant wind) the mean error is up to 5 seconds (for 15 minutes look-ahead time). A typical trend observed for varying quality of wind forecast information is demonstrated in Figure 7.

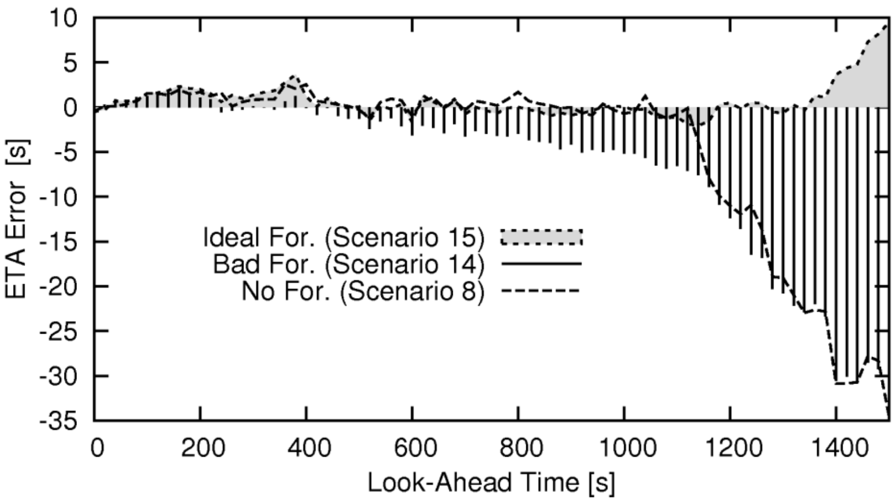


Fig. 7: Typical trend for varying quality of wind forecast information

(115) Temporal or along-track error on 15 minutes horizon is heavily affected by an error in value of wind magnitude & bearing forecast. There are couple of ways how to avoid significant increase of Airborne TP estimated error:

- Upgrade of meteo forecast service which provides more accurate wind information. For example, initial RUC forecast error is about 10 knots. This accuracy provides up to 20 seconds error for 95% of aircraft on 15 minutes horizon. It can be expected nearly proportional decrease of time error with increased initial forecast wind accuracy, so 5 knots accuracy would provide up to 10 seconds error. The methods to increase wind forecast service accuracy are described in details in D1.2.2 chapter 2.

- Upgrade of TP algorithm. Weather study in D1.2.2 chapter 3 describes in detail an evolution of wind under different conditions (e.g. pressure altitude, direction of flight). This information can be effectively utilized for design of upgraded weather forecast algorithm with significant increase of accuracy. Upgraded TP algorithm is able to produce two times better accuracy in 15 minutes horizon, so half error can be expected.

(116) The errors in altitude can reach very high values (i.e. thousands of feet) for CLIMB phase of flight where the aircraft is controlled according to aircraft performance objectives. The major sources of error are effectively two:

- A Flight Path as input for trajectory downlink is not constructed as precisely as DESCENT profile.
- A geometric vertical profile is not fully controlled.

(117) The geometric vertical profile of DESCENT phase of flight is very precisely calculated and it is actively controlled by guidance system. This functionality is reflected on a small vertical error (typically tens of feet). Very small error can be observed also in CRUISE phase of flight, where the wind conditions potentially affecting altitude error are usually very small (vertical component of wind is very small and negligible with respect to horizontal wind components [D1.1]) and altitude is actively controlled.

(118) The controlled accuracy of RTA algorithm is about 20 seconds. Open-loop mean accuracy can be considered in similar values as for ETA mean values. The RTA algorithm fully works only for CRUISE phase of flight in present day. There also exist on-going development activities to fully enable RTA functionality for CLIMB and DESCENT phase of flight.

(119) It is obvious that modern aircraft is able to flight very precisely in every aspect (i.e. temporal/along-track, cross-track, vertical) if it is controlled by appropriate control mechanism. The estimated accuracy of non-controlled errors usually decreases with the distance and it is largely affected by quality of wind forecast.

(120) It is envisioned that the weather analysis together with reliability concept enables the advanced assessment of trajectory prediction (Airborne and Ground-based) for Ground based ATM system such ERASMUS Server will be.

(121) Several candidate Air-Ground Data Exchange technologies (Figure 8) were explored and assessed in detail in D1.2.1.

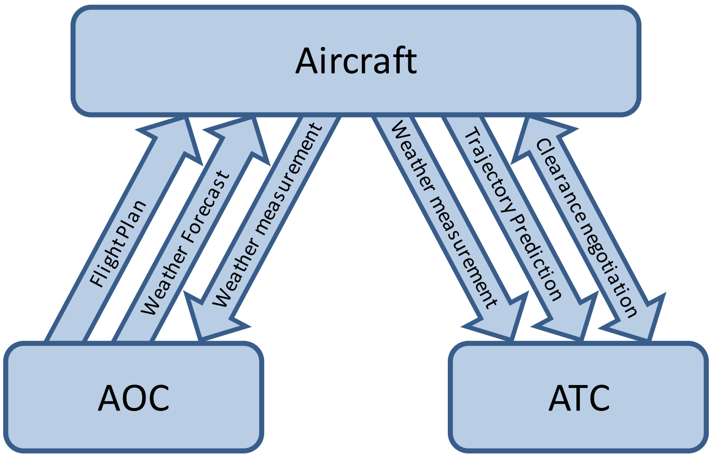


Fig. 8: Air-Ground Data Exchange to support ERASMUS

(122) There are three candidate technologies for weather measurement downlink:

- Today, **AMDAR** (Aircraft Meteorological Data Relay) is used to collect automated, local meteorological reports from commercial aircraft. Through cooperative participation by many global airlines, approximately 4000 aircraft provide worldwide coverage throughout each day. Periodic downlink reports are transmitted from the aircraft to ground systems via the ACARS data-link. The ground systems process and use the weather data to support weather predictions, such as RUC Weather Forecast Service.
- Essential meteorological information is supported by current development and deployment activities for **ADS-C** (Automatic Dependent Surveillance – Contract) data link service, which includes Meteorological Group. Use of ADS-C for weather downlink has several advantages. The ADS-C service is a part of the FANS package. It supports periodic/event contract available by request; and ADS-C technology is considered as important target technology for SESAR.
- Finally, **AUTOMET** (Digital Meteorological Monitoring System and Reporting) as described by standard (RTCA DO-252) for downlink of very detailed meteorological information. AUTOMET downlinks (i.e., aircraft-to-ground message) occur on a time-controlled, altitude controlled, or distance-controlled basis. AUTOMET operational requirements are not explicitly specified and the service is not defined as technology specific (e.g. the implementation can be as broadcast or point-to-point service over ACARS or ATN). The AUTOMET service is not directly implemented by any avionics so far, but it is partially supported by several existing systems (e.g. MDCRS).

(123) There are two candidate technologies for trajectory prediction downlink:

- **ADS-B** (Automatic Dependent Surveillance – Broadcast) technology describes a geometric path in the most complete way. In addition, the expected widespread usage of ADS-B technology has an additional anticipated benefit: There is expected that ADS-B frames will not be only broadcasted out form aircraft (ADS-B Out) but also received by aircraft (ADS-B In) for Situational Awareness purposes and Airborne Separation Assistance purposes. Despite ADS-B deployment cross-world activities, the equipment supports mostly only basic ADS-B functionality (i.e. State Vector Report) without Trajectory Change Report. Research upon another ADS-B reports support is already placed in SESAR.
- **ADS-C** standards include 4-D information in following waypoints only without any further description of transition between waypoints. The complex reconstruction of 4-D trajectory is not possible as in case of ADS-B Trajectory Change Report. There are several further limitations (e.g. Number of Waypoints in Predicted Route Group) of the technology described in detail in

D1.2.1. However ADS-C functionality is included in the most FANS enabled aircraft and on-going initiatives under SESAR consider ADS-C extension as main technology for 4D trajectory down link.

(124) There are two candidate technologies for weather measurement uplink:

- **Airline Operational Communication** (AOC) data link is used for flight plans, weather data, takeoff speeds, pre-flight initializations, etc., from the airline operations facility directly into the particular aircraft's FMS. This interface should allow uplink and crew controlled insertion of parameters that are enterable through the MCDU. The service provides weather forecast data in ready-to-use form for FMS Trajectory Prediction algorithms.
- There can be considered also various data-link **FIS** (Flight Information Service) broadcast services for meteorological forecast. In comparison with AOC data link format the information in FIS formats is often not suitable for direct insertion into FMS.

(125) There is a clear choice for Clearance Up-link and Clearance negotiation data link: the **CPDLC** (Controller-Pilot Data-Link Communication) application includes a set of messages which corresponds to existing phraseology used in current Controller-Pilot negotiation by voice. The combination of two standard CPDLC messages is utilized:

- Use clearances related to crossing constraints. Such clearances will be required if the implementation strategy will consider issuing RTA constraints on existing along track waypoints to solve conflicts (Group of Crossing Clearances),
- Use clearances related to route modifications. Such clearances are required if the implementation strategy relies on the use of RTA constraints on new along track waypoints to solve conflicts (Group of Route Clearances).

(126) As the most important avionics essentially affecting aircraft performance are these two equipments:

- **Flight Management System** (FMS) has the most significant impact on ERASMUS functionality. FMS guides the Aircraft along the predefined Flight Plan by orders to Auto-Pilot. ERASMUS enabled FMS should be able to provide these functionalities:
  - calculation of speed orders to meet RTA (Required Time of Arrival),
  - provision of TP as aircraft Intent,
  - Integrated support of AOC format for Flight Plan and weather forecast upload,
  - suitable repository for Temporary Flight Plan which includes modification of Active Flight Plan by RTA,
  - loading Datalink Request to Temporary Flight plan.
- **Datalink Unit** is the term used for various data link equipment providing downlink of TP and uplink of data link Instructions/Clearances. In most cases it can be considered as Communication Management Unit (CMU) or Air Traffic Service Unit (ATSU) or ADS-B equipment (e.g. 1090 MHz Extended Squitter). These units can be combined to provide at least essential information flow between Air and Ground but in a different manner and with different quality.

4.1.2.2. Ground System Performance

(127) The longitudinal variation (-6%, +3%) seems to be adequate according the flight envelop and the controller perception, while ensuring enough resolution for the capacity target. This range of variation is also consistent with ICAO and the official range of 10% of speed variation allowed without advising ATC.

(128) The temporal/along-track deviation is about ± 1 min and should remain inside the Reference Business Trajectory tolerance to-be-defined. The Real-time Business Trajectory adjustment policy, processing and performance shall be transparent to the following participants in the strategic de-confliction process.

(129) The fast time simulations done with increased traffic level demonstrated algorithm robustness and resistance to parameter variations (TP accuracy level, number of equipped aircraft …).

(130) The ratio of solved conflict depends mainly on the rate of equipment of the fleet. If 50% of the fleet is equipped then 40% of conflicts are solved. In 2008, only 14% of aircraft were equipped with FMS basic RTA capability.

