Impact assessment of policies and regulations to boost ATM technology adoption

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ITACA

INCENTIVISING TECHNOLOGY ADOPTION FOR ACCELERATING CHANGE IN ATM

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Abstract

This document presents the work related to the policy assessment, including case studies definition, simulation experiments through ABM and results analysis, deriving to final conclusions and recommendations. The case studies are defined based on a selection of most promising aviation/ATM technologies/solutions from a wide catalogue of solutions combined with the selected Policy Measures propose by ITACA project. Once operational framework in which the ABM is enclosed is defined, simulation is conducted to validate the effectiveness of the policy measures in terms of technology adoption rate, economic indicators and ATM operational KPIs. Additionally, a sensitivity analysis is also done to test the robustness of the ABM. Lessons learnt, conclusions and future work are derived from the results obtained.

EUROPEAN PARTNERSHIP

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1 Executive Summary

This deliverable provides the performance evaluation of the policy measures (PM) proposed by ITACA project through the execution of the Agent Based Model (ABM), created for this purpose. The ABM aims at capturing the decision-making process of each agent involved in the implementation of the technologies under study, as well as the human behaviour/criteria. The interrelations between the different agents when adopting the technologies are also a key point.

The model provides as outcome the adoption rate among the different agents depending on the technologies selected, together with the most relevant indicators for performance evaluation, such as economical and operational aspects/indicators.

A set of Case Studies (CS) are defined adapted to the policy measures to be validated. Three Case Studies are created: CS01 with historically failed technologies, CS02 with historically succeeded technologies and CS03 with some interesting future technologies to be deployed, located all three in their corresponding time horizons. At first, wide research on technologies to be used for validation is done, creating a catalogue of technologies/solutions. Then, a shortlist is created for each CS, based on operational interesting and technical feasibility. Finally, the selected policies (isolated or combined) are assigned to each CS to build the different Solution scenarios (SOL_SCN).

Once the operational framework is set, the ABM is executed for each CS scenario. The main results show that the policy Cost plus pricing performs the best, especially combined with other policies such as Best equipped-best served, Subsidies or Mandates, depending on the case. The policy combination that performs best also depends on the technology. Depending on its CBA, if the technology is already giving significant/promising benefits, some economic incentives are enough to obtain the desired uptake, but if the CBA of a technology has low return of investment rates, requiring large times to produce benefits, then penalty policies (e.g., mandates) are to be applied to increase the adoption of the technology.

As a general conclusion, the policy maker must use a carrot-and-stick approach: using economic incentives (Best equipped-best served, Subsidies or Cost plus pricing) and penalising when applicable to enforce the uptake (Mandates) but paying attention to the negative effects.

As recommendations for further research on this topic: (i) incorporate the post-processing of the outputs into the model to directly provide the graphs and values we are interested in; (ii) develop a simulator engine that automatically provides the benchmarking of the policies proposed for a given scenario, based on the indicators described in this deliverable or adding new ones.

A combination of both previous improvement steps could be consolidated by creating a meta-model that replicates the outcomes of the ITACA simulation model and linking it to an API that allows the user to obtain real-time data and visuals for a wide range of parameters and indicators. This tool would be highly beneficial for experts to perform what-if analysis of adoption for any SESAR solution.

2 Introduction

2.1.1 Scope and objectives

The air transport industry is constantly facing a host of new challenges. Accordingly, the Single European Sky (SES) initiative, through its technology arm SESAR, is leading a research process seeking to leverage the latest digital technologies to improve European's aviation infrastructure, focusing on combining future growth with safety, efficiency and minimal environmental impact. This strongly centres on technologies that automate, virtualise and enhance digital connectivity in air traffic management (ATM). However, despite all the efforts undertaken, the results have not lived up to the expectations, due to the high level of protection that surround ATM management, a general lack of customer awareness and competition, resulting in a slow pace in technology adoption.

It was recognised by experts that the SES initiative responded to a clear need to improve ATM efficiency. They therefore recommended analysing a variety of policy options to know how those policies can help to the improvement. In addition, the results of one of the first SESAR common projects -Pilot Common Project (PCP)- concluded the need to facilitate the transition from SESAR development phase to deployment. In this context, the development of an in-depth understanding of the factors that drive technology adoption in ATM and the identification of mechanisms to accelerate the Research and Innovation (R&I) lifecycle emerge as critical needs.

The ITACA project aims to shed light on these factors and the drivers and barriers for the adoption of new technologies in ATM, with the goal of supporting the identification, formulation and implementation of policies and regulations that accelerate ATM modernisation. At the ITACA project, we first took a step back and qualitatively assessed the main barriers and levers, how these could be linked to policy measures, and what was the acceptability and applicability of these measures. That analysis was based on a review of literature, involving case studies of successful and unsuccessful experiences with the uptake of new technologies, interviews and one online workshop. In the second part, we took a more quantitative approach with a theoretical analysis, which was illustrated with a numerical example. The result of this qualitative and quantitative assessment was a list of policy measures which should be implementable in a relatively short time frame. These policy measures have been assessed within the ITACA project using an Agent-Based Model (ABM).

The main objective of this deliverable, thus, is to present an operational framework in which the policies proposed by ITACA can be validated through the use of the ABM. The work started with the selection of a set of conceptual solutions and/or innovative technologies (Use cases), both in the past and in the future, with potentially high operational interest or aligned with ATM overall strategies. Then, these technologies are classified into different Case Studies, depending on the timeframe of these solutions, and, finally, some policy measures are assigned to each Case Study. The ABM has been used to validate the policy measures within each Case Study and show the benefit of these on the acceleration of the implementation of these Use Cases, as well as the estimated economic and operational benefits.

Furthermore, a sensitivity analysis has been carried out to test the robustness of the ABM and policies by modifying some exogeneous parameters as input to the ABM. The expected outcome is to demonstrate that the result of the analysis varies according to the variances done to the parameters.

In this deliverable, the main outcomes of both the policy measures benefits analysis and the sensitivity analysis results are presented, together with the feedback on these outcomes from the operational experts.

The methodology presented in this document could be easily extended to be applied to other ATM solutions, just by providing its CBA, as can be shown in Figure 1. By performing the CBA of a new solution, we can obtain the features of the technology needed by the model as input (costs and benefits per agent, etc.). The user should define as well the timeframe that wanted to be analysed and, only if needed, select the set of agents and economic variables (price-demand elasticity and salary growth) needed as input. Then, the model can be run as in any other case.

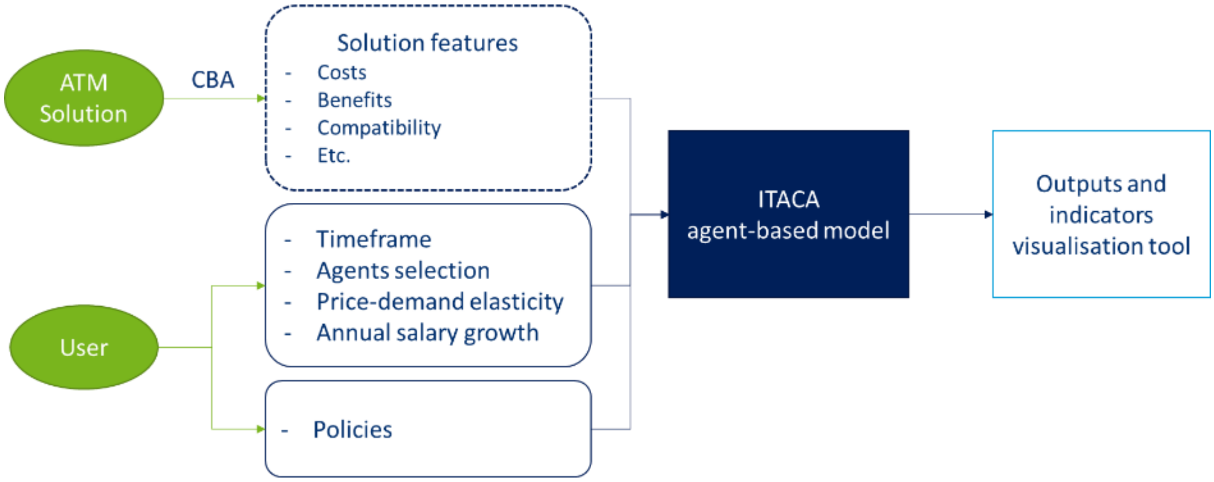

Figure 1: Flowchart to add new ATM solutions in the study

2.2 Structure of the document

The document is structured as follows:

- Section 3 provides an overview of the Case Studies, including the selection of the policy measures and the description of the Operational Framework.
- Section 4 presents how the validation simulation has been prepared, the calibration techniques used and the primary results of it.
- Section 5 presents the analysis of the validation results as well as the main feedback from different stakeholders.
- Section 6 summarises the main results and conclusions.

2.3 List of acronyms

Acronym	Definition
ACE	ATM Cost Effectiveness
ADMS	Asset Description Metadata Schema
AES	Advanced Encryption Standard

API	Application Programming Interface
ATM	Air Traffic Management
CSV	Comma-Separated Values
DCAT	Data Catalogue vocabulary
DMP	Data Management Plan
EU	European Union
FAIR	Findable, Accessible, Interoperable and Re-usable
GPS	Global Positioning System
HSM	Hardware Security Module
ISO	International Organisation for Standardisation
JSON	JavaScript Object Notation
HTTP	Hypertext Transfer Protocol
NAS	Network-attached storage
PDF	Portable Document Format
PKCS	Public Key Cryptography Standards
RAID	Redundant Array of Independent Disks
SFTP	SSH File Transfer Protocol
SHA	Secure Hash Algorithm
SJU	SESAR Joint Undertaking
SQL	Structured Query Language
SLA	Service Level Agreement
SSH	Secure Shell
SSL	Secure Sockets Layer
TLS	Transport Layer Security
URL	Uniform Resource Locator

Table 1: List of acronyms

3 Case studies

3.1 Introduction

The Case Studies are defined to set the operational framework for the validation of the policy measures selected. Different operational/conceptual solutions within the ATM Master Plan as well as the deployment of specific technologies are selected according to their technical and temporal compatibility with the policies. These Case Studies will be used to set the operational environment in both past and future scenarios in order to analyse the potential and effectiveness of the policy measures.

In the next sections, first, a recall of the process followed to obtain the final list of selected policies within WP2 is explained. Then, the applied research methodology is detailed to find the most promising solutions and technologies and their pairing with each of the selected policies. At the end, the final list of Case Studies and validation scenarios for the performance evaluation is derived.

3.2 Policies and regulations selection

Policies' selections are needed in both Reference and Solution scenarios. In the Reference scenario, the historical and current existing policies and regulations were selected, while in the Solution scenario the policies recommended by ITACA are presented. For the Reference scenarios, the policies can only be selected once the technologies are assigned to each Case Study, since they are associated to each specific technology.

In this section, the policy measures of the Solution scenarios are presented.

Policy measures selection for Solution scenarios

The results of the case studies, interviews and workshop, and the economic modelling performed previously during the project (see [1]) were used to come to a selection of policy measures to be investigated further. The selection was made from a long list of policy measures using multicriteria analysis. Criteria such as technical feasibility, economic feasibility, regulatory feasibility, acceptability by stakeholders and the feasibility to assess the policy measures using Agent Based Modelling techniques were included. To obtain robust results, different weighing factors were used. This analysis resulted in this concise list of six policy measures: "flexible charging regulation", "best equipped-best served", "subsidies for ANSPs", "demonstration projects", "involvement of the safety agency" and "realistic timelines" which will be described further down. In addition, two other policies were added: "increase maturity level of the technology" and "mandates". The first was added as it was deemed very important to the stakeholders although it is rather a policy goal than a policy instrument. Concerning, the policy instrument "mandates" it was at first omitted as it was very unpopular and had a very low score for acceptability but at the 1st ITACA stakeholders' workshop held in June 2021 some stakeholders disagreed and the policy was finally included. Below we list the policies with a brief description.

- **PM_001_SOL, Flexible charging regulation:** allows certain agents (ANSPs, Airports etc..) to charge different rates to the users of their services according to the technologies implemented (e.g., an ANSP can give a reduced rate to aircrafts using a particular technology). This kind of policy is known in economic theory to overcome last-mover advantage problems for technologies with network effects and/or decreasing costs with scale. It has been effectively used in Canada to encourage the use of DataLink.

- **PM_SOL_002, Best equipped-best served**: allows certain agents (ANSPs, Airports etc..) to provide a better service to airlines using a particular technology (e.g., give priority at take-off). This is similar to the flexible charging regulation but instead of a monetary incentive, an increase in service quality is used.

- **PM_SOL_003, Demonstration projects**: evidences better dissemination and demonstration of technologies to show their potential. This could help overcome the inherent reluctance to change observed in the sector which is often a barrier for the implementation of new technologies. Showing the benefits and hence increasing the credibility of the innovative technology can help reducing the opposition of the social partners and dissipate potential safety concerns.

- **PM_SOL_004, Involvement of the safety agency**: implies the involvement of the safety agent at an early stage of the technology development (even at research phase). As safety is a major concern in the aviation sector, the involvement of the safety agency in an early stage, increases confidence that the technology will not be abandoned later in the deployment phase due to safety concerns.

- **PM_SOL_005, Realistic timelines**: imposes a realistic timeframe to implement a certain technology, instead of postponing deadlines as targets are not reached. As is the case with increased demonstration efforts, realistic timeframes increase the credibility and facilitates the acceptance by the social partners

- **PM_SOL_006, Subsidies for ANSPs**: provides financial aid to the ANSP to implement a certain technology. For some technologies such as DataLink, the investments for the ANSPs can be large. The subsidies can help when there are stringent budget constraints. Moreover, subsidies are known to be able to overcome principal agent problems when the main investor and beneficiary are not the same agent.

- **PM_SOL_007, Increase matureness technologies**: decreases the gap between TLR4 and the deployment phase.

- **PM_SOL_008, Mandates**: implies economic sanctions imposed on agents not implementing the technologies (e.g., aircrafts that are not equipped are not allowed to use the airspace). Mandates are highly effective policy measures in theory when enforced, certainly when there is an inherent reluctance for change and other monetary policies give too low incentives. The acceptance of such measure can be problematic though.

In Table 2, all the policy measures are listed, together with the names that will be used within the document, the source instigating each policy (literature, stakeholder consultation or economic modelling), and the related issue it tries to resolve.

Name	Policy measure	Source	Related issue
PM_001_SOL	Flexible charging regulation	Case studies ATM Economic modelling	Overcome last-mover advantage for technologies with network effects and/or decreasing costs with scale

PM_002_SOL	Best equipped-best served	Case studies ATM Economic modelling	Overcome last-mover advantage for technologies with network effects and/or decreasing costs with scale
PM_003_SOL	Demonstration projects	Case studies ATM Stakeholder consultation	Overcome inherent reluctance to change, opposition social partners, safety concerns Showing the benefits and hence decreasing uncertainty
PM_004_SOL	Involvement of the safety agent	Stakeholder consultation	Overcome safety concerns
PM_005_SOL	Realistic timelines	Case studies ATM	Overcome inherent reluctance to change, opposition social partners
PM_006_SOL	Subsidies for ANSPs	Case studies ATM Case studies other industries Economic modelling	Overcome the discord between high costs and goal to lower ANSP charges Overcome strict budget constraints Overcome principal agent problem (main investor is not main beneficiary)
PM_007_SOL	Increase matureness technologies	Stakeholder consultation	Overcome gap between TRL4 and deployment Overcome reluctance to change Overcome human resource shortage at ANSPs
PM_008_SOL	Mandates	Stakeholder consultation	Overcome current charging regulation which creates low incentives Overcome reluctance to change, opposition social partners

Table 2: Selected policy measures

3.3 Operational framework

For the definition of the operational framework an iterative process has been followed, starting with extensive research for the identification of any relevant ATM solution. These solutions are related to different areas: *Capacity, Environment, Cost-Efficiency, Operational Efficiency* and *Digitalisation*.

The technology readiness level of the projects was considered, dividing the solutions into 3 categories: (i) Research (conceptual work); (ii) Development (some development is done, and prototype is available); and (iii) Deployment (fully operative and implemented at least in one location). This last one had some sub-categories according to the state of implementation, namely Succeeded, Failed (was developed but not eventually deployed in real ops room or, was deployed but finally unused, then removed from real operation), Delayed and Unknown.

Next iterations consisted of a ranking of the solutions considering different criteria such as availability of information and operational interest (current tendencies, future ATM challenges, etc.). The selection considered operational and technological solutions, and it was also aligned with the six ATM functionalities present in the SESAR's Pilot Common Project (PCP). After a few internal reviews with expert judgement and more iterations where possible limitations of the ABM model were also considered, the final list of possibilities comprised 43 solutions (technologies or conceptual solutions) grouped in 34 Use Cases (UC). Each Use Case only included solutions dealing with the same type of technology.

The Use Cases needed to be assigned to different Case Studies defined, which depended on the matureness of the solutions or implementation status. The proposed classification was *CS01 Historical Failed, CS02 Historical Succeeded, CS03 Future Mature* and *CS04 Future Immature*. All the solutions were assigned according to this classification, considering that the delayed solutions belonged to *CS01 Historical Failed*. Later, it was decided to unify *CS03* and *CS04* into one, resulting in *CS03 Future*. Thus, the final set of Case Studies (CS) were: *CS01 Historical Failed, CS02 Historical Succeeded, CS03 Future.*

Table 3 shows the questions to be answered for each Case Study, in addition to the expected benefit for each case.

Case study	Reference	Solution	Expected benefit
CS01: Historical failed	Which were the policy measures considered and why did they not work?	Would the new policy measures have contributed to achieve their deployment?	The policy measures would have made the deployment succeed.
CS02: Historical succeeded	Has the model achieved the same conclusions as in real case?	Would the new policy measures have contributed to accelerate their deployment?	The policy measures would have made the deployment faster.
CS03: Future	What will happen if we do not apply any policy measure?	Will the new policy measures contribute to accelerate/ease their implementation?	The policy measures would accelerate/achieve the implementation.

Table 3: Case Studies definition

3.3.1 Policy measures and Use Cases assignment

The initial list of solutions consisted of 43 technologies or operational concepts that were sorted into 34 Use Cases. The complete list of these Use Cases is integrated in the Annex A.1. From those 34 Uses Cases, the list was reduced to 10 Use Cases following the process below:

1. <u>Association of UC to PM:</u> Selection of Use Cases that would be/would have been most impacted by each policy measure in terms of faster or easier development/deployment, according to expert judgement. This is reflected in the column 'Use Cases by PM' in Table 4.

2. <u>Association of UC to CS for each PM:</u> Grouping of Use Cases to form scenarios per Case Study.

    2.1 Grouping of the assigned Use Cases to each PM per Case Study ('Use Cases by CS' column in Table 4), depending on their maturity level or implementation status.

2.2 Count of times a Use Case has been assigned to one policy measure (the more the better) per Case Study.

2.3 Compilation of the specific policy measures associated with Use Cases that are assigned to two or more PMs. If a Use Case is only assigned once but it is operationally interesting, it has been considered as well.

2.4 Association of Use Cases/PMs that can complement each other.

These last three steps are reflected in the 'Use Cases consolidated (by CS)' column in Table 4. The correlation between specific policies and technologies was done considering the foreseen effect of the former on the latter and favouring the ones that would be the most influenced or affected. Additionally, the result of this process went through a few internal adjustments.

In the next table, there is an example of the previously explained process that resulted in CS01's PMs. Only the process-involved PMs are included, and in the 'Use Case by CS' column, CS01 is highlighted for clarification purposes.

Policy ID	Policy Name	Use Cases by PM	Use Cases by CS	Use Cases consolidated (by CS)
PM_002_SOL	Best equipped-best served	001, 004, 005, 013, 016, 017, 018, 019, 020, 027	CS01: 001, 013 CS02: 004, 016, 017, 018, 019, 020 CS03: 005 CS04***: 027	CS01's Use Cases (UC): 001*, 013 **UC: assigned PMs** 001: 2,4,7 013: 2,6,7 **Provisional PMs in CS01:** PM_002, PM_004, PM_006, PM_007 *PM_004 discarded, favouring PM_006's operational interest (expert judgement) as both of them only appear once.* **Definitive PMs in CS01:** PM_001, PM_002, PM_006, PM_007, PM_008** **Definitive UCs in CS01:** 018* and 013
PM_004_SOL	Involvement of the safety agency	001, 004, 011, 012, 021, 022, 023, 026, 028	CS01: 001 CS02: 004, 012, 022, 026 CS03: 021, 023 CS04***: 028	
PM_006_SOL	Subsidies for ANSPs	023, 024, 026, 027, 013	CS01: 013 CS02: 026 CS03: 023 CS04***: 024, 027	
PM_007_SOL	Increase matureness technologies	001, 002, 004, 005, 007, 010, 013, 019, 023, 028	CS01: 001, 013 CS02: 004, 007, 010, 019 CS03: 002, 005, 023 CS04***: 028	

Table 4: Example for the process to select the Use Cases for each Case Study

*At the beginning of the analysis the ASAS (UC_001) was chosen as a Use Case of the CS01, but later due to the lack of information on this technology it was decided to discard it. Therefore, it was replaced with the EUROCONTROL Link 2000+

Programme (UC_013), as it was interesting for the study to introduce some solution related to datalink and it was categorised as failed in a general overview because the implementation process was much slower than initially expected.

**PM_001 and PM_008 appear as well in CS01's scenarios because they were added during the Workshop in July 2021, due to expert input and operational criteria.

***CS04 is stated in this table because it was than before merging the initial CS03 Future Mature and CS04 Future Immature into the definitive CS03 Future.

Following the previous steps for the rest of the Case studies, the final selection of Use Cases is the following:

- **UC_013**, Microwave Landing System (MLS): A precision radio guidance system intended to assist aircraft in landing.
- **UC_018**, EUROCONTROL Link 2000+ Programme: A programme to plan and co-ordinate the implementation of operational air-ground data link services for Air Traffic Management.
- **UC_007,** Airport Collaborative Decision Making (A-CDM): Improving the efficiency and resilience of airport operations by optimising the use of resources and improving the predictability of air traffic.
- **UC_011**, Remote towers: A solution to provide simultaneous air traffic control services to two airports from a single location.
- **UC_015**, Continuous Descent Operations (CDO) and Continuous Climb Operations (CCO): Aircraft operating techniques which allow aircraft to follow a flexible and optimum descend and climb flight paths that delivers major environmental and economic benefits.
- **UC_020**, Automatic Dependent Surveillance – Broadcast (ADS-B): A surveillance technology to determine an aircraft's position via satellite and broadcast it
- **UC_005**, System-wide Information Management (SWIM): System Wide Information Management facilitates the exchange of data between applications. The yellow profile services for flexible/affordable ground/ground data communications, while the blue profile services for fast/secure/reliable ground/ground data communications. Specification of the technical architecture and functions that are required to achieve full interoperability between air and ground SWIM segments.
- **UC_021**, SAFEDRONE: A project to acquire practical experience in Very Low Level (VLL) operations where general aviation, state aviation and optionally piloted aircrafts will share the airspace with drones.
- **UC_023**, Dynamic airspace configuration (DAC): A new operational paradigm that proposes a dynamic airspace capable of adapting to user demand.
- **UC_025**, Initial trajectory information sharing (i4D): It consists of the improved use of target times and trajectory information implying fewer tactical interventions and improved de-confliction situation.

In addition, in the following table the assignment of each Use Case to each Case Study is shown, as well as the operational areas they are facing and the impact on the principal stakeholders.

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Case Study	Use Case	Operational Areas	Impact on Stakeholder	
			Adopter	Beneficiary
CS01: Historical failed	UC_013: Microwave Landing System (MLS) deployment	Operational efficiency	ANSPs	Airport operators and ANSPs
	UC_018: EUROCONTROL Link 2000+ Programme	Digitalisation	Airlines and ANSPs	Airlines and ANSPs
CS02: Historical succeeded	UC_007: Airport Collaborative Decision Making (A-CDM)	Operational efficiency	Airport operators	Airport operator and Airlines
	UC_011: Remote Towers	Cost-efficiency	Airport operator and ANSPs	Airport operator and ANSPs
	UC_015: Continuous descent operations (CDO) & Continuous Climb Operations (CCO)	Environment	Airport Operators and ANSPs TMA	Airport operators, Airlines and ANSPs TMA
	UC_020: Automatic Dependent Surveillance – Broadcast (ADS-B)	Digitalisation	Airlines and ANSPs	Airlines and ANSPs
CS03: Future	UC_005: System-wide Information Management (SWIM)	Digitalisation	Airport Operators, Airlines, ANSPs and Network Manager	Airport Operators, Airlines, ANSPs and Network Manager
	UC_021: SAFEDRONE	Operational efficiency	ANSPs	Airlines, ANSPs and Network Manager
	UC_023: Dynamic airspace configuration (DAC)	Capacity	ANSPs and Network Manager	Airlines, ANSPs and Network Manager
	UC_025: Initial trajectory information sharing (i4D)	Operational efficiency	ANSPs	ANSPs, Airlines and Network Manager

Table 5: Distribution of Use Cases per Case Study and their challenge and impact on stakeholders

This table shows that the five operational areas established from the beginning (*Capacity, Environment, Cost-Efficiency, Operational Efficiency* and *Digitalisation*) have been covered. In addition, all stakeholders will be affected in one way or another in each of the Case Studies, even if they are not affected by all the Use Cases.

On the other hand, the assignment of policy measures to each Case Study is also shown in the following table.

Case Study	Solution policy measures	
CS01: Historical failed	PM_002_SOL. Best equipped- best served.	PM_006_SOL: Subsidies for ANSPs
	PM_007_SOL: Increase matureness technologies	PM_008_SOL: Mandates
CS02: Historical succeeded	PM_001_SOL: Flexible charging regulation	PM_002_SOL. Best equipped-best served.
	PM_003_SOL: Demonstration projects	PM_005_SOL: Realistic timelines
CS03: Future	PM_001_SOL: Flexible charging regulation	PM_002_SOL. Best equipped-best served.
	PM_003_SOL: Demonstration projects	PM_004_SOL: Involvement of the Safety Agent
	PM_005_SOL: Realistic timelines	PM_006_SOL: Subsidies for ANSPs
	PM_007_SOL: Increase matureness technologies	PM_008_SOL: Mandates

Table 6: Assignment of policy measures to Case Study

The combination of the policy measures and Use Cases in each CS to build the different validation scenarios is explained in the next section.

3.3.2 Validation scenarios

The validation scenarios (SCN) are divided into Reference scenarios (REF_SCN) and the Solution scenarios (SOL_SCN). Each scenario will consist of a combination of one or a set of policy measures of operational interest and solutions (technologies) aligned with or useful for the policy measures validation. Both scenarios will include the same Use Cases (technologies) with the only difference being the policy measures applied for the same Case Study. While the Reference scenario will include real policy measures, the Solution scenario will apply the ones proposed by the project to be further analysed.

