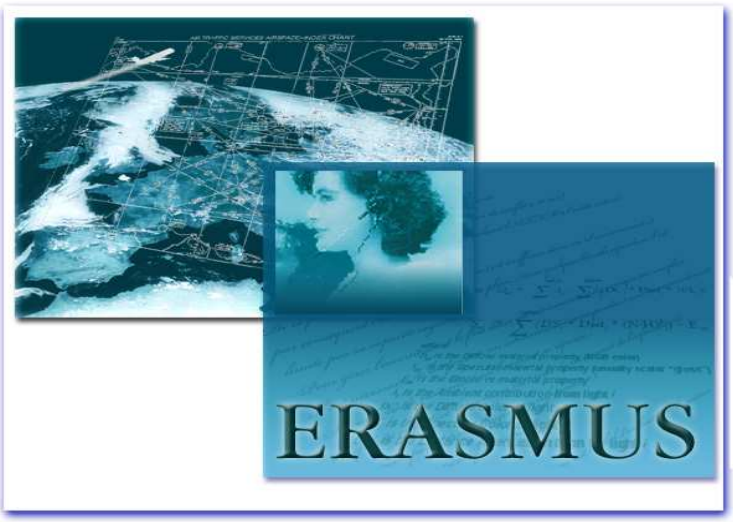
PRIORITY 4 - AERONAUTICS AND SPACE



ERASMUS – Anticipated Benefits

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Contents

1. Introduction

(1) The aim of this document is to outline the potential benefits and costs associated to the implementation of the ERASMUS concept of operations. The results of this analysis, which is mostly qualitative, have to be considered as main inputs to the D4.4 (Cost and Benefit Analysis ANNEX). At that stage, more explicit and exhaustive results should be available for making a comparison with quantified implementation costs.

(2) This document represents the ERASMUS project delivery D 2.3.1 part of the WP2 as defined in [1].

1.1. The ERASMUS project

(3) ERASMUS is a research project supported by the European Commission Directorate General "Transport and Energy" within the 6th Framework Programme.

(4) ERASMUS is an air-ground cooperative project aiming at defining and validating innovative automation and concepts of operations for the En-route phase. The goal is to propose an advanced automation while maintaining the controllers and the pilot in the decision-making loop and keeping situation awareness. The proposed automation approach is radically different compared to the current ones envisaged. There is no willing to replace the human being by a machine, but rather to closely associate the human being and the machine. Using the reasoning under uncertainty (default logic, fuzzy temporal logic) cognitive mechanisms, when extrapolating the present position and speed of each individual aircraft, the controller takes large margins of manoeuvre due to the limited accuracy of the data provided to the controller. In consequence, the fuzzy environment in which controllers work represents an area of autonomy (large margin of manoeuvre) in which the computer can act using Precision Area Navigation, air/ground communication facilities and airborne Flight Management System (FMS). Taking the comparison with the cockpit and the autopilot making minor adjustments not perceivable by the pilot, the ATC automation system would use minor adjustments (vertical/horizontal speed, rate of climb/descent) to resolve (or to dissolve) major part of the conflicts. Such minor actions are not directly perceivable and are not conflicting with their own action and responsibility. According to the air speed that can be safely and freely adjusted by this automatic control, it is estimated that the residual number of conflicts having to be considered by the controllers therefore be very significantly reduced.

(5) The ERASMUS project proposes three innovative applications:

- at the strategic level: subliminal application (located at the Multi Sector Planning function);
- at the tactical level: ATC autopilot and, enhanced Medium Term Conflict Detection (MTCD) applications (located at the sector entity function).

(6) ERASMUS raised a set of questions which represent some concept viability foundations. It is related to the technical, operational and ergonomics knowledge concerning:

- FMS trajectory prediction (accuracy, reliability, …);
- Aircraft speed management tolerance window in the en-route phase;
- Data Link enabler solutions;
- Reliable and accurate information representation on the HMI CWP and cockpit environment;
- Mechanism between the doubt management and the cognitive economy;

- Operator conflict perception versus doubt management;
- Operator trajectory deviation perception versus doubt management;
- Simplified traffic versus cognitive economy;
- Delegation of responsibilities (technical and human actors);
- Co-actions interferences (technical and human actors);
- Multiplicity, complexity and dependant control actions (i.e. sequencing);
- Layered Planning.

1.2. Document structure

(7) This documents is structured on 7 main chapters:

- Chapter 1 is a general Introduction of the present deliverable and provides a concise overview of ERASMUS;
- Chapter 2 gives an overview of the applied Methodology for Anticipated Benefits;
- Chapter 3 lists a set of Assumptions adopted in the context of ERASMUS;
- Chapter 4 describes the main Stakeholders for the ERASMUS subliminal application;
- Chapter 5 identifies major preliminary Benefits obtainable by implementing the ERASMUS tool;
- Chapter 6 identify in a qualitative way which are the major costs to be sustained in order to implement the ERASMUS concept of operation.
- Chapter 7 with conclusions.

1.3. Document evolution & approval

(8) The production and review cycles as defined in the ERASMUS Project Management Plan are applied to produce this ERASMUS Anticipated Benefits document.

1.4. Reference material

(9) The documents referenced in this document includes:

[1] The ERASMUS Description Of Work (Released version – ERASMUS annex 1 – DOW – V1.0 ed 10 03 2006.doc);
[2] ERASMUS Validation Plan
[3] ERASMUS Concept of Operation
[4] "CATS: A complete Air Traffic Simulator" authors: JM Alliot, JF Bosc, N Durand, L Maugis 16th DASC.
[5] SESAR D2, The Performance Target

1.5. Definition, abbreviations and acronyms

a/c	aircraft
ADS-B	Automatic Dependent Surveillance-Broadcast
APM	Aircraft Performance Model
ASAS	Airborne Separation Assurance System
ATC	Air Traffic Control

ATCC	Air Traffic Control Center
CAS	Calibrated speed
CATS	Complete Air Traffic Simulator
CD&R	Conflict Detection and Resolution
CPDLC	Controller-Pilot Data Link Communication
DST	Decision Support Tools
ERASMUS	
ETA	Estimated Times of Arrival
FAA	Federal Aviation Authority
FMS	Flight Management System
FTE	Flight Technical Error
FTS	Fast Time Simulation
HON	Honeywell
KPA	Key Performance Area
KPI	Key Performance Indicator
NM	Nautical Miles
PRC	Performance Review Commission
RTA	Required Time of Arrival
SRC	Safety Regulation Commission
TAS	True Air Speed
T	Tons
TC	Trajectory Change
TCP	Trajectory Change Point
TE	Trajectory Engine
TI	Trajectory integrity
TP	Trajectory Prediction
UP	Users Preferences

Table 1: Table of Acronyms

Activity	Real aspects of the human work (= the effective task)
ATCOs	Air Traffic Controllers
ATHOS	Airport Tower Harmonised cOntroller System
Attention process	Process by which controllers selectively concentre on one thing while ignoring other things
Automation Ironies	Review of the paradoxical or unexpected effects of the automation (principally at a human factor level, e.g. increase of the workload)
Co-action	Situation in where, at least, two agents (technical or human) potentially act on the same object, in the same temporal window, in a same geographic area
COCOM	COntextual COntrol Model. It corresponds to a functional model of human cognition in which intentions are determinant
Cognitive economy	Distribution (sustained by mechanisms and strategies) of the internal resources of the human in the activity achievement
Cognitive process	Human mental mechanism which are used during the activity achievement
Commitment feeling	Subjective commitment of the responsibility in the activity (to be distinguished from the prescribed responsibility)
CORA	COnflict Resolution Assistant
CSE	Cognitive Systems Engineering
CREED	Conflict Risk Evaluation based on Expert Detection
Difficulty feeling	Human subjective assessment and actual experience of the difficulty which is related to a given situation

Doubt management	Process which is linked to the cognitive economy strategy and which aims at determine the adequate level of resources involvement in the diagnosis refinement according to the workload feeling
EC	Executive Controller
ECOM	Extended COntrol Model. It corresponds to a multi-level model of control comprising of Targeting, Monitoring, Regulating and Tracking
ERATO	En Route Air Traffic Organiser
FR	Free Routing
HCA	Human Computer Automation
Human commitment	Level, nature and process which determine the way in which the human involve its resources and his responsibility in his task
HF	Human Factors: study of the human dimensions in a technical system
HMI	Human Machine Interface
JCS	Joint Cognitive System
MFF	Mediterranean Free Flight
MONA	MONitoring Aids
MTCD	Medium Term Conflict Detection
PC	Planning Controller
Perceived risk	Subjective assessment of the level of conflict risk for a given traffic pattern, which is based on perceptive process
Perceptive process	Process by which controllers interpret and organize sensation to produce a meaningful understanding of the traffic situation
Safety feeling	Human subjective assessment of the safety
SRK	Skill based, Rule based and Knowledge based. It corresponds to a human performance model
Task	Prescribed aspects of the human work
Workload feeling	Human subjective assessment and actual experience of the taskload/workload which is related to a given situation

Table 2: Table of terms: Human factors Acronyms and Definitions

2. Anticipated Benefits and Costs: Methodology and Tools

(10) The methodology applied for the Anticipated Benefits Analysis consists to have a first assessment concerning the ERASMUS performance target, identifying some order of magnitude about implementation costs (qualitative), both for the ground and the airborne side, and carrying out a preliminary estimation (quantitative) of the expected benefits.

(11) For the performance assessment it was used a fast time air traffic simulator (CATS) taking into account the subliminal concept of operation definition and hypothesis. The following table summarizes the setting of main parameters took into account during the FTS exercise.