(131) Through FTS run on 2020 traffic with solver separation threshold[1] of 8NM, we have obtained the following results

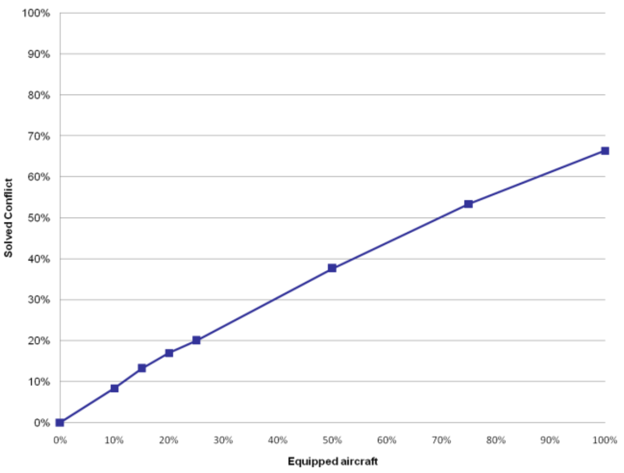


Figure 6: Solver performance function of the share of equipped aircraft

(132) Based on the TP accuracy values delivered by the previous study, the performance of the ground system is represented below by the percentage of solved conflicts as a function of the TP error for one aircraft. We have assumed that 100% aircraft are equipped with FMS capability and set the minimal aircraft separation to 5NM).

TP error x 2 aircraft	Percentage of solved conflicts
1NM	90,22%
2NM	88,44%
3NM	87,84%
6NM	81,59%

Figure 7: percentage of conflicts solved function of TP precision

(133) The performance of the ground system depends also of the cyclical update of the conflict detection & resolution algorithms computation (i.e. exe1 and exe2 comparison). Overall the FTS demonstrated that ERASMUS has the potential to meet the target of 80% of conflicts solved in case 100% aircraft are equipped with FMS capability. The value of the cyclical update depends on different constraints. When ERASMUS issues a clearance, the RTA is valid only during a specific time interval. Within this time interval, the pilot must accept the RTA and enter it into the FMS. Thus, the overall

[1] Solver separation threshold = Minimal aircraft separation + (TP Error x 2 aircraft)

ERASMUS/pilot interaction time must be assessed. As described above the mean airborne transaction time is approximately 104s. In consequence it was proposed to set up the cyclical update to 3 minutes.

Exercise name	Exe1	Exe2
TP error	5s	5s
CTO error	5s	5s
Global error[2]	2,7 Nm	2,7 Nm
Algorithm update cycle	3 minutes	5 minutes
Speed variation	[-6%, +3%]	[-6%, +3%]
Nb of conflicts	4031	4031
Nb of residual conflicts	570	882
Percentage of solved conflicts	85,7%	78,1%

Figure 8: FTS 1 main results

(134) The average number of residual conflict/hour/sector has been calculated (see Figure 9). Maximum averages of 3 residual conflicts/hour/sector, or a maximum average of 1 residual conflict each 20 minutes, were observed to be managed by the tactical controller.

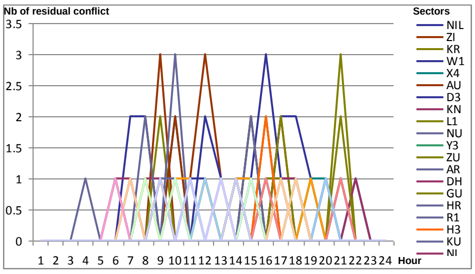


Figure 9: Average number of residual conflict/sector/hour (All ACC, France)

4.2. Residual Conflict Management

(135) In the chapter above, it was assumed that the strategic de-conflicting should be able to decrease drastically the number of conflicts. A number of residual conflicts will remain to be managed by the tactical controller. With regard to this key assumption, it was assumed that the reduction of potential conflicts will reduce controllers' interventions and workload. In consequence, it will save mental resources and will enable tactical controllers to handle more aircraft and therefore to support more capacity.

[2] The global error is calculated from the following formula: FMS 5s error + CTO 5s error * 2 aircraft = 20s error with 2 flight s at 480kts head to head (worst case), error will be 480/3600*20=2,7Nm

(136) In order to inform the controllers of the ongoing residual conflicts, an MTCD aid tool for the 2020 time horizon is proposed. This simply consists in displaying the list of conflicts on the controller working position.

(137) The other questions were also to investigate conflict resolution and a new role dedicated for the planning controller in a more strategic role (Meta-Sector Planner) in the 2020 scenario.

(138) These extra-services offered to manage residual conflicts in the 2020 scenario have not been yet clearly proven in term of feasibility and benefits assessment. Some trends have been demonstrated, but many pending questions remain.

4.2.1. Baseline Scenario

(139) For the Baseline scenario, it was explored how the tactical controller should identify and manage the residual conflicts without additional MTCD aid tools (i.e. list of conflicts). In this context, it was decided to make use of existing capabilities and ATM infrastructure. It was considered that doing so will minimize the technical, operational, financial and institutional impacts and pave the way to meet its ultimate goal (SESAR IP2).

(140) Experiments have shown that there is a threshold of 15 Nm beyond which the controller perceives that the risk of loss of separation (i.e. potential conflict) does not exist anymore. In actual fact, depending on geometrical features of the traffic, this perceived risk is triggered by an interval (roughly between 15 and 20 Nm) more than a single all-purpose value. Anyway, it is interesting to note that this value is far from the 5 Nm separation minima ICAO standards and represents the margin taken by the controllers to manage the uncertainty. In such a context, it means that the TC-SA must manage separation to resolve conflict with distance greater than 15 Nm, otherwise it will be considered as residual conflict by the tactical controller.

(141) Experiments demonstrated that the number of clearances was reduced with TC-SA in all conditions. In term of saving of tactical intervention TC-SA demonstrated a clear effect.

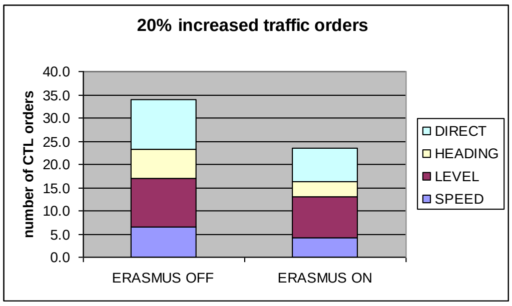


Figure 10: number of controllers orders with and without ERASMUS

(142) Results from real-time simulations suggest that with high and complex traffic, the TC-SA reduction of conflict lowers the controller workload.

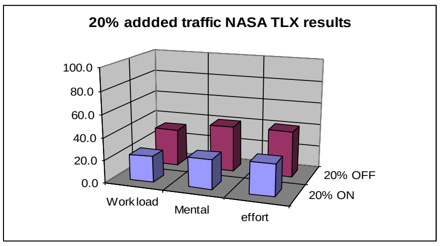


Figure 11: ERASMUS workload impact with NASA TLX

(143) Simulations showed that the controller's rating of subjective state and perception of comfort, measured through difficulty feeling, safety feeling, and risk perception, show significant improvement with TC-SA.

(144) Experiments demonstrated that controllers could cope efficiently with a +20% capacity increase TC-SA based in a baseline scenario environment.

(145) It was confirmed that four central criteria were correlated with the complexity reduction: number of simultaneous conflicts, number of actions to be achieved, number of aircraft, and available time to act. The hypothesis that the doubt situation could represent a key factor of the complexity was not confirmed.

(146) This baseline scenario provided the potential for quick wins to transfer to the SESAR 2020 picture.

4.2.2. SESAR 2020 Scenario

4.2.2.1. Conflict Detection

(147) For the SESAR 2020 scenario, the way in which the tactical controller should be able to manage residual conflicts with a MTCD aid tool was explored.

(148) Such a MTCD gaming prototype was developed to explore the controller working methods and to identify the pros and cons.

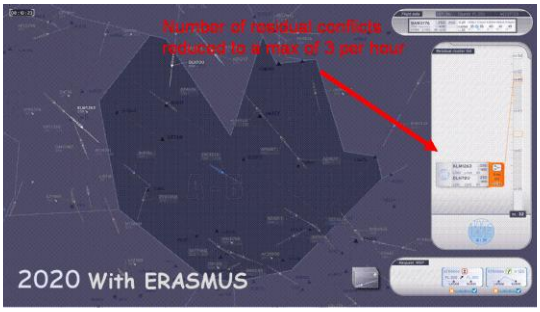


Figure 12: TC potential visualisation of residual conflicts with ERASMUS in 2020

(149) The idea that the increased traffic levels and the strategic actions inhibit the potential to be able to maintain full situation awareness and full control of all aircraft in the area of responsibility is commonly shared. How to overcome this issue and ensure a safe and efficient flow of traffic is not yet clear. Two speculative options can be envisaged, depending on whether we consider the conflict

detection aid tool as a cognitive support or as a cognitive substitute.

(150) The first option considers the reliability of the conflict detection aid tool at the 2015-2020 horizon, which will not be enough to ensure 100% of conflict detection and may display false conflicts or forget some real ones. In such a context, controllers accepted to consider this aid tool as a support to their cognitive activities because they recognised that maintaining situational awareness (SA) will not be possible in the form commonly accepted today. They will continue to build their own mental picture but will use the support provided by a 'conflict list picture' proposed by the support tool. The automation failure (information unreliability), combined with the reduced potential failure of the operator in conflict detection and conflict management, may not be greater than actually and safety levels could be maintained. Anyway, risk and robustness assessment should be done to assess the impact in term of overall safety levels.

Comment [a7]: SICTA - I don't agree with this vision. I don't remember to have considered two different "environments" for 2020 scenario. Moreover this statement is "in conflict" with what we have done in safety assessment for 2020, with the results obtained from safety assessment (e.g. FHA) which is also reported in the following sections of this report (e.g. see section 4.5).
I suggest to modify it in full

Comment [g8R7]: OK, removed

(151) Coupling human and machine in conflict detection and conflict management has a deep impact on responsibilities sharing in the ATM system. So far controllers are responsible and liable of the socio-technical potential problems. If in the future their tasks are delegated to a machine and they are inhibited from full control of situation, no one can expect that they will accept full responsibility for the system. The societal perception and acceptation of an error from automation may vary from erroneous action tolerance.

4.2.2.2. Conflict Resolution

(152) For the SESAR 2020 scenario, a second aid tool was proposed and explored: conflict resolution. This extra service proposed lateral and vertical aircraft trajectory deviation to resolve near-term conflicts (~ 8 minutes time horizon). The idea of support tool as conflict detection is well accepted. Operational experts considered that to efficiently resolve a problem, it is necessary to have first properly detected and analysed it. In the same line of thought, to monitor the achievement of a solution it is better to have elaborated it in order to understand if the expectations are effectively fulfilled. Detailed reasons explaining this reject has been given (D4.5.2).

4.2.2.3. Meta-Sector Planner

(153) For the SESAR 2020 scenario, it was explored and proposed to move the role of the Planner Controller towards a role of Meta-Sector Planner (MSP) (acting for a number of control sectors) in order to emphasize her/his strategic role and enhance her/his responsibility over tactical (eliminating conflicts while planning incoming traffic). The aim is to reduce the workload of tactical controllers in terms of conflicts detection/resolution and provide more optimal trajectories for aircraft. The purpose of the Meta Sector Planner is to ensure that the controllers of the individual sectors are never subjected to a workload where safety is jeopardised. Operational experts did not express any opinion, views or even raised concerns. This can be explained by the fact that the MSP concept is so novel and still in its infancy in term of maturity that operational experts have strong difficulty to imagine them selves in such a new role. However, the MSP issues should be explored and refined in further details in the SESAR programme.

4.3. Efficiency, Capacity and Predictability Issues

(154) The following table summarises the relationships between the efficiency research questions, the key performance indicators, the metrics and methods/tools to assess the efficiency.