❖ **Reference scenarios**

Research was done to identify the policies and regulations that were implemented in the past or are currently in force associated to each specific Use Case (technology) of each Case Study. These are the policy measures that will be used in the Reference scenario:

- **PM_001_REF**, 29/2009 Data link requirements: Brief introduction of data link services in continuous and homogeneous parts of the European airspace and explanation about why 75% flights should be equipped to allow sufficient capacity increase and the compliance between protocols and appropriate requirements should be ensured for maintaining correct interoperability functions

- **PM_002_REF**, AMC & GM of 965/2012 (Air-OPS) (CCO/CDO): Explanation and recommendations for CDFA and Sap techniques.
- **PM_003_REF**, 1207/2011 Interoperability Requirements (ADS-B): ADS-B 'Out' to enable deployment of ground and airborne applications.
- **PM_004_REF**, 2020/587 amending 1207/2011 (interoperability requirements) (ADS-B) ADS-B implementation deadlines for A/C.
- **PM_005_REF,** Technical and operational requirements for Remote Tower Operations (NPA of EASA)
- **PM_006_REF**, 2019/947 Rules and procedures for the operation of unmanned aircraft
- **PM_007_REF**, 2019/945 Unmanned aircraft systems: Requirements for the design and manufacture of UAS
- **PM_008_REF**, 2021/665 Requirements for providers of ATM/air navigation in U-space: Requirements on ATS providers regarding coordination with USSPs and Coordination procedures and communication facilities between ATS units and USSPs.
- **PM_009_REF,** ATM Master Plan general guidelines
- **PM_010_REF,** IATA Recommendations: Airport - Collaborative Decision Making

The most important aspects for building the reference scenarios have been:

- Reference SCN for CS01 and 02: historical policy measures that were really implemented in the time horizon that impacted on the selected Use Cases.
- Reference SCN for CS03: current policy measures to be extrapolated for future time horizons and available forecast on some new policies to be implemented in the future.
- The reference policy measures selected are related to real policies applied to the Use Cases in each Case Study.

The final picture of the Reference scenarios is the one shown in the following table.

CASE STUDIES		REF SCN
CS01 (Historical failed)	Reference Policy Measures	Isolated effect
		1
	Use Cases	MLS, Datalink
CS02 (Historical succeeded)	Reference Policy Measures	Combined effect
		2, 3, 4, 5, 10
	Use Cases	A-CDM, Remote Towers, CDO/CCO, ADS-B
CS03 (Future)	Reference Policy Measures	Combined effect
		6, 7, 8, 9
	Use Cases	SWIM, SAFEDRONE, DAC, Initial i4D

Table 7: Reference scenarios

❖ Solution scenarios

One of the most important aspects for building the different combinations of policies to create the Solution scenarios has been the identification of the impact that the selected policy measures will have in each of the Use Case selected. As stated before, each Case Study will have one REF SCN and several SOL SCNs, the number of SOL SCN depending on the number of combinations of PMs proposed.

The main reasons for the association proposed between PMs in each CS have been:

1. In Case Study 01, if the policy measures had been in place, the solutions could have been successfully deployed:
    - Both Use Cases are technologies to be equipped with, thus the AUs could have been better served. **(PM_002_SOL)**
    - Subsidies for ANSPs could have helped to recover the implementation costs. **(PM_006_SOL)**
    - Increasing the matureness could have helped the stakeholders to faster the implementation process. **(PM_007_SOL)**
    - The legal mandates could have helped to force the implementation of certain technologies that at first sight was not beneficial for some adopters. **(PM_008_SOL)**
2. In Case Study 02, if the policy measures had been in place, the solutions could have had better/faster deployment:
    - With flexible charging, the ANSP can recover its costs and add a margin to the charge necessary to implement the solutions: A-CDM, CDO&CCO and Remote Towers are conceptual solutions, where the ANSP make great investments, but they are not the main beneficiaries. **(PM_001_SOL)**
    - ADS-B is a pure technological solution, where a better equipment would derive to a better service. **(PM_002_SOL)**
    - Demonstration projects, mostly in Remote Towers, and realistic timelines, mostly in CDO&CCO could have helped these solutions spread and be implemented everywhere. **(PM_003_SOL and PM_005_SOL)**
3. In Case Study 03. If the policy measures are in place, the solutions will have a better/faster development:
    - The ANSPs can recover its costs and add a margin to the charge necessary to implement the solutions, especially for SWIM and DAC that is mostly implemented by ANSPs, so they could charge it through taxes to recover costs. **(PM_001_SOL)**
    - All solutions would have faster deployment with bigger subsidies from ANSPs. **(PM_006_SOL)**
    - Involving the safety agency in the research phase would accelerate the certification process for all solutions. **(PM_004_SOL)**
    - Performing more demonstration projects for product dissemination could reduce the uncertainties that stakeholders could have about the solutions, for instance SWIM and SAFEDRONE. **(PM_003_SOL)**

- The legal mandates would be able to force the implementation of certain technologies that at first sight will not be beneficial for some adopters. **(PM_008_SOL)**
- If better equipped (i.e., i4D), better services will be offered. **(PM_002_SOL)**
- More demonstration projects for SWIM would reduce the uncertainty in such a technology involving many stakeholders. **(PM_003_SOL)**
- Following a realistic timeline for the deployment of voice recognition solutions would ease its implementation duration. **(PM_005_SOL)**
- Increasing maturity level of the technologies to fill the gap between research and deployment would faster deployment for all solutions. **(PM_007_SOL)**

At the same time, the final definition of the different solution scenarios has been carried out with the following ideas in mind:

- To optimise **the effectiveness** of the policy measures in different case studies (e.g., some policies are more applicable to historical solutions and others to future solutions).
- To maximise the impact and effect of the policy measures on the selected solutions' deployment (**compatibility and applicability** of policy measures).
- To test an **isolated effect** of the policy measures individually, so if benefits obtained, we know it is caused by the specific policy measure. Thus, we can compare the effectiveness between them.
- To test the **combined effect** of some policy measures together in a same scenario: if a major benefit could be obtained than considering them separately. This is done subjectively with expert judgement. Other combinations are possible.

The final picture of the Solution scenarios is the one shown in the following table.

CASE STUDIES		SOL SCNs											
		#1_SOL	#2_SOL	#3_SOL	#4_SOL	#5_SOL	#6_SOL	#7_SOL	#8_SOL	#9_SOL	#10_SOL	#11_SOL	#12_SOL
CS01 (Historical failed)	Solution Policy Measures	Isolated effect					Combined effect			-	-	-	
		1	2	6	7	8	1,2,7	1,6,7	1,2,8	-	-	-	-
	Use Cases	MLS, DataLink											
CS02 (Historical succeeded)	Solution Policy Measures	Isolated effect				Combined effect		-	-	-	-	-	-
		1	2	3	5	3,5	1,2	-	-	-	-	-	-
	Use Cases	A-CDM, Remote Towers, CDO&CCO, ADS-B											
CS03 (Future)	Solution Policy Measures	Isolated effect								Combined effect			
		1	2	3	4	5	6	7	8	2,3,4	1,3,6	3,5,7	6,8
	Use Cases	SWIM, SAFEDRONE, DAC, Initial i4D											

Table 8: Solution scenarios

3.3.3 CBA Analysis of the selected Use Cases

A Cost Benefit Analysis has been made to provide the operational and economic aspects of the selected Use Cases. This is a required input for the ABM. A table has been designed, where each column of the table is a Use Case, grouped by Case Study, and each row is either an operational or economic variable/parameter that we need as input for the Agent Based Model.

Exhaustive research has been done in terms of finding operational and economic information about each of the use cases. Still, it has been impossible to find specific information of all the selected Use Cases. Thus, in some cases, assumptions have been made after getting familiar with the Use Cases background or from expert judgement. In those variables with lack of information for a specific Use Case, we have defined a scale (Low-Medium-High Impact) and we have set a numerical value for each level of impact, using as reference values the other Use Cases for which we did found the information.

This seek of information is based on official documentation and expert judgement. There are three sheets in the attached CBA table that indicates the information found and assumptions introduced ("Justified"), then the conversion factors used to transform this information into numerical values for the model ("Intermediate") and finally the values used by the model as input ("Model input").

In the table below, we include all the variables that have been analysed as well as an example of the "Model input" sheet of one of the Use Cases.

UC ID				015
Use Case				CCO & CDO
Case Study				CS02
Date				2018
Cost	Airlines	Retrofit cost	euro/aircraft	165000
		Increased cost for new aircraft	euro/aircraft	400000
		Training cost	euro/staff	1000
	Airport Operators	Cost of implementation in a big airport	euro	0
		Cost of implementation in a small airport	euro	0
		Training cost	euro/staff	0
	ANSP en-route	Cost of implementation	euro/service unit	2.5
		Training cost	euro/ATCO	1000
	ANSP terminal	Cost of implementation	euro/service unit	2.5
		Training cost	euro/ATCO	2000
Benefit	Airlines	Fuel saving	euro/flight	28.4
			litre/flight	43
		Delay reduction	euro/flight	31.1
		Air navigation charges reduction	euro	0
	Airport Operators	Capacity increase	Low/Medium/High	Medium
		Cost reduction	Low/Medium/High	0
		Indirect benefits	Low/Medium/High	High
	ANSP en-route	ATCO hour productivity increase	%	0.005
		Capacity increase	%	0.04
	ANSP terminal	ATCO hour productivity increase	%	0.005
		Capacity increase	%	0.04

<table>
<tr><td colspan="3">Compatibility with existing technology</td><td>TRUE/FALSE</td><td>TRUE</td></tr>
<tr><td colspan="3">Duration of technology research phase</td><td>Months</td><td>50</td></tr>
<tr><td colspan="3">In service life</td><td>Years</td><td>20</td></tr>
<tr><td colspan="3">Implementation requirements</td><td>Low/Medium/High</td><td>Low</td></tr>
<tr><td colspan="3">Implementation Time</td><td>Years</td><td>6</td></tr>
<tr><td rowspan="2">Effect on labour</td><td rowspan="2">Labour unions</td><td>Percentage of salary reduction</td><td>Low/Medium/High</td><td>FALSE</td></tr>
<tr><td>Redundancies</td><td>Low/Medium/High</td><td>FALSE</td></tr>
</table>

Table 9: CBA table example

Attached in the Annex A.2, the complete Cost Benefits Analysis table can be found, as well as a more complete explanation of how it was built.

3.3.4 Validation metrics

The successful benchmarking of regulations and policy measures requires a comprehensive assessment of their impact along different dimensions. To that end, the outputs of the model selected for the analysis are to be representative of the performance of the European ATM system in the situations tested.

For the sake of clarity, we will define the following concepts:

- Key Performance Area (KPA): a broad focus area encompassing one or several goals or objectives.
- Performance Indicators (PIs): indicators used for the purpose of performance monitoring, benchmarking and reviewing.
- Key Performance Indicators (KPI): are a mean of measuring and/or summarising the current position and the direction and rate of change of progress towards a particular goal or objective. They are those performance indicators used for the purpose of performance target setting.
- Output: they consist of any measurable variable or parameter within the model. Indicators are defined in terms of output values or functions of them.

This project aims to be consistent with previous literature, in particular with ICAO Performance Framework, the SES Performance Scheme, the SESAR Performance Framework and with the assessment framework defined in the SESAR projects ACCESS, APACHE and COMPAIR. Although the terms performance indicator and key performance indicator are often used as synonyms in other contexts, both the SES Performance Scheme and the SESAR Performance Framework differentiate between them. Therefore, in this project we will make the same distinction.

We first selected a subset of indicators from the mentioned literature that are considered more relevant for the objectives of the project. The criteria for the selection are based on finding a balance between the fields investigated, so it gives a sense of realism for policy makers, and on the expected capabilities of the model to capture said measures. Then, we have complemented these indicators with additional indicators aimed to capture dimensions that fall outside the scope of the aforementioned performance schemes but are considered necessary for a comprehensive assessment framework. For more information on the selection, see D3.1 ITACA Simulation model [2].

The ITACA project considers the following clusters of KPAs and associated indicators:

- Technology adoption KPAs and indicators
- Economic KPAs and indicators
- Operational KPAs and indicators

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KPA	Indicator	Description
Technology adoption effectiveness	**Time for adoption (global / per agent type)**	It is considered as the delay between availability date of the technology and average adoption year. The average adoption year is calculated as the average of the year of adoption, for a given technology, with respect to the number of agents that adopted the technology. The agents considered can be of a specific type or of any type of adopter. This metric is computed per technology.
	Market share (global / per agent type)	The market share is calculated as the percentage of agents that adopt a technology. The agents considered can be of a specific type or of any type of adopter. This metric is computed per technology.
	Speed of adoption (global / per agent type)	It is an alternative measure to the time for adoption. It considers the area behind the adoption curve of a technology. The faster the adoption, the larger the area for the same level of market share achieved. The agents considered can be of a specific type or of any type of adopter. This metric is computed per technology.

Table 10: Technology adoption KPA and indicators

KPA	Indicator	Description
Economic efficiency	**Social welfare**	It includes the consumer and producer surplus (sum of the effects on terminal ANSPs, en-route ANSPs, airlines, airports and passengers) plus the net benefits to third parties (externalities) and government surplus. For the externalities, it was considered the effect of CO_2 and SO_2 emissions. The cost per kg of each gas and the estimation of gases produced from the fuel consumption are obtained from [3].
Distributional effects	**En-route ANSP surplus**	En-route ANSPs' benefit minus cost. ANSP benefits include their income from navigational charges, calculated as the unit rate established for the period times the service units managed, and the regulatory benefits obtained. ANSP costs include labour costs (ATCO and non-ATCO staff), operating costs, depreciation costs (linked with adoption) and regulatory costs.

	Terminal ANSPs surplus	Terminal ANSPs' benefit minus cost. ANSP benefits include their income from navigational charges, calculated as the unit rate stablished for the period times the service units managed, and the regulatory benefits obtained. ANSP costs include labour costs (ATCO and non-ATCO staff), operating costs, depreciation costs and regulatory costs.
	Airline surplus	Airlines' benefit minus cost. The benefits include the income provided by the passengers, calculated per flight as the capacity of the aircraft times the load factor of the flight and its average airfare, and the regulatory benefits. Costs for airlines include labour costs, operating costs (fuel, navigational charges, landing fees, aircraft purchase and delay costs), depreciation costs and regulatory costs. The delay costs are calculated multiplying the average delay of the flights times the cost of delay as provided by [3].
	Airport surplus	Airports' benefit minus cost. Its income includes the aeronautical revenues paid by the airlines as landing fees and passenger fees and non-aeronautical revenues, modelled as a function of the total number of passengers representing the income from parking, commercial area rental, real estate, etc. The benefit sums the income and the regulatory benefits. The costs include labour, operating costs, depreciation costs and regulatory costs.
	Passenger surplus	Passengers' benefit minus cost. Passenger benefit per route, also called utility, has been calculated as 1.25 times the initial average price of the route for the first year of the simulation. The remaining years, this utility grows at the same rate as the annual change in salaries. Passengers' costs include the cost of the ticket, which evolves each year according to the actions of the agents, and the cost of delay. The cost of delay is calculated considering passengers' value of travel time [3] and an average delay per route modelled with the average delay associated to the ANSPs, airports and airlines involved in the route. The average delay is modified with the adoption of new technology.

	Government surplus	Government benefit minus cost. It includes cost of regulation (subsidies provided) and the benefit from application of fines to the stakeholders (mandates). Financial controls and regulatory oversight are considered negligible for the policies proposed.

Table 11: Economic KPAs and indicators

KPA	Indicator	Description
Environment (SES KPA)	**Average fuel burn per flight**	The model simulates flights individually, considering the time for each route of the flight and typical fuel consumptions at different regimes of the engines, it is possible to estimate the fuel burn per flight. The average is computed at each time step of the simulation.
Capacity (SES KPA)	**En-route throughput per unit time**	Throughput is considered as the number of flights managed by an en-route ANSP or a group of them in one day.
	TMA throughput per unit time	Throughput is considered as the number of flights managed by a terminal ANSP or a group of them in one day.
Cost-efficiency (SES KPA)	**Average union-wide Determined Unit Cost (DUC) for en-route ANS**	This KPI is computed in the same way as in the EUROCONTROL ACE reports, as the ratio of en-route ANSP costs (in real terms) to service units at charging zone level. For the calculation of total costs in the simulation we consider the labour costs, operating costs, depreciation costs, exceptional items and possible regulatory penalties.
	Average union-wide Determined Unit Cost (DUC) for terminal ANS	This KPI is computed in the same way as in the EUROCONTROL ACE reports, as the ratio of terminal ANSP costs (in real terms) to service units at charging zone level. For the calculation of total costs in the simulation we consider the labour costs, operating costs, depreciation costs, exceptional items and possible regulatory penalties.

Table 12: Operational KPAs and indicators

4 Design of simulation experiments

4.1 Overview

The **scenarios** feed the model, containing all the required information to perform the desired analysis. Since we aim at benchmarking policy measures for technology adoption, the scenario must include the policy (or policies) to be tested and the technologies available to be adopted. Other aspects included in scenario definition are the exogenous variables, the time step duration, the initial year and the simulation time horizon.

The **policies** to benchmark, and **available technologies** are information provided by the solution and reference scenarios defined in Section 3.

Exogenous variables provide boundary conditions to the simulation and can be seen as limiting factors for the action of the agents. They include aspects that do not depend on ATM evolution but affect the agents involved, such as passenger demand, fuel prices, engines' fuel efficiency, and consumption and unitary labour costs.

The model includes different types of **agents** representing the most relevant actors in ATM technology adoption: (i) regulatory bodies, which impose policies and regulations; (ii) technology providers, which develop the technological solutions to be adopted; (iii) ANSPs, which provide ATC services and adopt new technologies; (iv) airports, which also adopt ATM technology; (v) airlines, which perform their operations, pay for ATC and airport services, and adopt new technologies; and (vi) labour unions, which defend the labour conditions of their guild. Each of the mentioned agents possess a given behaviour derived from their own goals (e.g., profit maximisation), interactions with other agents and behavioural biases. Their goals and biases drive their decisions about technology adoption and operational decisions such as future projections, flight allocation, management of human resources and establishment of navigational unit rates.

By simulating the scenarios, we can obtain distributional and aggregated results for each time step of the simulation. The outputs of the simulations are analysed according to the **performance framework** that includes the metrics related to technology adoption, economics and operational performance, as described in Section 3.3.4.

Figure 2 provides a high-level overview of the workflow of the model and its main components. For more details, see D3.1 ITACA simulation model [2].

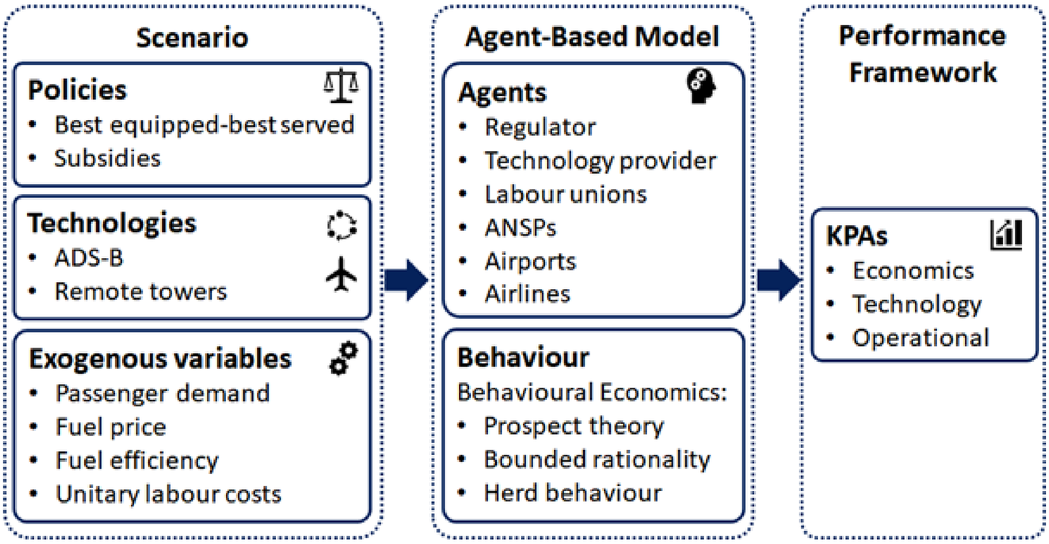

Figure 2: Overview of the workflow of the model

4.2 Simulation setup

Policy measures and technology characteristics (costs, benefits, requirements, etc.) that define each scenario have been defined in the previous section.

Apart from that, the model requires to define variables that are exogenous to the agents but affect them in their operations. Table 13 displays this information.

Exogenous variable	Description	Agents directly influenced
Passenger demand	The initial passenger demand between airport pairs is set as an external value to the agents. It affects the revenues of all the different agents involved in the industry. The past demand between airport pairs is obtained from EUROSTAT. To obtain projections of those values, the model considers the traffic annual growth rates from EUROCONTROL's 2040 traffic demand forecasts [4]. The effect of the COVID-19 pandemic has not been taken into account. Passenger demand includes price-demand elasticity, which modifies the demand that is captured by the airlines in relation to the ticket fares. Elasticities are non-dimensional variables. A negative elasticity means that the relationship is inverse: when prices increase, demand decreases. The more negative the number, the more elastic the demand is with respect to the price, i.e., the more sensitive to changes airfare ticket prices. For example, with an elasticity of -0,6, when price increases a 1%, demand would decrease by a 0,6%. We should differentiate between elasticities at route level and elasticities at airline level, which are more elastic compared with the corresponding route due to airline substitution. Elasticity values are taken from[5]￼ and set as –2 for airline elasticity and –0.6 for route elasticity.	Airlines, airports, en-route ANSPs and terminal ANSPs
Fuel Price	Fuel prices are subject to market rules out of the scope of the problem under investigation. Fuel is an important operational cost for airlines; thus, variations of its price are reflected in the model. The variation is the same for different spatial locations. Historical and forecasted Jet-A fuel prices (€/kg) up to 2050 provided by the US Energy Information Administration (EIA) are considered [6].	Airlines

Engine efficiency	Fuel consumption evolves over time with technology evolutions not related with ATM. The model considers two types of engines: one for a typical narrow-body aircraft (CFM Leap 1A). The fuel flow for those engines (kg/s) at 4 different stages of the flight (take off, cruise, approach and idle) is retrieved from the ICAO Aircraft Engine Emissions Databank. This data, together with the annual reduction rate of average fuel burn of new aircraft estimated by [7], allows us to estimate past and future engine efficiencies.	Airlines
Unitary labour costs	The labour costs of different positions are needed for the cost calculation of the agents: pilot unitary costs (MIT, 2020), non-cabin staff unitary costs (IAG, 2019), ATCO unitary costs (BOE, 2019), non-ATCO ANSP staff unitary costs (EUROCONTROL, 2017), and airport staff costs. The obtained labour costs are adapted to different regions employing unitary labour costs at country level [8]. Their growth in time is controlled by a user defined parameter, which was set to a growth of 1% each year.	Airlines, airports, en-route ANSPs and terminal ANSPs

Table 13: Exogenous variables

It is important to note that the exogenous variables are imposed to the agents in the simulation and are not modified by agents' actions. This is a simplification of reality but considered as feasible for our model since ATM is a relatively small sector within the aviation industry and we can assume that the changes on exogenous variables are not greatly affected by ATM technology or the policies proposed.

On the other hand, we are also assuming that the variables listed are not dependant between each other. This is a limitation of the model and the reader must note that labour costs, passenger demand and fuel price are highly interconnected: changes in global demand affect fuel prices and vice versa and an increase in salaries also affects positively to demand. However, the model is not able to capture those interactions which are outside the scope of the project. For example, traffic demand decreased after the economic crisis of 2008 and that lowered fuel prices (because of the lower demand of fuel). The lower fuel prices with no interaction with demand changes, make that airline agents lower their airfares, increasing the demand captured due to the effect of price-demand elasticities. We can see that demand during the crisis increases in the model contradicting reality.

According to the main objective of the model, to evaluate the technological adoption, and the different objectives and actions to be carried out by the stakeholders, the agents included in the simulator have been grouped into four groups:

- Adopters:
  - Agents included: en-route and terminal ANSPs, airports and airlines.
  - Main role and objective: to optimise their objective function (i.e., to achieve an optimal result in their operational tasks). New technology is for them an enabler to achieve this.
  - Decisions: technology adoption.
  - Agents they interact with: all.

- Technology providers or industry:
  - Agents included: technology providers (ground/airborne, including aircraft manufacturers).
  - Main role and objective: to provide a set of ATM technologies to the adopters.
  - Decisions: set market prices.
  - Agents they interact with: adopters.

- Regulators:
  - Agents included: policy makers.
  - Main role and objective: to monitor and execute the applicable policies in order to ensure global welfare.
  - Decisions: decisions derived from the policies and regulations in place.
  - Agents they interact with: adopters and labour union.

- Labour unions:
  - Agents included: labour unions.
  - Main role and objective: to lobby regulator and adopters in order to defend the labour conditions of their guild.
  - Decisions: obstruct or support a deployment.
  - Agents they interact with: adopters and regulator.

The adopters' group is formed by the stakeholders who are in a position to adopt new ATM technologies. The model aims at providing a representation as realistic as possible of their mechanisms and drivers for technology uptake; on the other hand, the behaviour of the technology providers, labour unions and regulator agents will be represented by simpler behavioural rules. The adoption decision of the agents takes into account several aspects:

- Costs and benefits of the technologies over time.

- Risk perception associated with each technology, which depends on parameters related to the time required for implementation, compatibility with the existent technologies and behaviour of the adopter agent.

- Behavioural economics aspects.

- Effect of the policies, which can modify the previously mentioned aspects.

- Interdependencies on the adoption. There is an exchange of information on the aim between the agents to assess the expected benefits more accurately. On one side, airlines will only adopt if some airport or ANSP adopts at the same time or have already adopted and vice versa. On the other hand, when airlines do not have to adopt, terminal ANSPs only adopt if the en-route ANSP or the airport(s) that share the charging region with them adopts or have already adopted. Other interdependencies not capture by the model might be possible for specific technologies, e.g., for MLS, the principal adopter are the airports but airlines and terminal ANSPs might adopt regardless the decision of the airports.