Traffic	Aix en Provence en-route center - W sector
TP accuracy RTA accuracy	0.5 NM 0.5 NM
Time Horizon	15 min
Speed variation	[-3%, +6%]

(12) CATS uses a genetic algorithm computing speed variations to be applied to solve a conflict (increase separation between conflicting aircraft). The solution contains one more step before the resolution, the clustering, which is a transitive closing on all pairs of aircraft. A cluster can be made of different conflict pairs which means different losses of separation. CATS then solves each cluster and try to apply the solution with the whole traffic to control any interference between clusters. The objective is to have an algorithm that is able to solve a loss of separation without creating other conflicts, elsewhere.

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3. Assumptions

3.1. Assessment of need or opportunity

3.1.1. ERASMUS overview

(13) In the current ATM system, the information is qualified as uncertain. This uncertainty represents a risk in such a system and explains why the information management is featured as a risk management. At the opposite, in the cockpit the information is certain because of high accuracy data, and a normative management should be envisaged dealing with nominal situation, closed-loop system and linear system. It represents the condition to allow an increased level of system automation. From decade, all the ATM concepts tried to move the cursor towards information of better quality with is a key issue to move to the full-automated system. However, ERASMUS considers that at the 2020 horizon, the available data quality will be better but far away of the perfect quality and the 2020 system will still remain in the area of uncertain and risk management.

(14) For the ground side, the key issues for the controllers will encompass the risk management (perceived risks, safety feeling) and the associated mental resources management. It required to address the ergonomic and the cognitive issue to optimise the human-machine coupling regards to these key issues.

(15) ATCOs real time tasks are highly complex and far away from being just an ordered series of conflicts detection followed by a sequence of conflicts resolution. They and build a mental overview of the entire traffic context 10 or 15 minutes in advance, whether or not, there is a tangible risk.

(16) The innovation is to consider that the main problem is more related to the complexity and perceived risk than to the classical conflict probe.

(17) In consequence, ERASMUS is proposing an innovative approach to decrease the controller cognitive complexity using FMS 4D prediction and contracting enablers, paving the way towards a more automated system and allowing to envisage an increase of the sector productivity at the 2020 horizon.

3.1.1.1. The forecast fuzziness

(18) Controllers are trained to detect conflicts, at first glance, on their Radar screen.Unfortunately, future positions forecasting is affected by an irreducible **fuzziness** induced by several factors: air vs ground reference speeds, rates of climb or of descent, winds and wind shears, so that there are numerous cases where neither a controller nor a computer can swear that some pairs of aircraft will be, or will not be, safely separated by the 5n.m. standard. Therefore, some non necessary separation manoeuvres are achieved (level change or Radar separation ….) or more tasks are added for surveying the evolution as time elapses. Moreover, making full use of the space offered by the 5n.m. separation standard would require a forecast accuracy of some 1/2 n.m. per aircraft (i.e. less than 4 seconds of flight) which is presently out of reach.

3.1.1.2. Transforming a weakness into an opportunity

(19) It can be shown that this forecast fuzziness could provide an up to now unnoticed most welcomed opportunity. In particular:

- experience has proven that up to a +/- 6 % speed change is unnoticeable by a controller and could in many cases be accepted by the pilots
- each +/- 1% speed change during some 6 minutes applied to conflicting aircraft will increase their separation by 1n.m.

(20) Therefore it exists a “no man’s spaces” allowing autonomous action for the computer action not perceptible by the controllers and not interfering with their strategy, their responsibilities and their own freedom of action. Such a “subliminal” control will do what the controllers would certainly do themselves if they had the necessary time and tools for doing it. It will provide the controllers with a “miraculously easy” traffic flow. It could be implemented with a “rendez-vous” clearance (RTA) that could be sent by any elementary data-link, such clearance as any other clearance having to be to be accepted and acknowledged by the concerned pilots.

(21) This innovative type of control could be rendered more and more efficient as soon as the aircraft are equipped with automated “closed loop” control (namely FMS) for increasing and guaranteeing the preciseness of the forecast during the 15, 20 or more minutes to come. The first equipped aircraft will benefit of a better service, this encouraging more and more user to progressively equip their fleet. Models show that most of the unnecessary “false conflicts” resolutions could thus be avoided and as much as 80% of the conflicts could be solved.

(22) The optimal leading time before conflict for starting the subliminal control could be extended upstream up to the point where the flow will benefit from the complementary pre-organization resulting from the “top down” approach as presently envisaged by SESAR.

3.1.1.3. A wide opened avenue for transition

(23) It can then be expected that ERASMUS will offer the means for getting round all the obstacles blocking the way to radical improvements: uniqueness of control in a given airspace, real time incommunicability between controllers and computers, benefit at each stage of implementation, progressive equipping of the fleets, prior certification.

(24) The way would therefore be opened for introducing all the possible concepts for implementing a progressive and friendly transition of the present system to a more and more efficient one making full and best use of all the available techniques.

3.1.2. ERASMUS Underlying Assumptions and Relevant constraints for the Operational Implementation

3.1.2.1. Assumptions

(25) According to the Concept of Operations and validation Plan, the operational and technical assumptions are the following:

Solutions to complexity problem	Hypotheses	Research Questions	Indicators
Act on traffic complexity delivered to controller	Situations of “doubt” and “no doubt” do exist for the controller.	Are there doubt situations?	Risk perception, safety feeling, difficulty feeling.

(i.e. change traffic distribution)	Reducing controller uncertainty will conserve mental resources.	Does the reduction of doubt situations release the attention processes?	Compare number of aircraft considered with number of aircraft not considered whereas they should be (safety).
Improve traffic prediction information	*ERASMUS applications 2 & 3*	*ERASMUS applications 2 & 3*	*ERASMUS applications 2 & 3*

Solutions to H–M interaction problem	Hypotheses	Research Questions	Indicators
Provide an autonomous system	ATCO will not be disturbed by the minor a/c speed variations computed by technical system	Is ATCO disturbed by modification of a/c trajectories?	Statement of dissatisfaction / frustration Excessive confidence or non confidence
		Do modifications generate added communications between ATCO & pilot?	Nb of ATCO – Pilot communications
		Do modifications create different understanding from ATCO & pilot?	Content of ATCO – Pilot communications
		Are there interferences between TS strategy & operators' strategy?	Nb of technical system actions interrupted
Provide an efficient interactive system	A dedicated HMI can provide info to reduce doubt without disturbing ATCO task performance or cognitive activities	ERASMUS applications 2 & 3	ERASMUS applications 2 & 3
Assess impact on on-board side	ERASMUS integration into the cockpit is acceptable and will not overload the pilot	Is it acceptable for pilot to receive an order coming from a machine instead of an ATCO?	Rate of technical system actions carrying out by the pilot
		Does the integration of ERASMUS in the cockpit overload the pilot? And are pilots disturbed by ERAMUS generated modifications?	Verbalisation (/workload)
Address responsibility issue	ERASMUS needs to be certified to be acceptable to the operators	Is not it mandatory to certify ERASMUS to make it acceptable to the operators?	Tbd
		Can ERASMUS be certified?	Tbd

3.1.3. Technical Issues

(26) According to the Concept of Operations and validation Plan, the initial level of requirements (REQ) and hypotheses (HYP) identified ERASMUS are as follows:

Requirements and Hypotheses applicable to Trajectory prediction

REQ-01	Meteorological information (wind speed & wind direction at different altitudes and temperature …) shall be provided to the Air Trajectory Prediction function with sufficient accuracy, resolution and frequency.

ASSUMP-01	The meteorological forecast data will be updated every 30 to 60 minutes and uplinked to the aircraft.

REQ-02	Meteorological information (wind speed & wind direction at different altitudes …) shall be provided to the Ground Trajectory Prediction function with sufficient accuracy, resolution and frequency.

ASSUMP-02	Sensed meteorological data will be downlinked every 1 to 10 minutes.

REQ-03	Available meteorological information shall be used for the computation of the aircraft flight trajectory predictions, by both the Air and Ground Trajectory Prediction functions.

ASSUMP-03	Standard deviation in wind prediction errors should be no more than 4-5m/s.

REQ-04	The downloaded 4 D trajectory data content, data accuracy and transmission frequency shall be sufficient to enhance the ground trajectory prediction accuracy necessary for the implementation of the ERASMUS Strategic De-conflicting application.

ASSUMP-04	The downlinked 4D Air Trajectory Prediction may consist of a list of active flight plan points, aircraft state and intent data, aircraft performance parameters for construction of speed profile, sensed local weather data and the RNP accuracy (on each point) corresponding to the next 20 to 30 minutes of flight.

REQ-05	Consistency between air trajectory predictions and ground trajectory predictions shall be ensured.

ASSUMP-05	Ground Trajectory Prediction and Air Trajectory Prediction must be within a 10 to 30% margin, depending on phase of flight, at least 95% of the time, both spatially and temporally.

REQ-06	Potential conflicts shall be detected and resolved within a time margin that allows the aircraft to adjust its flight path in a manner that remains within acceptable limits. (Speed tolerance window, passenger comfort, etc.)

Requirements and hypotheses applicable to Speed/RTA based conflict Resolution

ASSUMP-06	The Speed/RTA based conflict resolution manoeuvres should provide the aircraft with 5 to 20 minutes of flight time in which to meet the contracted flight (speed, RTA) constraint.

ASSUMP-07	The Speed/RTA based conflict resolution strategy shall be determined using speed variations bounded between [-12% to -3%] and [+3% to +6%] of the current aircraft speed and checked for speed envelope compatibility.

ASSUMP-08	The Speed/RTA based conflict resolution strategy shall be initiated for aircraft that are detected with minimum spacing of between 5 to 10 NM between aircraft anytime in the next 5 to 20 minutes of flight.