Research Questions	Indicator	Definition	Metrics	Methods/ Tool
Sector Load	KPI_CAP_WORKLOAD	Weighted combination of elementary events workloads	Complexity score Workload feeling	RT-Simulation

Research Questions	Indicator	Definition	Metrics	Methods/ Tool
			Safety feeling	
Sector Load	KPI_CAP_ELEMENTARY	Maximum number of flights exiting a sector per unit of time (e.g. an hour) without exceeding maximum tactical workload	Complexity score Workload feeling Safety feeling	RT-Simulation
Sector Load	KPI_CAP_SCATTERING	Scattering between workload per sector and the saturation threshold (70% ATCo Occupancy Time) *(This is an indicator of sectors capacity utilisation)*	Number of aircraft (ATCo occupancy time)	COSAAC (ATFCM Simulator)
Traffic Throughput	KPI_CAP_THROUGHPUT	Number of flights exiting Aix ACC by unit of time	Number of flights exiting Aix ACC by unit of time	FAP
Network Load	KPI_CAP_OVERALL	Maximum number of flights per hour in the Aix ACC Area taking into account traffic flows and sector capacity restrictions.	Maximum number of flights per hour in the Aix ACC Area taking into account traffic flows and sector capacity restrictions.	FAP
Traffic Delay	KPI_EFF_DURATION_OCC	Proportion of flights with additional flight duration (compared to their shared business trajectory duration) of more than 3 minutes	Proportion of flights with additional flight duration (compared to their shared business trajectory duration) of more than 3 minutes	FAP
Traffic Delay	KPI_EFF_DURATION_SEV	Average deviation time of flights with additional flight duration (compared to their shared business trajectory duration) of more than 3 minutes	Average deviation time of flights with additional flight duration (compared to their shared business trajectory duration) of more than 3 minutes	FAP
Flight Predictability	KPI_PRED_VARIATION	Coefficient of variation (standard deviation divided by mean) of gate-to-gate time differences between actual and last agreed values milestone times	Coefficient of variation (standard deviation divided by mean) of gate-to-gate time differences between actual and last agreed values milestone times	FAP

4.3.1. EUROCONTROL Methodology Overview

4.3.1.1. Building the traffic demand:

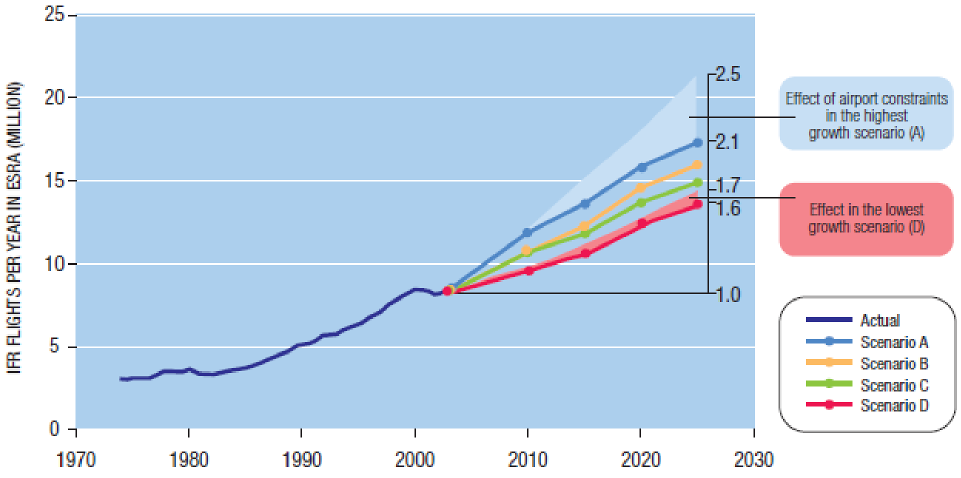
(155) The EUROCONTROL Statistical Forecasting service (STATFOR) processes air traffic statistics at European and regional level, from (inter alia) CFMU and CRCO data, and produces traffic forecasts. These forecasts take into account different sets of assumptions, e.g. economic growth, airline productivity, competition from other means of transport, as well as the 'maximum aircraft movements per year' at congested airports.

(156) The forecast considers four main scenarios, namely:

- Scenario A: Greater globalisation and rapid economic growth, with free trade and open skies agreements encouraging growth in flights at the fastest rate.
- Scenario B: Business as usual, with moderate economic growth and no significant change from the status quo and current trends (Note: EU expansion is at its fastest in this scenario).
- Scenario C: Strong economies and growth, but with strong government regulation to address growing environmental issues. As a result noise and emission costs are higher, which encourages a move to larger aircraft and more hub-and-spoke operations. Trade and air traffic liberalisation is more limited.
- Scenario D: Greater regionalisation and weaker economies leading to increased tensions between regions, with knock-on effects limiting growth in trade and tourism. Consequently, there would be a shift towards increased short haul traffic. Security costs increase further beyond 2010, with the price of fuel being at its highest in this scenario, it reaching close to 40% of the airline operating costs by 2020 and beyond.

(157) In 2020, traffic demand is forecast to be around two times higher than in 2005. With 9.1 Mn flights having taken place in Europe in 2005, this translates into approximately 18 Mn in 2020. Some European airports will struggle to accommodate such growth and in 2020 around 60 airports are expected to be congested while the top 20 airports are saturated for 8-10 hours/day.

(158) The effect of the lack of airports' infrastructure in constraining the demand is shown in Figure 2-3. The expectation is that the growth in air traffic will be constrained to be about 1.7 times higher than in 2005, resulting in the ability to accommodate only about 16 Mn flights.



4.3.1.2. Building the Traffic distribution to assess the capacity/efficiency KPA

(159) Due to the network effect (delays, congestion…) and interrelationship of traffics flows, the capacity is not equal to the traffic demand. The FAP methodology (Future ATM Profile developed by EUROCONTROL) modelled this demand/capacity mechanism taking into account the network effects that will allow studying a large number of control sectors. FAP carries out an economical analysis, balancing the cost of capacity provision and the cost of delay, on the assumption that each ACC is operating at or close to its economical optimum, and that the target level of delay has been achieved. After the economic analysis or cost optimisation for the future traffic demand is carried out, an iterative ATFM simulation by increasing capacity for an ACC is processed until the overall enroute delay target of 1 minute per flight is reached.

4.3.2. Baseline Scenario

(160) The table below shows the Impact on KEY Performance Indicators.

4.3.3. SESAR 2020 Scenario

Key Performance Indicator	Definition	Results
KPI_CAP_WORKLOAD	Weighted combination of elementary events workloads	Maintained with increased quality or service for High traffic load. Reduction in the range of 19 % for moderate and low traffic load.
KPI_CAP_ELEMENTARY	Maximum number of flights exiting a sector per unit of time (e.g. an hour) without exceeding maximum tactical workload	Potential savings of 5%
KPI_CAP_SCATTERING	Scattering between workload per sector and the saturation threshold for the Aix ACC *(This is an indicator of sectors capacity utilisation)*	16%
KPI_CAP_THROUGHPUT	Number of flights exiting Aix ACC by unit of time	1 aircraft each 12 seconds
KPI_CAP_OVERALL	Maximum number of flights per hour in the Aix ACC Area taking into account traffic flows and sector capacity restrictions	299 aircraft/hour
KPI_EFF_DURATION_OCC	Proportion of flights with additional flight duration (compared to their shared business trajectory duration) of more than 3 minutes	0 (due to the FAP methodology used with a fixed target delay of 1 minute)
KPI_EFF_DURATION_SEV	Average deviation time of flights with additional flight duration (compared to their shared business trajectory duration) of more than 3 minutes	0 (due to the FAP methodology used with a fixed target delay of 1 minute)
KPI_PRED_VARIATION	Coefficient of variation (standard deviation divided by mean) of gate-to-gate time differences between actual and last agreed values milestone times	1 minutes delay variation

(161) It appears that the FAP methodology suitable for the short-term issues will no longer be consistent with medium-term and long-term investigations. It is due to new constraints for the 2015-2020 timeframe: in particular new route network FAB (Functional Airspace Block), airspace structure), news constraints (en-route sectors, airports, terminal areas…), new delay target.

(162) The consequence is that the current FAP method "1 min per flight delay" is no more valid to perform 2015-2020 studies. In the context of the Episode 3 and SESAR project, it has been decided to re-design a new FAP with new methodology and algorithms. This new FAP methodology will not be available before 2010.

(163) With the absence of a consistent FAP methodology it is not possible to build the traffic distribution over the future route network and thus not possible to predict the 2020 global capacity.

(164) In consequence, it is not possible to assess the capacity/efficiency KPA for 2020 SESAR scenario due to the unavailability of the new FAP methodology.

4.4. Cost-benefits Issues

(165) Different environments have been analysed addressing what should be expected in terms of costs and benefits to the ANSP and airlines in ERASMUS implementation. The time frame considered was first the 2007, and secondly 2020. As result, for each level of ERASMUS implementation, we obtained the expected costs until year 2020 where the new concept should be integrant part of the ATC working method.

(166) The primary aim of ERASMUS is to increase en-route capacity, assuring or increasing the level of safety. The new concept should facilitate the management of traffic complexity and separation, that, in terms of benefits, should mean fuel, flight time, ATCO workload and delay decrease.

(167) Both ANSP and Airlines are the major stakeholders involved in the ERASMUS concept implementation. Regarding the costs, they are expected to participate in the Deployment and In-operation phases. Following, the above mentioned costs are listed:

- Deployment Costs:
    - Airlines costs for avionics and installation;
    - Cost of ERASMUS Server and installation;
    - Information infrastructure (CPDLC implementation, ADS ground station);
    - Training of ATCOs;
    - Training of Pilots;
    - Other supporting activities for Deployment phase.
- In Operation costs per year:
    - Cost of all ERASMUS manoeuvres per aircraft;
    - ERASMUS Server maintenance activities;
    - Additional cost related with Avionics maintenance;
    - Maintenance of information infrastructure;
    - Regular on-going training;
    - Other supporting activities for in operation phase.

(168) The costs are distributed in two phases taking into account that the basic scenario of ERASMUS (2007) should be considered as the initial arrangement to provide short term benefits. It is a fundamental step to the gradual implementation of the full ERASMUS concept. In fact, with the implementation of the additional functionalities (2015 onwards), improved performance are expected.

(169) Different sizes in relation to costs have been envisaged with reference to the two timeframes. With respect to the second environment, more considerable costs, as operating and investment ones, may occur.

(170) Regarding to the ANSP, the 2020 environment will not allow major issues or impediments for the establishment of ERASMUS from the ground infrastructure perspective, while, investment costs for the implementation of ERASMUS server are expected to increase. The added functionalities require the Solver upgrade that in terms of cost means about 1.5 M € per ACC.

(171) The Airlines costs are related to the upgrade of FMS and its significant functionalities required for ERASMUS applications:

- Calculation of speed orders to meet Required Time of Arrival;
- Provision of Trajectory Prediction as Aircraft Intent;
- Suitable repository for Temporary Flight Plan which includes modification of Active Flight Plan by RTA;

- Optionally the Loading Data-link Request to Temporary Flight plan.

(172) It is assumed Aircraft delivered between 2007 and 2015 will have FMS requiring upgrading to be fully compliant with the new concept.