In the context of ITACA, we differentiate between en-route and terminal air navigation services (ANS). The former provides services during the en-route operations. The latter includes approach ANS (ascending, descending) and aerodrome ANS (landing, take-off and taxi operations). This distinction is important since terminal ANS have been partially or fully privatised in some European countries (e.g., UK, Spain, Sweden and Germany). En-route and terminal ANSPs may have different objectives (cost-recovery vs profit maximisation). The interviews with different ATM stakeholders reported in [1] show that the technology adoption dynamics may be significantly different depending on the ownership model (private vs public) and the revenue scheme (cost recovery vs liberalised market).

The number and initial conditions of a range of features of each adopter agent in the model are stored in data files accessible by the model. Those initial parameters include economical (operating costs), operational (airlines' load factor, ANSPs' number of ATCOs, service units, etc.) or behavioural characteristics and have been defined considering real adopters financial and operational data. The user is able to add or modify the existing agents if needed, for example, to input the parameters asked to participants in the serious gaming experiences. For further details on the definition, features and behaviour of each agent, the reader may refer to D3.1 ITACA simulation model [2].

The agents have to react to the application of the policies proposed in [1], listed in section 2.2. To that end, we made an effort to translate the idea behind the policies to actions that affect the agents in the simulation model. Agents' behaviour was designed to be affected by the policies. However, modelling the policies implies some assumptions to them that limit the outcome that we can appreciate with the model.

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Policy	Modelling assumptions	Parameters involved
Flexible charging regulation	ANSPs are allowed to add a margin to its unit rate when they adopt a given technology. This margin is calculated as a given percentage of its unit rate. There are different manners of applying a flexible charging regulation, the one proposed here is the case of a *Cost plus pricing.* Then, for now on we will refer to this policy with this name. The margin obtained by ANSPs with the Cost plus pricing policy is considered for them as regulatory benefit. The extra margin paid by airlines due to this policy is considered part of their flights' operating costs.	Unit rate margin (%)
Best equipped-best served	ANPSs that implement a given technology are able to apply an asymmetric charging regulation: i) flights that have equipped the technology have a reduction of a given percentage on its unit rate, and ii) flights not equipped with the technology have an increase of a given percentage on its unit rate. The margin obtained by ANSPs with the Best equipped-best served policy when they apply a charge penalty is considered for them as regulatory benefit. The reduction in charges applied is considered as a regulatory cost. The extra margin paid by airlines due to this policy is considered as regulatory costs for them while the reduction in charges is considered as regulatory benefit.	Charge reduction (%) Charge penalty (%)
Demonstration projects	Uncertainty related to technology implementation costs would be reduced. This is modelled by reducing the risk perception of the technologies by a given percentage.	Risk perception reduction (%)
Involvement of the safety agency	Uncertainty related to expected research phase times would be reduced for the different technologies in which the safety agency has been involved in. This favourable advice provided by the safety agency is modelled as a reduction in risk perception.	Risk perception reduction (%)
Realistic timelines	The modification of targets and mandatory implementation deadlines set in the SESAR ATM Masterplan, based on consultation with the stakeholders is modelled as a reduction of the risk perception on the technologies.	Risk perception reduction (%)

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Subsidies	This policy gives funding and subsidies to the different adopters with the end of paying the implementation costs. It is modelled as an injection of capital to the agents equal to a percentage of the implementation costs of a technology. The capital is provided in a given number of fractions, one each year, after the implementation is made. Subsidies are considered by the adopter agents as regulatory benefits.	Percentage of implementation cost subsidised (%) First year subsidy, delay since adoption (years) Number of fractions of the subsidy
Increased maturity level of the technology	Reduction of expected development phase times for some of the different technologies. Since the R&D phase of the technologies is out of the scope of this model, this policy is modelled as a reduction in the risk perception of the technologies involved.	Risk perception reduction (%)
Mandates	The mandates impose sanctions if adoption is not achieved by the stakeholders. If the technologies are not adopted by the agent, a percentage of their revenues has to be paid to the regulator (e.g., 2%). The fines paid by the adopter agents are considered for them as regulatory costs.	Percentage of benefit subtracted (%)

Table 14: Policy modelling

As it can be seen in Table 14, the modelling of Demonstration projects, involvement of the safety agency, realistic timelines and increased maturity level of the technology implies the same actions to the agents. Therefore, we propose to merge them for the study as "Policies aimed at reducing the risk perception associated with the ATM technologies".

After running the model and applying a post-processing, we obtain the outputs listed in Section 3.3.4.

4.3 Calibration and validation

Calibration and validation are necessary processes to obtain reliable results from the simulations to be analysed.

For calibrating the model on first place, real data from the represented stakeholders has been used for defining their initial conditions within the model, e.g., initial cost distribution, number of passengers, pilots, etc. Regarding the adoption, the behavioural parameters were calibrated in order to match the levels and rate of adoption of the historical use cases.

Once calibrated, the model has been validated in different ways: (i) employing a first face validation conducted by the members of the consortium; (ii) employing participatory simulations to validate both the assumptions and behaviour of the agents at individual and aggregated level and (iii) through the application of a sensitivity analysis to the input parameters of the model.

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Finally, a calibration of the parameters that define the different policies has been performed through an exploration of their combinations. This exploration allowed not only to calibrate the parameters to be used as reference but also to discuss the effects of the policies depending on how their parameters are defined.

In this section we present the methodology followed to conduct the participatory experiments, sensitivity analysis of the inputs and exploration of the policy parameters.

4.3.1 Participatory experiments

Participants have been engaged in validating the ABM model at two levels: (i) through a behavioural analysis of the model, which aims to validate its assumptions, and (ii) involving them in participatory simulations, which aim to validate the ABM in an individual/agent level and in an aggregated/system level, using both formal and informal methods.

The aim of the behavioural analysis of the ITACA ABM is to validate and enable the fine-tuning of the conceptual model, meaning the assumptions made by the modellers while building the ABM and the behavioural aspects embedded in the ABM. Those behavioural aspects include the behavioural economic biases included to agents: hyperbolic discounting, prospect theory and herd behaviour. In order to gather data for conducting the behavioural analysis, interviews with experts in the field of air traffic management were conducted. The most interesting results which helped to fine-tune the ABM are the following:

- The acceptance rate was on average more than or equal to 80% for all technologies. Past technologies had a slightly higher, though not significantly, acceptance rate. This confirms to a small extent the time dimension (e.g., hyperbolic discounting) of behavioural economics.
- Airports and ANSPs were the most critical and resistant to accept new technologies, which is probably because they are the stakeholders that usually bear the heaviest weight on the implementation of new technologies and enjoy less of the benefits.
- 6 participants did not value the risk of failure and the prospect of success equally, confirming the prospect theory.
- 3 participants had some kind of feedback which conditioned in some way their opinion about the technology.
- Only 1 participant changed their answers when informed on the decisions of the other agents.

Participatory simulation was chosen as the validation method because it enables the acquisition of data from an environment closely related to a real-world setting. In the sessions, experts representing the main adopters’ agents (i.e., airlines, airports, ANSPs) participated, giving answers that allowed three independent validation experts from KTH to further assess the validation. The final results showed that the model behaves in a very realistic manner, from the perspective of all three agents, even when faced with extreme values and outliers. Some limitations were highlighted after this study:

- The model has only been validated for three agents/adopters and not for any other participating agent, like labour unions, manufacturers, technology providers etc.

- The combination of technologies and policies forming the scenarios, in which case while chosen from domain experts, it is not possible to exclude the possibility of producing biased datasets and enabling the overfitting of the model.

Both limitations by no means undermine the study and they could serve as a guide for improving the model. For further insights on this regard, the reader may refer to ITACA D4.1 Participatory simulations [9].

4.3.2 Sensitivity analysis

We use sensitivity analysis to assess how changes to the key input parameters influence the outputs of the simulation.

The methodology for the assessment consists of varying the input parameters one at a time, maintaining the remaining parameters with their reference value. A number of samples have been considered for each parameter in a range of potential values found in the literature [4], [5], [6] and [8].

All the parameters will be tested for the reference scenario of CS03 (future technologies). The results and discussion of the sensitivity analysis performed is included in Section 5.4.

4.3.2.1 Input

We selected a set of input parameters based on their expected potential impact and the uncertainty associated with their value. The complete list of parameters, divided by economic and exogenous variables, can be seen below.

Category	Parameter	Description	Reference value	Range	Selection criteria
Economic	Price demand elasticity route	Elasticity of the demand of a route with respect to the average price of the route.	-0.6	-0.2 to -1	It will greatly influence the final ticket prices and the ability of airlines to capture more demand.
	Price demand elasticity airline	Elasticity of the demand of an airline in a route with respect to the average airfare provided by the airline in the route.	-2	-1.2 to -2.8	It will greatly influence the final ticket prices and the ability of airlines to capture more demand.

	Annual salary change	Percentage of growth of the salaries each year	1%	-1% to 3%	It will greatly influence the total costs of the agents, affecting the final ticket price. It has an elevated uncertainty related.
Exogenous variables	Demand growth	Level of growth of the traffic demand. Linked to the scenarios in the EUROCONTROL challenges of growth 2018 document [4]: • 'Low': 'Fragmenting World', • 'Medium': 'Regulation & Growth', 'High': 'Global growth'	Medium	Low, Medium, High	It will affect agents' revenues. It has an elevated uncertainty related.
	Fuel price	Forecast and historic values of Jet-A fuel.	Current historic (up to 2019) and forecast excluding COVID situation	x0.75 to x1.25	It will greatly influence the total costs of the airlines, affecting the final ticket price. It has an elevated uncertainty related.

Table 15: Input parameters for the sensitivity analysis

4.3.2.2 Output

The outputs of the model selected for assessment include the indicators described in Section 3.3.4 and additionally include the number of flights, load factor and airfare at the end of the simulation. The complete list of outputs selected for the sensitivity analysis with their selection criteria is shown in Table 16.

Area	Indicator	Description
Technology	Time for adoption	Time between the availability of the technology in the market and its deployment.
	Market share of the technology	Percentage of agents that adopted a given technology.
Economic	Social welfare	Sum of producers' surplus, consumers surplus and externalities.
	En-route ANSP surplus	En-route ANSP’s profit.
	Terminal ANSP surplus	Terminal ANSP’s profit.
	Airline surplus	Airline’s profit.
	Airport Surplus	Airport’s profit.
	Passenger surplus	Sum of passengers' airfare cost and travel time cost.
Operational	En-route throughput	Throughput per hour for an en-route ANSP.
	TMA throughput	Throughput per hour for a terminal ANSP.
	En-route Determined Unit Costs	Determined Unit Costs (DUC) are calculated as the ratio of en-route ANS costs (in real terms) to service units at charging zone level.
	Terminal Determined Unit Costs	Determined Unit Costs (DUC) are calculated as the ratio of terminal ANS costs (in real terms) to service units at charging zone level.
	Number of flights	Total number of flights in the last simulation time step.
	Load factor	Average load factor at the end of the simulation.
	Airfare	Average airfare at the end of the simulation.

Table 16: Output parameters considered for the sensitivity analysis

4.3.3 Policy parameters exploration

As seen in Section 4.2, the policies modelled have parameters that define their behaviour and their final outcome. As the policies proposed are most of them a novelty in the field, it is not possible to anticipate reference values for them based on the literature, as done for the input parameters of the sensitivity analysis.

We have explored the effect of tweaking those parameters in a range that we consider, a priori, reasonable for the policies proposed under the judgment of the consortium members. After comparing the outcomes obtained, we selected the reference values for each parameter trying to maximise, when possible, (i) the adoption rate and (ii) the economic indicators (e.g., social welfare) with respect to the same case without any new policy applied. Those reference values have been used for the obtention

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of results in the different case studies that treat this document. The results and discussion of the exploration is presented as well in the next chapter, in Section 5.5.

The complete list of parameters explored and the reference values selected is shown in Table 17.

Policy	Parameter	Description	Reference value	Range	Selection criteria
Cost plus pricing	Margin in the unit rate	Margin in the unit rate applied in the Cost plus pricing policy	5%	0.1% - 9%	They will greatly affect the outcome of the different policies. There is a high uncertainty related to the optimal value of these parameters.
Best equipped-best served	Charge penalty	Charge penalty and charge reductions applied in the Best equipped-best served policy	2.5%	0.1% - 9%	
	Charge reduction		0.1%	-1% - 9%	
Demonstration projects	Risk perception reduction	Reduction of risk perception of a policy provided by Demonstration projects	15%	5% - 25%	
Subsidies	Costs subsidised	Percentage of the implementation costs paid to the agents in the Subsidies policy	50%	10% - 90%	
Mandates	Benefit subtracted	Benefit taken away to the agents in the Mandates policy measure (when they do not adopt)	0.1%	0.01% - 5%	

Table 17: Policy parameters

5 Simulation outcomes: Results and discussion

In this section the results obtained for each of the case studies defined in the deliverable are presented and discussed. After that, the results from the sensitivity analysis are shown in order to discuss how the model performs under different changes of the input parameters. Finally, the results from the exploration of parameters of the policy measures is shown to give further insights on the performance of the policies when varying their definition.

Before getting into the subject, it is advisable to explain the format applied in the tables corresponding to the technological KPA of each of the three Case Studies. Each table represents the technological uptake of Y technology for XX stakeholder. Besides the figures of the technology adoption, blue cells show the reference values; meanwhile solution scenarios are coloured in either green, for those years when the uptake is greater than the reference and/or reaches the full implementation, or red when the deployment is below the latter. Finally, if the adoption rate of the solution scenario is the same as the reference value, cell is coloured in yellow.

5.1 CS01 Analysis

CS01 focuses on historically failed Use Cases (013_MLS and 018_Datalink) and the solution scenarios proposed in this Case Study include these policy measures:

- SOL_SCN_1: Cost plus pricing
- SOL_SCN_2: Best equipped – best served
- SOL_SCN_3: Subsidies
- SOL_SCN_4: Increase matureness technologies
- SOL_SCN_5: Mandates
- SOL_SCN_6: Cost plus pricing & Best equipped – best served & Increase matureness technologies
- SOL_SCN_7: Cost plus pricing & Subsidies & Increase matureness technologies
- SOL_SCN_8: Cost plus pricing & Best equipped – best served & Mandates

5.1.1 Technological results

MLS

Table 18 and Table 19 represent the technological uptake of MLS technology for airlines and Terminal ANSP, respectively.

UC_013_MLS Airlines		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013 - 2021
REFERENCE SCENARIO		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
SOLUTION SCENARIOS	SOL_SCN_1	0%	88%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	SOL_SCN_2	0%	0%	0%	0%	0%	0%	0%	0%	75%	75%	75%	75%	75%	75%	75%	75%	75%	75%	94%
	SOL_SCN_3 & SOL_SCN_6	0%	94%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	SOL_SCN_4	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	SOL_SCN_5 & SOL_SCN_7 & SOL_SCN_8	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 18: MLS - Airlines

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UC_013_MLS Terminal ANSP		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013 - 2021
REFERENCE SCENARIO		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
SOLUTION SCENARIOS	SOL_SCN_1 & SOL_SCN_5 & SOL_SCN_6 & SOL_SCN_7 & SOL_SCN_8	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	SOL_SCN_2	0%	0%	0%	0%	0%	0%	0%	0%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	18%
	SOL_SCN_3	0%	0%	0%	0%	0%	0%	0%	0%	64%	73%	82%	82%	82%	82%	82%	82%	82%	82%	82%
	SOL_SCN_4	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 19: MLS - Terminal ANSPs

From both Table 18 and Table 19, it can be drawn that some ITACA's policy measures would have fostered the deployment of MLS technology for the airlines and Terminal ANSPs by quickening the deployment and ensuring a full implementation as well. Those policies are gathered in the first row of solution scenarios: SOL_SCN_1 (Cost plus pricing), SOL_SCN_5 (Mandates), SOL_SCN_6 (Cost plus pricing & Best equipped best served & Increase matureness of technologies), SOL_SCN_7 (Cost plus pricing & Subsidies & Increase matureness of technologies) and SOL_SCN_8 (Cost plus pricing & Best equipped best served & Mandates).

However, ITACA's policies do not impact on the MLS deployment for the airports. This is because this technology is very costly for airports and the only policies that affect them in the economical side are the Mandates. In this case, they choose to pay the fine of not adopting as it is lower than the implementation costs. When increasing the fine, a change in behaviour is observed, driving the airports towards adopting the technology. Apart from that, if the technologies would have been modelled considering their specific characteristics and dependencies, since no airport adopts this technology, none of the other agents would have adopted it because this technology could have not been used in practise.

On one hand, with the reference scenario (i.e., the technology uptake with the policies that were in place by that time) no stakeholder adopted the technology. The reason for this is explained by the fact that airports prefer to pay the fine since the adoption of the technology would be more expensive.

On the other hand, SOL_SCN_1 (Cost plus pricing), SOL_SCN_3 (Subsidies), SOL_SCN_5 (Mandates), SOL_SCN_6 (Cost plus pricing & Best equipped best served & Increase matureness of technologies), SOL_SCN_7 (Cost plus pricing & Subsidies & Increase matureness of technologies) and SOL_SCN_8 (Cost plus pricing & Best equipped best served & Mandates) indicates a full deployment for airlines and terminal ANSPs. Since SOL_SCN_6, SOL_SCN_7 and SOL_SCN_8 include the combined effect of three policy measures which contain the Cost plus pricing measure, the latter is deemed as the best policy measure, asides from the Mandates itself.

EUROCONTROL Link 2000+ Programme

Table 20, Table 21 and Table 22 represent the technological uptake of Datalink for airlines, Terminal ANSPs and Enroute ANSPs, respectively.

UC_018_Datalink Airlines		1995 - 1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016 - 2021
REFERENCE SCENARIO		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	6%	13%	19%	19%	25%	38%	69%	100%
SOLUTION SCENARIOS	SOL_SCN_1	0%	75%	75%	75%	75%	81%	81%	81%	88%	88%	88%	88%	88%	88%	88%	88%	88%	94%	100%
	SOL_SCN_2	0%	25%	25%	31%	31%	38%	38%	38%	38%	44%	50%	50%	56%	56%	75%	81%	94%	100%	100%
	SOL_SCN_3	0%	81%	81%	94%	94%	94%	94%	94%	94%	94%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	SOL_SCN_4	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	6%	13%	19%	19%	25%	38%	69%	100%
	SOL_SCN_5	0%	88%	88%	88%	88%	94%	94%	94%	94%	94%	94%	100%	100%	100%	100%	100%	100%	100%	100%
	SOL_SCN_6	0%	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	100%	100%	100%	100%
	SOL_SCN_7	0%	81%	88%	94%	94%	94%	94%	94%	94%	94%	94%	94%	100%	100%	100%	100%	100%	100%	100%
	SOL_SCN_8	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 20: Datalink - Airlines

UC_018_Datalink Enroute ANSP		1995 - 1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016 - 2021
REFERENCE SCENARIO		0%	0%	0%	0%	0%	0%	0%	0%	18%	18%	18%	27%	27%	27%	27%	36%	36%	55%	82%
SOLUTION SCENARIOS	SOL_SCN_1 & SOL_SCN_6 & SOL_SCN_7 & SOL_SCN_8	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	SOL_SCN_2	0%	18%	18%	18%	18%	18%	18%	18%	27%	27%	27%	36%	36%	36%	45%	64%	64%	64%	64%
	SOL_SCN_3	0%	82%	91%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	SOL_SCN_4	0%	0%	0%	0%	0%	0%	0%	0%	18%	18%	18%	27%	27%	27%	27%	36%	36%	55%	82%
	SOL_SCN_5	0%	55%	64%	64%	73%	73%	73%	73%	82%	82%	82%	91%	91%	91%	91%	91%	91%	91%	91%

Table 21: Datalink – En-route ANSPs

UC_018_Datalink Terminal ANSP		1995 - 1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016 - 2021
REFERENCE SCENARIO		0%	0%	0%	0%	0%	0%	0%	0%	0%	9%	9%	18%	18%	18%	18%	27%	27%	55%	82%
SOLUTION SCENARIOS	SOL_SCN_1 & SOL_SCN_6 & SOL_SCN_7 & SOL_SCN_8	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	SOL_SCN_2	0%	18%	18%	27%	27%	27%	27%	27%	27%	27%	27%	36%	36%	36%	45%	73%	73%	73%	73%
	SOL_SCN_3	0%	82%	91%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	SOL_SCN_4	0%	0%	0%	0%	0%	0%	0%	0%	0%	9%	9%	18%	18%	18%	18%	27%	27%	55%	82%
	SOL_SCN_5	0%	55%	64%	64%	73%	73%	73%	73%	82%	82%	82%	91%	91%	91%	91%	91%	91%	91%	91%

Table 22: Datalink - Terminal ANSPs

The results show that the policy measures proposed by ITACA would have mean both a full deployment of datalink technology for all the stakeholders impacted by the concept and an early implementation. According to these results, all the policy measures and its combinations imply full adoption for airlines. On the other hand, the policy measures included in SOL_SCN_1 (Cost plus pricing), SOL_SCN_3 (Subsidies), SOL_SCN_6 (Cost plus pricing & Best equipped best served & Increase matureness of technologies), SOL_SCN_7 (Cost plus pricing & Subsidies & Increase matureness of technologies) and SOL_SCN_8 (Cost plus pricing & Best equipped best served & Mandates) indicates a full deployment for airlines and ANSPs.

However, although all the previously mentioned policy measures provide positive results, it is worth noting that, for airlines, SOL_SCN_8 achieves full adoption rate years earlier that the others. In the case of the ANSPs, SOL_SCN_1, SOL_SCN_6, SOL_SCN_7 and SOL_SCN_8 are the ones that stand out in terms of the earliest full adoption.

Global results

Table 23 is included as a summary of the results presented, in which the scenarios that have given the best results for each agent and each Use Case are indicated. The grey cells represent the cases in which the stakeholders are not affected by the deployment of the corresponding technology. Additionally, in cases where the solution scenario does not improve with respect to the reference scenario, the cell is filled with '-'.

	UC_013_MLS	UC_018_Datalink
Airlines	SOL_SCN_5 SOL_SCN_7 SOL_SCN_8	SOL_SCN_8
Airports	-	
En-route ANSPs		SOL_SCN_1 SOL_SCN_6 SOL_SCN_7 SOL_SCN_8
Terminal ANSPs	SOL_SCN_1	SOL_SCN_1

	SOL_SCN_5 SOL_SCN_6 SOL_SCN_7 SOL_SCN_8	SOL_SCN_6 SOL_SCN_7 SOL_SCN_8

Table 23: Summary of CS01 Technological results

From that table some conclusions can be pointed out.

- On one hand, those policy measures that mean a major incentive either providing more economical support or improving the service received (e.g., Cost plus pricing, Best equipped-best served or Subsidies) end up fostering the deployment of the analysis in both ways: advancing deployment times and getting fully deployment scenarios.
- On the other hand, considering the obligation of adopting each technology, even though Mandates get better results that those from the reference scenario, ANSPs do not get the full implementation.

The SOL_SCN_8 (Cost plus pricing & Best equipped- best served & Mandates) appears to be the best option for the Use Cases selected, which contains both the incentives and the mandatories to make the deployment feasible and faster.

5.1.2 Economic results

The main economic indicator is the impact of the different policy solutions on social welfare (SWF) over the whole period. SWF is defined as the sum of the surplus of the airlines, the airports, the en-route ANSPs, the terminal ANSPs and the passengers. From these surpluses we subtract the external costs and the costs of the policies for the regulator. The surplus for the airlines, airports and ANSPs is defined as their profit. These profits consider the costs and benefits the policy solutions have on them. For passengers, the surplus is defined as the reduction in delays minus the change in the ticket fare. The external costs include the costs of the emissions of both CO_2 and SO_2.

It is important to note that the following two model assumptions impact the calculation of the social welfare and hence also the ordering of the policy measures. Firstly, the yearly surplus of the ANSPs is around zero as it is assumed that ANSPs cannot make a profit. If they make a profit in one year, the ANSPs will lower it charges such that the profits decrease – or even become a loss – in the year after[1]. The second assumption is related to the costs of the measures for the regulator. It is assumed that only the Subsidies come with a cost. Mandates, on the other hand, have a benefit in the form of income to the regulator from the fines collected from non-compliant entities. While it is true that policies such as Cost plus and Best equipped-best served have a lower cost; this is, the cost of changing the regulation; increasing the matureness of a technology might come at a certain positive cost.

[1] The SES regulation actually allows taking into account profits and losses on the actual route charges two years later instead of one year. Changing the assumption in the model to take into account two years will have no real impact. The main effect would be that unit rate fluctuations are smoothed down.

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Within CS01 the most important elements of social welfare are the airline surplus (53%), the airport surplus (41%), passenger surplus (10%) and externalities (5%)[2]. As profits of ANSPs fluctuate around zero, the share of the ANSPs within SWF also is about zero in the reference.

The policy instruments included in the analysis of CS01 are Cost plus pricing, Mandates, Best equipped-best served, Increased the matureness of the solutions, Subsidies and some combinations of these policy instruments. The table below shows the impact on SWF starting with the highest gain.

Name	Policy instrument	Change in SWF over period 1995-2021
SOL_SCN_6	Cost plus pricing & Best equipped-best served & Increased matureness technologies	2.2%
SOL_SCN_1	Cost plus pricing	2.1%
SOL_SCN_7	Cost plus pricing & Increased matureness technologies	1.8%
SOL_SCN_8	Cost plus pricing & Best equipped-best served & Mandates	1%
SOL_SCN_4	Increased matureness technologies	0%
SOL_SCN_3	Subsidies	- 0.1%
SOL_SCN_2	Best equipped-best served	-1.1%
SOL_SCN_5	Mandates	-2.2%

Table 24: Impact on Social Welfare – CS01

The best scoring solution is the combination of the policies Cost plus pricing, Best equipped-best served and Increased matureness technologies. This is a solution where all players – apart from the airports- adopt the technology 100%. Looking at the distribution of the gains we see that over the whole period considered the en-route and the terminal ANSPs have a positive surplus. This is due to the fact that the Cost plus measure is included in this combination and hence that ANSPs are now allowed to make a profit. There is also a small positive effect on the external costs.

On the other hand, the other players (airports, airlines and passengers) have a net loss – although small. The rationale behind these losses is the following: airlines lose profit as the navigational charges increase sharply (+14,6%). The losses are however hampered by the Best equipped-best served rule and the sharp decrease in delay costs (-18,85%). This is compensating for part of this increase as overall the average airfare remains constant and even shows a small decrease (-0,21%). Although the airfare (-0,21%) and the delay costs decrease, we see a small decrease in traffic (-0,23% in 2021) leading to the small loss in surplus for the airports (-0,08%). The reason for this decrease in demand is that airlines might underestimate future demand and then they lower the number of flights leading to non-

[2] sum is larger than one as externalities are negative

captured demand. This is plausible since route elasticity is -0.6 and airline elasticity is -2, which means that demand is less sensitive to generalised changes in ticket prices (led by an increase in costs) than they would be when only one airline change their prices. The losses for airlines and airports make that their support for this solution will probably be low. We note that a similar picture arises for all policy solutions. There is no solution where all parties involved gain, there are always winners and losers.