REQ-07	The uplinked speed or RTA constraint shall be automatically uploaded to the airborne system (e.g., CCL, FMS) and inserted into the active flight plan upon pilot acceptance.

REQ-08	The aircraft shall adhere to the “contracted” RTA constraints within acceptable tolerance margins (to be determined by ERASMUS research).

ASSUMP-09	The spatial error for the Air Trajectory Contracting (RTA, speed) function may not exceed 0.5 to 2NM from its contracted position, 95% of the time, when given a time window of 5 to 20 minutes to adjust the aircraft’s flight path.

ASSUMP-10	The temporal error for the Air Trajectory Contracting (RTA, speed) Function should be no more than 4 to 12 seconds, 95% of the time, when given a time window of 5 to 20 minutes to adjust the aircraft’s flight path.

REQ-09	The aircraft shall downlink a “cannot comply” when a RTA or speed constraint can not be met. The aircraft will also notify ATC when a previously accepted RTA or speed constraint can no longer be achieved, even if previously accepted.

<u>Requirements and hypotheses applicable to Route/Level change based conflict resolution</u>

REQ-10	The user shall be able to request the system to provide at least one conflict resolution through the designation of a conflicting pair of aircraft.

REQ-11	On this user request, the system shall identify at least one conflict resolution using : - a level change on one of the two aircraft, - or a route change on one of the two aircraft, - or a level change for one aircraft and a route change on the other one.

REQ-12	The conflict resolution based on Route/Level change shall only be applied on controller request.

<u>Requirements and hypotheses applicable to ERASMUS User's Services</u>

REQ-13	The system shall display all conflicting aircraft by pairs.

REQ-14	On a specific position, the system shall display only conflicting aircraft for a set of 2-4 sectors. (i.e. non-conflicting aircraft are not displayed on this position). These conflicts correspond to the conflicts that have not been solved by a conflict resolution based on Speed/RTA.

ASSUMP-11	The specific position mentioned in REQ-14 is dedicated to a MSP.

REQ-15	On user request, the system shall be able to display the speed constraints applied by the Speed/RTA based conflict resolution.

REQ-16	On user request, the system shall be able to display the guaranteed distance between two aircraft.

REQ-17	The system shall enable the user to assess all conflict resolutions based on Route and/or Level change. For that, graphical tools and "what-if" function shall be provided to display how the conflict is solved.

REQ-18	The system shall enable the user to assess its own resolution strategy.

REQ-19	The system shall provide a workload/complexity indicator per sector for the next 20 minutes.

ASSUMP-12	The workload/complexity indicator corresponds to the number of conflicts to be managed in a given sector.

ASSUMP-13	The workload/complexity indicator will be used by a Multi-Sector Planner. This information will be used to choose a resolution strategy impacting tactical controllers having a low/acceptable workload. MSP will thus request a TC for the implementation of a strategic conflict resolution only when the TC can perform the action.

REQ-20	The system shall alert a specific user when a workload/complexity threshold is raised.

ASSUMP-14	The MSP will be this specific user. When the workload/complexity threshold is raised for a sector, the MSP will take some appropriate actions (e.g. sector re-configuration)

(27) The following table provides the links between technical issues, hypotheses, research questions and indicators.

Solutions to technical issues	Hypotheses	Research Questions	Indicators
Impact of meteorological data on the air trajectory prediction	REQ-01 and ASSUMP-01	What is the impact on Air Trajectory Prediction accuracy as a result of periodic meteo forecast uplinks during the flight?	Metric: Prediction accuracy at a given time horizon (t) and with a periodicity (p) for the meteo uplink, A(t,p) Accuracy Difference (t) = A(t,p) – A(t,0) Indicator: Measure accuracy differences between FMS prediction accuracy generated without the use of meteo forecast uplinks and FMS prediction accuracy generated with meteo uplink forecast.

Solutions to technical issues	Hypotheses	Research Questions	Indicators
	REQ-01 and ASSUMP-01	Will more frequent updates of meteo forecast data improve the accuracy of the air Trajectory predictions? If yes, by how much?	Metric: Prediction accuracy at a given time t horizon and with a p periodicity for the meteo uplink A(t,p). p' = more frequent update Accuracy Difference (t) = A(t,p) – A(t,p') Indicator: Measure accuracy difference between two FMS predictions using different meteo forecast uplink rate.
	REQ-01 and ASSUMP-01	What benefits does the increased meteo information accuracy provide to the stakeholders? (Airlines, ATM…)	Indicator: Assessment of savings (costs, workload, etc.) for stakeholders.
Identify air/ground data to be exchanged and the associated datalink solution	REQ-04 and ASSUMP-04	Are existing datalink standards and technology sufficient to provide the data exchange deemed beneficial on ERASMUS ?	Metric: presence of required data, data resolution, adequate periodicity. Study of existing standards and technology.
	REQ-04 and ASSUMP-04	What is the most effective way to transmit an aircraft's speed profile ?	Metric: presence of required data, data resolution, adequate periodicity. Study of existing standards and technology.
	REQ-01 and ASSUMP-01	What is the most effective way to transmit weather data to aircraft? What are the data to be transmitted?	Identify the impact of each weather data on the air trajectory prediction accuracy. (metric : loss of accuracy when a given meteo data is not used) Study the possible datalink solution. (metric: existence of datalink solution, cost for a new solution)
	REQ-02 and ASSUMP-02	What is the most effective way to transmit weather data from aircraft to the ATC ground system? What are the data to be transmitted?	Study the possible datalink solution. (metric: existence of datalink solution, cost for a new solution) Identify the impact of each weather data sent by aircraft on the ground trajectory prediction accuracy.

Solutions to technical issues	Hypotheses	Research Questions	Indicators
	REQ-07	Can an updated version of CPDLC enable the RTA constraint to be automatically uploaded to the airborne system? Does this uplinked RTA constraint provide enough detail so that it can be directly inserted into the active flight plan upon pilot acceptance? Is the definition of a new datalink application required?	Metric : Safety impact, Development cost. Evaluate the constraint, technical feasibility and cost of such development.
Improve ground trajectory prediction	REQ-04 and ASSUMP-04	What is the impact on Ground Trajectory Prediction accuracy as a result of individual downlinked aircraft parameters?	Metric: Prediction accuracy at a given time horizon t AccuracyDiff (t) = GTP_without_AC_params (t) – GTP_with_AC_params(t) Indicator: Measure accuracy differences between Ground Trajectory Prediction (GTP) accuracy generated without downlinked aircraft parameters and GTP accuracy generated using downlinked aircraft parameters.
	REQ-04 and ASSUMP-04	What set of downloaded aircraft parameters provide the greatest gain in Ground Trajectory prediction accuracy?	Metric: Prediction accuracy at a given time horizon t AccuracyDiff (t, param) = GTP_without_AC_params (t) – GTP_with_AC_param(t, param) Indicator: Measure accuracy differences between Ground Trajectory Prediction (GTP) accuracy generated without downlinked aircraft parameters and GTP accuracy generated using a given aircraft parameters.
	REQ-04 and ASSUMP-04	Is aircraft performance data (e.g RNP, cruising speed) available on ground databases such as BADA, sufficient to meet ASSUMP-05 ?	Indicator: Data available on ground databases as an input into GTP to meet ERASMUS accuracy requirements.

Solutions to technical issues	Hypotheses	Research Questions	Indicators
	REQ-02 and ASSUMP-02	What is the impact on Ground Trajectory Prediction accuracy as a result of periodic meteo downlinks during the flight ?	Metric: Prediction accuracy at a given time horizon t and with a p periodicity for the meteo downlink A(t,p) Accuracy Diff (t) = A(t,p) – A(t,0) Indicator: Measure accuracy differences between Ground Trajectory Prediction (GTP) accuracy obtained without the use of meteo downlink and GTP accuracy obtained with meteo downlink.
	REQ-03 and ASSUMP-03	What is the impact to Ground Trajectory Prediction accuracy if wind prediction errors are more than 2-3m/s ?	Metric: Prediction accuracy at a given time horizon and q quality for wind prediction errors < 2-3m/s and q' for wind predicton > 2-3m/s ; Accuracy Diff (t) = A(t,q) – A(t,q') Indicator: Measure accuracy differences between Ground Trajectory Prediction (GTP) accuracy obtained using "correct" wind (i.e < 2-3m/s) and GTP accuracy obtained with "inaccurate" wind (i.e > 2-3m/s) downlink.
	REQ-04 and ASSUMP-04	What is the overall benefit of this increased ground-based Trajectory Prediction accuracy ?	Metric: Number of false MTCD alarm, Number of effective conflict resolution. Indicator: Compare the number of false MTCD alarm obtained with this enhanced GTP with the number of false MTCD alarms obtained with the initial GTP. Compare the number of effective conflict resolution obtained with this enhanced GTP with the number of effective conflict resolution obtained with the initial GTP.