(173) The FMS upgrade will absorb about the 70% of the avionic costs, 450.000 € per aircraft, while the data-link equipment will be in 2 variants (CPDLC/ADS-C coupling and CPDLC/ADS-B coupling): both will be able to support ERASMUS, but with different quality.

(174) The main operating costs involve the ANSPs and will be due to the Controllers training inasmuch as the new functionalities, introduced by ERASMUS, will need of more time to be understood.

(175) The economic benefits induced by ERASMUS may be additional to the SESAR expected ones.

(176) For the Airlines there will be necessarily a trade off to be made between flight efficiency and selected manoeuvres for conflict resolution. The direct benefits to the different selected manoeuvres are flight time and a potential delay decrease. The reduction in delays means that less fuel needs to be loaded and thence improved efficiency.

(177) One of the consequences of increased capacity derived from ERASMUS could be that airlines will potentially reduce schedule buffers.

(178) The ANSPs can avoid the staff cost enabling ATCO to control more aircraft per person. ERASMUS will reduce traffic management complexity so it is expected that the traffic increase will potentially be managed from the same staff operating in the ACC.

(179) Taking into account this, the results of the FTS and RTS have been showed that the 80% of conflicts, in the en-route phase, will be resolved by ERASMUS. As a consequence, it is expected that the controller workload should decrease. The high level of workload is one of the main restrictions to the capacity increase; ERASMUS concept is just based on the reduction of conflicts which implies a significant decrease of tactical intervention of the controllers.

(180) A summary of the main conclusion regarding the benefits is showed in the following table:

Benefit type	Main conclusion
Capacity increase	Capacity is determined by the Controller workload reduction and by the increase of ATCO productivity.
Workload decrease	The reduction of potential conflicts should improve the ATCO working method.
Cost avoidance	More aircraft could be managed by the same number of controllers in the ACC.
Flight time reduction	An appropriate manoeuvre selection could reduce the flight time.
Delay reduction	An appropriate manoeuvre selection could reduce the delay.
Fuel consumption reduction	An appropriate manoeuvre selection could reduce the fuel consumption.

Table 1 ERASMUS Benefits

4.5. Safety Issues

(181) The safety assessment was performed focusing on both scenarios considered in the context of ERAMUS: the short-term scenario (2012 horizon), characterised by the use of current technology and long-term scenario (2020+ horizon), compliant with SESAR environment and addressing the next generation technology endowed with more functions.

(182) Complementary methods have been applied to identify (and assess) failures (equipment failures, procedural failures or human errors) within ERASMUS system and to assess the benefits in terms of safety deriving from the implementation of ERASMUS. Adequate Fast Time and Real Time Simulations was the key to demonstrating acceptable safety performance at this stage.

(183) This approach tried both to determine how safe the system shall be by specifying the safety objectives of the system (failure approach), and to demonstrate, through quantitative safety measures carried out by means of post-processing analysis of Real Time Simulations, that the ERASMUS system will deliver an increase level of safety.

(184) In the former approach, in accordance with the EUROCONTROL SAM, a preliminary FHA was performed. It followed a top-down iterative approach consisting of several steps for identifying potential hazards resulting from functional/operational failures or errors, and assessing their consequences on the overall system. The results and conclusions of the preliminary FHA were documented in D441 and D442 and will enable the implementers of the ERASMUS to get valuable information in support of their design and operating procedures choices. An initial list of potential hazards with different level of severity of their effects and the identified Safety Objectives will enable the derivation and allocation of System Safety Requirements so that the proposed system architecture achieves an acceptable level of risk.

(185) In the latter approach, appropriate criteria and metrics to evaluate the impact deriving from the application of ERASMUS and to show the beneficial effect of the Erasmus in terms of safety, were defined.

(186) The aim of this assessment is to show that ERASMUS can improve, or at least maintain, the level of safety provided by the existing (baseline) ATM system: more traffic being handled for the same level of safety.

(187) A higher traffic level foreseen in next years would lead to a greater number of potential conflicts, but this would be compensated for by the increase in the conflict-resolution capability due to ERASMUS services.

(188) The main operational assumption of ERASMUS is the strategic de-conflicting, which aims at reducing the number of conflict, i.e. to generate conflict-free segments feasible on short route segment (15 min segment) will deserve the objective to reduce drastically the number of conflict handle by the tactical controller. It allows to save controller’s mental resources and to provide a more comfortable and safe situation.

(189) The level of safety was explored:

- providing figures related to the reduction of conflict number, the increase of the a/c distance separation average, the delay between ATCO intervention and conflict time, the reduction of ATCO interventions, the absence of conflict created by the technical system, the manageability for the Tactical Controller of traffic configuration generated by the ERASMUS, etc…
- and collecting feedback and expert judgement from controllers and pilots during exercises and debriefing sessions.

(190) One of objectives of ERASMUS is to provide the controller with traffic partition which minimizes the

occurrences of doubtful traffic. The results of experiments have demonstrated that the speed adjustments is sufficient to move the aircraft involved from the “doubt” partition (7-15NM) to the “no-doubt” partition (>15NM). This means that ERSAMUS creates enough space between aircraft with regard to the controller’s perception criteria. This goal has been achieved through a constant improvement of a/c separation carried out by ERASMUS at which corresponds a reduction of number of a/c that at the closest point approach are between 7NM and 15NM.

(191) This measured decrease of the encounters in the doubt area with the use of ERASMUS is largely profitable to the controller as they represent the most hazardous ones. A decrease in this category does not bring an objective increase in safety, strictly speaking, but a major improvement “pressure release” for controllers since these encounters largely solicit sustained attention from them in order to decide about the necessity or not to intervene. It is achieved by ERASMUS minimising the number of traffic situations that the controller feels must be monitored due to the perceived level of conflict risk.

(192) Similarly, a greatly improvement of level of safety and a workload decrease are brought by a significant reduction of number of separation below the 7NM and by a consequent high percentage of conflict resolved by ERASMUS (about 75%). The reduction of tactical conflict showed to TC, carried out either through an autonomous conflict resolution, without the intervention of any controllers, or through a supported strategic de-confliction which assists the Planning Controller to evaluate and to change the traffic situation, implies a reduction of the operational risk associated to a conflict, in terms of “cluster of encounters in a given area”. The figures confirm that the proposed automation allows to achieve an important decrease of tactical intervention of executive controller aiming to solve a conflict and reduces consequently the risk associated to a given procedure in terms of operational errors. In definitively, the reduced quantity of potential conflicts may contribute to decrease the risk associated to a conflict and the stress level of executive controllers.

(193) ERASMUS is a collection of software data processing functions designed to assist controllers in the search, detection and resolution of conflicts in a particular time frame. The solver achieves conflict detection and the strategic de-conflicting through continuous monitoring of aircraft predicted trajectory.

(194) ERASMUS is a feature that shows the conflict, the trajectory of a conflict aircraft, the predicted point of minimum separation, the predicted minimum distance, and other relevant information which provides the controllers with a more accurate traffic picture. The use of ERASMUS displays contributes to build and update mental picture and situation awareness of controllers. Rather than having a picture of current and future individual aircraft positions, the situational awareness of controllers may be more in terms of sets of potentially conflict aircraft, classified as resolved conflicts and residual conflicts. The presentation of potential/residual conflicts allows the controller to use this information to retrieve the plan of action basing on an idea of the space of action he has to resolve the residual conflicts.

(195) The reduction of the information processing and working memory demands associated with mental projection of future a/c positions can be arisen as a consequence of improved situational awareness on potential conflicts. Conflict detection, analysis and resolution change from tasks that are based on mental projection and computation to tasks based to a larger extent on visual perception, on the options provided by server to resolve the conflicts and on the results of query regarding to the effects of solutions proposed by controllers, facilitating the identification and application of conflict resolution strategies. The trajectory displays, the spatial and graphical representation of the conflict aid the controllers’ understanding of the location, geometry and severity of the conflict, thus reducing the requirement for the controller to remember conflicts and conflict details, as well as the mental resources and workload required to the detection and resolution in conventional way (without the support of ERASMUS). Moreover, we should consider that certain types of conflicts, occurring after turns or with a complex geometry, have to be detected early and more accurately than human mental projection. Thus, the ERASMUS services allow a less reactive approach to dealing with conflicts and a more effective time management. This results from the fact that ERASMUS facilitates the early detection of conflicts and of all relevant information, and then provides an autonomous resolution and

strategic de-conflicting strategies in order to assist the controllers in the identification and in the solving of the potential conflicts before the a/c enters the sector under control (i.e. within the strategic timeframe). These aspects have an considerable impact on the reducing controller's workload and result in the opportunity to save controller mental resources inasmuch the controller is provided with a global and complete picture of the traffic situation which allows a reducing in the effective mental activities avoiding to make a mental assessment of the future potential situation and of the possibilities of actions.

(196) Moreover, the improved situational awareness about the potential conflicts supports the multi-sector planner in evaluating his own workload as well as the workload of executive controllers. The number of residual conflicts displayed in the window provides an indication of traffic complexity in each sector and allows the MSP to dynamically changes the threshold of detection and of autonomous resolution in order to ensure the workload and the complexity levels for each sector under his responsibility do not exceed an acceptable threshold value. The MSP can take into account the workload of both executive controllers when choosing a solution or transferring a conflict to EC, thereby helping to even out the workload between ECs of sectors in the MSP area.

(197) The autonomous and supported strategic de-confliction have a direct consequences on the task distribution sharing between several actors (human and machine). The integration of automation in the ATC activity and a new sharing of tasks between planning and tactical controllers implies that the prescribed sub-task of the tactical controller's (e.g. conflict identification, de-conflict and modification of trajectory, ensuring of separation between a/c, monitoring of traffic evolution and solutions achievement, etc..) will be differently allocated. The strategic actions performed either automatically by ERASMUS or by the planning controller, provide the tactical controller with a smooth traffic situation. This results in a reduction of the quantity of tactical actions of tactical controller, in a consequent decrease of TC workload allows to free up some of controller's mental resources.

(198) Widening this argument, we can affirm that the implementation of ERASMUS implies a more specific change in working practise and controller cognitive activities, which may have a potential safety impact. Some examples may be represented from the changes in proportions of time and cognitive effort spent on different task, changes in allocation of task and workload between PC and EC, changes in nature and extent of communications between PC, EC and Pilot:

- The integration of automation places the controller in a more monitoring function. The controllers are asked to monitor the achievement of a solution and to evaluate if the expectations are effectively fulfilled through the availability of information that will be more accurate and the knowledge of flights intentions. The EC has to ensure that an aircraft's passage through a sector is orderly and in accordance with ATC clearance. Thus, the executive controller is required both to monitor whether the flight adheres to the cleared trajectory (conformance monitoring), and to monitor the flight progress against actions required for efficient flight handling (progress monitoring).
- Depending on the number of conflicts that are not solved in autonomous manner by ERASMUS Solver, the MSP can take actions, with the support of ERASMUS, in order to meet an acceptable tactical controller workload. The MSP aims to de-complexity the whole traffic situation at strategic level, supporting the EC on how to manage a/c and to handle a potential conflict, by applying instruction that are given for the benefit of the next sector or sectors. Thus the EC is required to facilitate the resolution of conflict which will affect next sector or sectors, keeping the responsibility for separation assurance of traffic in own sector. This means that the flight managed autonomously by ERASMUS as well as the resolution strategy proposed by MSP (based on ERASMNUS proposal) for a strategic resolution of conflict of next sectors could interfere in some way with EC's activities and his decision.