The figure below shows the evolution of social welfare over the different scenarios. Note that the SWF under increased matureness is the same as in the reference case. Hence the green line shows both the reference as the mentioned policy. Over time we see that SWF increases for all solution scenarios but that from the start the SOL_SCN_6 scores the best at all points in time. The fluctuations within the path are mostly related to the surpluses of the ANSPs which try to balance their profits around zero. This fluctuating pattern is most dominant until the year 2010 after which we see a steady increase for all scenarios. One reason for this is that around this period the costs for implementing the technology are made and hence the benefits from the technologies dominate. Another reason might be the exogenous increase in fuel prices and the lower demand in 2010 following the financial economic crisis.

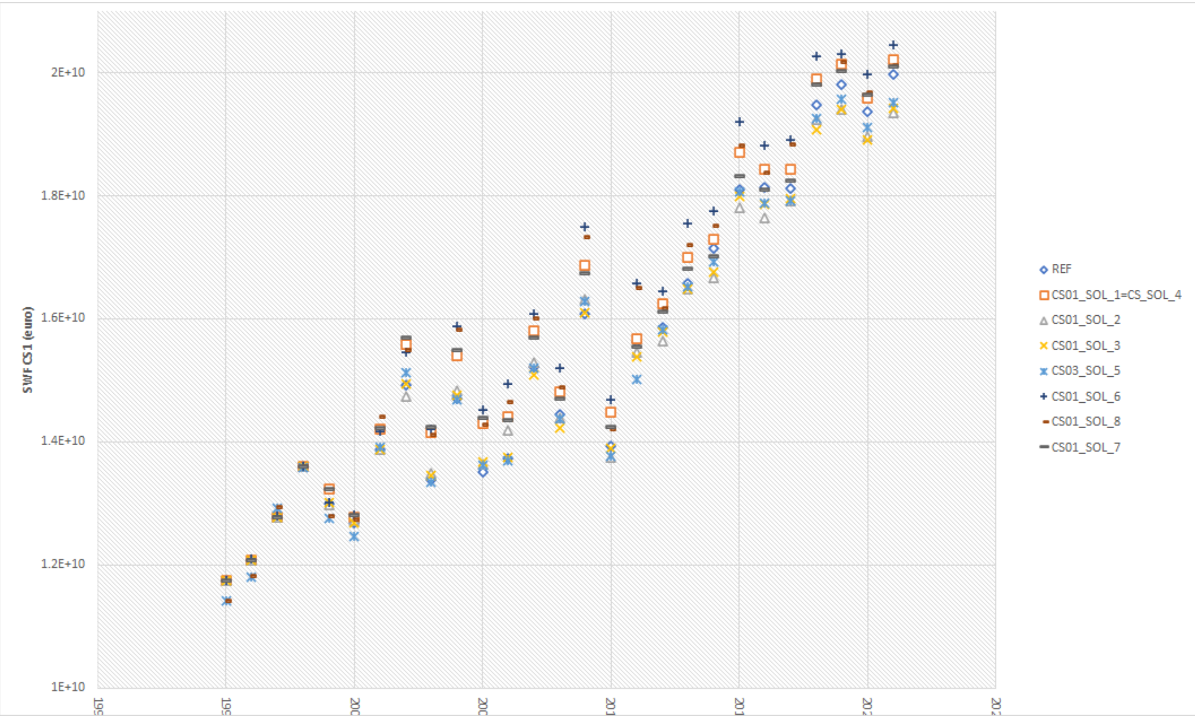

Chart 1: Evolution of social welfare – CS01

Overall, we see that the measures including Cost plus pricing lead to the highest changes in welfare. The reason for this is that within Cost plus pricing the ANSPs (both en-route and terminal) start to make profit, leading to high increases in the absolute surplus. Relatively speaking their importance is still relatively small with a share of about 1% each in total SWF. Within the reference the surpluses of ANSPs were about 0% of the social welfare.

We note that Mandates and Subsidies lead to a loss in SWF. This is also the reason why the combinations of these measures with Cost plus pricing score worse than Cost plus pricing alone. Hence the best solutions are SCN_SOL 6 and SCN_SOL 1 for CS01.

Mandates lead to the highest social (-2.2%) loss. The reason for this is the loss in surplus for the airlines (-4,4%) even though they must pay a lower navigation charge (-5.2%), they are charging a higher airfare (+1,5%) and the decrease in the delay costs (-15,5%). The reason for this loss is most likely the decrease in passenger km. Compared to the reference we see that airports still have not adopted the measure despite the fine; airlines and terminal ANSPs now also adopted MLS. Interesting is that MLS is more adopted than in the reference but still not by all ANSPs. This means that for some ANSPs it is cheaper to pay the fine than to implement the solution. Within a Cost plus regime they can charge the users for these additional costs and hence there we do see a full implementation by the ANSPs.

Using Subsidies to increase the uptake of technologies does lead to a better implementation of the technologies compared with the reference but the social impact is negative. The main reason for this is the lower revenues for airlines in the last years while their costs remain constant. The reason for this is a reduction in the airfares on the main route pairs. Another reason is the costs associated to the measure – especially compared with Cost plus pricing where these costs are assumed to be zero. Another reason is that the Subsidies allow for lower airfares leading to an increase in traffic and hence an increase in the external costs.

For CS01 we do not see any impact on the results when the policy related to the increase in technology maturity is active. This is partly due to the way they are modelled. They are modelled in the same way as a demonstration project but their parameter is lower, leading to less – or no – changes in the adoption.

	Ref	Cost plus	Best eq	Subsidies	Mand	Inc Mat	Cost&Best&Inc mat	Cost&Best&Mand	Cost&Sub&Inc mat
In 2021		CS01_SOL_1	CS01_SOL_2	CS01_SOL_3	CS03_SOL_5	CS01_SOL_4	CS01_SOL_6	CS01_SOL_8	CS01_SOL_7
average Airfare	95.54	0.84%	1.36%	-0.07%	1.52%	0.00%	-0.21%	0.12%	-0.42%
Airport charges	22.80	0.00%	0.29%	0.29%	0.00%	0.00%	0.29%	0.00%	0.29%
Navigation charges/DUC	59.64	-3.05%	-5.49%	-1.07%	-5.18%	0.00%	14.63%	18.90%	0.30%
Terminal charges (DUC)	506.09	-0.70%	-0.45%	0.50%	-0.13%	0.00%	-0.50%	1.31%	-0.18%
Passengerkm (demand)	888894	-0.46%	0.22%	0.38%	-0.13%	0.00%	-0.23%	-0.63%	-0.34%
ATCO employment en route	6060	-1.55%	0.96%	-1.24%	0.30%	0.00%	1.44%	-1.09%	-1.86%
ATCO employment terminal	4411	-0.43%	0.14%	-1.18%	0.29%	0.00%	0.39%	-1.65%	-1.36%
Delay cost	1260447	-17.26%	-3.64%	-18.36%	-15.47%	0.00%	-18.85%	-20.30%	-19.02%

Table 25: Detailed results for different economic indicators - CS01

From Table 25 we can draw the following interesting conclusions:

- The changes in airfare are relatively small. The largest increase is seen in the Best Equipped – Best served and the mandatory policies. The changes in airport and terminal charges are also relatively modest. Bigger changes are seen in the navigation charges. When policies are used on their own, we see that the navigation charges decrease (-1,1% up to -5.5%). When a combination of policies is used, we see a sharp increase in two of them- +14,6% in the solution with the highest social welfare (SCN_SOL_6) up to 18,9% in SCN_SOL_8.
- The passenger traffic in the year 2021 remains relatively constant with changes between -0,63% and +0,38% compared to the reference.
- The uptake of the technologies does not seem to indicate a consistent decrease in ATCO employment. Under SCN_SOL_07 the employment en-route decreases with 1,9% while under SCN_SOL_6 the employment increases with 1,44% while the only difference between the two

policy combinations is the use of Subsidies in SCN_SOL_7 while in SCN_SOL_6 Best equipped-best served is used.

- Apart from under increased maturity in which nothing changes, delay costs decrease substantially in all policy scenarios (-15,5 % in the Mandates up to -22.28% under Cost plus + Best equipped best served + Mandates)

5.1.3 Operational results

Within the operational metrics, Chart 2 provides a further analysis of the fuel burn and represents the mean value of the fuel burn for the analysed years (i.e., 1995-2021). According to the latter figure, SOL_SCN_1 and SOL_SCN_7, which comprise Cost plus pricing policy measure either individually or in combination, leads to a lower fuel burn per flight. Moreover, SOL_SCN_3 (i.e., Subsidies) allows getting lower fuel burn per flight than in the reference scenario too.

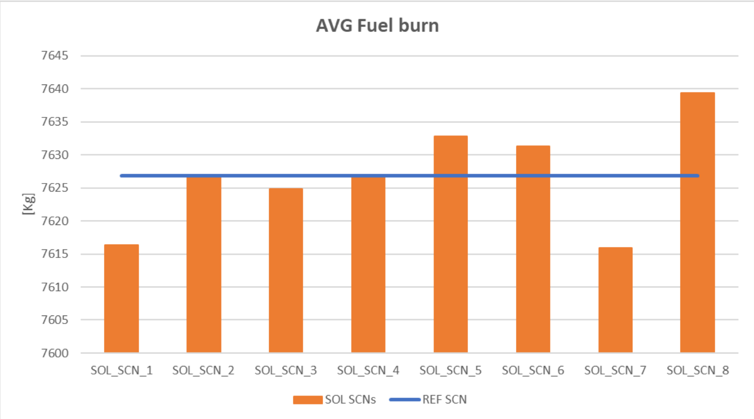

Chart 2: Average fuel burn - CS01

As in the study of fuel burn metric, the mean value of each scenario for En-route throughput is shown in the chart of the average value. Higher values than those from the reference scenario mean greater number of flights per day and all the solution scenarios except for the one comprising Increased matureness technologies show this improvement. Moreover, the SOL_SCN_3, SOL_SCN_5 and SOL_SCN_7 are the ones which show the best results, involving Subsidies, Mandates and the combined effect of Cost plus pricing, Subsidies and Increased matureness technologies respectively.

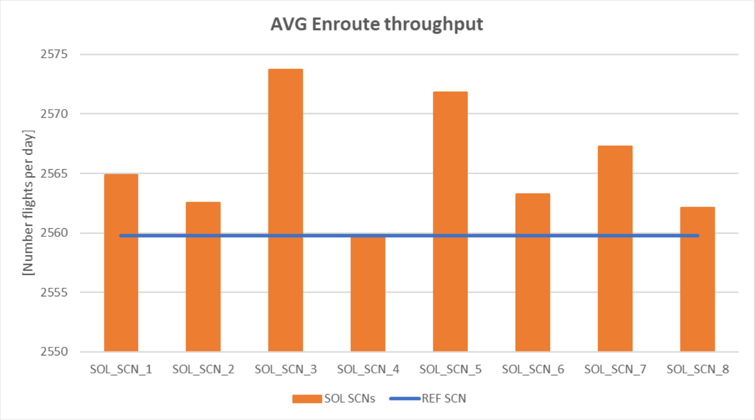

Chart 3: Average En-route throughput - CS01

Regarding En-route DUC, in Chart 4**Error! Reference source not found.**, it is observed that SOL_SCN_3, corresponding to the Demonstration projects policy measure, shows the best results for the DUC. SOL_SCN_5 (Mandates) and SOL_SCN_7 (Cost plus pricing & Subsidies & Increase matureness technologies) also show better results that the reference scenario, but the impact is not that remarkable.

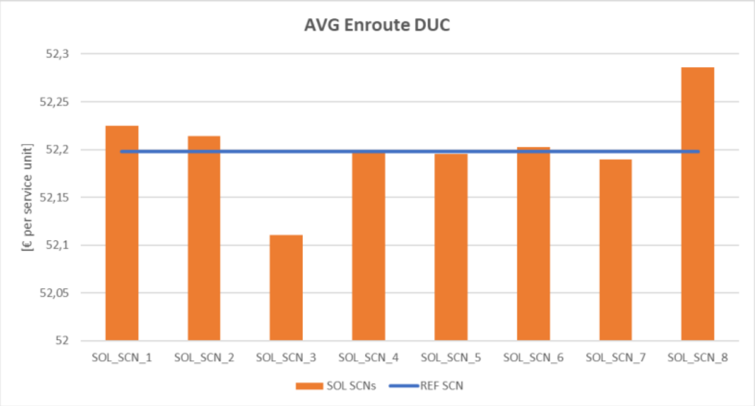

Chart 4: Average En-route DUC

For the case of the terminal throughput, looking the average values displayed in the Chart 5, it is clearer that the SOL_SCN_2, SOL_SCN_3 and SOL_SCN_5 outperform the reference results, highlighting the effects of Best equipped-best served, Subsidies and Mandates policies.

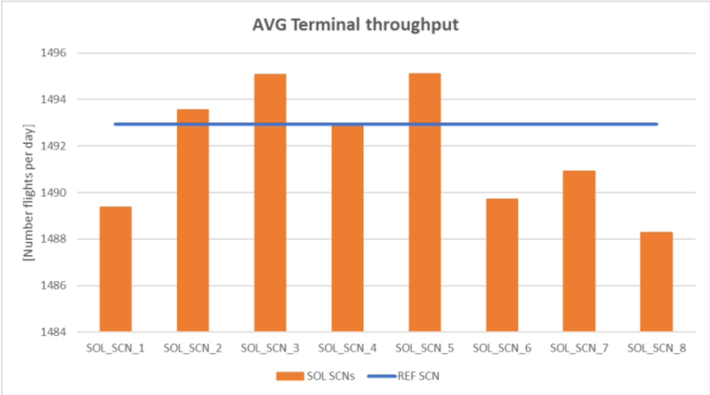

Chart 5: Average Terminal throughput – CS01

Finally, in terms of Terminal DUC, practically all the solution scenarios show an improvement in terms of total average values, although this increment is very small. Still, SOL_SCN_3 (Subsidies) and SOL_SCN_7 (Cost plus pricing & Subsidies & Increase matureness technologies) can be highlighted compared to the others.

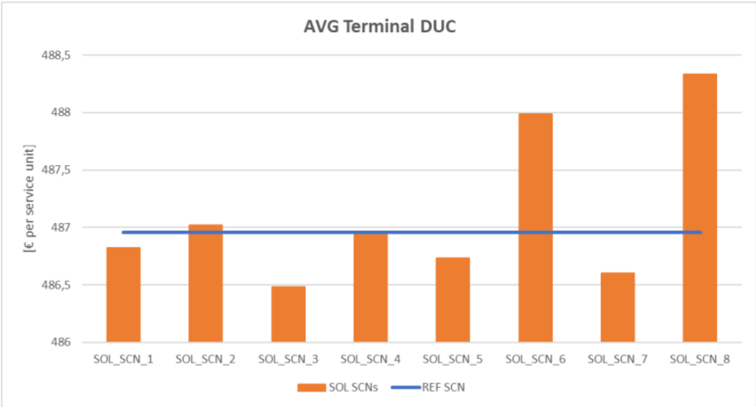

Chart 6: Average Terminal DUC – CS01

Table 26 summarizes all the results presented above, ordering the scenarios with the best results for each indicator.

Indicator	Scenarios
Fuel burnt	SOL_SCN_7 - SOL_SCN_1 - SOL_SCN_3
En-route throughput	SOL_SCN_3 - SOL_SCN_5 - SOL_SCN_7
En-route DUC	SOL_SCN_3
Terminal throughput	SOL_SCN_5 - SOL_SCN_3 - SOL_SCN_2
Terminal DUC	SOL_SCN_3 - SOL_SCN_7 - SOL_SCN_5

Table 26: Summary of CS01 Operational results

From this table it can be concluded that the solution scenario which in general implies the most positive improvements in operational indicators is SOL_SCN_3, involving Subsidies policy measure. Indeed, it is the unique scenario that gives significantly positive results for En-route DUC metric.

Moreover, it gives some of the best results in all other indicators. On the other hand, SOL_SCN_5 and SOL_SCN_7 can also be pointed out among the rest of the scenarios.

5.2 CS02 Analysis

CS02 focuses on historically succeeded Use Cases (007_A-CDM, 011_Remote Towers, 015_CCO/CDO and 020_ADS-B) and the solution scenarios proposed in this Case Study include these policy measures:

- SOL_SCN_1: Cost plus pricing
- SOL_SCN_2: Best equipped-best served
- SOL_SCN_3: Demonstration projects
- SOL_SCN_4: Realistic timelines
- SOL_SCN_5: Demonstration projects & Realistic timelines
- SOL_SCN_6: Cost plus pricing & Best equipped- best served

5.2.1 Technological results

A-CDM

Overall, it can be said that for A-CDM technology there is no great improvement for both airlines and airports and no relevance for terminal and en-route ANSPs.

UC_007 A-CDM Airlines		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019 - 2021
REFERENCE SCENARIO		0%	81%	81%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	94%	100%
SOLUTION SCENARIOS	SOL_SCN_1 & SOL_SCN_4	0%	81%	81%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	94%	100%
	SOL_SCN_2 & SOL_SCN_6	0%	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	100%	100%
	SOL_SCN_3 & SOL_SCN_5	0%	81%	81%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	94%	100%	100%

Table 27: A-CDM Airlines

In the case of airlines, all agents will adopt this technology by 2019 at the latest, as in the reference scenario. However, in certain solution scenarios, an increase of adoption for certain solutions comes earlier. As it can be seen in the following table, SOL_SCN_6 (Cost plus pricing & Best equipped- best served) is one of the solutions with better results and comprises both Cost plus pricing and Best equipped-best served policy measures. Looking in more detail, we can see that while the implementation of the Best equipped- best served alone (SOL_SCN_2) implies almost complete adoption from the start, for the Cost plus pricing policy (SOL_SCN_1) there is no improvement. From this we can extract that the Best equipped-best served is the policy measure with the greatest effect on the adoption of the A-CDM by airlines.

UC_007 A-CDM Airports		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018 - 2021
REFERENCE SCENARIO		0%	47%	47%	47%	53%	53%	53%	53%	53%	53%	53%	53%	53%	53%	53%	53%
SOLUTION SCENARIOS	SOL_SCN_1 & SOL_SCN_2 & SOL_SCN_4 & SOL_SCN_5	0%	47%	47%	47%	53%	53%	53%	53%	53%	53%	53%	53%	53%	53%	53%	53%
	SOL_SCN_3 & SOL_SCN_5	0%	47%	47%	47%	53%	53%	53%	53%	53%	53%	53%	53%	53%	53%	60%	67%

Table 28: A-CDM – Airports

For airports, most of the solution scenarios have an adoption rate equal to that of the reference scenario, although there are two scenarios that improve in the last five years of application. In this case, the SOL_SCN_3 and SOL_SCN_5 are the ones that show a different adoption rate. As before, the SOL_SCN_5 includes the SOL_SCN_3, which is Demonstration projects policy measure, and it has the greatest influence for airports. This increase in the number of airports adopting it for the last years may be due to the demonstration of the credibility and benefits of this technology in previous years with other airports. However, in no case, be it a reference or solution scenario, the complete implementation of A-CDM technology is achieved at airport level.

Remote Towers

As for the Remote Towers, regarding the airports, there is no change in any of the solutions from the reference scenario, as the maximum implantation was 27%. So, the Policies Measures do not interfere in this case.

UC_011 Remote Towers Airports		2003 - 2018	2019 - 2021
REFERENCE SCENARIO		0%	27%
SOLUTION SCENARIOS	SOL_SCN_1 & SOL_SCN_2 & SOL_SCN_3 & SOL_SCN_4 & SOL_SCN_5 & SOL_SCN_6	0%	27%

Table 29: Remote Towers – Airports

For terminal ANSPs, there are three solution scenarios that show a great improvement over the rest of the scenarios, including the reference one. The solution SOL_SCN_1, SOL_SCN_2 and SOL_SCN_6 implement the technology for all the agents since the first year of application, which is 2019, and all involve Cost plus pricing or Best equipped-best served either individually or in combination.

The use of remote towers for the terminal ANSPs is a benefit to them and their work, but the cost can be high for their application, that is why the implementation of the Cost plus pricing policy measure (SOL_SCN_1), which implies giving a monetary incentive, or the Best equipped-best served (SOL_SCN_2), which improves the work of these agents, helps this technology to be adopted.

Being SOL_SCN_6 a combination of the other two solutions, the application of any of these two policy measures individually would suffice to improve the total implementation of Remote Towers.

UC_011 Remote Towers Terminal ANSP		2003 - 2018	2019 - 2021
REFERENCE SCENARIO		0%	36%
SOLUTION SCENARIOS	SOL_SCN_1 & SOL_SCN_2 & SOL_SCN_6	0%	100%
	SOL_SCN_3 & SOL_SCN_4 & SOL_SCN_5	0%	36%

Table 30: Remote Towers – Terminal ANSPs

CDO & CCO

For CDO & CCO the results show different situations. There are some solution scenarios that improve with respect to the reference scenario, but there are also other scenarios where the results are worse.

For airlines, there is a wide application since it was decided to implement this technology in 2018 and in almost all solution scenarios a full adoption is achieved. In particular, as shown in the table below, SOL_SCN_1 and SOL_SCN_6 stand out from the others one because in these cases the total implementation is achieved from their first year of implementation, 2018. Therefore, between the two solutions, the implementation of the Cost plus pricing policy measure would suffice, since the Best equipped-best served does not influence it and it would be more profitable to apply a single policy measure.

UC_015 CDO&CCO Airlines		2003 - 2017	2018	2019	2020 - 2021
REFERENCE SCENARIO		0%	94%	94%	100%
SOLUTION SCENARIOS	SOL_SCN_1 & SOL_SCN_6	0%	100%	100%	100%
	SOL_SCN_2	0%	56%	63%	63%
	SOL_SCN_3 & SOL_SCN_4 & SOL_SCN_5	0%	63%	81%	100%

Table 31: CDO&CCO – Airlines

The effects on the adoption of the CDO & CCO technologies for en-route and terminal ANSPs are very similar. In both cases, SOL_SCN_1 and SOL_SCN_6 stand out. The SOL_SCN_1 involves the Cost plus pricing policy measure, and the effect of this can also be seen in SOL_SCN_6, as it is likely to be the one that leads to the good results of this scenario.

UC_015 CDO&CCO En-route ANSP		2003 - 2017	2018	2019	2020 - 2021
REFERENCE SCENARIO		0%	55%	55%	55%
SOLUTION SCENARIOS	SOL_SCN_1 & SOL_SCN_6	0%	100%	100%	100%
	SOL_SCN_2	0%	9%	9%	18%
	SOL_SCN_3 & SOL_SCN_4 & SOL_SCN_5	0%	36%	45%	55%

Table 32: CDO&CCO – En-route ANSPs

UC_015 CDO&CCO Terminal ANSP		2003 - 2017	2018	2019	2020 - 2021
REFERENCE SCENARIO		0%	55%	55%	55%
SOLUTION SCENARIOS	SOL_SCN_1 & SOL_SCN_6	0%	100%	100%	100%
	SOL_SCN_2	0%	18%	18%	18%
	SOL_SCN_3 & SOL_SCN_4 & SOL_SCN_5	0%	36%	45%	55%

Table 33: CDO&CCO – Terminal ANSPs

ADS-B

For the latest technology applicable to this case study, the ADS-B, there is a late application, as it is first implemented in 2018. Overall, there is always at least one solution scenario for each agent that improves over the reference scenario.

For airlines, the SOL_SCN_1, SOL_SCN_2 and SOL_SCN_6 show a higher percentage of adoption. For SOL_SCN_1 and SOL_SCN_2 there is a slight increase in % of adoption. But when combining them, forming the SOL_SCN_6, the positive effect is much greater. So it could be said, that it would be better to combine Cost plus pricing and Best equipped-best served policy measures rather than implementing them in an isolated way.

It appears that the way both Demonstration projects and Realistic timelines policy measures have been modelled (i.e., increasing the stakeholders' confidence and easing the reluctance to change) mean a slight negative impact on the deployment for airlines, airports and terminal ANSPs relative to the reference scenario.

UC_020 ADS-B Airlines		2003 - 2017	2018	2019	2020	2021
REFERENCE SCENARIO		0%	81%	81%	81%	94%
SOLUTION SCENARIOS	SOL_SCN_1	0%	88%	88%	94%	94%
	SOL_SCN_2	0%	94%	94%	94%	94%
	SOL_SCN_3 & SOL_SCN_4 & SOL_SCN_5	0%	75%	81%	81%	94%
	SOL_SCN_6	0%	100%	100%	100%	100%

Table 34: ADS-B – Airlines

In the case of airports, for certain solution scenarios, adoption occurs earlier and involves more airports than the reference scenario. The scenarios with a better performance are both SOL_SCN_6 and SOL_SCN_2, including both the Best equipped-best served policy measure.

UC_020 ADS-B Airports		2003 - 2017	2018	2019	2020	2021
REFERENCE SCENARIO		0%	67%	67%	73%	73%
SOLUTION SCENARIOS	SOL_SCN_1	0%	67%	67%	73%	73%
	SOL_SCN_2	0%	80%	80%	80%	80%
	SOL_SCN_3 & SOL_SCN_4 & SOL_SCN_5	0%	53%	67%	67%	73%
	SOL_SCN_6	0%	80%	80%	80%	80%

Table 35: ADS-B – Airports

The effects on the adoption of the ADS-B for en-route and terminal ANSPs are very similar. In both cases, solution SOL_SCN_1 and SOL_SCN_6 stand out. The SOL_SCN_1 involves the Cost plus pricing policy measure, and the effect of this can also be seen in SOL_SCN_6, as it is likely to be the one that leads to the good results of this scenario.

UC_020 ADS-B En-route ANSP		2003 - 2017	2018	2019	2020	2021
REFERENCE SCENARIO		0%	55%	64%	73%	82%
SOLUTION SCENARIOS	SOL_SCN_1 & SOL_SCN_6	0%	100%	100%	100%	100%
	SOL_SCN_2	0%	18%	18%	18%	18%
	SOL_SCN_3 & SOL_SCN_4 & SOL_SCN_5	0%	55%	64%	73%	82%

Table 36: ADS-B – En-route ANSPs

UC_020 ADS-B Terminal ANSP		2003 - 2017	2018	2019	2020 - 2021
REFERENCE SCENARIO		0%	82%	82%	82%
SOLUTION SCENARIOS	SOL_SCN_1 & SOL_SCN_6	0%	100%	100%	100%
	SOL_SCN_2	0%	64%	64%	64%
	SOL_SCN_3 & SOL_SCN_4 & SOL_SCN_5	0%	73%	73%	82%

Table 37: ADS-B – Terminal ANSPs

Global results

Table 38 summarizes the values presented above and indicates the scenarios that have given the best results for each agent and each Use Case. As in Table 23, the cells coloured in grey represent the stakeholders that are not affected by the corresponding technology deployment and the cells with the symbol '-' refer to situations where any solution scenario has improved the outcome of the reference scenario.