Solutions to technical issues	Hypotheses	Research Questions	Indicators
Behaviour of Conflict detection function	REQ-05 and ASSUMP-05	What is the impact on the Conflict Resolution results if trajectories predicted by airborne trajectory predictors (TP) and ground-based TP's deviate more than 10 to 30% from each other?	Metric: Number of false MTCD alarm, Number of non-effective conflict resolution. Indicator: compare the number of effective and non-effective conflict resolution obtained with good airborne and ground TP's with effective and non-effective conflict resolution obtained with airborne and ground TP's deviating more than 10 to 30% from each other.
Define/Assess Conflict resolution strategy	REQ-06 and HYP-07	Do speed variations between [-12% to -3%] and [+3% to +6%] of the average cruising speed fall within the airline recommended speed changes?	Indicator: Perform a study on this topic, which include airlines consultation and cost effectiveness study based on simulation if needed.
	REQ-06 and ASSUMP-06	What is the impact of various parameters (time window to detect & deconflict the airspace, speed variation used for resolution, aircraft type being managed (max. cruising speed), on aircraft spacing achievable with ERASMUS subliminal control action ?	Indicator: Perform a study on this topic, which include results of accuracy and sensitivity study.
	REQ-06 and ASSUMP-06	What is the range of RTA errors under all combinations of flight time, airspeed adjustment, for several aircraft types flying in European airspace? (e.g., Air France/KLM fleet).	Indicator: Perform a study on this topic, which include results of accuracy and sensitivity study. Indicator: equations (conditions)
	REQ-06 and ASSUMP-06	Given various wind errors, what are the recommended time window and speed/RTA constraints that provide the needed Ac separation?	Metric : validated time window , speed constraints, RTA constraints Indicator: Assessment based on air/ground simulations.

Solutions to technical issues	Hypotheses	Research Questions	Indicators
Define/Assess trajectory prediction function	REQ-06 and ASSUMP-06	Can we mathematically model the ability for an aircraft to meet the required constraint, given the time window, cruise speed flexibility, and needed aircraft spacing?	Indicator: Perform a study on this topic, which include FMS core performance functions analysis.
	REQ-08 and ASSUMP-09	What is the required navigation performance (RNP) to meet the required aircraft separation upon completion of the ERASMUS action?	Metric : validated RNP value Indicator: Assignment of RNP values to required aircraft separation demands.
	REQ-07	Is Multiple –RTA concept needed to meet ERASMUS requirements?	Indicator: Assessment of single RTA efficiency to build an efficient Conflict Resolution function.
Assess existing aircraft equipments and standards	ASSUMP-11	Is the Air Trajectory Prediction and Contracting performance (accuracy, integrity) of current aircraft equipped with modern FMS sufficient to implement the Subliminal Control application?	Indicator: Perform a study to assess if ground trajectory prediction and conflict resolution required performance are achievable with aircraft equipped with modern FMS.
	ASSUMP-11	What is the minimum percentage of RTA /speed constraint capable aircraft needed to obtain initial ERASMUS benefits?	Metric: percentage of equipped aircraft needed to obtain first benefits. Indicator : Perform a theoretical study on this subject
	ASSUMP-11	What is the percentage of fleet already equipped with FMS having RTA capability in the European core area?	Indicator: Perform a study on the fleet operating in Europe.
	ASSUMP-12	Is the RTA capability on current aircraft sufficient for the implementation of Subliminal control application?	Indicator: Perform a study to assess if ground trajectory prediction and conflict resolution required performance are achievable with current RTA capability.

Solutions to technical issues	Hypotheses	Research Questions	Indicators
	ASSUMP-13	Is ADS-B an acceptable communication mechanism to implement the Subliminal Control concept?	Indicator: perform a paper study on this topic.
	ASSUMP-13	Do existing ADS-B equipped aircraft report prediction data including aircraft state parameters (e.g CAS, intent) ? If yes, is this data accurate enough to compute a ground trajectory prediction with sufficient accuracy in respect to Subliminal Control application?	Indicator : data down linked
	ASSUMP-14	Do existing CPDLC standards enable the transmission of RTA clearances?	Indicator: Analysis of standards, existence of required messages.
	HYP-15	Identify and quantify the drawbacks of using fixed prediction accuracy per a/c type for the conflict resolution function.	
	HYP-15	Identify and quantify the drawbacks of using fixed speed envelope for the conflict resolution function	

Table 3: Traceability matrix of technical issues, hypotheses, research questions and indicators

3.1.3.1. Relevant Constraints for the Operational Implementation

(28) In the context of ERAMUS, two scenarios have been considered:

1) 2015 horizon: use of current technology

Awaiting the availability of standards allowing the exchange of required data between air and ground systems, a solution is envisaged to initiate the implementation of Subliminal Control concept. It consists in using:

- Aircraft currently equipped with RTA guidance function,
- Automatic Dependent Surveillance-Broadcast (ADS-B) application, as currently defined, to transmit the aircraft trajectory intent data to the ground systems,

- Controller Pilot Data Link Communication (CPDLC) application, as currently defined, to enable the exchange of clearances (RTA constraints) and messages between controllers and pilots.

ADS-B in Europe will use 1090Mhz Extended Squitter as the preferred initial technology in line with the recommendations made at ICAO ANC-11. It uses transponders that are already on board aircraft through the Mode S and TCAS mandates for the European airspace, thus minimising investment for airlines.

The use of existing air/ground applications (ADS-B and CPDLC) and current aircraft capabilities required to slightly update the overall system design using the following assumptions:

- ASSUMP-01: The current Air Trajectory Prediction performance enables the implementation of the Subliminal Control concept despite the lack of updated meteorological information and the simplistic meteo model used for the computation of estimates.
- ASSUMP-02: RTA capability available on current aircraft is sufficient for the implementation of Subliminal Control concept.
- ASSUMP-03: ADS-B provides sufficient air trajectory prediction information to implement the Subliminal Control concept in the transition phase.
- ASSUMP-04: Existing CPLDC standards enable the transmission of RTA clearances in the transition phase.
- ASSUMP-05: The pilot will manually configure the FMS to enter the RTA clearance.
- ASSUMP-06: The Subliminal Control concept can be implemented using fixed speed envelope and prediction accuracy per aircraft type in the transition phase.

2) 2020+ horizon: use of next generation technology endowed with more functions and additional accuracy

The key technical enabler for ERASMUS project relies on the use of advanced FMS capabilities and a better air/ground integration. A main objective consists in allowing airborne advanced navigation systems to make possible flying the aircraft in the most cost-efficient manner according to operator preferences and air traffic control constraints. The ERASMUS Subliminal Control application assumes that airborne equipment and ground based system share a 4D trajectory which is consistent and as accurate as needed.

The Subliminal Control application envisages an automatic closed loop to adjust, if necessary, the 4th dimension (time) related to a given segment of aircraft trajectories, in order to solve potential conflicts an make the traffic less complex. This control loop is based on the FMS's Required Time of Arrival (RTA) guidance function. The RTA guidance function is the ability to provide targets for active speed control so as to meet a specified crossing time at a selected waypoint within a certain tolerance. This RTA capability is available in the new generation of FMS.

(29) The physical architecture of the overall Subliminal Control system is illustrated in.

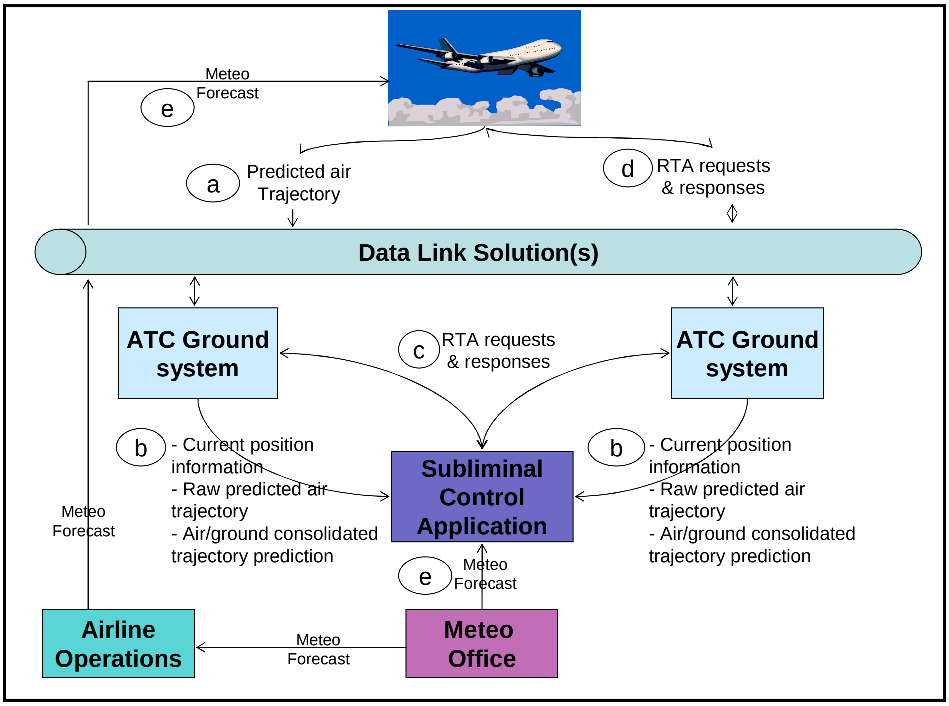

Figure 3-1 Architecture of Subliminal Control System

(30) The Subliminal control application performs periodically the following actions:

- computes the traffic at look-ahead time of about 30 minutes,
- detects the potential conflict,
- identifies strategies to solve the conflicts,
- defines the subliminal control constraints to be implemented by the aircraft
- and sends the corresponding RTA clearance to the ATC ground system responsible for this flight which finally disseminates the clearance to the aircraft (step (c) and (d).