(199) However, the exact nature and direction of these changes cannot foreseen in detail, as it will depend on a number of factors that are specific to the detailed design and implementation of the system.

4.6. Security Issues

(200) The security assessment was performed focusing on both scenarios considered in the context of ERAMUS: the short-term scenario (2012 horizon), characterised by the use of current technology and long-term scenario (2020+ horizon), compliant with SESAR environment and addressing the next generation technology endowed with more functions.

(201) The goal of this analysis is the identification of vulnerabilities and threats, the risk assessment, and the determination of security objectives. The current operational environment, its systems and the equipment in use are assumed to be safe and secure, therefore only the impacts of the changes introduced by ERASMUS have been considered within the scope of this analysis. The last goal is to obtain recommendations for solutions – e.g. proposals for unacceptable risk mitigation.

(202) According to the different scenarios and the concept of ERASMUS, the air-ground communication related to the Subliminal control (and implicitly the half-Subliminal control) was assessed in the Security analysis of the short-term horizon, while, in the 2020+ horizon, the distinctive communication associated with the Supraliminal control was considered and assessed with the communication associated with the Subliminal control already analysed in the 2012 horizon.

(203) For the assessment of communication the first step was the identification of data which are relevant from the communication point of view. Airborne Trajectory Prediction is provided by one-way air-ground datalink service from aircraft surveillance systems to Air Traffic Service provider computer. Trajectory negotiation is facilitated through the use of two-way air-ground data link between the Air Traffic Service (ATS) provider's computer system and the Flight Management System (FMS) on the aircraft flight deck. So, the system and operational environments were described and relevant data were identified:

- Meteorological information (uplink);
- 4D trajectory data (downlink);
- a list of active flight plan points:
    i. aircraft state data – this data includes time critical flight status information and will be transmitted from the aircraft periodically by air-ground data link;
    ii. aircraft intent data – this data describes all aircraft intentions coming from the FMS-calculated trajectory prediction and reflecting the user preferred trajectory preferences;
    iii. aircraft performance parameters for construction of speed profile with sufficient accuracy included Figure of Merit (e.g. Estimated Position Uncertainty, Navigation Accuracy Category for Velocity);
    iv. sensed local airborne weather data.
- RTA constraint, which may, as an option, include coordinates (or similar suitable definition of position) of the waypoint on which the RTA is to be applied and other information in the form of a free text data-link message (uplink);
- "STANDBY", "WILCO" or "UNABLE" (downlink).

(204) Moreover, according to the used methodology, some aspects related to a dependability of the predicted trajectory were considered in order to evaluate the impact and the effect of their non-standard behaviour:

- **Confidentiality** of the information refers to the necessity of transmitted information secrecy (against potential aggressors). So, Confidentiality can be described as a property that guarantees the property that information is not made available or disclosed to unauthorized individuals, entities or processes.
- **Authentication** or **Integrity** of the information determines the requirement of certainty that the information was sent by the appropriate authority, and that it is complete and relevant for the

current specific situation (e.g. without significant delay). So, Authentication and Integrity guarantees that data has not been altered or destroyed in an unauthorised manner.

- **Availability** of the information indicates the need for information in order to compute relevant algorithm and/or to prepare relevant processes. So, information is available if it is delivered to the right person and/or machine, when it is needed.

(205) The impact of a loss of the service on security was classified by the following scale:

- "**None**" means that loss of the service would have no practical adverse effect on operations;
- "**Low**" means that loss of the service would have only a limited adverse effect on operations;
- "**Medium**" means that loss of the service could have a serious adverse effect on operations;
- "**High**" means that loss of the service could have a severe or catastrophic effect on operations.

(206) From security point of view the system could be perceived from two complementary perspectives: internal and external. Internal perspective means the identification and analysis of system's weaknesses. External perspective meant the identification and analysis of a potential aggressor's opportunities for a preparation and a realisation of an attack. So, the vulnerabilities (internal sources of risk) and the threats (an external sources of risk) were identified (there were constructed threats' scenarios for the threats identification). A potentiality of the threats was estimated by an assessment of a natural exposure, impunity of the aggressor, and a realization of the easiness. The risks were identified as combinations of reciprocally associated vulnerabilities and threats. The risks with following combinations of likelihood and severity were considered Unacceptable:

- Likely x High;
- Highly likely x High;
- Highly likely x Medium.

(207) As results of this security analysis, three identified risks associated to ERASMUS have been defined Unacceptable due to the combinations of the vulnerabilities and the threats:

- **Feeble transmission** (the distance between transmitter and receiver is too long or the transmitter or the receiver or both of them have too "weak" equipment for a successful transmission) x **Interruption of the data transmission** (an attacker achieves that the transmitted data won't reach its recipient or it is not complete);
- **Partially uncontrolled communication** (ATCO doesn't know that the information is dispatched) x **Fake transmitter** (an attacker modifies the information in order to bring about a conflict);
- **ERASMUS solver** (there is a possibility of hardware's and/or software's failure) x **Hacking** (an assault on the computer with ERASMUS solver).

(208) The first one was identified as unacceptable only in the case of the long-term horizon; the second and the third ones were identified as unacceptable in both cases.

(209) On the basis of physical environment, assumptions and assessed risk, it has been possible to identify Security objectives which have a relevance to ERASMUS:

- **Common Controls Security Objective** – Aircraft systems should use common security controls as much as possible;
- **Minimize Administration Security Objective** – Security controls for aircraft systems should require minimal administrative and operational overhead;
- **Secure Security Objective** – Security controls for aircraft systems should mitigate the risks to aircraft systems to a level that is acceptable based on airline business needs.
- **Existing Systems Security Objective** – Security solutions for new systems should require as few changes as possible to existing systems.

(210) In order to achieve the defined Security objectives, it has been necessary to identify a mitigation

strategy to reduce the risk identified as unacceptable. The possible way for a mitigation of the unacceptable risks was:

- lower the liability of the risk and/or
- lower the impact / the severity of the risk.

(211) Thus, a set of precautions have been identified and recommended for a possible implementation of ERASMUS:

- To guarantee the confidentiality of the relevant communication by a reliable encryption;
- In cases where a pilot doubts the authenticity of a message source, the pilot should be trained ask "questions about own aircraft – flight plan, position (in any case it has to be something what cannot be said without display – for a certainty that the responder is authorised)";
- To develop a secure firewall of the ERASMUS solver computer;
- To separate the ERASMUS solver computer from INTERNET;
- To install a reserve computer that is able to take over an activity in case the primary computer is compromised or disabled;
- To use some emergency canal for a connection with an aircraft for which ERASMUS data connection was interrupted;
- To inform other near aircraft about and control them with respect to this situation (an interruption of the ERASMUS data connection for an aircraft).

(212) These propositions provide effective mitigations which achieve the defined Security objectives. Implementation of these mitigations would allow one to responsibly conclude that all security risks related to ERASMUS are acceptable, and consequently that **the ERASMUS system is secure**.

4.7. Environmental Issues

(213) Air traffic impacts on the environment through noise and emissions from aircraft in all phases of flight. Gaseous emission from aircraft produces the three main pollutions: Nitrogen oxides (NOx) that produce ozone, Carbon dioxide (CO2) that has a long residence time in the atmosphere and water vapour (H2O) that at high altitude triggers the formation of condensation trails which can bring to a global warming (keeping the earth's heat in) and cooling effects (stopping solar radiation).

(214) Activities and research, with the aim of minimising the environmental impact of aircraft, are currently being conducted. Part of this work is direct towards the reduction of emission of aircraft, while other research allows more efficient air traffic management.

(215) The most efficient way to reduce aircraft engine emissions is to reduce fuel consumption itself.

(216) The high level expectations of airspace users are to be able to conduct their operations with minimum restrictions, maximum flexibility and cost-effectiveness, whilst minimising the environmental impact. The ATM can play an important role in developing an environmental sustainable Air Transport System, but in doing so, interdependencies with other aspects (such as capacity, efficiency, etc.) and between the environmental aspects themselves have to be take into account.

(217) ANSPs will continue to modernise ATM operations with the goal of achieving further efficiency gains and thus contributing to fuel saving and CO2 emission reductions. The aims are to reduce environmental impacts, to ensure that air traffic related environmental considerations are respected, and that as far as possible new environmentally driven non-optimal operations and constraints are avoided or optimised as far as possible.

(218) In the context of ERASMUS, the areas of potential improvement are emissions and noise. However,

there was no possibility to address the noise issue as it is too specific. Performance changes having an impact on the environment were addressed through the performance analysis of flight paths and fuel consumption only. It allowed to carry out a preliminary and rough evaluation merely dealing with emission aspects.

(219) The cruise phase is considered as the most important phase regarding the fuel savings and the emissions in the atmosphere. In order to minimize the environmental impact and to reduce fuel usage as much as possible, some opportunities related to ERASMUS concepts have been considered:

- When advised that a hold is expected, most aircraft wish to slow down in order to absorb as much time en-route as possible. These reductions, in terms of speed and time, will also serve to reduce fuel consumption.
- Most aircraft will want to stay at preferred altitude as long as possible. The experimentations demonstrated the number of aircraft that were able to reach their RFL increased significantly, and that the controllers involved in the simulation seemed better able to accommodate the aircraft request when ERASMUS was working.
- More efficient flight profiles and a reduction of traffic flow complexity should help to reduce fuel burn and greenhouse gas emission per flight. The results of experimentations demonstrated a potential for ERASMUS to reduce the perceived complexity.

(220) ERASMUS reduces the number of ‘last minute” manoeuvres related to ATC’s interventions. Because such interventions are the most fuel demanding, ERASMUS can directly reduce the impact of air traffic on the environment.

(221) Appropriate metrics, to determine distance flown and fuel consumption, were addressed in Fast Time Simulations to assess efficiency as well as emissions. However, the results obtained from FTS showed that the ERASMUS adjustments have no major impact on fuel consumption per flight so that they are not significant from the environmental point of view.

(222) These results come from different fuel consumption associated with ERASMUS manoeuvres (Speed up, Speed down, Level change and heading change). It is obvious that the speed reduction is in major cases the most fuel efficient manoeuvre. However an appropriate selection of manoeuvre for ERASMUS Conflict Resolution may have direct impact on flight efficiency and on fuel consumption. This would allow a greatly reduction of fuel consumption and consequently of CO_2 emissions due to the direct connection between these two aspects. Therefore appropriate criteria for the selection of manoeuvres should be integrated into ERASMUS Conflict Resolution solver and further investigated.

(223) However an appropriate selection of manoeuvre for ERASMUS Conflict Resolution may have direct impact on flight efficiency and on fuel consumption. The Cost-Benefit assessment has demonstrated in certain case an airline can have significant financial benefit from Slow down manoeuvres. This would allow a greatly reduction of fuel consumption and consequently of CO_2 emissions due to the direct connection between these two aspects.

(224) The Speed down instead of Heading/Level change or Speed up is considered the most fuel efficient manoeuvre. Therefore appropriate criteria for the selection of manoeuvres should be integrated into ERASMUS Conflict Resolution solver and further investigated.

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5. DISCUSSION OF ARGUMENTS

5.1. In principle, is ERASMUS acceptably safe?

(225) The main goal related to the implementation of new ATM system is to maintain or improve the current level of safety minimising the air navigation services' contribution to the risk of an aircraft accident as far as reasonably practicable.