	UC_007_A-CDM	UC_011_Remote Towers	UC_015_CDO&CCO	UC_020_ADS-B
Airlines	SOL_SCN_2 SOL_SCN_ 6		SOL_SCN_1 SOL_SCN_ 6	SOL_SCN_ 6
Airports	SOL_SCN_3 SOL_SCN_ 5	---		SOL_SCN_2 SOL_SCN_ 6
En-route ANSPs			SOL_SCN_1 SOL_SCN_ 6	SOL_SCN_1 SOL_SCN_ 6
Terminal ANSPs		SOL_SCN_1 SOL_SCN_2 SOL_SCN_6	SOL_SCN_1 SOL_SCN_ 6	SOL_SCN_1 SOL_SCN_ 6

Table 38: Summary of CS02 Technological results

From this table it can be extracted that the main reason for the improvement in the adoption of each technology lies in increasing the incentives in the different Use Cases, either by providing more economic support or improving the service received. The policy measures that comprise this are mostly Cost plus pricing and Best equipped – best served. In addition, the solution scenarios that appear most frequently are 1, 6 and 2, in order of influence.

SOL_SCN_6 combines two policy measures included in SOL_SCN_1 (Cost plus pricing) and SOL_SCN_2 (Best Equipped-best served) and it also appears among the best results of most of the agents and Use Cases. So, it can be concluded that at the level of technology adoption, the combination of these two policy measures is one that offers the best results.

5.2.2 Economic results

As discussed in the section below the impact of the different policy measures is rather limited in this case study. This is also reflected in the social welfare (SWF) where we see very small changes. It is worthwhile to note however that for some technologies the decision to implement the technology is taken only four years before the end of the period. This means that technologies are only adopted at the very end of the calculation period, 2021, and therefore the changes in adoption in the different scenarios are not sufficiently appreciated.

The policy instruments included in the analysis of CS02 are Cost plus pricing, Best equipped-best served, Realistic timelines, Demonstration project and some combinations of these policy instruments. The table below shows the impact on SWF starting with the "highest" gain.

Name	Policy instrument	Change in SWF over period 2003-2021
SOL_SCN_5	Demonstration projects& Realistic timelines	0%
SOL_SCN_3	Demonstration projects	0%
SOL_SCN_4	Realistic timelines	0%
SOL_SCN_1	Cost plus pricing	0%
SOL_SCN_2	Best equipped-best served	-0.3%
SOL_SCN_6	Best equipped-best served + Cost plus pricing	- 0.3%

Table 39: Impact on Social Welfare – CS02

Although the first four scenarios give the same result, the SWF change is zero, the Cost plus pricing solution (SCN_SOL_1) appears in the last position because it slightly reduces the surplus of the ANSPs, making this measure less attractive for these agents.

The application of the Best equipped-best served policy entails a net loss of –0.3% in SWF. If we look in more detail individually for each agent, it is remarkable that in the case of terminal ANSPs the situation worsens with the application of the policy. However, en-route ANSPs show an improvement. The reason for the different impact is related to the distribution of the costs and the benefits, as explained in the cost benefit analysis above. This also means that the support for such a policy will be much greater for en-route ANSPs than for terminal ANSPs. Note that airlines and airports will less likely support this policy as the impact on their surplus is slightly negative.

The figure below shows the evolution of social welfare over years for the different scenarios. Note that some of the solutions have the same results and hence we can only distinguish between three elements. Orange stands for the combination of demonstration and realistic timelines but also for Demonstration projects and realistic timelines on their own. Hence there is no added benefit from combining these. It is also more or less equal to the reference, indicating that even on their own there is little reason for applying these policies. The green dots is sometimes a bit higher than the reference, but most of the time lower and ends also with the lowest SWF. This is the Cost plus pricing policy in combination with best-equipped – best served. The grey dots stands for the Best equipped –best served policy and follows mostly the green dots but ends with a somewhat higher SWF at the end of the period. It would be interesting to see how the SWF would evolve further over time. The fact that most technologies only have an uptake around 2018-2019 can also be clearly seen in the graph.

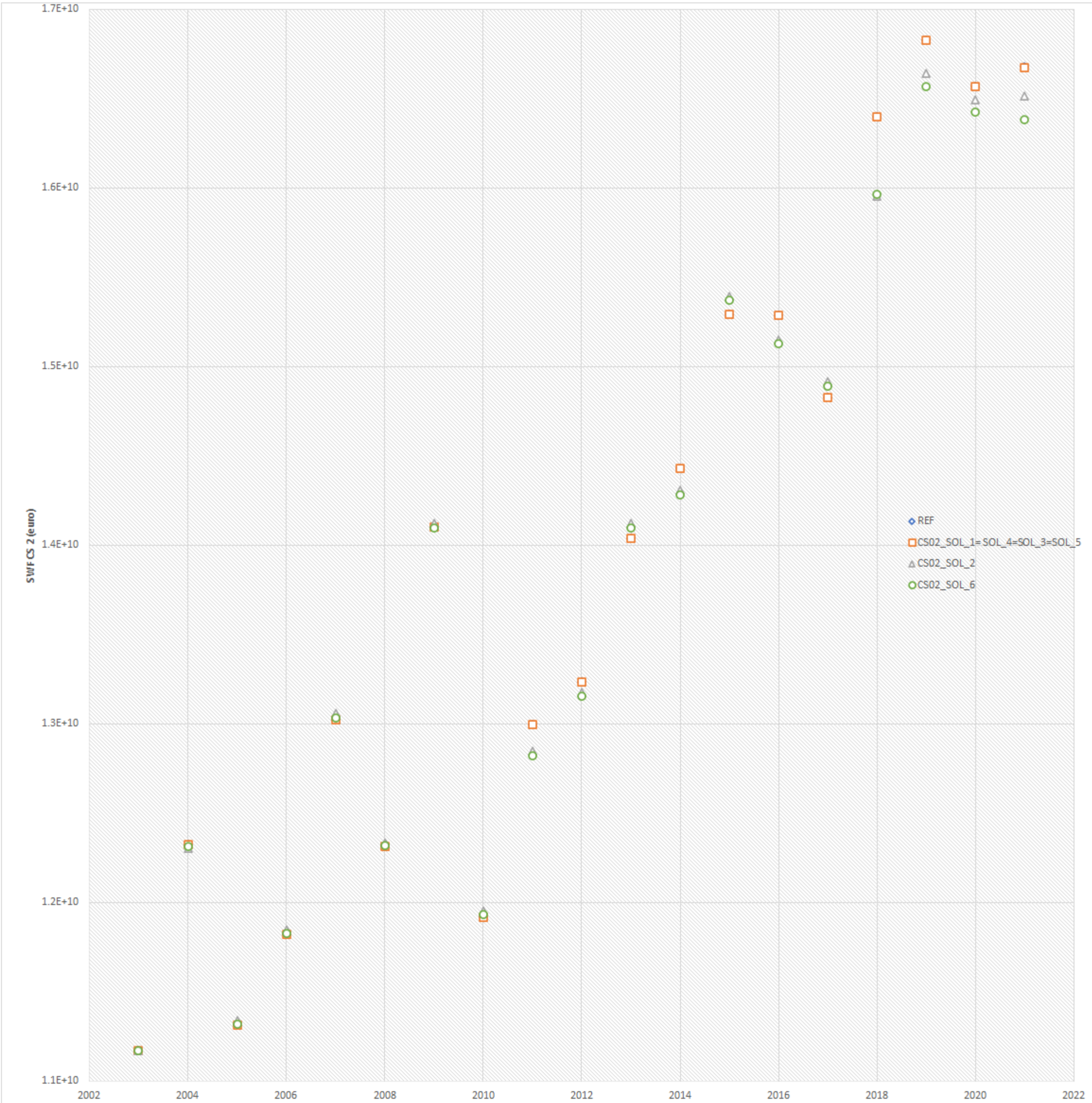

Chart 7: Evolution of social welfare – CS02

Policy measure	Ref	Cost plus	Best eq	Realistic	Demo	Cost&Best	Demo&Real
Policy measure ID		1	2	4	3	1 & 4	3 & 4
Solution scenario		1	2	4	3	6	5
average Airfare	148.88	-0.04%	-0.17%	0.00%	0.00%	-0.08%	0.00%
Airport charges	22.73	0.00%	0.29%	0.00%	0.00%	0.29%	0.00%
Navigation charges/DUC	58.64	0.00%	-5.89%	0.00%	0.00%	-5.89%	0.00%
Terminal charges (DUC)	510.82	0.00%	0.16%	0.00%	0.00%	0.25%	0.00%
Passengerkm (demand)	804679	0.00%	-0.24%	0.00%	0.00%	-0.24%	0.00%
ATCO employment en route	5490	0.00%	1.86%	0.00%	0.00%	1.79%	0.00%
ATCO employment terminal	4038	0.00%	0.37%	0.00%	0.00%	0.15%	0.00%
Delay cost	792408	0.00%	0.46%	0.00%	0.00%	0.45%	0.00%

Table 40: Detailed results for different economic indicators - CS02

From Table 40 we can draw the following interesting conclusions:

- The average airfare either remains constant or decreases slightly with a maximum of –0,17% under Best equipped-best served. Airport charges increase in situation whet the Best equipped-best served policy is included. On the other hand, navigation charges decrease significantly (-5,9%) under solutions including Best equipped-best served. However, terminal charges increase slightly under the same solutions.
- Even though airfare decreases, we see that in solutions including Best equipped-best served the number of passengers decrease. This might be due to the fact that the delay costs increase under these solutions.
- The uptake of technologies does not lead to a decrease in the number of ATCOs. Under solutions including Best equipped-best served we see a modest increase which is slightly higher for en-route ANSPs than for terminal ANSPs.

5.2.3 Operational results

Regarding the fuel burn, the Chart 8 provides a further analysis of the fuel burn by displaying the mean value of the fuel burn for the analysed years (2003 – 2021). Based on these results, it is evident that none of the policy measures improve the performance to reduce fuel consumption.

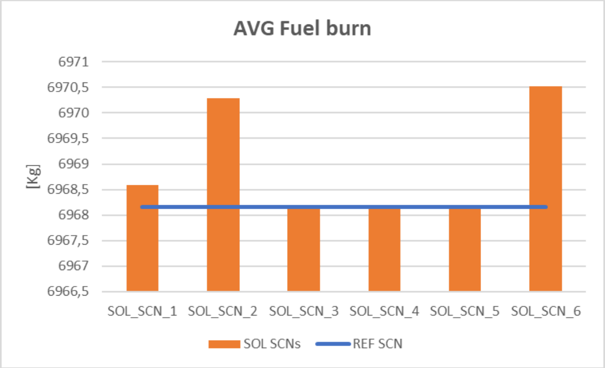

Chart 8: Average Fuel burn – CS02

The results for en-route throughput (number of flights per day) show the same trend as the results for fuel burn, no solution scenario improves the results of the reference scenario. The best solution scenarios for this case are SOL_SCN_3, SOL_SCN_4 and SOL_SCN_5 whose values match the reference scenario.

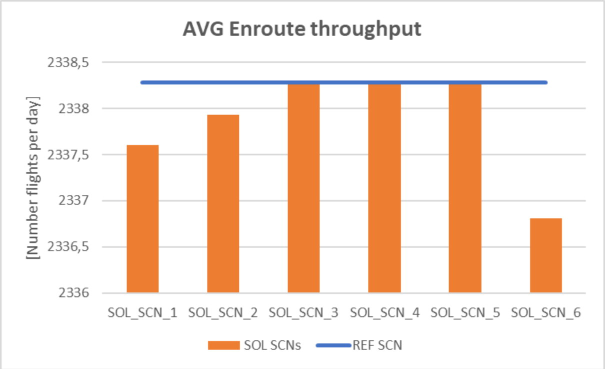

Chart 9: Average En-route throughput – CS02

When evaluating the En-route Determined Unit Cost (DUC), a value lower than the reference scenario is considered an improvement. Analysing the results of Chart 10, we can see that only 2 scenarios have lower values than the reference scenario, these are SOL_SCN_2 and SOL_SCN_6. In any case, for the cases where no improvement is seen, the difference with respect to the reference scenario is not very large.

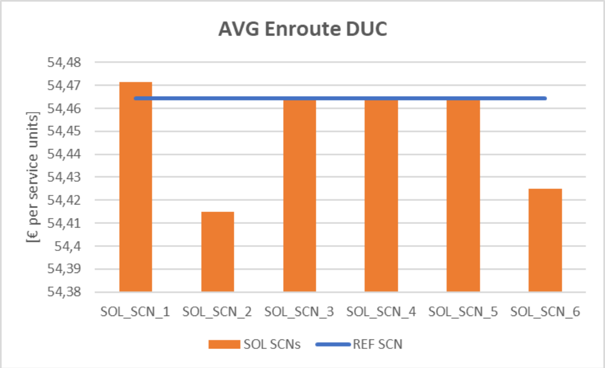

Chart 10: Average En-route DUC – CS02

Compared to the En-route throughput results, for the Terminal throughput there is an improvement for two of the solution scenarios: SOL_SCN_2 and SOL_SCN_6. However, the improvement is not very significant, as the number of flights per day increases less that one flight per day with respect to the reference value.

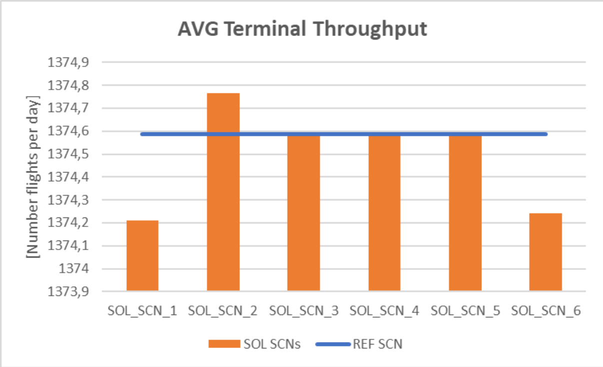

Chart 11: Average Terminal throughput – CS02

Finally, the values for the Terminal DUC indicator show that the mean value of SOL_SCN_2 and SOL_SCN_6 is higher than the mean value of the reference scenario, which implies an improvement. SOL_SCN_6 consists of Cost plus pricing (SOL_SCN_1) and Best equipped-best served (SOL_SCN_2) policies, but since the Cost plus pricing scenario shows a worse performance, the combination of both policies in the SOL_SCN_6 worsens the results of SOL_SCN_2 where it only applies the Best equipped-best served measure.

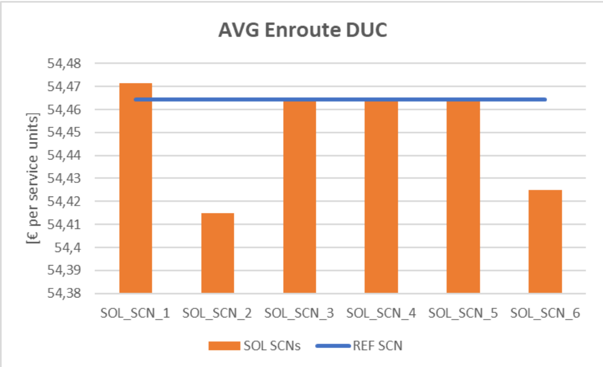

Chart 12: Average Terminal DUC – CS02

For a better summary of all the results presented above, the Table 41 is included, in which the solution scenarios that have given the best results for indicator are highlighted in order. Those cells where no solution scenario is included is because no solution scenario has improved the outcome of the reference scenario.

Indicator	Scenarios
Fuel burnt	---
En-route throughput	---
En-route DUC	SOL_SCN_2 – SOL_SCN_6
Terminal throughput	SOL_SCN_2 – SOL_SCN_6

Terminal DUC	SOL_SCN_2 – SOL_SCN_6

Table 41: Summary of CS03 Operational results

From this table can be concluded that the solution scenarios which imply the most positive improvements in operational indicators are SOL_SCN_2 and SOL_SCN_6, the first one corresponding to Best equipped-best served policy and the second one being the combination of the latter and the Cost plus pricing policy.

For fuel burn and en-route throughput there is no solution scenario that stands out over the others, since the SOL_SCN_3, SOL_SCN_4 and SOL_SCN_5 have the same results as reference scenario. In this particular case, the SOL_SCN_2 is considered the best option since with lower effort on policy implementation, we obtain the same result.

5.3 CS03 Analysis

CS03 focuses on future Use Cases (005_SWIM, 021_Safedrone, 023_DAC and 025_i4d) and the solution scenarios proposed in this Case Study include these policy measures:

- SOL_SCN_1: Cost plus pricing
- SOL_SCN_2: Best equipped-best served
- SOL_SCN_3: Demonstration projects
- SOL_SCN_4: Involvement of the safety agency
- SOL_SCN_5: Realistic timelines
- SOL_SCN_6: Subsidies
- SOL_SCN_7: Increase matureness technologies
- SOL_SCN_8: Mandates
- SOL_SCN_9: Best equipped- best served & Demonstration projects & Involvement of the safety agency
- SOL_SCN_10: Cost plus pricing & Demonstration projects & Subsidies
- SOL_SCN_11: Demonstration projects & Realistic timelines & Increase matureness technologies
- SOL_SCN_12: Subsidies & Mandates

5.3.1 Technological results

SWIM

In general, the results indicate that most of the policies included in the solution scenarios equal or better the adoption of SWIM technology.

In the case of airlines, all adopt this technology by 2035 at the latest, as in the reference case. However, in certain solution scenarios, 100% adoption comes much earlier, including SOL_SCN_12 and SOL_SCN_10, which reach 100% adoption in 2025 and 2027 respectively. SOL_SCN_12 is made up of the combination of two policies, Subsidies and Mandates, whose application separately also returns good results. However, according to Table 42, when these policies are combined, the positive effect is greater. On the other hand, SOL_SCN_10 is also made up of a combination of policies, among which we again find Subsidies. From this it can be concluded that the policy with the greatest impact on the adoption of the SWIM technology by airline is the Subsides policy measure.

UC_005_SWIM Airlines		2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035 - 2040
REFERENCE SCENARIO		0%	50%	63%	69%	88%	88%	88%	88%	88%	88%	88%	94%	94%	100%
SOLUTION SCENARIOS	SOL_SCN_1	0%	63%	75%	81%	88%	88%	88%	88%	88%	88%	88%	94%	94%	100%
	SOL_SCN_2	0%	88%	88%	88%	88%	88%	88%	88%	94%	94%	94%	94%	100%	100%
	SOL_SCN_3 & SOL_SCN_11	0%	38%	56%	69%	69%	75%	75%	88%	88%	88%	88%	94%	94%	100%
	SOL_SCN_4 & SOL_SCN_5	0%	38%	56%	69%	69%	75%	88%	88%	88%	88%	88%	94%	94%	100%
	SOL_SCN_6	0%	75%	88%	88%	94%	94%	94%	94%	94%	100%	100%	100%	100%	100%
	SOL_SCN_7	0%	38%	56%	69%	69%	75%	88%	88%	88%	88%	88%	94%	94%	100%
	SOL_SCN_8	0%	94%	94%	94%	94%	94%	94%	94%	94%	100%	100%	100%	100%	100%
	SOL_SCN_9	0%	88%	88%	88%	88%	88%	88%	88%	94%	94%	94%	94%	100%	100%
	SOL_SCN_10	0%	81%	88%	94%	94%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	SOL_SCN_12	0%	94%	94%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 42: SWIM - Airlines

For airports, although most of the solution scenarios have an adoption rate equal to that of the reference scenario, there are, however, three scenarios that break this rule. In SOL_SCN_8 and SOL_SCN_12, which include the Mandates policy measure individually or in combination with other policies, full adoption is seen in 2023. This means that, in this case, the effect of the Mandates is greater than the effect of the Subsidies, which means that the application of former policy individually achieves the same effect as the combination of both. On the other hand, SOL_SCN_10 achieves full adoption in the fourth year of the simulation by combining Cost plus pricing, Demonstration projects and Subsidies.

UC_005_SWIM Airports		2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036 - 2040
REFERENCE SCENARIO		0%	33%	33%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	47%	47%
SOLUTION SCENARIOS	SOL_SCN_1	0%	33%	33%	33%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	47%
	SOL_SCN_2	0%	33%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	47%	47%	47%
	SOL_SCN_3 & SOL_SCN_11	0%	20%	33%	40%	40%	40%	40%	40%	40%	40%	40%	47%	47%	47%	47%
	SOL_SCN_4 & SOL_SCN_5 & SOL_SCN_7	0%	20%	33%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	47%	47%
	SOL_SCN_6	0%	47%	47%	47%	53%	53%	60%	60%	60%	60%	60%	60%	60%	60%	60%
	SOL_SCN_8 & SOL_SCN_12	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	SOL_SCN_9	0%	33%	40%	40%	40%	40%	40%	40%	47%	47%	47%	47%	47%	47%	47%
	SOL_SCN_10	0%	73%	93%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 43: SWIM - Airports

Regarding the en-route ANSPs, no significant changes are observed with respect to the reference scenario. For most solution scenarios, full adoption is achieved in 2023, as in the reference scenario. For the others, full adoption is obtained one year later.

UC_005_SWIM Enroute ANSPs		2022	2023	2024 - 2040
REFERENCE SCENARIO		0%	100%	100%
SOLUTION SCENARIOS	SOL_SCN_1 & SOL_SCN_2 & SOL_SCN_6 & SOL_SCN_8 & SOL_SCN_9 & SOL_SCN_10 & SOL_SCN_12	0%	100%	100%
	SOL_SCN_3 & SOL_SCN_4 & SOL_SCN_7 & SOL_SCN_11	0%	82%	100%
	SOL_SCN_5	0%	91%	100%

Table 44: SWIM - En-route ANSP

Finally, for the terminal ANSPs, the results are disparate, compared to the reference scenario there are solution scenarios in which the adoption is faster while there are also others in which the adoption is slower. Among those where adoption is faster, SOL_SCN_1 and SOL_SCN_10, both including the Cost plus pricing policy measure, and SOL_SCN_8 and SOL_SCN_12, with the Mandate policy measure, stand out. All these solution scenarios present a 100% adoption by 2023. SOL_SCN_6 is also noteworthy, it completes the adoption of all agents one year later, which implies that the Subsidies also have a great impact both individually and in combination with other policies.

UC_005_SWIM Terminal ANSPs		2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038 - 2040
REFERENCE SCENARIO		0%	55%	55%	55%	64%	73%	73%	73%	82%	91%	91%	91%	100%	100%	100%	100%	100%
SOLUTION SCENARIOS	SOL_SCN_1 & SOL_SCN_8 & SOL_SCN_10 & SOL_SCN_12	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	SOL_SCN_2 & SOL_SCN_9	0%	82%	82%	82%	82%	82%	82%	82%	82%	82%	82%	82%	82%	82%	82%	100%	100%
	SOL_SCN_3	0%	36%	55%	55%	55%	55%	64%	73%	73%	82%	82%	82%	82%	82%	91%	91%	100%
	SOL_SCN_4	0%	36%	55%	55%	64%	64%	82%	82%	82%	91%	91%	100%	100%	100%	100%	100%	100%
	SOL_SCN_5 & SOL_SCN_7	0%	36%	55%	55%	64%	64%	82%	82%	91%	91%	91%	100%	100%	100%	100%	100%	100%
	SOL_SCN_6	0%	91%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	SOL_SCN_11	0%	36%	55%	55%	55%	55%	64%	73%	82%	82%	82%	100%	100%	100%	100%	100%	100%

Table 45: SWIM - Terminal ANSP

Safedrone

The results for the Safedrone technology show different effects. Variations in the level of adoption with respect to the reference scenario are always positive, but at the same time there are many policy measures that have no effect on the different actors implemented. This may be due to the fact that most of the policy measures are more oriented towards piloted aircraft and not so much towards drones.

For airports only the policy measures of Mandates and Subsidies cause an effect, but the effect of Subsidies can be neglected since the same result is obtained by applying only Mandates than by combining the two.

UC_021 Safedrone Airports		2022	2023	2024	2025	2026	2027	2028	2029	2030 - 2040
REFERENCE SCENARIO		0%	0%	0%	0%	0%	0%	0%	0%	0%
SOLUTION SCENARIOS	SOL_SCN_8 & SOL_SCN_12	0%	0%	0%	0%	0%	0%	0%	0%	100%
	SOL_SCN_1 & SOL_SCN_2 & SOL_SCN_3 & SOL_SCN_4 & SOL_SCN_5 & SOL_SCN_6 & SOL_SCN_7 & SOL_SCN_9 & SOL_SCN_10 & SOL_SCN_11	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 46: Safedrone – Airports

The effects on the adoption of the Safedrone project for en-route and terminal ANSPs are very similar. In both cases, solution scenarios SOL_SCN_ 1, SOL_SCN_ 2, SOL_SCN_ 9, SOL_SCN_ 10 and SOL_SCN_ 12 stand out.

- SOL_SCN_1 involves the Cost plus pricing policy measure, and the effect of this can also be seen in SOL_SCN_10.
- SOL_SCN_2 involves the Best equipped-best served policy measure, and the effect of this can also be seen in SOL_SCN_9.

- SOL_SCN_12 combines the policy measures of Subsidies and Mandates, which individually do not cause any adoption but when combined do.

UC_021_Safedrone Enroute ANSPs		2022	2023	2024	2025	2026	2027	2028	2029	2030	2031 - 2040
REFERENCE SCENARIO		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
SOLUTION SCENARIOS	SOL_SCN_1 & SOL_SCN_2 & SOL_SCN_9 & SOL_SCN_10 & SOL_SCN_12	0%	0%	0%	0%	0%	0%	0%	0%	100%	100%
	SOL_SCN_8	0%	0%	0%	0%	0%	0%	0%	0%	0%	9%
	SOL_SCN_3 & SOL_SCN_4 & SOL_SCN_5 & SOL_SCN_6 & SOL_SCN_7 & SOL_SCN_11	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 47: Safedrone – En-route ANSP

UC_021_Safedrone Terminal ANSPs		2022	2023	2024	2025	2026	2027	2028	2029	2030 - 2040
REFERENCE SCENARIO		0%	0%	0%	0%	0%	0%	0%	0%	0%
SOLUTION SCENARIOS	SOL_SCN_1 & SOL_SCN_2 & SOL_SCN_9 & SOL_SCN_10 & SOL_SCN_12	0%	0%	0%	0%	0%	0%	0%	0%	100%
	SOL_SCN_3 & SOL_SCN_4 & SOL_SCN_5 & SOL_SCN_6 & SOL_SCN_7 & SOL_SCN_8 & SOL_SCN_11	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 48: Safedrone - Terminal ANSP

DAC

DAC only affects ANSPs en-route, so results are only displayed for this agent. In general, as can be seen in Table 49, the improvement in adoption with respect to the reference scenario is very notable. While in the reference scenario this technology was only adopted in SOL_SCN_ 2 of the 11 ANSPs, the vast majority of solution scenarios achieve higher adoption. Among them, SOL_SCN_ 1, SOL_SCN_ 2, SOL_SCN_ 9 and SOL_SCN_ 10 achieve full adoption by 2023, highlighting the effect of the Cost plus pricing and Best equipped-best served policy measures. Similarly, although the solution scenarios that contemplate the Mandates and Subsidies policy measures individually do not achieve full adoption, SOL_SCN_12, which combines the two, does so in year 5 of the simulation.