(31) From a functional perspective, the overall Subliminal Control system is designed around seven main functions as shown in:

- The **Air Trajectory Prediction function** determines and updates the list of waypoints that will be overflow by the aircraft with their time estimates for the entire flight trajectory (i.e from departure to arrival airports).
- The **Datalink function** downlinks the list of waypoints that will be overflow in the next 30 minutes to the ground systems and enables the uplink of RTA constraints (subliminal control clearance) to the aircraft. It also enables the uplink of meteo forecast from the airline operations to the aircraft.
- The **Meteorological forecast function** computes periodically the weather forecast. This information is disseminated to the Air and Ground Trajectory Prediction functions to improve the accuracy of the corresponding trajectory predictions.
- The **Ground Trajectory Prediction function** computes consolidated trajectories at an horizon time of about 30 minutes using data collected from the Air Trajectory Prediction from the ATC ground systems.
- The **Conflict Detection function** probes the interference between the trajectories (provided by the ground TP function) and detects the potential conflicts.
- The **Subliminal Conflict Resolution function** selects the potential conflicts to be fixed,

identifies the subliminal control constraint(s) to be sent to the aircraft.

- The **Trajectory Contracting function** adjusts the aircraft speed to implement the RTA constraint (speed control).

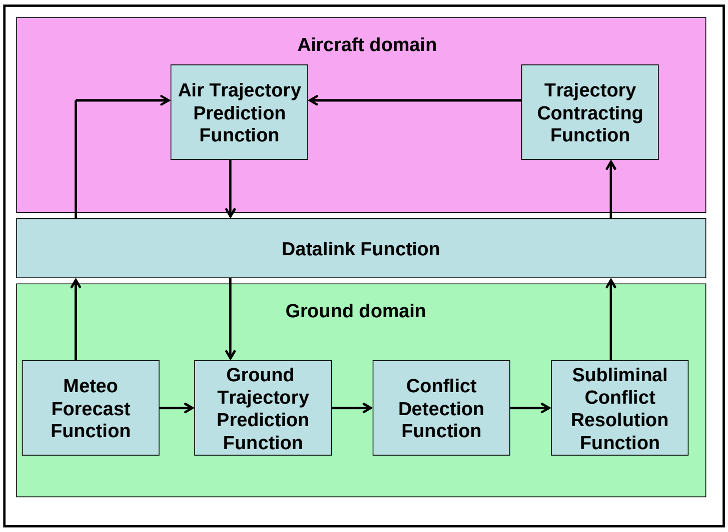

Figure 3-2: The Subliminal Control System - Functional Design

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4. ERASMUS – Main Stakeholders

(32) The CBA process must lead to a shared belief, whether the outcome is positive or not. To achieve this shared belief, a well managed and constructive dialogue must take place between all stakeholders involved in the decision making process. Following sections aim to provide the reader with a short overview of the main ERASMUS stakeholders' perspectives.

4.1. ATC Service Providers

(33) The ATM system needs to maintain the **Air Traffic Controllers** in the loop. There is no willing to replace the human being by a machine, but rather to closely associate the human being and the machine. One of main duty for ATCOs is to foresee if two aircraft are really in a potential conflict situation or not.

(34) Thus, one of the most relevant action of an automated ATC support tool, such as ERASMUS, would have to concern the "doubt" management. It would aim at decreasing the situations generating doubt, in facilitating the perception of conflict risk. The ERASMUS ATC automation tool, in fact, getting profits of more accurate positioning and navigation data, allows to save a significant amount of ATCOs' mental resources by producing a list of potential conflicts and providing resolution advisories to solve them. Moreover, the ERASMUS subliminal application reduces the number of adjustments to be implemented by ATCOs to resolve most of scheduled conflicts. Furthermore, minor actions are not directly perceivable and are not conflicting with their own action and responsibility. The action of the automatic function is not to directly reduce the complexity, but to make it more manageable for the human in optimising the opacity.

(35) Let us recall that the controller task consists in integrating the flights, detecting conflicts, resolving them, doing the required coordination and communicating with pilots. To achieve that, the controller has to carry out complex activities which serve the goal to know the traffic and act efficiently and safely on it.

(36) To sum up, the main idea of ERASMUS is to act on the complexity in exploiting the opacity of the situation to make decrease the doubt and, conjointly improve the safety feeling. Thus, the manageable character of the situation is enhanced without increasing the difficulty feeling of the controller. The system does not provide transparency (that could replace complex situations by complicated ones that the human is not effective to manage) and does not add information or tools to manage. It respects the basic conditions of the controller activity.

4.2. Airspace Users/Pilots

(37) As one of the most relevant end-users, Aircraft Operators are looking forward the functional improvement of the Airspace. They are aiming to capture the future market for air transport services in a sustainable manner and meet the needs of increasingly sophisticated end customer. From that perspective, the notion of a so called "business trajectory" has emerged as being fundamental.

(38) The "business trajectory" is "the representation of the business intention of an airspace user with respect of a given flight. It is aimed at guaranteeing the best business outcome for the flight as seen from the airspace user's perspective. Depending on the airspace users priorities this outcome may be with respect to the minimum time for the flight, the minimum cost, or any other characteristic of the trajectory. Although it may not be as obvious as for commercial airlines, business aviation, general aviation and the military also have some kind of "business"

intention, even if the detailed terminology to define it, and the criteria upon which it is based, are different. Notwithstanding these differences, the accent is on “intention” and naturally, all must be carried out in a manner which guarantees the safety of life and takes into account the need to meet environmental and security requirements. Ref.[5]

(39) ERASMUS is seen as one of main enablers to implement the aforementioned concept of the business trajectory.

(40) Moreover, the flight crews, who will remain legally responsible for the safe operations of the ERASMUS “controlled” aircraft, will necessarily be active players in ERASMUS. Given that any ATM system has to be seen as complex and interdependent, the ERASMUS success or failure will depend on the effectiveness of the onboard avionics interface which has to be efficient and user friendly.

4.3. CFMU/FMUs

(41) The ERASMUS Subliminal application is able to provide a capacity gain. This increment is obtainable in a dynamic way (i.e. in real time). As this dynamic increase of capacity is beneficial only when it is exploited to manage more traffic demands, the Air Traffic Flow and Capacity Management (ATFCM) function will have to use this new capacity.

(42) The subliminal control application can be considered as a new layer towards a real-time management of traffic demand and capacity balancing within the European ATFCM strategy.

(43) The current ATFCM overall approach relies on the planning of the required capacity and on the optimisation of its use to overcome as far as possible the slot allocations in order to minimise the impact on Aircraft Operators. The ATFCM considers continuously and pro-actively all possible ATFCM solutions through an iterative seamless process as from the strategic planning until the execution of operations.

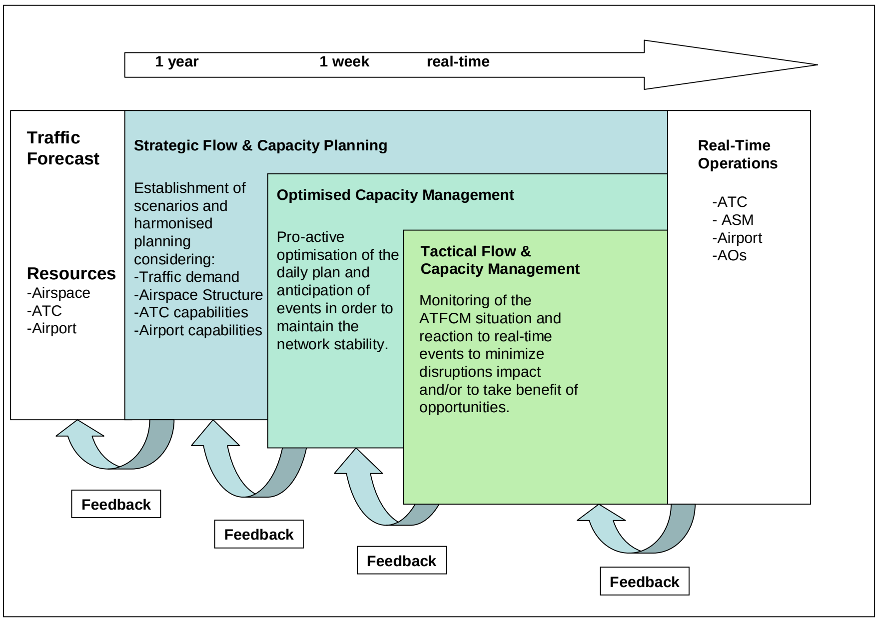

Figure 4-1: ATFCM Seamless Process

(44) In the Tactical Flow & Capacity Management process, the ATFCM monitors the situation and react to real-time events. The subliminal control layer can be considered as an ultimate ATFCM step which interacts on the traffic to create capacity opportunity. The idea is to move from a "static traffic monitoring and reactions" based concept towards a concept based on anticipation and dynamic interactions on traffic.

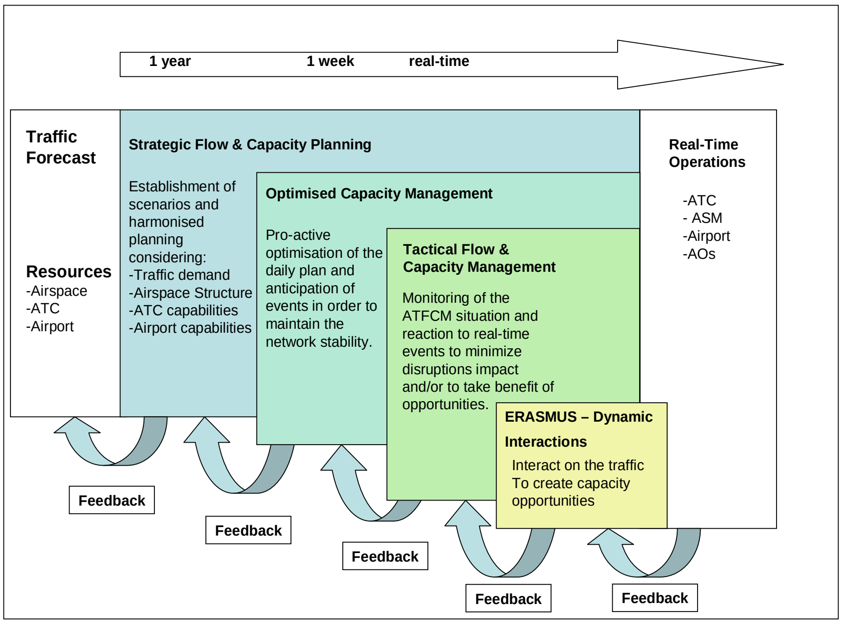

Figure 4-2: ATFCM process including Subliminal Control Application

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5. Benefits Identification

5.1. Performance Objectives

(45) The demand for air transport continues to grow (5% traffic increase/year). In order to cope with this challenging traffic demand the European Commission launched the SESAR project. SESAR is expected to deliver a future Air Traffic Management System for 2020 which can enable-up a 3-fold increase in air traffic movements whilst reducing delays, improve the safety by a factor 10, enable a 10% reduction in the effects aircraft have on environment and provide ATM services at a cost which is at least 50% less.