(226) In 2020, traffic demand is forecast to be around two times higher than in 2005. The 9.1 Mln of flights having taken place in Europe in 2005 translates into approximately 18 Mln in 2020. The complexity of the 2020 traffic in terms of problem to solve according to an increased number of aircraft is such that the assessment done showed that without aids the controllers will not be able to handle the traffic in 2020. ERASMUS aims at providing a number of functionalities to the end-user, based on services provided by the Solver, through tools that support the controllers in their work. Their provision is done through several applications which significantly reduce controller's workload associated with routine monitoring and conflict detection, as well as reducing ATC interventions to change flight profiles to resolve potential conflicts.

(227) ERASMUS aims at reducing the complexity of sectors by automatic traffic adjusting through speed modification and producing a list of potential conflicts providing resolution advisories to solve them.

(228) The preliminary FHA, aiming at identifying and evaluating potential hazards and their operational consequences, showed that the ATM system will not be impacted by Hazardous situations and that the identified hazards will be easily managed in order to ensure "acceptably safe" operations. No class 1 and class 2 hazards have been identified for any of the ERASMUS services defined in this standard.

(229) Moreover, the experimentations demonstrated that the proposed automation (autonomous and support services) allows to achieve an important decrease of tactical intervention of executive controller aiming at solving a conflict and reducing consequently the risk associated to a given procedure in terms of operational errors. In the RTS, the traffic situation considered as highly dense was perceived less dense by controllers. ERASMUS enabled the reduction of the peak of traffic and a quicker accommodation of traffic, reducing the perceived level of complexity and difficulty for both reference traffic and increased traffic. These through a reduction of the number of potential conflicting situation, the reduction of complexity of conflict situation (in terms of geometry and severity), the decrease of total number of clearances given by the controller for both lower and higher traffic loads and so on.

(230) Definitely, the performed assessments experiments and studies showed that not only hat severity associated to potential hazards is low, meaning that ERASMUS operations will be easily acceptably safe, but also that the functionalities and performance of the system are sufficient to reduce the pre-existing risks (number of conflicts, complexity of traffic, average of separation between aircraft, number of ATCO tactical intervention, delay between ATCO intervention and conflict time) to an acceptably level.

5.2. Is ERASMUS operationally consistent and robust?

5.2.1. The Positive Issues

(231) The strategic de-confliction based on Trajectory Control by Speed Adjustment (TC-SA) demonstrated

through Fast Time Simulation (FTS) that ~80% of conflicts can be removed 15 minutes ahead. It follows that the resulting traffic to be managed by the tactical controller drops to a very low number of residual conflicts to be managed (approximately 3 conflicts per hour/sector) which yields a very significant decrease of workload. Therefore, strategic de-confliction offers big potential to save controller mental resources and allows controllers to cope with a 70% traffic increase.

(232) In addition, the autonomous feature of the TC-SA approach is well accepted by controllers and pilots. It is reinforced by the fact that trajectory longitudinal variations are not perceptible by controllers and therefore will not disturb their cognitive activity.

5.2.2. The Weaknesses Issues

(233) The level of aid that ERASMUS can provide is foreseen as a means to provide the controller with a sufficient level of situation awareness (SA) to be able to act strategically. A commonly shared concern by today's controllers is that the increased traffic levels and strategic actions can potentially interfere with their ability to maintain full SA and full control of the aircraft in their area of responsibility. How to address this concern and ensure a safe and efficient flow of traffic is not yet clear.

(234) In the baseline scenario, experiments demonstrated the risk that controllers' tactical interventions interfered with ongoing ERASMUS conflict detection and resolution actions. In our demonstrations we chose to tag those aircraft under ERASMUS autonomous control and highlight those aircraft managed via MSP strategic resolution guidance. Experts were not able to reach an agreement on the desire to tag aircraft under ERASMUS control. Some advantages and disadvantages have been raised and further assessments will be required.

(235) In the future, the use of 4D RBT, improvements in TP accuracy, and the systematic exchange of trajectory information will provide controllers with a better understanding of aircraft flight intentions. In addition it will save mental resources because controllers will not have to infer information. However, controllers may still have to handle exceptions (degraded mode, unexpected situations) and residual conflicts using tactical interventions. The anticipation and situational awareness concerns associated with today's modus operandi will be reduced. A more reactive mode closer to anti-collision working methods will arise. However, will this mode be sufficient to cope with situations of exception, knowing that the level of control situation is usually linked to the level of anticipation in dynamic environments? More generally, if controller contributions consist of very punctual adjustments, they will not rehearse their skills sufficiently and these skills will progressively erode. ATCo will be in a paradoxical situation where they are being pulled out of the global management of the situation, leading to loss of practical skill of de-confliction and yet still be in charge of the most difficult problems that cannot be handled by the automation.

(236) The evolution of the controller function from tactical interventions to controlling trajectory conformity assumes, by nature, a highly monitored activity. As a consequence, the expected gain in terms of attention resources will probably not be fulfilled. To cope with those concerns, SESAR proposes to maintain the current expertise of controllers, i.e. the current reasoning modes. However, the cohabitation of two very different control logic methods does not seem to be cognitively consistent for the same operator: Exception handling puts the controller in a passive position. Inaction makes it easier for controllers to lose concentration. Thus, some mental resources are necessary to maintain controller attention.

(237) Due to the aim of separation delegation, the transfer of responsibility will probably occur in the form of target transmission (i.e. the operator hands off a target to fulfil) and not by means transmission (i.e. the operator dictates detailed actions or means). This process may suppose additional effort to recognize the executive strategy of the separator on the one hand, and to memorize it on the other hand. To decide actions and means facilitates working memory, which contributes to the situation awareness.

5.3. To what extent is ERASMUS technically feasible ?

(238) The technical feasibility of the ERASMUS concept of operation depends on ground and board systems. Thus, in this section, technical feasibility will be discussed from these two perspectives, but using a common approach based on a 2007 and a 2020 scenario. For both these scenarios are reminded the main environmental hypothesis, the external (to ERASMUS) technical assumptions before assessing the feasibility itself.

(239) The TC-SA technical performance has been assessed based on setup of different parameters:

- FMS TP error for cruising aircraft;
- FMS TP error for climb/descent aircraft;
- Variation of aircraft speed change;
- Solver processing lifecycle;
- The calculation cycle of the solver;
- Number of aircraft;
- Rate of fleet equipment (FMS TC-SA compliant).

(240) In the table (Table 3) hereafter is presented the value of parameters used to build the reference scenario.

FMS TP error for cruising aircraft	10s
FMS TP error for cruising aircraft	10s
Variation of speed change	-6%
Solver processing lifecycle	3 min
Number of aircraft	Traffic 2007 and Traffic 2020
Fleet equipment	100%

Table 3: Fast-Time simulation parameters

5.3.1. ERASMUS feasibility from ground perspective

5.3.1.1. Ground Feasibility Discussion in the 2007 Baseline environment

(241) This discussion relies on several environmental hypotheses:

- Air traffic, air control sectors are those of today.
- Regarding the working methods, the provision of ATC services is predominantly a tactical process supported by a number of traffic management planning functions. The Planning Controller (PC) works ahead of the Tactical Controller (TC), organising traffic so that when it reaches the sector it is more organised and a number of conflicts have already been resolved. The TC works with a shorter look-ahead time, separating aircraft in real-time and ensuring a safe and expeditious throughput across the sector under control.
- The ERASMUS solver provides the TC-SA service. Clearances are directly uplinked to the cockpit without being displayed on TC tools (subliminal mode).
- ATCO interacts with flight crews using predominantly Radio-Traffic. Data-Link is used to get Trajectory-Prediction from board systems and to provide ERASMUS clearances to aircraft.

5.3.1.2. External technical assumptions made in the baseline scenario

(242) In order for ERASMUS to detect and solve conflicts accurately enough, it is assumed that 15-20' ahead of time 4D predicted trajectories are available with a reliable 4D accuracy around 10 seconds.

(243) Now, let's make clear the fact that a sufficiently accurate trajectory prediction is required by ERASMUS so that the solver can firstly detect conflicts that would "almost surely" occur if no control action was applied and secondly generate 4D trajectory modifications that are real solutions to the conflicts.

(244) The fleet equipment might have been a problem, if some aircraft are not able to send accurate trajectory prediction or are not able to receive orders. But this is not the case, the solver is able to work with a heterogeneous fleet and of course, results will depend on the quantity of aircraft that can provide all required services. Nonetheless a trajectory prediction is needed for all aircraft, even if it is not as accurate as the one that could be downlinked from the aircraft,. The figures are available in details in the D1.3.2 (FTS results) but the main point is that with 30% of fully equipped aircraft it solves 15% of conflicts and with 50% of equipped aircraft it solves 30% of conflicts.

(245) In order to resolve the conflicts, we use a genetic algorithm because for that problem deterministic algorithms cannot find global and optimal solutions. For more details see Durand 96 (Page 48)[3].

(246) The solver has to be fast enough to work in real time. Genetic algorithm and parallelization of computation are the key enablers to real time. This is still being investigated and the margins for optimizing the solver are big enough to handle some more computation load.

(247) The solver must find solutions and during this study one point has been clearly a challenged namely the validity in time of a solution. The validity duration of the solution should be long enough for the pilots (users) pilots) to accept this solution but this validity is linked to the resolution update. Every resolution cycle produces a complete new set of resolution and invalid previous solutions. If this cycle is too long then the solver efficiency is very reduced (see D1.3.2) while if it is too short then the pilots will not have time to proceed the solver clearance. Because the resolution is available once it has been computed, it follows that the computation duration has an influence on the available pilot's decision time.

5.3.1.3. Ground Feasibility Discussion in 2020 envisioned environment

(248) In the 2020 environment, the main environmental hypothesis are :

- Traffic is multiplied by 1.7 but control sectors remain unchanged.
- Working methods have changed. the role of the Planning
- Controller (PC) will be replaced by a Multi-Sector Planning controller (MSP), responsible for a number of sectors, in a time window of 20 to 40 minutes before the entry of an aircraft in a sector. The MSP ensures that the workload and complexity levels for each sector under her/his responsibility do not exceed an acceptable threshold value and coordinates with other MSPs, in the same way that PCs coordinate today. When the TC takes the aircraft under control, the responsibility is of the TC and no longer the MSP. There is no Planning controller and coordination is done automatically. The TC in a 2020 environment controls by exception, thus only to resolve residual conflicts that the MSP has not been able to resolve earlier on.
- The ERASMUS provides TCSA as a core service, and also extra services such as heading and levels computed consistently with TC-SA clearances. The supraliminal mode gives more efficiency to human-automation interaction.
- Radio-Traffic becomes the exception and Data-Link the main channel of ground-board

[3] Optimisation de trajectoires pour la résolution de conflits (Phd 96) Trajectory optimization for conflicts resolution.

cooperation.

5.3.1.4. External technical assumptions made in the 2020 scenario

(249) In the studies related to the 2020 scenario we adopt the same trajectory prediction accuracy as that of the baseline scenario namely an overall accuracy of 10'. It is envisioned that future aircraft guidance system will include enhanced algorithm to secure this value better than today or the ERASMUS Solver will include advanced TP accuracy & reliability assessment functions to allow Solver work with flexible accuracy numbers which will outweigh potential decrease of accuracy by flexibility. It is worth pointing out that if a more accurate trajectory prediction is input and processed in ERASMUS then a performance increase of the solver and therefore of the overall ATM system follows.