UC_023_DAC Enroute ANSPs		2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
REFERENCE SCENARIO		0%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	18%
SOLUTION SCENARIO	SOL_SCN_1 & SOL_SCN_2 & SOL_SCN_9 & SOL_SCN_10	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	SOL_SCN_3 & SOL_SCN_4	0%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%
	SOL_SCN_5	0%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	18%	18%	18%	18%	18%
	SOL_SCN_6	0%	55%	55%	55%	64%	64%	64%	64%	73%	73%	73%	73%	73%	73%	73%	73%	73%	73%	73%
	SOL_SCN_7	0%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	18%
	SOL_SCN_8	0%	45%	45%	45%	45%	45%	45%	45%	45%	45%	64%	64%	64%	64%	64%	64%	64%	64%	64%
	SOL_SCN_11	0%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	27%
	SOL_SCN_12	0%	91%	91%	91%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 49: DAC - En-route ANSP

i4d

Finally, for the i4d technology, the results of the solution scenarios are very similar to those of the reference scenario, which were already quite positive.

In the case of airlines, SOL_SCN_ 8 and SOL_SCN_ 12 show the best results, since they reach full adoption of the technology 11 years earlier than in the reference scenario. The Mandates policy is included in both scenarios, which shows that it is a good lever to encourage adoption in this case.

UC_025_i4D Airlines		2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035 - 2040
REFERENCE SCENARIO		0%	81%	81%	81%	88%	88%	88%	88%	88%	94%	94%	94%	100%	100%
SOLUTION SCENARIOS	SOL_SCN_1	0%	81%	81%	88%	88%	88%	88%	88%	94%	94%	94%	94%	100%	100%
	SOL_SCN_2 & SOL_SCN_9	0%	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	100%	100%
	SOL_SCN_3 & SOL_SCN_4	0%	81%	81%	81%	88%	88%	88%	88%	88%	94%	94%	94%	94%	100%
	SOL_SCN_5	0%	81%	81%	81%	88%	88%	88%	88%	88%	94%	94%	94%	100%	100%
	SOL_SCN_6	0%	81%	88%	88%	88%	88%	88%	88%	94%	94%	100%	100%	100%	100%
	SOL_SCN_7	0%	81%	81%	81%	88%	88%	88%	88%	94%	94%	94%	94%	100%	100%
	SOL_SCN_8 & SOL_SCN_12	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	SOL_SCN_10	0%	81%	88%	88%	88%	88%	94%	94%	94%	100%	100%	100%	100%	100%
	SOL_SCN_11	0%	81%	81%	81%	88%	88%	88%	88%	94%	94%	94%	94%	94%	100%

Table 50: i4D - Airlines

Something similar happens for en-route ANSPs, in all solution scenarios full adoption is achieved. In addition, in 6 of them it is achieved in 2023, much earlier than for the reference case. It is important to note that many of the policies achieve this full adoption individually, for instance Best equipped - best served, Cost plus pricing, Subsidies and Mandates; so, it would be unnecessary to combine them with each other or with others.

UC_025_i4D Enroute ANSPs		2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037 - 2040
REFERENCE SCENARIO		0%	91%	91%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
SOLUTION SCENARIOS	SOL_SCN_1 & SOL_SCN_2 & SOL_SCN_6 & SOL_SCN_8 & SOL_SCN_9 & SOL_SCN_10 & SOL_SCN_12	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	SOL_SCN_3	0%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%	100%
	SOL_SCN_4 & SOL_SCN_11	0%	91%	91%	91%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	SOL_SCN_5 & SOL_SCN_7	0%	91%	91%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 51: i4D - En-route ANSP

Global results

Table 52 summarizes the results presented previously. The colour and symbol coding of the table follows the same guidelines as for the Table 23 and Table 38.

	UC_005_SWIM	UC_021_Safedrone	UC_023_DAC	UC_025_i4D
Airlines	SOL_SCN_12			SOL_SCN_8 SOL_SCN_12
Airports	SOL_SCN_8 SOL_SCN_12	SOL_SCN_8 SOL_SCN_12		
En-route ANSPs	---	SOL_SCN_1 SOL_SCN_2 SOL_SCN_9	SOL_SCN_1 SOL_SCN_2	SOL_SCN_1 SOL_SCN_2

		SOL_SCN_10 SOL_SCN_12	SOL_SCN_9 SOL_SCN_10	SOL_SCN_6 SOL_SCN_8 SOL_SCN_9 SOL_SCN_10 SOL_SCN_12
Terminal ANSPs	SOL_SCN_1 SOL_SCN_8 SOL_SCN_10 SOL_SCN_12	SOL_SCN_1 SOL_SCN_2 SOL_SCN_9 SOL_SCN_10 SOL_SCN_12		

Table 52: Summary of CS03 Technological results

From these results it can be drawn the conclusion that there are two main systems for accelerating the adoption of each technology.

- The first includes policies related to increasing incentives, either by providing more economic support or by improving the service received. Some examples are: Cost plus pricing, Best equipped – best served and Subsidies. These policies give very good results.
- The second corresponds to the obligation to adopt the different technologies through a policy based on Mandates. Although this system is effective, it has a greater negative impact on economic aspects.

SOL_SCN_ 12 mixes these two systems. Through the Subsidies, economic support is increased and, on the other hand, the Mandates imply the obligation to adopt them compulsorily. This combined solution scenario offers the best results for most agents and Use Cases, so it can be concluded that, at the level of technology adoption, the combination of these two policy measures is the most appropriate.

5.3.2 Economic results

We start the economic analyses by looking at the changes in social welfare when the different policy measures are in place compared to the reference scenario. The Table 53 shows the impact on SWF of the different policies for CS03.

Name	Policy instrument	Change in SWF over period 2021-2040
SOL_SCN_1	Cost plus pricing	+5%
SOL_SCN_10	Cost plus pricing & Demonstration projects & Subsidies	+4.9%
SOL_SCN_5	Realistic timelines	+2.2%
SOL_SCN_4	Involvement of the safety agency	+2.2%
SOL_SCN_3	Demonstration projects	+2%

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SOL_SCN_7	Increase matureness technologies	+1.8%
SOL_SCN_12	Subsidies & Mandates	+1.6%
SOL_SCN_11	Demonstration projects & Realistic timelines & Increase matureness technologies	+1.6%
SOL_SCN_8	Mandates	+1.5%
SOL_SCN_2	Best equipped-best served	+0.7%
SOL_SCN_9	Best equipped-best served & Demonstration projects & Involvement of the safety agency	+0.6%

Table 53: Impact on Social Welfare – CS03

As can be seen in Chart 13, and similarly to the other case studies, the most dominant elements of Social Welfare are surpluses from airlines (50%) and surpluses from airports (46%). On the other hand, the passenger surplus amounts to 6% of social welfare, while externalities are only 3%. Finally, the surpluses of the en-route and terminal ANSPs fluctuate around zero, which means that they have little or no effect here.

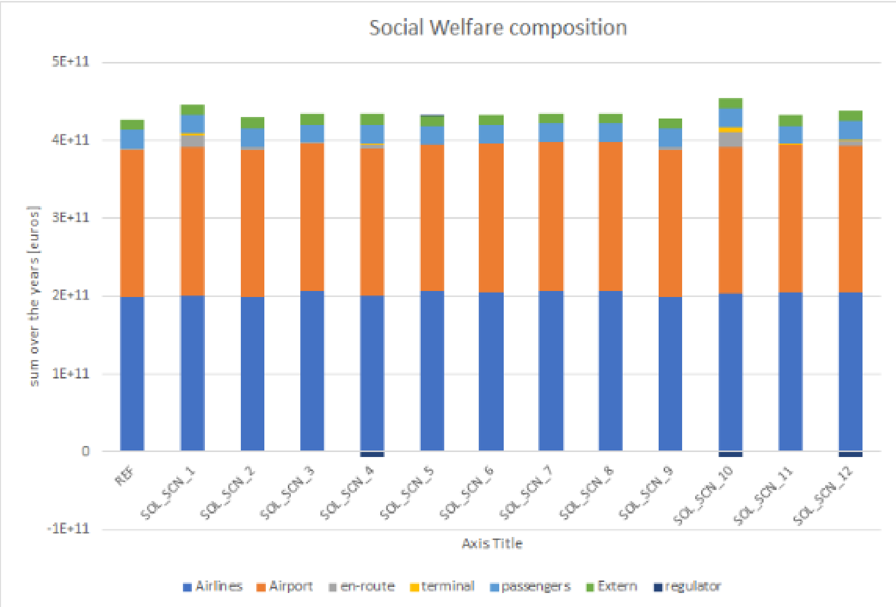

Chart 13: Social Welfare composition - CS03

The best performing scenarios are those including the Cost plus pricing policy. When this measure is implemented individually, a net gain is seen for all agents, with the sole exception of passengers, whose situation worsens slightly. The general increase in social welfare is explained by the fact that ANSPs obtain a positive profit under this price regime. At the same time, increased navigation charges and increased costs for airlines are passed on to passengers through increased airfares. On the other hand, the decrease in delay costs (-16.6%) cannot offset this increase and passengers' surplus decreases (-0.16%). Finally, airline surplus increases (+0.68%) as more ANSPs now adopt the technologies (particularly terminal ANSPs), benefiting airlines.

When Cost plus pricing is combined with better Demonstration projects and Subsidies policies, the overall impact on social welfare remains the same, but the situation of the different agents' changes. On the one hand, airlines enjoy a higher profit gain (+1.75%) while airport profits decline (-0.82%) due, on one hand, to an increase in the labour cost to accommodate the increase in passengers and in the other hand, given the decrease in profits as airports reduce their fees per passenger. Finally, passengers do not experience an increase in charges and the decrease in delay costs increases their surplus (+0.31%).

The policies aimed at reducing the risk perception such as Demonstration projects, Involvement of the safety agency, Realistic timelines and Increased maturity level of the technology all have very similar impacts as can be expected. The 2% increase in social welfare here is explained by an increase in the profits of airlines (around 3.5%) and airports (around +0.6%).

By applying the Mandates policy, the adoption rates also improve compared to the reference scenario, however, a complete adoption is not achieved. Here, all agents improve their situation in terms of social welfare, with the exception of airports (-0.76%). For this scenario, the airports adopt the Safedrone technology, although this system does not have benefits for them, but rather costs. On the contrary, as passengers do not face higher airfares, as was the case in the Cost plus price scenario their surplus increases (+1.59%).

The Subsidies policy presents the worst results, however maintaining a positive impact. On the other hand, it is one of the most beneficial policies for passengers, who see their surplus increase by (+1.62%). Regarding the externalities, this policy has only a small impact (-0.04%) but there is a decrease in delay costs of 16%, which explains the increase of passenger surplus. If we combine Subsidies with Mandates we see that Mandates have a greater impact, although the results are in line with the values obtained when only Mandates are imposed.

Finally, it can be seen that the Best-equipped-best-served policy has a lesser impact, probably because this policy aims to encourage airlines to adopt, but in these cases they already adopt. The surpluses of airlines and airports decrease by -0.21% and -0.14% respectively.

As illustrated in the graphs below, all scenarios lead to higher social welfare, but most of the changes are modest. The results for each agent vary considerably between scenarios. Most scenarios increase the airline surpluses (only the best-equipped-best served scenario leads to a decrease in surplus), whereas most scenarios are not beneficial to the airports (except the policies aimed at reducing risks and the Cost plus pricing). Additionally, due to the assumption on the ANSPs profits and the way the navigational charges are modelled, these agents will only experience positive profits for the scenarios including Cost plus pricing, Best-equipped-best-served or Subsidies policies. The result for the passengers is very mixed.

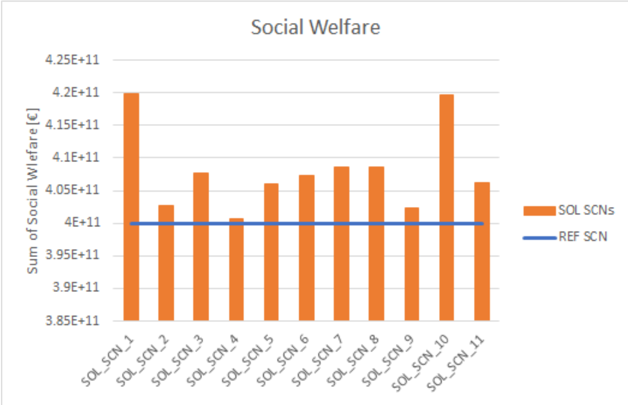

Chart 14: Impact of Social Welfare per solution scenario - CS03

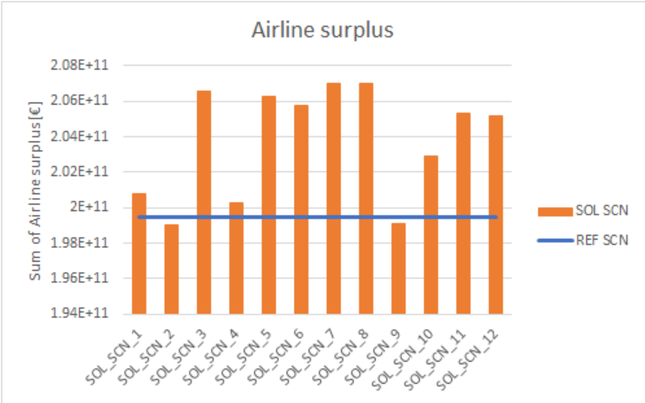

Chart 15: Airline surplus - CS03

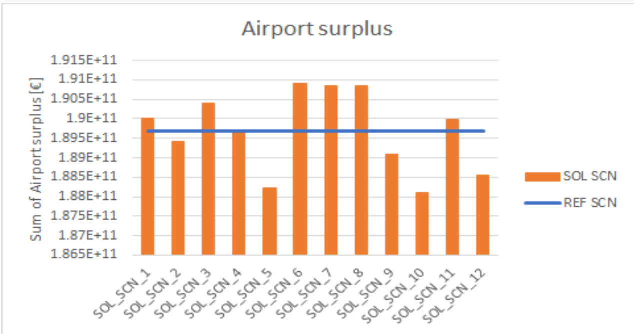

Chart 16: Airport surplus - CS03

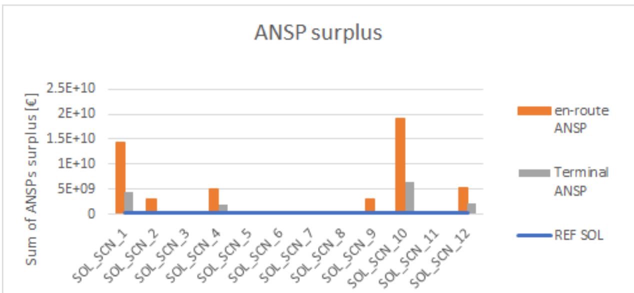

Chart 17: ANSP surplus

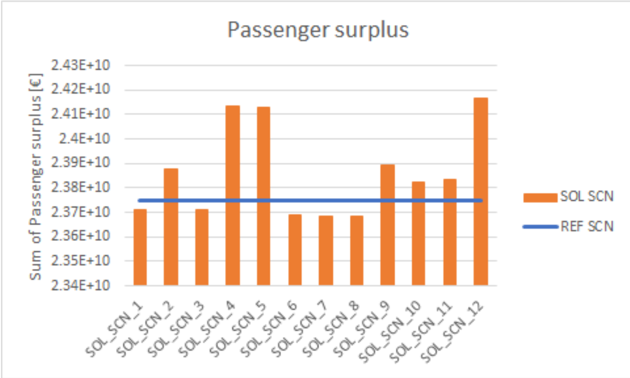

Chart 18: Passenger surplus

In terms of underlying variables, we note that there is little impact on the number of passenger km but delay costs do improve for some scenarios. Scenarios including any of these policies, Cost-pricing (-16.6%), Subsidies (-16%), Mandates (-10%) and Best-equipped-best-served (-14.6%) or any combination between them, perform the best. The policies aimed at reducing the risks have only a small impact on delay costs (less than 1%). Externalities are slightly reduced for all scenarios (between –0.04% and –0.25%).

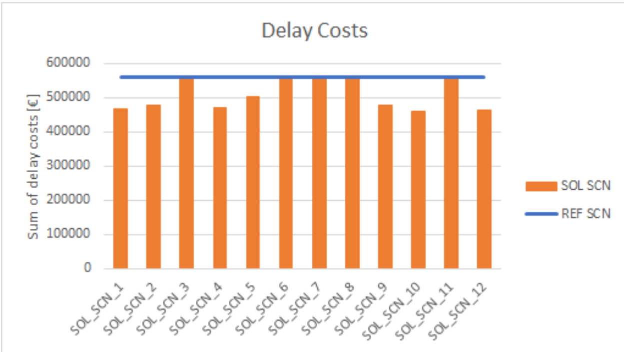

Chart 19: Delay costs - CS03

In summary, looking at the social welfare alone, the scenarios with Cost plus pricing are the most desired. As airlines, airports and the ANSPs gain in this scenario it is likely to be well accepted. Passengers, however, will be worse off. They will best off with Subsidies or Mandates.

5.3.3 Operational results

The Chart 20, displays the average value over all simulation years. From there is clear that the fuel burnt is lower than in the reference scenario for almost all the scenarios, with SOL_SCN_ 1, SOL_SCN_ 8 and SOL_SCN_ 12 showing the greatest reduction, which enhances the effect of Cost plus pricing, Mandates and Subsidies Policy Measures

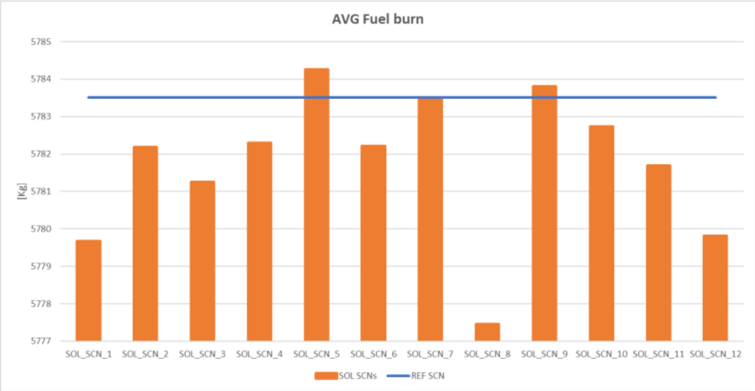

Chart 20: Average fuel burnt - CS03

Regarding the En-route throughput, when analysing the results of Chart 21, it can be seen that there are 4 scenarios where the results improve, especially in SOL_SCN_ 12 (Subsidies & Mandates), where there are 15 more flights per day on average.

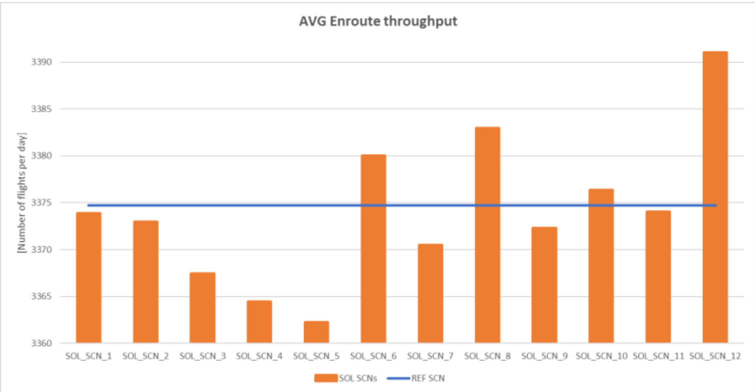

Chart 21: Average En-route throughput - CS03

Looking the results shown in Chart 22, it can only be appreciated improvements for en-route SOL_SCN_ 8, SOL_SCN_ 10 and SOL_SCN_ 12, comprising Mandates, Cost plus pricing & Demonstration projects & Subsidies and Mandates & Subsidies Policy Measures respectively. In any case, in the scenarios in which the mean value is higher, the difference with respect to the reference is not very big.

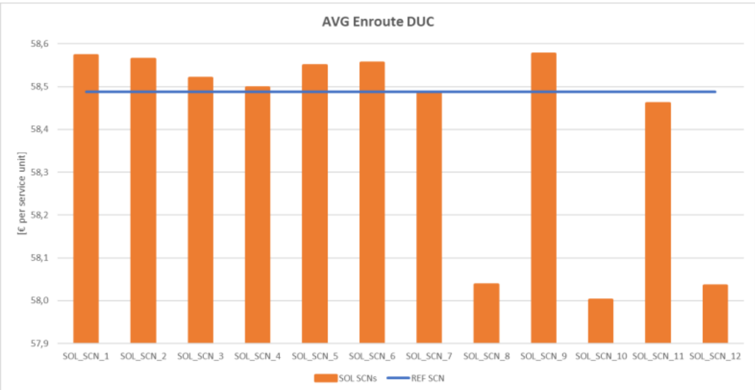

Chart 22: Average en-route DUC - CS03

The results for terminal throughput follow the same logic as for en-route throughput. Chart 23 clearly shows that SOL_SCN_6, SOL_SCN_11 and SOL_SCN_12 give the best results, so Demonstration projects, Realistic timelines, Increase matureness technologies, Subsidies and Mandates could be considered as the best options.

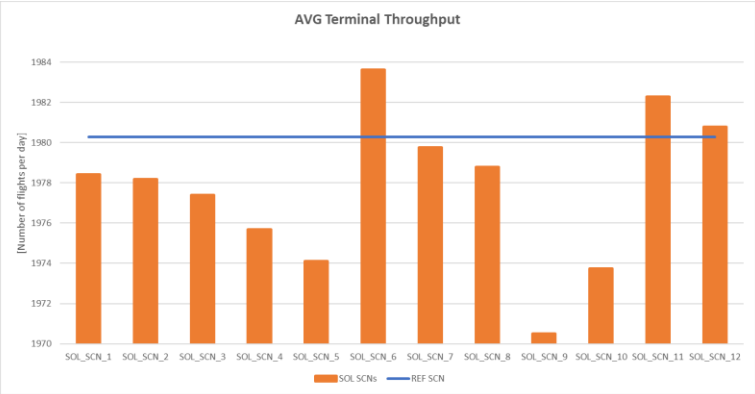

Chart 23: Average terminal throughput - CS03

Finally, as far as the DUC Terminal is concerned, the results are pretty bad. The Chart 24 shows that the mean value of the solution scenario always exceeds the mean value of the reference scenario.

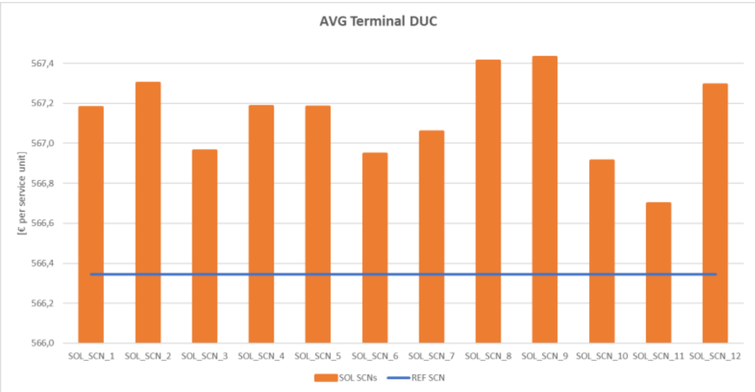

Chart 24: Average terminal DUC - CS03

For a better summary of all the results presented above, the following table is included, in which the 3 solution scenarios that have given the best results for indicator are highlighted in order.

Indicator	Scenarios
Fuel burnt	SOL_SCN_8 – SOL_SCN_1 – SOL_SCN_12
En-route throughput	SOL_SCN_12 – SOL_SCN_8 – SOL_SCN_6
En-route throughput	SOL_SCN_10 – SOL_SCN_8 – SOL_SCN_12
Terminal throughput	SOL_SCN_6 – SOL_SCN_11 – SOL_SCN_12
Terminal DUC	---

Table 54: Summary of CS03 Operational results

From this table can be concluded that the solution scenario which in general implies the most positive improvements in operational indicators is the SOL_SCN_12, the one corresponding to the combination of Mandates and Subsidies policy measures.

5.4 Sensitivity analysis

In this section we present the sensitivity results of the model following the methodology detailed in the Section 4.3.2.1, where the different inputs that are taken into account in the analysis are also illustrated. All the tests have been performed for the reference scenario of CS03. The technologies included in this Case Study are listed below along with a reference to the stakeholders involved in their application and their adoption levels for the reference scenario:

- SWIM: It applies to all the agents. In the reference case, it achieved a high adoption rate.
- Safedrone: It applies to ANSPs and airports. The technology has the particular feature that provides no benefits to the adopters in the CBA considered, then, it has not been adopted in the reference case.
- DAC: It only applies to En-route ANSPs. The market share obtained in the reference case was of 18% of the possible adopters.
- I4D: It applies to En-route ANSPs and airlines. The technology reaches full adoption.

As explained in Section 4.3.2.1, the inputs have been analysed separately, so the insights obtained for the sensitivity study of each individual input individually are presented below. The complete results for each sample, together with the slope for the linear regression of the outputs with respect to the inputs and its correlation factor are included in Annex A.3.

Price demand elasticity in routes

Price demand elasticity in routes has a small effect on technology adoption metrics. Market share only varies for DAC, with a positive relation, but the correlation is relatively small to consider a linear relation between the variables. Time for adoption is reduced for SWIM and DAC but increased for i4D. The changes are not significant and the correlation is small for those indicators with the input variable.

Social welfare has a strong direct correlation with respect to the route price demand elasticity. This means that the less elastic the demand of the routes, the greater the social welfare. This effect is mainly produced by airlines' and airports' surplus, which increase their profit when the routes are less elastic because the demand is less sensitive to price increases and their benefit margin increases. We can confirm the effect looking at the airfare, which increases when the demand becomes more inelastic. Moreover, load factor is increased providing airlines a reduction in unitary costs, increasing even more their surplus.