(46) ERASMUS is expected to provide some targets contribution to SESAR in the en-route sector productivity area.

(47) The Performance Review Report (PRR 2005) of the EUROCONTROL Performance Review Commission (PRC) analyses the performance of the European Air Traffic Management System in 2005 under a number of Key Performance Areas (KPA): Safety, Delays, Cost-Effectiveness and Flight Efficiency.

(48) Following this approach and the E-OCVM[1] recommendations, the ERASMUS project selected a subset of KPA within the current performance framework proposed by PRC, SRC or ICAO[2].

(49) It's worth noting that SESAR has revised this performance framework[3] and possible adjustments might be envisaged during the project, if necessary.

(50) ERASMUS is focusing mainly on the Capacity issue while maintaining and possibly improving the current level of Safety. The capacity will be gained indirectly by improving the controllers' productivity for En Route sectors: the cost effectiveness study is not driven by cost reduction but aims at finding capacity gain. Minor adjustments of speed should improve the flight efficiency by preventing controllers' actions such as vectoring.

(51) Impacts on other performance areas will be assessed during the validation process of the project.

(52) The table below lists the KPAs as identified by the PRC and their correspondence in the ICAO/SESAR framework (Columns "KPA"). The "ERASMUS Target" columns indicate which KPAs are "for the ERASMUS project and provide comments on the objectives of ERASMUS in each performance area.

Key Performance Area		**ERASMUS Target**	
Current Regime	**ICAO proposed**	**Selected KPA**	**Objective**
Safety		Yes	Maintain or improve current level.
Delay, Capacity,	Capacity	Yes	Improve en route capacity:

[1] E-OCVM: European Operational Concept Validation Methodology

[2] Refer to ICAO OCD: Global ATM Operational Concept Document

[3] Refer to SESAR Deliverable 1 (The Current Situation) and Deliverable 2, (The Performance Target).

Key Performance Area		ERASMUS Target	
Current Regime	**ICAO proposed**	**Selected KPA**	**Objective**
Airport Capacity			+20% in 2015 (current airborne equipment) +50% in 2020 (new FMS generation) Maintain and possibly improve the amount of en route delay. Airport and Approach capacity/delay not considered.
Cost Effectiveness		Yes	Improve controller's productivity in en route sectors
Flight efficiency	Efficiency	Yes	Prevent vectoring control actions by minor speed adjustments
Punctuality and Predictability	Predictability	No	Investigate enhancement of ground and air trajectory prediction
Environmental sustainability	Environment	Yes	Reduce adverse environmental impact, optimising the performance of aircraft operations

(53) As mentioned in the section 2, the following results and diagrams are based on a Fast Time Simulation exercise carried out using a Complete Air Traffic Simulator (CATS) model Ref.[4].

5.1.1. Capacity Issue

(54) This diagram presents for one day the traffic partition shift with and without Erasmus working. To solve the different traffic situations in terms of separation (less than 7 Nm, between 7 Nm and 15 Nm and more than 15 Nm) we apply speed modifications between -6% and + 6%. The 7 Nm separation is considered as the dangerousness threshold D. The 15 Nm separation is considered as the "Free of Conflicts" threshold F.

(55) We apply Speed modifications only with the following scenarios:

- Erasmus works on the overall traffic with a separation less than 15 Nm;
- Erasmus works only if at least one aircraft got a separation greater than 7 Nm and all the others;
- Erasmus works only if there is no aircraft with a separation less than 7 Nm.

(56) On the following diagram (Fig. 5-1) N counts aircraft with a separation between 7 and 15 Nm, n counts aircraft with a separation less than 7 Nm.

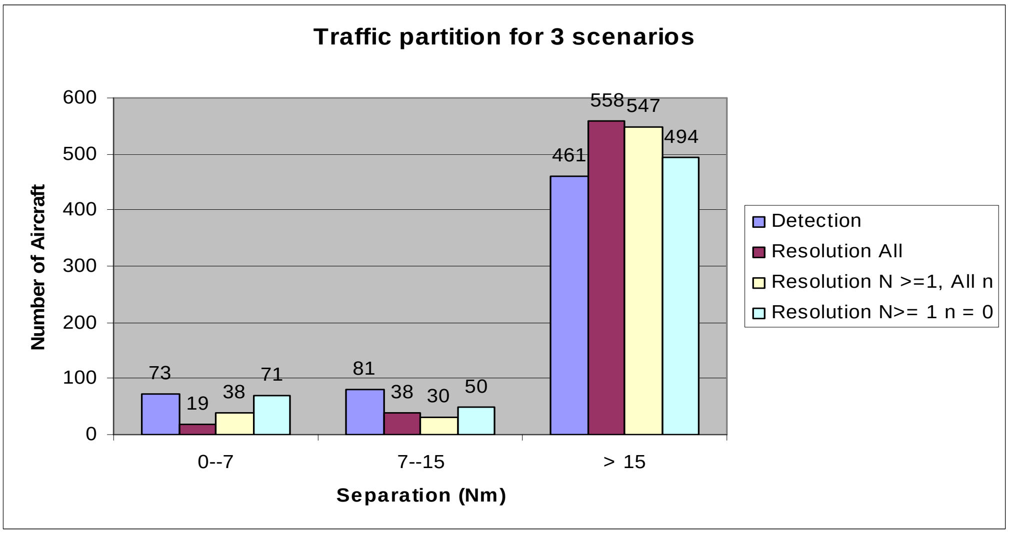

Fig. 5-1 – Traffic Partition with and without ERASMUS (1 day traffic – Aix ACC)

(57) At a glance we can see than the scenario where we apply Erasmus on all the traffic less than F is more efficient than the others. If we present the same kind of drawing but covering only two peak hours the result is more impressive.

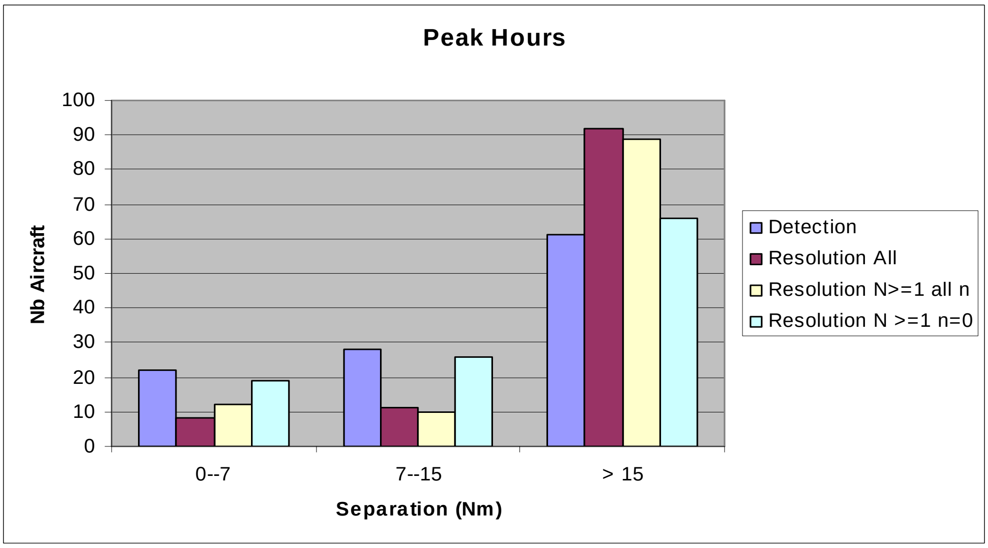

Fig. 5-2 – Traffic Partition with and without ERASMUS (Peak hours – Aix ACC)

- ***Which is the capacity gain provided by ERASMUS?***

(58) Based on our explanation about the capacity source the drawing here after (Fig. 5-3) apply this postulate on the peak hours analyzed on the scenario applying Erasmus on the overall traffic

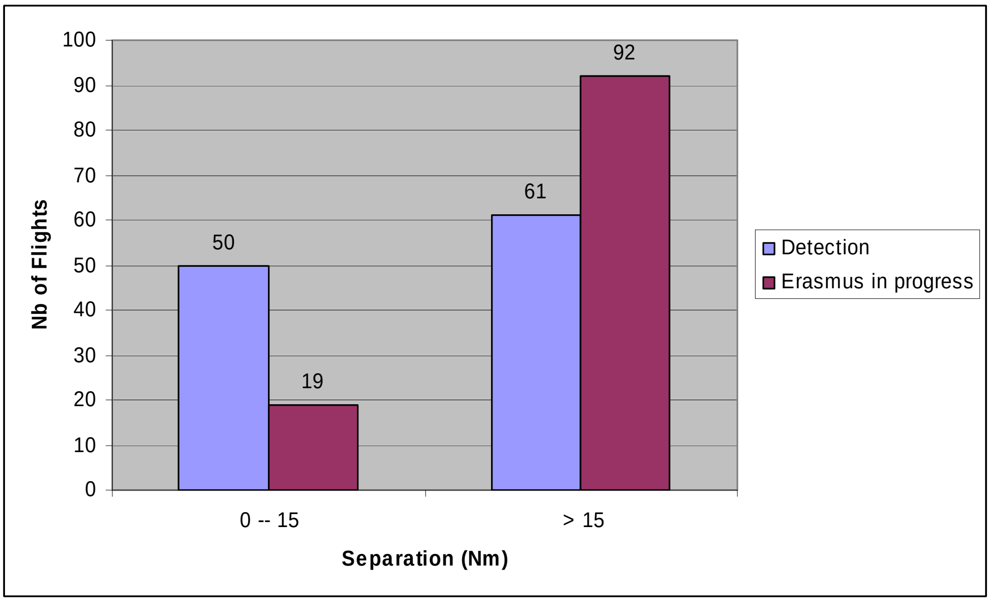

Fig. 5-3 – ERASMUS capacity gain

(59) In this case we merge aircraft which got less than 7 Nm (A) and those which got between 7 and 15 Nm (B).