(250) It is very likely that there will be quite a large share of equipped aircraft in 2020. Since, the solver is more efficient whenever the share of equipped aircraft is larger, there's great hope that the Solver will be, from that point of view, able to handle the traffic (see Figure 6: Solver performance function of the share of equipped aircraft.

(251) Regarding the traffic density it is more than probable that it will be higher in 2020. Therefore, the solver will have to handle more complex situations and higher computation time will be required. Despite these remarks, the different result described in D1.3.2 show the solver is still efficient even with a higher traffic density.

(252) In 2020, we might expect better fleet equipment and trajectory prediction which will probably yield extra services as defined in the Conception Document (what-else, what if…). Those extra services will induce additional actors (MSP for example), which will, in turn, requires an increase of the resolution cycle duration so that the different actors have time to consider the solution, and approve or reject it. Furthermore, the solver will need extra computation time for computing the expected extra services. Thus, the duration of the resolution cycle will probably tend to increase within the limit of 6 minutes in order to maintain solver performances (more information can be found in D1.3.2).

5.3.2. ERASMUS feasibility from an On-board perspective

5.3.2.1. On-board Feasibility Discussion in 2007 Baseline environment

(253) This discussion relies on several environmental hypothesis (D4.2.1 in detail):

- Only speed changes (in shape of RTA orders) are generated as Conflict Resolution clearances.
- The Aircraft is able to communicate by data-link.
- The Pilot is trained in data-link communication.
- It is assumed that the pilot is willing to accept ERASMUS generated Instruction/Clearance under normal circumstances.
- The magnitude of ERASMUS Instructions/Clearances is in-line with airlines preferences and with operational standards defined by the ATM regulatory authorities. The pilot understands that these clearances are issued by an automated system, without the ATCO knowledge; thus renegotiation of this clearance is not an option.
- Weather influences on the temporal part of TP (15 minutes prediction horizon) causes only about 5s mean error during the CRUISE phase of flight.

5.3.2.2. External technical assumptions made in the baseline scenario.

(254) These assumptions can be considered as the minimal aircraft equipage to support essential functionality of ERASMUS. In particular, the completeness of information included in the Trajectory

Prediction (TP) down-link can significantly change the effectiveness of the ERASMUS CD&R process. The essential functionalities include:

- Ability of aircraft to fly in accordance with the constraints in the agreed route and update the predicted trajectory (i.e. FMS on board). The description of FMS abilities is included in D1.1.
- Ability of Aircraft to downlink Predicted Trajectory. The predicted trajectory should be down-linked in a periodic manner at least as a set of 4D (latitude, longitude, altitude and time) at each trajectory waypoint for the next 20 minutes of flight required horizon. The suitable candidates for TP downlink are described in D1.2.1 in detail.
- ERASMUS relies on TP which should be as accurate as possible. The most accurate source of TP is provided by aircraft avionics. The predicted trajectory accuracy is discussed in D1.1 and D1.2.2 in great detail.
- Ability of Aircraft to meet an RTA at a point within the flight trajectory within a predefined tolerance. The RTA functionality and performance results are discussed in D1.1 and issues related to pilot RTA acceptability in D4.5.1.
- The preferable Speed Clearance from ERASMUS Solver is not a SPEED clearance but a clearance to insert RTA on a selected (already existing or being inserted by ERASMUS on the flight plan) Waypoint. The choice of RTA was made because of the different accuracy properties of RTA and SPEED clearances. The ground based Solver works with a ground reference system. However, the aircraft flies constant speed in the air mass so the reference system is adherent to the aircraft. The accuracy of predicted position of the aircraft decreases with distance in the case of SPEED orders but accuracy of predicted position increases around RTA waypoint. The discussion of RTA functionality is included in D1.1 and in Appendix D of D2.3.2.
- Ability of aircraft to uplink data-linked clearances – CROSS+RouteClearance+FREETEXT. Three essential CPDLC messages were selected for ERASMUS Instruction/Clearance (UM51/UM83/UM169). A Data-link Unit onboard the aircraft must be able to process these messages and respond in an appropriate manner (UNABLE/WILCO/STANDBY). The messages and their properties are described in D2.2.2. One additional function was included under experiments involving the 2007 baseline scenario - Automated Clearance forwarding between on board Data-link Unit and FMS. This functionality decreases the time needed by the pilot to review the Clearance and reduced potential errors in re-typing the Clearance into FMS. Whether this functionality must be provided depends in large part upon the length of time associated with the ERASMUS Solver CD&R cycle. The short time cycle (i.e. 3 minute) employed in the ERASMUS evaluations demonstrated the importance of this functionality in facilitating successful conflict resolution. However, it should not be considered as an essential functionality.

5.3.2.3. On-board Feasibility Discussion in 2020 envisioned environment

(255) In the 2020 environment, the main environmental hypotheses are (D4.2.2 in detail):

- Conflict Resolution issued by ERASMUS Solver includes speed changes (in shape of RTA orders), Lateral route modifications and Vertical route modifications.
- Aircraft trajectories are RBT compliant.
- Aircraft is able to communicate by data-link.
- Pilot is trained to handle data-link communication.
- It is assumed that pilot is willing to accept ERASMUS generated Instruction/Clearance under normal circumstances.
- The magnitude of ERASMUS Instructions/Clearances is in-line with airlines preferences and with operational standards defined by the ATM regulatory authorities. Pilot understands ERASMUS Concept.
- Weather influence on temporal part of TP (15 minutes prediction horizon) causes only approx. 5s mean error during CRUISE phase of flight.

(256) External technical assumptions made in the 2020 scenario are based on envisioned SESAR target

state. In many cases the assumptions would be speculative so the list effectively highlights the functions which are envisioned to increase the ERASMUS solver effectiveness:

- Automated Instruction/Clearance forwarding between on board Data-link Unit and FMS. Especially in case when Clearance includes definition of new waypoint the existence of LOAD functionality is very beneficial. The Instruction/Clearance is forwarded to FMS, understood by FMS and inserted automatically to Secondary/Temporary Flight Plan. As it was highlighted in pilot-in-loop studies the processing of Instruction/Clearance by Pilot can be relatively time consuming (about 160s for 95% cases – D4.5.1) even in presence of this functionality. The further delays should be eliminated as much as possible in general.
- Ability of Aircraft to uplink Wind Forecast. The presence of accurate Weather Forecast directly affects quality of TP accuracy. In relatively short TP horizons (about 20 minutes), during the en-route phase of flight, it is possible to rely only on measured local weather condition, but any increase of weather forecast accuracy is welcome in general. The discussion about quality of Ground based Weather Forecast and impact onto Ground based TP is included in D1.2.1 and D1.2.2.
- FMS support of Flight Level changes between two waypoints. Vertical Flight Planning is basically much more complicated than Lateral Flight Planning. The request for Vertical changes cannot be processed fully automatically. The increase in automation of Vertical change requests can reduce the time needed for Instruction/Clearance handling and increase TP reliability during applying Instruction/Clearance.
- The process of Data-link Clearance assessment by pilot to be simplified on avionics. The pilot-in-loop experiment demonstrates the need for speed up of handling Instruction/Clearance on board aircraft. Simplification of process by avionics software modification would be beneficial. The CPDLC message processing OnBoard is described in D2.2.2.
- Wind Forecast can be inserted also on waypoints during CLIMB and DESCENT. The impact of the quality of Weather Forecast is much higher in altitude transitions than in level flight. Studied avionics did not allow Weather Forecast to be placed onto WP’s during CLIMB and DESCENT phases of flight. Such functionality is envisioned as a major enabler for increased TP accuracy during altitude transitions.
- CLIMB profile in FMS to be constructed more precisely. As mentioned in previous chapter the performance objective of aircraft during CLIMB phase of flight is not to keep geometric profile. This can lead onto significant inaccuracies even between the FMS computed Vertical profile and the actually flown trajectory. The upgrade of FMS algorithm can significantly increase Vertical and Spatial accuracy of TP. The aircraft accuracy in different flight phases is described in D1.2.2.
- Full phase RTA. The ERASMUS solution is based on RTA functionality present on FMS. The availability of this functionality in the all phases of flight (i.e CLIMB, DESCENT, CRUISE) directly increases the applicability of ERASMUS.
- Enhanced weather forecast prediction algorithm in FMS to produce better open-loop accuracy. As mentioned before any upgrade of weather forecast will directly impact TP accuracy. The upgrade of FMS internal wind forecast algorithm can produce increase TP accuracy (about 2 times better as tested in D1.2.2).
- Closed-loop accuracy of RTA to be set at 5 seconds. The investigated RTA algorithms installed on today’s FMS control ETA to within approx. ±20 seconds of the RTA. Decrease of this heuristic can lead to Conflict Resolutions with smaller deviation from current and preferred aircraft speed. The 5s value is driven by requirement to convert mean open-loop accuracy of RTA algorithm into closed-loop accuracy.
- TP downlink includes Pseudo Waypoints (e.g. Top of Climb). The Pseudo Waypoints are often much more important from TP Accuracy & Reliability point of view than Waypoints. The Pseudo Waypoints determines CLIMB, CRUISE, DESCENT part of trajectory and also constrained legs. Inclusion of Pseudo Waypoints in TP downlink can significantly increase the quality of Flight Path reconstruction on Ground. Pseudo Waypoints are included in ADS-B Trajectory Change Report as described in D1.2.1.
- TP downlink includes leg transitions. An inclusion of arc radii (Lateral and Vertical as well) with

every down-linked waypoint obviously increases the reconstructed TP accuracy around waypoints. Arcs are also included in ADS-B as described in D1.2.1

- TP downlink includes assessed accuracy on waypoints. Such functionality would significantly simplify the ground process of Conflict Detection. Otherwise the Conflict Detection engine must reconstruct this information from various sources (e.g. Quality of weather forecast, active control mode of aircraft, etc.). This functionality is not supported by any current data-link standard.
- Aircraft state downlink includes aircraft weight. It was highlighted in Ground TP studies that the presence of actual weight of aircraft will significantly released data-link standard but an inclusion is currently discussed on standardization committees (e.g. SC214/WG78).
- The knowledge of Cost Index can be processed in aircraft performance model and enable the cost effectiveness assessment of Conflict Resolution manoeuvres. So ERASMUS Solver can produce the most cost effective resolution for particular aircraft. However it should be highlighted that Cost Index is currently considered as airline's confidential information. The theory and practical use of Cost Index is described in Appendix A of D1.3.2 and in D4.4.2.

5.3.3. Conclusion

(257) The results that we have obtained through Real Time and Fast Time simulations rely on several assumptions regarding the overall ATM system as well as its ground and onboard sub-systems. As a consequence, if these assumptions are met, it is believed that the concepts and techniques studied and developed in ERASMUS could be technically feasible in the sense that they could be a strong basis for further investigation and eventual implementation.

(258) Many interesting technical issues remain to be studied in particular for a 2020 application:

- Non-nominal cases (weather perturbation, unexpected trajectory modification, technical failure…
- Enrichment of the conflict risk detection models so that it takes into account not only the separation distances but also other criteria (controller stress, angles between aircraft trajectories)
- Input in ERASMUS of aircraft performance models together with airline cost functions related to trajectory modifications and airline operational constraints
- Further assessment of the expected trajectory prediction accuracy for 2020, so that the adopted accuracy and reliability will meet the one provided by future systems.
- The new algorithms for Trajectory Prediction to increase accuracy of TP.
- Implementation of advanced TP accuracy & reliability assessment functions to increase ERASMUS flexibility.
- The simplification of Instruction/Clearance handling of aircraft.
- The impact of different on board functionalities on Conflict Detection and Resolution process.
- The interaction between on-board ASAS functionality and ground based CD&R automation.