On the operational side, throughput for both en-route and terminal ANSPs increase, this is aligned with the increase in number of flights when the demand becomes more inelastic. This effect is again explained due to the lower sensitivity of the demand with respect to price increases and the overall growth in demand approaches to the one defined by the exogenous variable. Determined Unitary Costs are reduced when the demand is less elastic.

Price demand elasticity in airlines

Price demand elasticity for airlines affect technology adoption for all the technologies considered in the same manner: the more elastic the demand of the airlines, the slower they adopt technologies. Market share can eventually suffer an increase when demand is less elastic, as it can be observed for DAC. This is aligned with insights from [1] about the relationship between market structure and the incentives for R&I: “perfect competition leaves no profit for innovation, while within a perfect monopoly there are no real incentives”. The increase in competition is translated into a slower adoption of new technology.

Social welfare decreases sharply with the increase in demand elasticity. This behaviour is heavily affected by airports' surplus, which presents a similar trend. The huge increase in airport surplus when demand is less elastic is produced by a non-linear effect of airports' calculation of optimal landing and passenger charges, which quickly increase when demand becomes less elastic, driving airfare prices to reach high rates. One should be careful with this outcome because the non-linearity makes the behaviour very different from reality. The assumptions on airports’ demand elasticity with respect to their charges per passenger should be reviewed. It is possible that a different elasticity value should be included to separate the effect of airlines’ price demand elasticity and airports’ price demand elasticity. We should review further in the literature on this topic.

If we exclude airports’ surplus from social welfare, we can see that there is an inverse relationship: the social welfare increases with the competition between airlines (more elastic demand). This behaviour is given by the important increase in passengers’ surplus with the competition and the fact that airlines' surplus is not specially hindered by the increase in competition. Excluding the first value (-1.2), which is the one most affected by airports' non-linear behaviour, airlines face an increase in surplus with the increasing competition, driven by the increase in load factor and number of flights, which compensates the reduction of airfare. ANSPs increase their surplus with the increased elasticity given by the increment of number of flights.

On the operational side, throughput is increased due to the increase in demand, on turn produced by the reduction of airfares. Determined Unitary Cost are reduced.

Annual salary change

Salary changes affect importantly companies cost evolution but also passengers utility, which was modelled to evolve in the same rate as the evolution of the salaries, an important indicator of passengers' acquisitive power.

Annual salary changes affect technology adoption by reducing times for adoption and increasing market share when the salary presents higher growth rates. As mentioned, this increases costs for companies, which need to be more cost efficient to stay competitive and implementing technologies that improves reduce their costs becomes more and more attractive. There is a good agreement on all the parameters with this behaviour, except for SWIM’s market share, which already presented a high rate.

Social welfare does not present a good correlation with the linear approximation of the output in this case. Looking at the results, it presents a U-shaped behaviour given by 2 different effects: low salary increases are beneficial for airports' surplus but passenger surplus increases with the increase in salaries. ANSPs surplus vary but, since they are based on a cost-recovery scheme, their surplus does not present significant variations. Airlines surplus evolution has also a U-shape, but with good agreement with the linear regression, which indicates that they increase their surplus with the increase in salary evolution. This outcome is a priori counter-intuitive because their costs grow, but it can be explained looking at the number of flights, airfare and load factor: while their unitary costs increase with the annual salary increase, airlines increase their airfares, reducing the total number of flights due to the price demand elasticity. However, their margin of revenues can be maintained by increasing the utilisation of the aircraft, as seen with the increase in load factor, which reduces their unitary costs.

En-route and TMA throughput are reduced due to the reduction of demand and Determined Unitary Costs suffer huge increases due to the labour cost increase.

Demand growth

Time for adoption is reduced for SWIM and i4D, while for DAC, it does not present a specific relationship. There are not special variations on the market share side.

Social welfare and the profit seeker stakeholders (airlines and airports) perceive an increase with the increased demand growth, this effect was expected as their total revenue depends on their business volume. As seen when analysing the price demand elasticity of the airlines, airports behaviour is more abrupt than expected. The increased demand growth drives the airport fees to high rates that affect final airfare. It can be seen that the airfare increases with the demand growth, which in turn reduces passenger surplus in the scenario of highest growth.

On the operational side, throughput increases as expected due to the demand growth and Determined Unitary Costs are slightly reduced.

Fuel price

Technology adoption is not very sensitive to the change in fuel prices. The most important changes are seen for SWIM’s time for adoption, but there is not a big correlation between the parameters.

Fuel price affects mainly airlines' costs, which in turn increase airfares. This is well evidenced in the results with a strong correlation between the input (fuel price) and the airfare at the end of the simulation. Social welfare decreases, as it was expected, but the individual surpluses do not evolve as they are supposed to do a priori. Airlines increase their surplus, which can be explained with the increase in airfare given that the number of flights is approximately constant. However, in the case of passengers, they increase their surplus despite the increase in airfare. This strange behaviour is caused because of the initial assignment of the demand in the model: initial demand only depends on the initial year, it does not take into account variations in other external variables (e.g., fuel price, salary increase) that affect the demand. On the contrary, initial prices for the flights are estimated based on their costs, which will be higher with an increase in fuel cost, and then it is assumed that the demand is willing to pay those initial airfares. Since initial airfare is higher, the increase in airfare perceived is relatively smaller, and demand is less affected if we consider the same price demand elasticity, giving extra benefit to airlines. Passenger surplus depends on the definition of its utility, which is calculated as 1.25 times the initial average airfare of a route and it grows at the same rate as the annual salary change. This definition leads to an increase in utility given the increase of initial airfare. This exploration provides us insight on the limitations of the model when initial conditions are affected between each other. The guidelines of use of this assessment tool will include remarks on the need for correct calibration of the initial demand and other related conditions that may affect it. Taking this into account, the model is useful to test what may happen in hypothetic scenarios.

The throughput is reduced when the fuel price increases with a very high correlation. This is due to the decrement on number of flights. Load factor decreases and airfare increases as the costs for the airline are bigger. Determined Unitary Costs are steady as the change in fuel does not affect their costs and the productivity is similar between cases given the similar adoption of technology.

Summary

The results of the sensitivity analysis are summarised in the following table in order to provide a holistic view of the analysis. In the table, the relationship between inputs and outputs are depicted, stating when the output increase or decrease and its magnitude of change. When the relationship is positive, the cells are coloured in green; when it is negative, they are coloured in orange; and when the output is not very sensitive to the input, the cells are coloured in yellow.

			Price demand elasticity in routes	Price demand elasticity for airlines	Annual salary change	Demand growth	Fuel price
			When less elastic	**When less elastic**	**When salaries increase**	**When demand increases**	**When price increases**
Indicators	Technology	Time for adoption	Faster adoption in some cases	Faster adoption	Faster adoption	Faster adoption in some cases	Faster adoption in some cases
		Market share	Higher market share	Higher market share in some cases	Higher market share	Higher market share in some cases	Lower market share in some cases
	Economic	Social welfare	Moderate increase	Important increase	Small decrease	Important increase	Moderate decrease
		Enroute surplus	Moderate decrease	Important decrease	Small increase	Important decrease	Small decrease
		Terminal surplus	Important decrease	Important decrease	Small increase	Important decrease	Small decrease
		Airline surplus	Small increase	Moderate increase	Small increase	Moderate increase	Moderate increase
		Airport Surplus	Important increase	Extreme increase	Important decrease	Important increase	Important decrease
		Passenger surplus	Small increase	Important decrease	Important increase	Small increase	Small increase
	Operational	En-route and TMA throughput	Moderate increase	Moderate decrease	Moderate decrease	Important increase	Moderate decrease
		Enroute and TMA DUC	Small decrease	Small increase	Moderate increase	Moderate decrease	No effect

Table 55: Sensitivity Analysis results

5.5 Policy parameters exploration

In this section we explore how the outcomes of the simulation are affected by the parameters used to model the policies to be benchmarked. The purpose is twofold: assess the mechanisms that arise when the policies proposed are applied and help us to decide on the reference parameters defining the policies included in the detailed analysis of the case studies.

The complete results for each parameter, together with the slope for the linear regression of the outputs with respect to the inputs and its correlation factor are included in Annex A.4.

Cost plus pricing - unit rate margin

Cost plus pricing impacts positively in the technology adoption indicators: technologies are adopted faster and market shares are increased even for low values of the margin in the unit rates allowed for ANSPs. Regarding Safedrone UC, the market share reaches a maximum of 66.67% since airports are not affected by this policy and keep on rejecting it, while all ANSPs decide to adopt (note that this technology is not applicable to airlines). DAC, which only applies to ANSPs reaches complete adoption.

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On the economic side, as the unit rate margin increases, social welfare also increases, driven by the increase in ANSPs surplus. On the other hand, airlines, airports and passengers suffer a decrease in their surplus given that they have to pay for the increase in charges. It is important to note that for low unit rate margin values, passengers' surplus increases with respect to the reference value. This is provided by the benefits of the increased technology adoption on delays.

Throughput presents a decrease when increasing the margin, given by the increase in airfare produced by the increase navigational charges. Determined Unitary Costs are steady for the different values considered and are slightly higher than in the reference case (without application of the policy). This increase could be driven by the adoption of the Safedrone UC, which implies implementation costs but provides no benefit to the ANSPs, according to the CBA used for the technology.

Considering a balance between the increase in adoption and the surpluses of the different agents, we decided to use a margin of 5% as reference value for conducting the use cases.

Best equipped-best served - charge penalty and charge reduction

In the Best equipped-best served policy there are 2 important factors that play a role in adoption and the relation between them is to be taken into account. Therefore, for this case we have analysed the variation of both in combination. Charge penalty is considered between values from 0.1% to 9% of air navigational fees increment when ANSPs adopt a technology and an airline has not adopted it. On the other hand, charge reduction between -1% to 9% air navigational fees have been considered when ANSPs adopt a technology and an airline adopts it as well. The negative -1% decrease in this case is equivalent to an increase of the charges, which only makes sense a priori when the charge penalty is set to be higher than 1%. After testing the different combinations, we have found the following interesting conclusions:

- As it was expected, for a charge penalty of 0.1%, a charge reduction between -1% and 0.1% produce improvements in the technologies that do not depend on airline adoption (Safedrone and DAC) but hinders adoption of the other technologies
- Large charge reductions lead to a decay in the adoption market share for all the technologies. The effect is driven by ANSPs behavioural change: when the incentives to airline (charge reduction) are higher than the penalties, ANSPs profit when adopting decay and adoption becomes less attractive for them; the rejection of the technologies by ANSPs makes that the airlines obtain no benefit from adopting because the benefits are dependent on the adoption on air and ground sides and produce the rejection of the technology by airlines too.
- On the economic side, airlines' surplus tends to increase and other agents' surpluses decrease when charge reduction percentage is increased.
- The number of flights tend to decay when increasing the charge reduction. This drives throughput, which follows the same trend. Determined Unitary Costs increase with the charge reduction, which is explained considering the lower adoption rates that present the technologies. Airfare is reduced as the charge reduction increases, as expected because of the reduction in costs (navigational charges) of the airlines.
- Increasing charge penalties improve the results in the three areas analysed.
- For charge penalties between 2% and 9% of the unit rate, a low bonification to airlines (charge reduction 0.1%) provides a maximum in the technology adoption market share and rate of

adoption, improving the values of the reference case (without policy applied) for all the technologies in the case study. Economic indicators present the same optimum for 0.1% of charge reduction for all, except for airlines, but the reduction on their surplus with respect to the reference case is minimal.

Demonstration projects - risk perception reduction

The risk perception change induced by the Demonstration projects induce small changes on the adoption of technologies, presenting an unexpected reduction of DAC adoption.

The economic indicators have small correlation with the changes in the risk perception, this is given by the adoption rates and market share that do not follow a specific trend in general. We find maximum values for the social welfare with a reduction of 15% of the risk perception.

Regarding the operational values, the throughput is aligned with the changes in number of flights and DUC barely suffer changes. Airfare increases and it is higher than the case without applying the technology.

Given the difficulty to find a trend on the results, we decided to use a 15% of reduction of risk perception as reference value for the case studies, given that it maximises the economic indicators for most of the agents.

Subsidies - percentage of implementation cost subsidised

Subsidies have, as expected, a direct relationship with the rate of adoption. It can be seen that all the indicators for any technology are improved: higher adoption rate and lower adoption time with a good correlation between the percentage of implementation cost subsidised and the adoption rates. It should be noted the case of Safedrone: given the CBA used, it provides no benefits to the adopter, then one may question why the adoption is made if not all the costs are subsidised. The answer is given by the Behavioural Economics biases that affect agents' behaviour. The implementation costs are distributed along the lifetime of the technology, they are not considered as a punctual cost but depreciated along their lifetime. On the other hand, Subsidies are distributed only along a few years after the implementation. By applying hyperbolic discounting bias in the adoption decision, the adopters feel more important the immediate benefit of the subsidy than the prolongated depreciation cost of the technology, leading to adoption even when the technology itself is not economically beneficial for the adopters.

Social welfare tends to increase with the increment of the percentage of implementation cost subsidised, but as seen from the low correlation value, this increase is not linear. When technologies reach a high adoption rate, the benefits they provide no longer increase. If we keep increasing the percentage of implementation costs subsidised, the cost for the regulator (not included in the table but included for the calculation of the social welfare) keeps increasing and hinders social welfare. Agents' surplus increase with the percentage of Subsidies.

On the operational side, throughput increases as it increases the number of flights. The Determined Unitary Costs for en-route ANSPs decrease for low percentages and increase again for high percentages. This might be related with the increase in adoption of beneficial technologies at the beginning and then the increase of Safedrone UC increases the costs with no improvement on productivity.

The reference value selected for the percentage of implementation cost subsidised was 50%, which provided decent adoption results and maximises the economic indicators.

Mandates - benefit subtracted

Mandates have a strong influence on adoption indicators when they imply the payment of a fine when technology is not adopted. The fines are established as a percentage of the revenues of the agents each year. Even for low percentages (0.01%) the effect on adoption is noticeable both in the increase of the market share and in accelerating the adoption time. For percentages equal or greater than 1% the technology adoption does not increase anymore.

Social welfare increases with the fines presented mainly because of the increase in the regulator surplus. Passenger surplus increases until full adoption is achieved for the technologies involved and then it starts decreasing due to the increase in ticket price.

A maximum on the number of fights is achieved for 0.1% of benefit subtraction and this drives the behaviour of the en-route and terminal throughput. Determined Unitary Costs increase with the quantity of the fine, with a good correlation between the variables.

Give the steep increase in adoption produced by this policy, we decided to use 0.1% as the reference value for this variable, because some operational indicators are maximised for the samples tested and there is still room for improvement on the adoption when analysing this policy in combination with others.

6 Conclusions and recommendations

6.1 Main conclusions of the case studies

6.1.1 CS01 Conclusions

The table below summarises the scenarios that provided the best results on each of the KPAs considered for the benchmark of the policies. As we can see, there is no agreement in the options that scored the best in each area, however, the combination of Cost plus pricing & Best equipped-best served is repeated in the technological and economic sides.

	Solution scenario	Policy measures
Technological	SOL_SCN_8	Cost plus pricing & Best equipped-best served & Mandates
Economic	SOL_SCN_6	Cost plus pricing &Best equipped-best served & Increased matureness technologies
Operational	SOL_SCN_3	Subsidies
	SOL_SCN_7	Cost plus pricing & Subsidies & Increase Matureness Technologies

Table 56: Best scenarios for CS01

In the technological side, it should be noted that SOL_SCN_7, SOL_SCN_6 and SOL_SCN_1 also get the same market share than SOL_SCN_8 and improve the adoption rate with respect to the reference case. Regarding economic indicators, solution scenarios SOL_SCN_1 and SOL_SCN_7 obtain a social welfare indicator comparable to the best case noted. SOL_SCN_8 improves with respect to the reference case but is considerably lower scored than SOL_SCN_6. All the solution scenarios share the inclusion of the Cost plus pricing policy, whose behaviour seems to enhance the benefits provided by other policies. On the operational side, Subsidies are the best scoring policy (SOL_SCN_3) with SOL_SCN_7 in second place, which also includes Subsidies. Subsidies alone is a priori preferred, because they are easier to be implemented by the policy maker than a combined policy. The inclusion of Mandates seems to considerably hinder operational results while the policies including Cost plus pricing, although they are not the best scoring ones, perform correctly. The operational indicators lack some important measures and should be better analysed with high fidelity micro-models, reproducing the levels of adoption obtained with the ITACA ABM.

This agreement seems to indicate that the Cost plus pricing measure, especially in combination with others, is a good candidate to have improved the adoption of the technologies in the first case study considered. SOL_SCN_6 (Cost plus & Best Equipped–best served & increased matureness) and SOL_SCN_7 (Cost plus pricing & Subsidies & Increase Matureness Technologies) can be considered as the ones that obtained and overall higher score in the 3 different areas. Note that SOL_SCN_7 includes Subsidies, which are the best scoring policy in the operational area.

6.1.2 CS02 Conclusions

The table below summarises the best solution scenarios under the three areas analysed – technological, economic and operational. We note that there is not one solution which scores best on all three areas.

	Solution scenario	Policy measures
Technological	SOL_SCN_6	Cost plus pricing & Best equipped-best served
Economic	SOL_SCN_3	Demonstration projects
	SOL_SCN4	Realistic timelines
	SOL_SCN5	Demonstration projects & Realistic timelines
Operational	SOL_SCN_2	Best equipped-best served

Table 57: Best scenarios for CS02

From a technical point of view, the policy measure which lead to the highest uptake of the technologies is the combination of Cost plus pricing and Best equipped-best served. This is exactly the scenario which scores the worst in the economic analysis although the effect on social welfare is relatively small (-0,3% change). We also need to note that the scenarios which scores "best" from an economic point of view have almost no impact on the implementation of the technologies and in fact lead to no change in social welfare (0% change). This issue might be caused by the fact that we do not capture the full benefits of the technologies because the decision to implement (2018) is very close to the final year of the period considered (2022) and the benefits are only perceived in the medium-long term. From an operational point of view, it seems that Best equipped-best served scores the best, although we should note that also SOL_SCN_6 scored well in the operational area. The main reason for opting for SOL_SCN_2 over SOL_SCN_6 was the fact that it requires the implementation of only one policy.

From a general perspective, when optimum situation is desired from the all three areas, the preferred option for these technologies would be Best equipped–best served combined with Cost plus pricing (SOL_SCN_6). This decision, contradicting social welfare results is made considering the lower score of SOL_SCN_2 in the technical area and the fact that some technologies did not have enough time to provide full benefits in the simulations in spite of its higher adoption rate.

6.1.3 CS03 Conclusions

After the analysis in the previous section, for CS03, concerning future Use Cases, there is no policy masure that offers benefits in the three areas that have been analysed. In the table below, the scenarios providing the best results for each indicator category are shown.

	Solution scenario	Policy measures
Technological	SOL_SCN_12	Subsidies & Mandates
Economic	SOL_SCN_1	Cost plus pricing
Operational	SOL_SCN_12	Subsidies & Mandates

Table 58: Best scenarios for CS03

While for the operational and technological indicators, the combination of the Mandates and Subsidies policy measures generally offers the best results, for the economic indicators, the Cost plus pricing policy measure shows the highest social welfare increase (5%). In fact, the Cost plus pricing policy measure also accelerates the adoption leading to lower fuel consumption. Among the economic indicators, the passenger surplus is also greatly benefited by the combination of Mandates and Subsidies.

Consequently, it could be concluded that for a set of extended variety of Use Cases (SWIM, Safedrone, DAC and i4D) the best option to incentivise and accelerate the adoption of technologies, as well as to maximise their economic and operational benefits, two different kinds of policies shall be implemented: the ones related to the use of economic support (incentive) such as Subsidies and Cost plus pricing (especially for the ANSPs) but also penalisations with Mandates to enforce the implementation.

6.2 Policy guidelines

In this report, 3 case studies with different characteristics and timelines have been considered. Out of them, it could be seen that Cost plus pricing performs the best, specially combined with other policies such as Best equipped-best served, Subsidies or Mandates depending on the case. Mandates with economic penalties are clearly an efficient way of obtaining a rapid uptake of ATM technology. It could be justified to apply them, once identified the strictly needed penalty, when the CBA of the technology is not attractive for adopters but the operational benefits at network level outrates the individual losses. However, the policy makers should note (i) the low popularity of this measure and (ii) the low scoring in the economic indicators related with case studies that included this measure. They should be, therefore, always applied along incentive penalties.

From the analysis of the results we can see that the ‘best’ policy choice depends on the indicator or set of indicators considered: there is always a trade-off between them. In most of the cases, the trends are similar, i.e., a policy that maximises technology adoption also improves operational indicators or social welfare. Therefore, the final goal of the policy (social welfare maximisation, fuel burnt reduction, technology adoption market outreach, etc.) has to be considered in order to weight the different indicators. We opted for the policy measures that obtained a balanced high score in the three areas. Our decisions on the policy measure selection in each case study is based on our perspective on the different importance of the indicators, which may be biased by our judgment and might differ from policy makers’ perspective.

Additionally, it is clear that there is not a unique policy measure that fits all technologies, a previous assessment of the technology is needed for the identification of the policies that will incentivise its adoption. Technologies proven to be effective and beneficial can be incentivised just using changes in navigational charges (depending on who is the principal adopter and the distribution of benefits and costs per stakeholder) while technologies with more interdependencies or may suffer negative market effects that need enforcement mandates to be overcame. The policy maker has to push in both sides: using economic incentives (Best equipped-best served, Subsidies or Cost plus pricing) and penalising when applicable to enforce the uptake (Mandates) but paying attention to the negative effects.

In addition to the insights obtained from the analysis of the case studies, the exploration of the effects of the parameters that define the policies gave us the following insights, useful for the application of the policies proposed:

- While the policies provide an increase in adoption, other effects arise from its application such as a decrease in the surplus of some stakeholders or the passengers. A compromise solution has to be found when adjusting the definition of the policy to be applied.
- The policies do not affect equally the adoption of every technology. Therefore, a policy might need fine tuning depending on the CBA and the specific adopters of the technology it aims to implement.
- In some cases, the traffic is hindered by the costs of the policy, which increases ticket prices.
- The correct calibration of the parameters of the policy is needed to avoid negative effects. For example, high incentives to airlines in the Best equipped-best served policy change the behaviour of the ANSPs, lowering the technology adoption with respect to the reference case. This issue might be solved by subsidising those incentives but the costs for the governments would be affected.

These conclusions are compatible with the lessons learnt form the economic modelling exercise performed in [1]. There we saw that (i) the adoption of technologies that require several parties to make investments can be problematic as often, one or some of the agents required to invest are not seeing any benefits and will need some extra incentives to adopt, (ii) adoption behaviour depend on the technology and (iii) while the Best-equipped-best-served policy gave the right incentives for the airlines, they can be detrimental for the ANSPs.

6.3 Recommendations and further research

The ITACA project has delivered an enhanced assessment framework of technology adoption processes by combining a set of methodologies that range from the classic innovation and technology adoption and diffusion research methods, economic models, state-of-the-art computational behavioural modelling and a new validation methodology through gaming experiments that involved real ATM experts.

Along this report we have seen the strengths of the ITACA agent-based model developed. The representation of the most important actors in the European ATM industry allows it to capture general trends and mechanisms inherent in the system regarding their interactions that affect the technology adoption process. The model has been validated through a set of participatory simulations, in which the participants and experts that analysed the results concluded that the individual and global behaviour of the agents involved is represented as they would expect, providing plausible results.

The design of the individual behaviour of each agent was designed from the beginning following the insights obtained from experts on the sector and their behavioural parameters have been fine-tunned comparing the adoption with historical cases. Moreover, the sensitivity analysis of the input variables of the model provides results that follow what should be expected a priori. The only negative point to be mentioned on this would be the non-linear behaviour shown by the airport agents when the price demand elasticity is set close to the bounds of the value found in literature. A different assumption on the elasticity of the demand with respect to airport charges is likely to fix their behaviour. Next improvement step would be to look into literature on this topic to change the hypothesis of the airport agents.

Other limitations of the model reported are:

- Lack on information on the who is principal adopter for each technology, leading to non-realistic adoption scenarios.
- Missing actors in the model that may play an important role in real technology adoption given certain situations. There is room to represent in more detail labour unions and technology providers behaviour.
- Strong assumptions on the exogenous variables. Some of them present interconnections (e.g., fuel-demand, salary change-demand) that are not represented. The actions of the airlines would be more realistic if they modify each other.
- The modelling of the policies proposed imply limitations to the ideas behind them. To solve this problem, there are two possible solutions: (i) to include the R&I phase in the model and see how changes such as the involvement of the safety agency actually affect changes in behaviour; and (ii) to explore operational implications of the policies proposed, such as banning the aircrafts to fly in the mandate policy measure or applying prioritisation (and therefore reduction in delays) to airlines that adopt technology in the Best equipped-best served policy.

Apart from the limitations of the model listed before, the model presented has been validated, allowing to use it as a simulation engine for further applications on the analysis of adoption and benchmarking of policy measures. This simulator engine could be coupled with a module that would automatically provide the benchmarking of the policies proposed for a given scenario, based on the indicators described in this deliverable or adding new ones. This would ease enormously the computation effort made in the project but would not eliminate the analysis of the results and provision of explanations for the different outcomes provided by the project. The path dependence of the results provides as well important insights for the policy makers when analysing the policies proposed.

This enhanced simulator could be further evolved by creating a meta-model that replicates the outcomes of the ITACA simulation model used to fed an API that allows the user to obtain real-time data and visuals for a wide range of parameters and indicators. This tool would be highly beneficial for researchers, ATM experts and policy makers to perform what-if analysis of adoption for any SESAR solution.

7 Reference

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8 Annexes

A.1 Catalogue of solutions

This annex includes the table containing the initial list of solutions which the final list of Use Cases has resulted from.