(60) We obtain M = A+B = 50 before partition shift, we obtain after partition shift M2 = 19.

(61) Based in the postulate describing the capacity gain with the traffic Partition the theoretical capacity gain would be 31. It has to know than the possible number of aircraft in the partition C (flights which have more than 15 Nm as separation is not infinite. For this reason the theoretical gain of 31 in this case need to be decrease by the relevant threshold of the C partition: e.g.: if the threshold is 85, the capacity gain would be : 31 – 92 + 85 = 23, that's means +20% Capacity increase. This +20% capacity must be carefully interpreted and this value represents an order of magnitude of the potential capacity gain. This +20% value is aligned with the 2015 capacity target.

5.1.2. Safety Issue

(62) On the diagram (Fig. 5-4), the figure gives quantitative measures based on mathematical modelling. From this approach, the number of theoretical and potential occurrences related to mid-air collision (aircraft separation < 5 Nm) has been reduced by 75% (19 remaining aircraft of the 73 initial aircraft). It represents a qualitative safety gain to take into account.

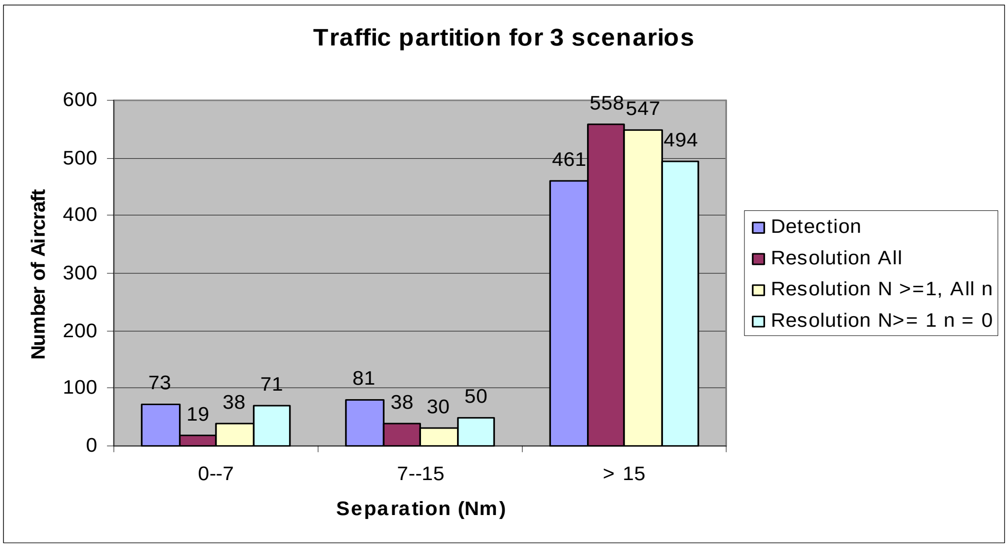

Fig. 5-4 – Traffic Partition with and without ERASMUS (Peak hours – Aix ACC)

5.1.3. Flight Efficiency Issue

(63) The ERASMUS speed adjustment actions impact the route length and the fuel consumption.

(64) The sample concerned a set of 694 flights at the ATCC of Aix en Provence going through the W sector on the 9 of July 2006.

(65) The goal of the resolution is to succeed to have 15 nm miles of separation in the sector. Erasmus only tries to manage separations, between aircraft, which are less than 15 Nm using speed variations. The speed can be adjusted without going beyond the interval -6% and -3%.

(66) The time window is 10, 15, 20 and 25 minutes.

(67) The following data present the fuel consumption and the route length with and without the Erasmus solver working.

Tw	Sp	Nbc	Dm	Dt	Tm	Ct	Cm
600	-6,-3	229	485	336	70	814	3,156
600	-3,-3	247	485	336	70	813	3,151
900	-6,-3	162	485	336	70	815	3,157
900	-3,-3	185	485	336	70	814	3,153
1200	-6,-3	89	485	336	70	818	3,162
1200	-3,-3	124	485	336	70	816	3,159
1500	-6,-3	53	485	336	70	817	3,157
1500	-3,-3	77	485	336	70	816	3,161

With no Resolution							
		Nbc	Dm	Dt	Tm	Ct	Cm
		319	485	337	70	816	3,158

(68) Explanation of the different values :

- **TW**: Time window in seconds;
- **SP**: Speed variation in %;
- **Nbc**: Number of remaining conflicts;
- **Dt**: Distance of the overall flights;
- **Dm**: Average flights distance in Nm;
- **Tm**: Average duration of all flights;
- **Ct**: Fuel consumption for all flights (T);
- **Cm**: Average fuel consumption (T).

(69) We can see than the fuel consumption is not important and presents a way to confirm the Erasmus concept.

5.1.4. Environmental Issue

(70) The ATM system shall have to function in a way that respects local and global environmental constraints. Aviation has a diverse impact on the environment, but not all aspects can be

influenced by the Air Traffic Management system. This addresses the role of Air Traffic Management in the management and control of environmental impacts, which is to proportionately reduce adverse impacts (per flight) by a given traffic demand, and to ensure that traffic constraints (of an environmental nature) imposed on airports and airspace are respected; and, that, as far as possible, new environmentally driven non-optimal operations and constraints are avoided, mitigated and optimised

(71) As environment is inextricably linked with social and economic imperatives, it is essential that the Air Traffic Management approach to address environmental management is set in the wider context of sustainability. The ERASMUS concept and tools indirectly influences the Environmental Sustainability area, through its impact on the synchronization of 4D trajectories.

(72) Areas of potential improvement are emissions and noise. In the context of ERASMUS Fast time Simulations 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 make a preliminary and rough evaluation merely dealing with emission aspects.

(73) Metrics addressed, to determine distance flown and fuel consumption, were used to assess efficiency as well as emissions (environmental sustainability). The results obtained from the first simulation step showed that minor speed adjustments, less than 6%, have no major impact on fuel consumption per flight so that they are not significant from the environmental point of view (emissions).

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6. Costs Identifications

6.1. Costs associated with airborne adoption of ERASMUS

(74) As a major avionics supplier, HWY have analysed the airborne Flight Management Systems (FMS) capabilities on existing, and soon to be launched, commercial and business/commuter aircraft which are expected to be flying within European controlled airspace in the timeframe (2011 – 2020) being evaluated for the ERASMUS concept.

(75) The following FMS types have been analysed: HT9100, GNS-X, GNS-XLS, FMZ-900/920, FMZ-2000, Primus Epic, F70/100, A300/A310, A320 Legacy, A320 Pegasus, A330/340 Legacy, A330/340 Pegasus, A350, A380, MD80, MD90 Legacy, MD90 Pegasus, MD10/11 Legacy, MD10/11 Pegasus, B717, B777, B747-400, B757/767 Legacy, B757/767 Pegasus, B787 and B747-8.

(76) The following table shows us the FMS equipment upgrades needed to meet the requirements set forth by the ERASMUS program. The capabilities listed are not standard equipment on two or more FMS types in the above list of FMS's.

FMS Feature	
Position updating	GPS/GALILEO
RNP Holding	Availability
	Compliant with DO236B/ED75A
	Entry/Exit Procedures compliant with DO236A/ED75A
RTA (Required Time of Arrival)	Enroute: max. achievable tolerance at RTA waypoint
	Enroute: warning threshold to pilot
	Descent/approach: max. achievable tolerance at RTA waypoint
	Descent/approach: warning threshold to pilot
	Multiple RTAs in one flight plan
VNAV	Idle descent with variable speed to control path
	Idle descent with fixed speed but taking into account altitude constraints
	Warning threshold to pilot
Speeds	Speed constraints
	Ability to fly speed profile without VNAV engaged
	Accuracy
	Warning threshold to pilot
Datalink	Up- and downlinking of flight plan data to ATC according RTCA DO219 message set
	Transmission of ADS data
	Compliance with Arinc 702A
Other	Automatic (cold) temperature corrections for altitudes
	SBAS approach capability
	GBAS/SBAS correction

6.2. FMS improvement required to support ERASMUS Subliminal application

(77) The following sections give some further details, in a list format, about the improvements needed by the FMS to support the ERASMUS subliminal application with the expected benefits and the associated costs.