5.4. Is ERASMUS economically viable?

(259) ERASMUS concept is well integrated in the future ATM scenario. From the economical point of view this means that most of the air/ground requirements, that the new concept needs, will be already part of the ATM environment and some of the costs that ERASMUS requires will be covered by other projects and initiatives (SESAR IP1 and IP2). Taking into account the importance of the information infrastructure costs both for Airlines and ANSP, the major effort, which will be transferred on the specific ERASMUS costs, is related to the development of the new server and the upgrade of the FMS, as well as, regarding the operating costs, the training of ATCOs and pilots. These will be unavoidable costs in the ERASMUS implementation, also if at the start of the implementation, through the basic services, the new concept will provide clear benefits with no considerable costs.

(260) At the moment, one of the main objectives of the ANSP and Airlines is to accommodate the future traffic increase. The driver for the 2020 vision is the throughput and thus the need to expand ATM Capacity to handle the projected growth in traffic. SESAR expects a fully flexible ATS capacity with a major progress on tools and automation. Controller task load is one of the major factors in airspace capacity; this requires a decrease in tasks and a more automation that should not replace people, but, instead give them a different, place them in a different way in the management of the traffic. The cost-benefit study performed in ERASMUS context showed that the improvement should go in this direction. The data examined showed that ERASMUS, for the ANSP, would improve both cost effectiveness and productivity. In 2020, the controllers will not be able to handle the traffic without appropriate and useful aids. ERASMUS will enable the reduction of the peak of traffic and a quicker accommodation allowing the controllers to manage more aircraft in the same time period. This would bring to an increased sector capacity with the possibility to accommodate the future traffic demand.

(261) From the technical point of view, Airlines will have awareness of the flight efficiency and will potentially decide how to perform the flight. There will be the opportunity for an optimised flight and so the possibility to reduce fuel and flight time choosing the appropriate manoeuvre related to ERASMUS concept. The case study demonstrated the direct potential financial benefits for medium size Airlines in terms of millions of Euro per year. The return of investment has been estimated for the short-medium term (i.e., two-four years) in the case of appropriately selected manoeuvres for Conflict Resolution. Cost & Benefit analysis of manoeuvres has demonstrated the need of such a function in ERASMUS Solver.

(262) Definitively, ERASMUS will allow potential benefits which will be evident for the Airlines and for the ANSP

(263) The benefits for the ANSPs will be more easily seen taking into account that the Controller will be supported by the new ERASMUS services. They will be able to have a clear vision of the management of the flights and in the same time to avoid further workload by the resolution of conflicts. This will allow to manage more flights avoiding recruitment of additional staff.

(264) ERASMUS should be, so, directly beneficial for the Controller workload and in terms of flight efficiency, further it should be indirectly beneficial for the end users because these savings shall be passed to them reducing the unit rate.

(265) In the following paragraph some recommendations to be followed before to implement the ERASMUS implementation are showed. They are based on the above initial findings and on the preliminary assessment of costs and benefits.

5.4.1. Recommendations and best practices

(266) In general, it is recommended to perform a detailed CBA for each specific ACC or Airline, approaching in a more pragmatic way and taking into account the particular costs and benefits characterising that ACC and that Airline. Further it is suggested:

- To carry out low level CBA taking into account also other projects or studies regarding to the improvement of technologies as well as ground and airborne infrastructures which may have an influence on the ERASMUS Cost and Benefits. This would allow to perform an effective assessment of ERASMUS implementation.
- To identify realistic specific schedule, a roadmap to implement ERASMUS considering the particular requirements and needs in order to optimise costs and benefits. In fact not all the ACC or Airlines require the same effort for the ERASMUS implementation.
- To involve and consult stakeholders in each phase of implementation specially in the development and validation phase in order to guarantee the ERASMUS feasibility.
- To cover the full range of stakeholders affected by ERASMUS.
- To assess step by step the ERASMUS costs and benefits taking into account the several

services provided by ERASMUS, starting from the basic ones up to the integration of added functionalities, in order to illustrate the range of possibilities to the stakeholders involved.

5.5. Is ERASMUS environmentally compliant?

(267) The ATM has a important role in the management and control of environmental impacts. Although the aviation has a diverse impact on the environment, not all aspects can be influenced by the ATM System. The aims of ATM Target concept are to ensure that air traffic related environmental considerations are respected and, as far as possible, to reduce adverse environmental impacts (average per flight) in terms of noise, fuel burn, CO2 emissions and so on.

(268) The ERASMUS validation activity performed performance assessments experiments and studies to assess the impact of new concept elements also on the environment aspects. ERASMUS has provided a set of arguments in order to ensure that the concept is environmentally compliant: the impacts on environment, and more specifically the atmospheric issues such as gaseous emissions, were assessed during FTS and through a “case study”.

(269) Most of the ATM impacts on the environment are linked to flight efficiency. The improving fuel efficiency (on the basis of the flight efficiency initiatives) is the most potentially rewarding approach to directly reduce air transport’s atmospheric impacts that encompass gaseous emissions (CO2, NOx, H2O, etc.) and other secondary effect such as contrail triggered cirrus (not addressed). Optimum trajectories allow to reduce the environmental impact of individual flights: trajectory optimum profile reduces fuel burn as well as minor trajectory modifications avoid the most fuel demanding manoeuvres.

(270) Although the FTS results showed that ERASMUS does not bring a significant impact on fuel consumption per flight, the results of experimentation demonstrated that ERASMUS would reduce the number of flight manoeuvres, preserving the executed trajectory as much as possible: minor trajectory modifications, slight and smooth deviations to avoid tactical intervention. Any manoeuvre not planned in Flight plan effectively degrades airline preferences represented by Cost Index (time-related cost/cost of fuel) while an appropriate selection of manoeuvre for Conflict Resolution has direct impact on flight efficiency and fuel burn. From test results is evident that different manoeuvres to solve same situations have different effect on fuel consumption. The test case (the methodology applied to derive the manoeuvre cost in terms of fuel burn has also been used for a comparison analysis of the ERASMUS environment budget) determines that ERASMUS can reduce significantly the CO2 emission (the estimated CO2 reduction has been calculated from sum of fuel saving per year) and consequently the impact of air traffic on the environment. The difference between fuel consumption due to ERASMUS driven manoeuvres and standard trajectory changes to avoid potential conflict, under selected conditions, can be considered as an advantage of ERASMUS approach to ATM CD&R task. Although the effective CO2 savings are strongly dependant on the appropriate manoeuvre selected by the ERASMUS Solver, the direct connection between fuel consumption and CO2 emissions leads to positive and valuable conclusions about the impact of ERASMUS on environment.

6. CONCLUSION

(271) The 'TC-SA based Strategic De-conflicting' design and validation represents the major achievement of the ERASMUS project. Feasibility and benefits assessment clearly demonstrated the high added-value of this approach. During the Project Management Committee in Linköping (September 2007), it was decided to focus on the algorithms Solver and the services provided to the strategic de-confliction activity of the controller. This ERASMUS project re-scoping also aimed at making ERASMUS SESAR-compliant. **Therefore, ERASMUS can be seen as a strategic and political success.**

(272) The ERASMUS strategic de-conflicting service aims at adjusting the 4D Business Trajectory in order to reduce separation management activity. This service provides conflict free trajectory on a short segment of 15 minutes, reducing controllers' workload associated with routine monitoring and conflict detection. Furthermore, the number of ATC interventions to change flight profiles in order to resolve potential conflicts is reduced.

(273) To adjust the 4D Business Trajectory, the ERASMUS project validated:

- A high-precision **Trajectory Prediction** (TP) for both Ground and Air segments performance assessment, which will deliver more accurate and reliable trajectory prediction information;
- Conflict detection and resolution – the Solver - via **Trajectory Modification** performed through minor speed adjustments, with the aim of not being perceived by the controller in order to minimise interference with their actions and cognitive process (notion of subliminal action).

(274) ERASMUS addressed two scenarios (defined by SESAR) regards to the separation management function:

- Baseline scenario (current ATC system);
- SESAR 2020 scenario aiming at demonstrating the feasibility and efficiency of ERASMUS in 2020. To define this 2020 scenario we need to take into account the SESAR 2020 ATM Capability Level, e.g. the ATM capability level 3.

(275) On the basis of fast-time simulations (FTS), it was estimated that with TC-SA the number of potential conflicts to be considered by controllers can be significantly reduced (i.e. up to 80%). With a time horizon of 15 minutes, this corresponds to a small speed change applied to pair of aircraft so as to increase their separation to above the established minimum of separation threshold (e.g. 7 Nm with a reference speed of 560kts). The resulting traffic to be managed by the tactical controller was characterised by fewer conflicts (e.g. 3 conflicts per hour/sector) and a significant decrease in complexity. This is offering an important potential in saving controllers' mental resources and in allowing controllers to cope with a +70% traffic increase.

(276) In addition, the autonomous feature of the TC-SA approach was well accepted by controllers and pilots. The TC-SA acts before the controller takes traffic into account, through minor speed adjustments that modify the longitudinal aircraft trajectory but are not perceptible by controllers, therefore not disturbing their cognitive activity. On the on-board side, pilots with respect to the concerns of their airlines at stake also accepted the idea because the speed changes:

- the objectives of the experiments were more often than not acceptable,
- did not violate the aircraft speed envelope,
- had minimal impact on fuel consumption,
- did not impact the authority of the pilot.

(277) The technical feasibility of the ERASMUS concept of operation heavily depends on ground and board system performances. One among the environmental hypotheses on which the feasibility discussion

relied is the weather influence on the Trajectory Prediction at 15 minutes horizon. This influence was supposed to cause only about 5s error during the cruise, climb and descend phases of the flight. For each scenario, all aircraft were supposed to be equipped so that TP performance was similar to all flights. **Therefore the major risk concerning the feasibility of the ERASMUS concept in the frame of SESAR is a miss match between the defined required accuracy for trajectory prediction and the real trajectory accuracy future systems will be able to provide**.

(278) Even with promising results already demonstrated, ERASMUS is nevertheless calling for further investigations as the current results are based on specific hypothesis with a wide range of open issues still to be addressed, in order to refine and assess the concept especially in the frame of SESAR. Possible follow-up of ERASMUS could cover operational concept development and assessment activities such as:

- Investigation of further manoeuvres than speed adjustments under the general goal to develop a concept for automated Conflict Detection and Resolution via data link exchange between air and ground.
- Introduction of automated systems for Conflict Detection and Resolution opens issues related to Transfer of Legal responsibility which will be addressed in connection with Operational aspects (Safety & Security).
- Further development of automated Conflict Detection and Resolution tools under Legal limitation will be addressed together with new methods of Conflict Detection and Resolution.
- Definition of the modus operandi proposing solutions to issues related to Transfer of Legal responsibility which will be addressed in connection with Operational aspects.

(279) Also, in order to proper enable advanced concept such as ERASMUS strategic de-conflicting services, it is of prime interest to assess the technical enablers of such advanced concept, such as:

- Air and ground trajectory prediction accuracy including the definition of the ground trajectory prediction as well as the air trajectory prediction required.
- FMS capabilities in order to achieve an efficient conflict detection and resolution (i.e. conflict dilution).
- Definition of the required accuracy of Wind prediction and wind modelling.

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