6.2.1. FMS Upgrades – generally

(78) The general upgrades of the FMS are:

- Enhanced RTA capability (one RTA, in future maybe the multiple RTAs capability in cruise, climb and descent phase of the flight).
- Enhanced data-link interface – to receive weather information and AT constraints via data-link directly to the FMS.
- Enhanced pilot interface for communication with ATC (e.g. CCL, 4D Navigation Display).

Benefits • Greater airborne TP range and accuracy, thus safety increases, • Faster adaptation to flight plan changes directed by the ground, • Earlier conflict detection.
Costs • Upgrade FMS with needed capabilities (see above table), • Pilot training, • Maintenance training, • Integrations, installations and certifications.

6.2.2. RNP – RNAV

(79) The RNP-RNAV upgrades are:

- Improvement of aircraft equipage which allows aircraft to fly within defined airspace with high accuracy, reliability, repeatability of all procedures and routes.
- RNP is consistent with previous concepts B-RNAV, P-RNAV. Note, that RNP 0.1 type is under development by all major producers of aircraft equipage.

Benefits: • RNP enables more efficient routing which resulting in shorter paths, fewer delays and lower fuel consumption. • RNP approaches have constant rate of descent which eliminate non-precision approach paths. Both the noise and the risk of controlled flight into terrain (CFIT) are reduced in this manner. • RNP approaches can follow complex paths to avoid obstacles reducing fuel burn and decreasing crew workload. • RNP allows approaches in closely spaced runways in near future[4]. • RNP approaches have lower minima (compared with traditional approaches) resulting in fewer weather-related diversions. • RNP allows for better missed approach guidance (better accuracy thus better safety).
Costs: • Implementation and certification of aircraft for RNP. In fact, a dominant part of the latest produced aircraft (Airbus, Boeing) were certified at or below RNP 0.3 RNAV, however, most aircraft in operation today are still lacking this capability. • Pilot and controller training. This cost is reduced by a direct consistency with the previous

[4] The remaining 3 benefits are not applicable to the enroute phase of flight, which only includes the descent down to FL190.

concepts (B-RNAV, P-RNAV). • Certification of RNP procedures for airports, airways (integration, implementation).

6.2.3. Data-Link

(80) The Date-Link upgrades are:

- Improvement and automation of air to ground communication.
- E.g. the implementation of VHF Data Link Mode 2 (VDL2) for airline operational communication and a first set of ATM applications grouped under the name of LINK 2000+ and 1090 MHz Extended Squitter (1090 ES) for a first set of ADS/B applications.

Benefits

- Decreased controller workload,
- Enhanced air to ground and air to air communication
- Enhanced meteorological situation awareness (including temperature, wind)
- More robust data on aircraft position which enables reduced spacing between AC,
- Uplinks:
  - Better airborne TP accuracy,
  - Earlier anticipation and avoidance of strong winds, thus reduced fuel usage
- Downlinks:
  - Greater GTP accuracy, thus fewer false alarms (conflict detected)
  - Fewer controller interventions
  - Increased safety due to more precise knowledge of AC position,
  - Limited vectoring, development towards Continuous Descent Approach (thus greater fuel economy and significant noise reduction),
  - Greater freedom for the AC to fly optimal routes, speeds, which results in fuel savings.

Costs

- Pilot training,
- Controller training,
- Maintenance training,
- Hardware,
- Integrations, installations and certifications

6.2.4. Cockpit Control Language (CCL)

(81) The Cockpit Control Language (CCL) is a human-centred interaction concept that uses existing pilot/controller knowledge about aircraft operations to provide a common conceptual framework for managing changes to aircraft flight path guidance. It will allow pilots to manage onboard auto-flight systems and incoming ERASMUS directives with minimal impact on current operational practices and training.

Benefits

- Consistent and Uniform Interaction Logic
  - CCL implemented into various airborne systems (e.g. INAV) will ensure that the pilot entered ATC commands are non-ambiguous, legal and correctly inserted into the active flight plan.
  - Provides unifying interaction logic across flight deck systems (autopilot guidance, FMS guidance) and between ground and airborne systems based upon pilot and controller

tasks.
  - Integrates and simplifies information provided in multiple places (tactical/strategic).
  - Reduced errors (operational, procedural, Mode).
  - All flight phases flown with the same crew procedures, controls, display, and training.
  - Significant reduction in pilot misunderstanding of ATC clearances, thus resulting in faster processing of ERASMUS ground to aircraft requests.
  - Provides the pilot with a clear understanding of what automation is engaged, what it is doing now, and what it will do next.
  - System input is consistent with ATC clearance syntax.
  - Provides a consistent interface within which controllers and pilots can negotiate ERASMUS directives and manage tactical DataLink communications.
    Note: Using the same display for crew entry of text flight plan commands and CPDLC messages puts both message types in a similar interface environment; this is appropriate because both types have similar functions (textual representations of flight plan changes that are loadable into the flight guidance system). It also enables crew editing of ATC messages for on-line negotiations with ATC.
  - Provides a tactical interface to pilots that can also be used for ERASMUS as well as existing flight deck systems. This capability can be implemented in an incremental fashion.
  - Supports pre-flight to post-flight planning and conduct of mission by providing a collaborative decision making environment between aircraft, air traffic management, and airline operations centers.
  - Minimizes violations of existing flight deck design philosophies.
  - Interventions are integrated with the plan so that airplane intent is always known to the crew and available to ATC and other airplanes (likely future ATM requirement).
- Consistency between Automation vs. Manual Operations
  - CCL functional logic is consistent with CPDLC, so automatic and manual operations use the same underlying logic and procedures.
  - Logical and procedural consistency between manual operations and system automation making it easier for pilots to intervene (i.e., take over for the automation.).
- Reduces Mode Management
  - Combines FLIGHT MANAGEMENT, AUTOPILOT & AUTOTHROTTLE targets into a single conceptual framework. This integrated interface allows the pilot to think in terms of targets rather than devices and eliminates mode management.
  - Reduces the number of modes and improves consistency in their behavior with manual flying techniques.
  - Simplifies lateral and vertical mode management.
  - Provides the pilot with a clear understanding of what automation is engaged and what it will do
- Adaptability/Extensibility
  - Provides a method of gracefully accommodating changes in the CNS/ATM operational environment (e.g., addition of new targets such as conditional clearances or negative clearances, introduction of new Datalink capabilities) with minimum additional hardware investment. Maintains flight deck commonalities over time.
  - CCL's object-oriented structure allows new functionality to be introduced with no hardware impact and minimal software impact.
  - CCL interaction logic can be used across a variety of input methods.
  - Protects flight crew ability to perform tasks while expanding capability of airline and ATM operations.
- Minimal Training
  - Reductions in overall training costs (FMS programming, mode management).
  - System functionality directly supports pilot tasks.
  - All flight phases flown with the same crew procedures, controls, display, and training.
  - Provides a pilot-centered interface to autoflight system.
  - Intuitive operation that leverages existing pilot knowledge of air traffic control clearance language eliminates most FMS training.

- Input is consistent with ATC clearance syntax. • Reduced Workload - Increased "heads-up" time. - Minimizes discrete steps required to program system. - Minimizes memory load required to learn FMS/Datalink procedures. - Increases recall of rarely used functions (system functions are easily available to the pilot/controller). - Strategic tasks accomplished to the greatest extent with directly available controls and displays. - Improvement and automation of ATC to FMS communication. - All tactical tasks performed with directly available controls and displays. - Decreases pilot workload by integrating GUI, keyboard, and hardware control inputs into a single conceptual framework so the pilot can choose whatever interface is easiest for a given operation – each type of interface can be used optimally, and no procedure requires use of a sub-optimal interface.
Costs • Pilot training, • Controller training, • Maintenance training, • Hardware, software development. • Integrations, installations and certifications • Requires extensive system retrofitting for most existing aircraft (less so for those aircraft equipped with newer FMS w/Graphical Flight Planning) • May require differentiation between ERASMUS directives that are automatically uplinked and those manually uplinked by the controller.

6.2.5. Navigation

(82) The Navigation upgrades are:

- The implementation of SBAS system EGNOS (European Geostationary Navigation Overlay Service) for precise navigation purposes (with GALILEO).
- Certify AC to meet emerging Vertical RNP standards.

Benefits • Accurate navigation enabling direct and optimised lateral routes reduces the flight length, • Increased accuracy and integrity supporting all weather landing operations • Safety is increased thanks to better accuracy, • Smoother descent reduces both a noise, and emissions.
Costs • Pilot training, • Controller training, • Maintenance training, • Integrations, installations and certifications.

6.3. Costs associated with ground adoption of ERASMUS

(83) Main costs to be considered for the ground-side are mainly related to the Subliminal Control Application and in particular to:

- Ground Trajectory Prediction Function;
- Conflict Detection Function;
- Subliminal Conflict Resolution Function.

(84) For the implementation of these functions following costs have to be taken into account:

Costs associated to the implementation of the ERASMUS Tool (ground-side)	
Infrastructure	Total infrastructure costs. Working Life ~ 30 years. • Building: • Auxiliary infrastructure systems: (Energy, Acclimatisation, Supervision systems, Security) • Operational adaptation of the building: (Furniture, Phone systems)
Computer systems	Total computer equipment costs. Working Life ~ 4 years. • Installations, • Integrations and • Certifications
Training	• ATCOs training • Maintenance training

7. Conclusions

(85) Preliminary and brief conclusions, dealing with benefits, are reported in the section 5. The exiguity of results collected up to now, as well as the pure qualitative estimation of implementation costs, carried out in the context of the present document, have not allowed to make a comparative analysis and to draw significant conclusions from the economic point of view, at this stage. More exhaustive evidence will be outlined in the D4.4 (Cost Benefit Analysis Annex) on the basis of a wider set of results and a quantitative appraisal of costs.

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