Use Case ID	Solution/Technology	Implementation Status (Type)	Sub-type	Challenge
001	Airborne Separation Assurance System (ASAS)	Development	Failed	Safety
002	BIO4A. Advanced sustainable BIOfuels for Aviation	Development	Unknown	Environment
003	Noise Abatement Program NBAA, USA.	Deployment	Succeeded	Environment
004	Airborne Collision Avoidance System (ACAS)	Deployment	Succeeded	Safety
	Enhanced Airborne Collision Avoidance System (ACAS). Solution #105	Deployment	Succeeded	Safety
005	SWIM-enabled OCC (AF5 SWIM yellow) Ref. 2017_018_AF5	Development	Unknown	Digitalisation
	Initial ground-ground interoperability (SWIM blue profile). Solution #28	Deployment	Unknown	Digitalisation
	SWIM TI (technical infrastructure) purple profile for air/ground advisory information sharing. Solution PJ.17-01	Development	Unknown	Digitalisation
006	SlotMachine (H2020). A Privacy-Preserving Marketplace for Slot Management	Development	Unknown	Cost-Efficiency
007	Airport Collaborative Decision Making EUROCONTROL	Deployment	Succeeded	Operational efficiency
008	Airport integration into the network CWP AIRPORT - LOW COST AND SIMPLE DEPARTURE DATA ENTRY PANEL Solution #61	Deployment	Succeeded	Cost-Efficiency
009	Enhanced ATFM Slot Swapping. Solution #56	Deployment	Succeeded	Operational efficiency
010	Integrated surface management. Solution #47	Deployment	Succeeded	Capacity
011	Remote Tower for two low density aerodromes. Solution #52	Deployment	Succeeded	Cost-efficiency
012	Time based separation. Solution #64. Heathrow deployment #097AF2	Deployment	Succeeded	Capacity

013	Microwave Landing System (MLS) deployment	Deployment	Failed	Operational efficiency
014	AMAN and point merge. Solution #108	Deployment	Succeeded	Operational efficiency
	Point Merge in complex TMA. Solution #107	Deployment	Succeeded	Operational efficiency
	Arrival Management into Multiple Airports. Solution #08	Deployment	Succeeded	Capacity
015	Continuous descent operations (CDO). Solution #11	Deployment	Succeeded	Environment
	Continuous Climb Operations ENV03	Deployment	Succeeded	Environment
016	Iris Programme. Inmarsat and ESA. Satellite datalink COM for 4D operations	Deployment	Succeeded	Digitalisation
	Precision approaches using GBAS CATII/III. Solution #55	Deployment	Succeeded	Capacity
	LPV approaches using SBAS as alternative to ILS CAT I. Solution #103	Deployment	Succeeded	Operational efficiency
017	D-TAXI service for CPDLC application. Solution #23	Deployment	Succeeded	Digitalisation
018	EUROCONTROL Link 2000+ Programme. Implementation of the CM and CPDLC applications and the derived data link services across States to which EC Regulation No 29/2009 applies	Deployment	Succeeded	Digitalisation
019	Air Traffic Services datalink using SatCom Class B. Solution #109	Deployment	Succeeded	Digitalisation
020	Automatic Dependent Surveillance – Broadcast (ADS-B)	Deployment	Succeeded	Digitalisation
021	SAFEDRONE. Activities on drone integration and demonstration in VLL operations	Development	Unknown	Operational efficiency
022	U-space U1 — foundation services. Solutions U1S-01 to 03	Deployment	Succeeded	Digitalisation
023	Dynamic airspace configuration. Solution #44	Development	Succeeded	Capacity
024	Advanced short-term ATFCM measure STAM (phase 1 implemented). Solution #17	Development	Delayed	Capacity
025	Initial trajectory information sharing (i4D). PJ.31 DIGITS (demonstration)	Development	Unknown	Operational efficiency
026	FRA for flights in cruise and vertically evolving above a specified FL. Solution #33	Deployment	Succeeded	Capacity

	Free route through the use of free routing for flights both in cruise and vertically evolving in cross ACC/FIR borders and within permanently low to medium complexity environments. Solution #32	Deployment	Succeeded	Capacity
027	MALORCA. Machine Learning of Speech Recognition Models for Controller Assistance	Development	Unknown	Digitalisation
028	Evolution of separation minima for increased runway throughput. Solution PJ.02-W2-14	Research	Unknown	Capacity
029	Digital evolution of integrated surface management. Solution PJ.02-W2-21	Research	Unknown	Digitalisation
030	Virtual centre concept. Solution PJ.16-03	Development	Unknown	Digitalisation
031	ASSURED-UAM. Acceptance, Safety and Sustainability Recommendations for Efficient Deployment of Urban Air Mobility	Development	Unknown	Environment
032	CIRRUS. Core noIse Reduction foR Uhbr (ultra-high bypass ratio) engine	Development	Unknown	Environment
033	OPTAG (6th RTD Framework Programme). Improving Airport Efficiency, Security and Passenger Flow by Enhanced Passenger Monitoring	Development	Unknown	Digitalisation
034	Efficient aircraft separation during take-off and final approach. Solution PJ.02-01. Solution PJ.02-03	Deployment	Succeeded	Operational efficiency

Table 59: Initial catalogue of solutions

Co-funded by the European Union

A.2 CBA of technologies under study

In order to obtain the final CBA table, numerous iterations have been carried out in order to consolidate as much as possible the data required. In the excel attached called “CBA Table” the final result of all these iterations can be seen, in the sheet called "Justified". In this sheet, there is information that has been directly obtained from different documents of each of the technologies (UC), which has then served as a guide for the assumptions that have had to be made, even for other technologies. These estimates are due to the lack of information on some of the UCs and it has been necessary to ask for expert judgment in order to obtain the necessary information. In addition, as some of the found information is not directly the one required, it has been used to be able to make assumptions as realistic as possible. On this "Justified" sheet, it can be seen how the assumptions just mentioned appear in italics, and the green text is the most relevant information that would serve as input to the ABM. Note that the cells in red were information that could not be found and will be filled with assumptions eventually.

UC ID			013	018
Use Case			Microwave Landing System (MLS) deployment	EUROCONTROL Link 2000+ Programme
Case Study			CS01	CS01
Cost	**Airlines**	**Retrofit cost**	*Important cost, beacuse retrofit in this case implies the need of keeping the aircraft on the ground, replacement of systems (no room for MLS and ILS equipment at the same time), new antennas and a process of certification. Strong reluctance from the airlines, that would not see any benefits in the short term.* *Operation with ILS was not going to disappear, so airlines did not want to install the system unless absolutely necessary.* *High = 10 M€*	The equipment necessary for the aircrafts will carry costs to the AUs, requiring anything from 50,000 to 100,000 euros depending on aircraft type and system complexity. Source: Link 2000+: CPDLC System Steams Ahead From 50,000 € to 100,000 € per aircraft depending on aircraft type and system complexity.
		Increased cost for new aircraft	*No significant cost* *No impact*	The equipment necessary for the aircrafts will carry costs to the AUs, requiring anything from 50,000 to 100,000 euros depending on aircraft type and system complexity. Source: Link 2000+: CPDLC System Steams Ahead From 50,000 € to 100,000 € per aircraft depending on aircraft type and system complexity.
		Training cost	*Important cost, crews need to be trained in new approach procedures MLS would enable. Not a practical option to train only certain crews that operate in airports with MLS installed, as that would lead to workforce fragmentation.* *Medium - High = 50,000 €*	*Medium = 20,000 €*
	Airport Operators	**Cost of implementation in a big airport**	*Due to the course of the situation, the implementation of MLS was additional to the ILS, not a substitution, so it implied an extra cost.* *The headings of each runway need to be equipped.* *It is a relevant cost but not very high (around 2M€ for an airport with 4 runways, which is similar to the implementation of ILS and GBAS).* *Medium - High = 1 M€*	*No impact*
		Cost of implementation in a small airport	*The difference in small airports is the number of runways, because the cost of implementation of the equipment is the same per runway heading, and the separation between runways. If they are close enough, one equipment could provide for two headings.* *Medium = 500,000 €*	*No impact*
		Training cost	*System maintenance costs. They are complex systems so maintenance personnel needs to be trained.* *Medium-High = 50,000 €*	*No impact*
	ANSP enroute	**Cost of implementation**	*No impact*	The equipment necessary in the Air Traffic Control positions will carry costs to the ANSPs. This costs will be around 5-10 millions of euros per ACC. Source: Link 2000+: CPDLC System Steams Ahead, AviationToday From 5 M€ to 10 M€ per ACC
		Training cost	*No impact*	*High = 75,000 €*

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	ANSP terminal	Cost of implementation	No impact	The equipment necessary in the Air Traffic Control positions will carry costs to the ANSPs. This costs will be around 5-10 millions of euros per TMA. Source: Link 2000+: CPDLC System Steams Ahead, AviationToday From 5 M€ to 10 M€ per TMA
	ANSP terminal	Training cost	Some cost to train in new procedures (i.e. curved approach), but not very high Medium = 20,000€	Medium = 20,000 €
	Airlines	Fuel saving: Litres fuel / ASK, flight hour	Benefits only when using different (and better) procedures than ILS. Incentives would be needed for the airlines to adopt the technology (such as prioritisation in arrival to avoid delays if they have the systems implemented), but this never happened. For this reason, the main benefits are in arrivals to airports with complicated configurations (such as Alaska). Medium = 10 M€	Low = 5,000 €
	Airlines	Delay reduction: minutes / flight	Benefits only when using different (and better) procedures than ILS. Incentives would be needed for the airlines to adopt the technology (such as prioritisation in arrival to avoid delays if they have the systems implemented), but this never happened. For this reason, the main benefits are in arrivals to airports with complicated configurations (such as Alaska). No impact	Induced delays will be reduced by 14%. Source: Link 2000+: CPDLC System Steams Ahead, AviationtToday Medium = 10,000
	Airlines	Air navigation charges reduction	No impact	No impact
Benefit	Airport Operators	Capacity increase	Better runway capacity if ATC can organise the traffic with more flexibility Medium = 500	No impact
Benefit	Airport Operators	Cost reduction	No impact	No impact
Benefit	Airport Operators	Indirect benefits	Reduction of noise in surrounding areas if flight paths don't need to go through them (curved approach). This may imply a small increase in airline costs (fuel) or emissions. Medium = 200	No impact
Benefit	ANSP enroute	ATCO hour productivity increase	No impact	Reduced controller workload and fewer misunderstandings, so better ATCO hour productivity. Source: Preparing for data link implementation, EUROCONTROL Medium = 400
Benefit	ANSP enroute	Capacity increase	No impact	Overall capacity gain: 11% (if 75% of aircraft become equipped) Source: Link 2000+: CPDLC System Steams Ahead, AviationtToday Source: Preparing for data link implementation, EUROCONTROL +11% (if 75% of aircraft become equipped) High = 10
Benefit	ANSP terminal	ATCO hour productivity increase	No impact	Reduced controller workload and fewer misunderstandings, so better ATCO hour productivity. Source: Preparing for data link implementation, EUROCONTROL Medium = 300
Benefit	ANSP terminal	Capacity increase	If ATC can rearrange traffic with more flexibility, they don't need to concentrate all the flights in the same area, which would result in an increase of capacity (although a smaller one than in the airport). Low-Medium = 25	Overall capacity gain: 11% (if 75% of aircraft become equipped) Source: Link 2000+: CPDLC System Steams Ahead, AviationtToday Source: Preparing for data link implementation, EUROCONTROL +11% (if 75% of aircraft become equipped) High = 100
Compatibility with existing technology			Strictly speaking, no It was compatible in the sense that ILS and MLS could work in parallel, but they were two different systems with two different technologies. However, there were multimodal receptors for runways or aircrafts that could work with both of them. False	Compatible True
Duration of technology research phase			3-4 years, the technology came from the military so it did not need a very long phase of research for commercial. 3-4 years	EUROCONTROL tasked by European Commission with drafting the implementing rule, which started in early 2006 and was officially adopted by European Commission in January 2009. 30 months
In service life			15-20 years, similar to ILS. However, it was never deployed in Europe, only in Alaska. 15-20 years	

Implementation requirements		Technological	*Infrastructure will be needed in airports to provide them with a precision radio guidance system to assist aircraft landings. Aircrafts will also need equipment to be connected with that infrastructure.* *High*	*CPDLC system is necessary to be implemented in aircrafts and also special systems for ATCOs in order to maintain certain connection between them* *High*
		Operational	*New landing procedures will be implemented.* *High*	*Procedures to interchange datalink data must be developed.* *Medium*
		Effort	*Low*	*High*
Implementation Time			Development in the 1970s (FAA, NASA, USDD). In the United States, the FAA suspended the MLS program in 1994 in favor of the GPS. The only major installation in Europe was London Heathrow Airport, decommissioned in 2017. Alaska is the only country with airports that still operate with MLS, mainly due to meteorological reasons.	1999 - present (mandatory for flights above FL285 since 2018 although postponed to 2020)
Effect on labour conditions	Labour unions	Percentage of salary reduction	*No impact*	*No impact*
		Redundancies	*No impact*	*No impact*

Sources	Expert judgement	Link 2000+: CPDLC System Steams Ahead, AviationtToday
		Preparing for data link implementation, EUROCONTROL

Table 60: Justified" CBA table example for CS01

The next sheet, called "Intermediate", contains the information resulting from the previous one, the one marked in green as the most relevant information for each of the required variables. However, this information has been processed in such a way that it matches the units with which the model works. Some examples of this process are the following:

- When making assumptions, a scale of Low/Medium/High was marked and in numerous cases this scale had to be transformed to numerical values. This scale is to give a relative value of all technologies/UC (columns) of a specific variable (row).
- Some data were presented as a global value, so that a disaggregation had to be made in order to have more concrete data per airport, per service unit or per flight.
  - In the case of airports, 530 of the more than 2000 airports in Europe have been considered, as they are the ones that handle 98% of all flights.
  - For en-route service units, it was estimated that 152.5 million service units were counted across Europe in 2019 for a total of 61 ACCs.
  - For terminal service units, it was estimated that 152.5 million service units were counted across Europe in 2019 for a total of 166 TMAs.
  - The number of flights has been considered depending on the year to which the information found belongs.

UC ID			013	018
Use Case			Microwave Landing System (MLS) deployment	EUROCONTROL Link 2000+ Programme
Case Study			CS01	CS01
Cost	Airlines	Retrofit cost	High = 100,000 € per aircraft	From 50,000 € to 100,000 € per aircraft depending on aircraft type and system complexity.
		Increased cost for new aircraft	No impact	From 50,000 € to 100,000 € per aircraft depending on aircraft type and system complexity.
		Training cost	Medium - High = 50,000 €	Medium = 20,000 €
	Airport Operators	Cost of implementation in a big airport	Medium - High = 1 M€	No impact
		Cost of implementation in a small airport	Medium = 500,000 €	No impact
		Training cost	Medium-High = 50,000 €	No impact
	ANSP enroute	Cost of implementation	No impact	From 2 to 4 € per service unit
		Training cost	No impact	High = 40,000 €/ATCO
	ANSP terminal	Cost of implementation	No impact	From 66.4 € to 132,8 € per service unit
		Training cost	Medium = 20,000€/ATCO	Medium = 20,000 €/ATCO
Benefit	Airlines	Fuel saving: Litres fuel / ASK, flight hour	Medium= 17 € per flight	Low = 5 € per flight
		Delay reduction: minutes / flight	No impact	Medium = 1 minute per flight or 30 € per flight
		Air navigation charges reduction	No impact	No impact
	Airport Operators	Capacity increase	Medium = 500	No impact
		Cost reduction	No impact	No impact
		Indirect benefits	Medium = 200	No impact
	ANSP enroute	ATCO hour productivity increase	No impact	Medium = 0.5 %
		Capacity increase	No impact	High = 11 %
	ANSP terminal	ATCO hour productivity increase	No impact	Medium = 0.5 %
		Capacity increase	Low-Medium = 2.5 %	High = 11 %
Compatibility with existing technology			False	True
Duration of technology research phase			3-4 years	30 months
In service life			15-20 years	
Implementation requirements		Technological	High	High
		Operational	High	Medium
		Effort	Low	High
Implementation Time				
Effect on labour conditions	Labour unions	Percentage of salary reduction	No impact	No impact
		Redundancies	No impact	No impact

Sources				
Sources			Expert judgement	Link 2000+: CPDLC System Steams Ahead, AviationtToday Preparing for data link implementation, EUROCONTROL

Table 61: "Intermediate" CBA table example for CS01

Finally, the last table, the so-called "Model Input", is the actual input to the model. The one that only collects the information that the model is going to read and use for the calculation of results, in the format required by the Model. This table is the result of the intermediate one and has only suffered a couple of changes to adapt the information to the model input format. Some units have had to be adapted, and some of the variables (rows) have disappeared because the information they contained was repetitive. In addition, a row with the start date of each of the UC has also been added, and the cells that were still empty (the ones in red) have been filled in using as a reference the information from the UCs with similar implementation and effects.

UC ID				013	018
Use Case				Microwave Landing System (MLS) deployment	EUROCONTROL Link 2000+ Programme
Case Study				CS01	CS01
Date				1975	1999
Cost	Airlines	Retrofit cost	euro/aircraft	100000	100000
		Increased cost for new aircraft	euro/aircraft	0	100000
		Training cost	euro/staff	50000	20000
	Airport Operators	Cost of implementation in a big airport	euro	1000000	0
		Cost of implementation in a small airport	euro	500000	0
		Training cost	euro/staff	50000	0
	ANSP enroute	Cost of implementation	euro/service unit	0	2
		Training cost	euro/ATCO	0	8000
	ANSP terminal	Cost of implementation	euro/service unit	0	5.88
		Training cost	euro/ATCO	5000	7500
Benefit	Airlines	Fuel saving	euro/flight	17	5
			litre/flight	25.8	7.6
		Delay reduction	euro/flight	0	30
		Air navigation charges reduction	euro	0	0
	Airport Operators	Capacity increase	Low/Medium/High	Medium	0
		Cost reduction	Low/Medium/High	0	0
		Indirect benefits	Low/Medium/High	Medium	0
	ANSP enroute	ATCO hour productivity increase	%	0	0.005
		Capacity increase	%	0	0.11
	ANSP terminal	ATCO hour productivity increase	%	0	0.005
		Capacity increase	%	0.025	0.11
Compatibility with existing technology			TRUE/FALSE	FALSE	TRUE
Duration of technology research phase			Months	40	30
In service life			Years	20	20
Implementation requirements			Low/Medium/High	Medium	Medium
Implementation Time			Years	3	3
Effect on labour conditions	Labour unions	Percentage of salary reduction	Low/Medium/High	FALSE	FALSE
		Redundancies	Low/Medium/High	FALSE	FALSE
Sources				Expert judgement	Link 2000+: CPDLC System Steams Ahead, AviationtToday Preparing for data link implementation, EUROCONTROL

Table 62: Model Input” CBA table example for CS01

The complete table of CBA for the selected Use Cases can be found in the attached Excel file “CBA Table”.

Finally, all the sources used for completing the CBA Table are listed in the Section 7.

A.3 Sensitivity analysis data

Table 63: Price demand elasticity in routes sensitivity analysis

				Value					Slope	Correlation
				-1	-0.8	-0.6	-0.4	-0.2		
Indicators	Technology	Time for adoption	SWIM	713	729	728	716	733	13.50	0.487
			Safedrone	0	0	0	0	0	0.00	NA
			DAC	19	17	19	16	23	3.50	0.412
			i4D	459	458	456	457	455	-4.50	-0.900
		Market share	SWIM	0.87	0.87	0.87	0.87	0.87	0.00	0.000
			Safedrone	0.00	0.00	0.00	0.00	0.00	0.00	NA
			DAC	0.18	0.09	0.18	0.09	0.36	0.18	0.516
			i4D	1.00	1.00	1.00	1.00	1.00	0.00	NA
	Economic	Social welfare		3.81E+11	3.87E+11	4.00E+11	4.12E+11	4.32E+11	6.45E+10	0.984
		En-route surplus		2.56E+08	1.79E+08	2.48E+08	2.82E+08	1.60E+08	-4.45E+07	-0.267
		Terminal surplus		2.68E+08	1.64E+08	2.19E+08	1.89E+08	9.75E+07	-1.58E+08	-0.787
		Airline surplus		1.95E+11	1.96E+11	1.99E+11	1.99E+11	2.02E+11	8.08E+09	0.940
		Airport Surplus		1.75E+11	1.81E+11	1.90E+11	2.03E+11	2.21E+11	5.69E+10	0.978
		Passenger surplus		2.31E+10	2.35E+10	2.37E+10	2.37E+10	2.36E+10	6.16E+08	0.725
	Operational	En-route throughput		62068	63161	64119	64838	65648	4418	0.997
		TMA throughput		36212	36968	37625	38203	38801	3207	0.998
		En-route DUC		59.07	58.86	58.61	58.44	58.29	-0.99	-0.996
		Terminal DUC		573.40	570.99	567.64	565.55	563.19	-12.93	-0.997
		N flights		7138	7306	7618	7750	7981	1065	0.994
		Load factor		0.904	0.904	0.907	0.910	0.915	0.01	0.951
		Airfare		109.84	112.48	111.72	112.60	113.20	3.42	0.832

Table 64: Price demand elasticity for airlines sensitivity analysis

				Value					Slope	Correlation
				-1.2	-1.6	-2	-2.4	-2.8		
Indicators	Technology	Time for adoption	SWIM	716	718	728	678	670	33	0.799
			Safedrone	0	0	0	0	0	0	NA
			DAC	33	19	19	22	18	6.75	0.686
			i4D	454	460	456	449	442	8.75	0.797
		Market share	SWIM	0.867	0.867	0.867	0.867	0.867	0	0.000
			Safedrone	0.000	0.000	0.000	0.000	0.000	0	NA
			DAC	0.364	0.182	0.182	0.182	0.182	0.091	0.707
			i4D	1.000	1.000	1.000	1.000	1.000	0	NA
	Economic	Social welfare		7.02E+11	4.64E+11	4.00E+11	3.84E+11	3.86E+11	1.78E+11	0.832
		En-route surplus		8.42E+07	1.69E+08	2.48E+08	3.24E+08	5.57E+08	-2.75E+08	-0.964
		Terminal surplus		1.49E+08	1.17E+08	2.19E+08	3.16E+08	5.05E+08	-2.28E+08	-0.922
		Airline surplus		2.19E+11	1.95E+11	1.99E+11	2.00E+11	2.07E+11	4.58E+09	0.313
		Airport Surplus		5.10E+11	2.68E+11	1.90E+11	1.67E+11	1.59E+11	2.01E+11	0.864
		Passenger surplus		-1.65E+10	1.29E+10	2.37E+10	3.02E+10	3.27E+10	-2.89E+10	-0.913
	Operational	En-route throughput		50293	60002	64119	65719	66785	-9675	-0.911
		TMA throughput		29151	35070	37625	38638	39332	-5983	-0.915
		En-route DUC		60.48	59.05	58.61	58.55	58.48	1.13	0.850
		Terminal DUC		584.10	571.84	567.64	566.97	566.39	10.07	0.859
		N flights		5644	7104	7618	7563	7722	-1153.75	-0.845
		Load factor		0.897	0.902	0.907	0.916	0.921	-0.015	-0.995
		Airfare		183.37	129.52	111.72	102.39	99.40	48.77	0.893

Table 65: Annual salary change sensitivity analysis

				Value					Slope	Correlation
				-1%	0%	1%	2%	3%		
Indicators	Technology	Time for adoption	SWIM	660	727	728	735	754	19.6	0.869
			Safedrone	0	0	0	0	0	0	NA
			DAC	17	18	19	59	101	20.9	0.891
			i4D	438	439	456	461	460	6.6	0.916
		Market share	SWIM	0.798	0.898	0.867	0.867	0.867	0.010	0.450
			Safedrone	0.000	0.000	0.000	0.000	0.000	0.000	NA
			DAC	0.091	0.091	0.182	0.545	0.818	0.191	0.932
			i4D	0.955	0.955	1.000	1.000	1.000	0.014	0.866
	Economic	Social welfare		4.23E+11	4.10E+11	4.00E+11	4.06E+11	4.20E+11	-1.07E+09	-0.176
		En-route surplus		1.38E+08	1.90E+08	2.48E+08	1.95E+08	1.59E+08	4.64E+06	0.177
		Terminal surplus		1.02E+08	1.13E+08	2.19E+08	1.59E+08	2.44E+08	3.31E+07	0.832
		Airline surplus		2.01E+11	2.00E+11	1.99E+11	2.06E+11	2.09E+11	2.33E+09	0.847
		Airport Surplus		2.39E+11	2.13E+11	1.90E+11	1.74E+11	1.67E+11	-1.83E+10	-0.977
		Passenger surplus		-2.74E+09	1.02E+10	2.37E+10	3.89E+10	5.49E+10	1.44E+10	0.999
	Operational	En-route throughput		67417	66108	64119	61772	59104	-2096	-0.992
		TMA throughput		39589	38768	37625	36254	34743	-1221	-0.994
		En-route DUC		47.24	52.51	58.61	65.82	74.09	6.70	0.996
		Terminal DUC		445.89	502.00	567.64	645.73	735.36	72.27	0.996
		N flights		7937	7810	7618	7125	6644	-327	-0.966
		Load factor		0.903	0.904	0.907	0.913	0.920	0.004	0.962
		Airfare		102.00	106.25	111.72	122.07	136.68	8.52	0.968

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Table 66: Demand growth sensitivity analysis

				Value Low	Value Medium	Value High	Low-medium variation	Medium-high variation
Indicators	Technology	Time for adoption	SWIM	672	728	763	0.0833	0.0481
			Safedrone	0	0	0	NA	NA
			DAC	23	19	22	-0.1739	0.1579
			i4D	448	456	471	0.0179	0.0329
		Market share	SWIM	0.827	0.867	0.867	0.0476	0.0000
			Safedrone	0.000	0.000	0.000	NA	NA
			DAC	0.273	0.182	0.273	-0.3333	0.5000
			i4D	1.000	1.000	1.000	0.0000	0.0000
	Economic	Social welfare		3.21E+11	4.00E+11	5.27E+11	0.2464	0.3187
		En-route surplus		2.45E+08	2.48E+08	1.33E+08	0.0117	-0.4614
		Terminal surplus		2.57E+08	2.19E+08	7.43E+07	-0.1497	-0.6602
		Airline surplus		1.81E+11	1.99E+11	2.01E+11	0.1047	0.0071
		Airport Surplus		1.29E+11	1.90E+11	3.22E+11	0.4660	0.6952
		Passenger surplus		2.14E+10	2.37E+10	1.94E+10	0.1095	-0.1844
	Operational	En-route throughput		51834	64119	69716	0.2370	0.0873
		TMA throughput		30404	37625	40820	0.2375	0.0849
		En-route DUC		61.12	58.61	58.14	-0.0411	-0.0081
		Terminal DUC		588.28	567.64	565.66	-0.0351	-0.0035
		N flights		5525	7618	8186	0.3788	0.0746
		Load factor		0.906	0.907	0.913	0.0008	0.0060
		Airfare		109.55	111.72	122.20	0.0198	0.0938

Table 67: Fuel price multiplier sensitivity analysis

				Value					Slope	Correlation
				0.6	0.8	1	1.2	1.4		
Indicators	Technology	Time for adoption	SWIM	709	690	728	712	741	43	0.700
			Safedrone	0	0	0	0	0	0	#DIV/0!
			DAC	21	18	19	19	20	-0.5	-0.139
			i4D	461	444	456	454	461	5	0.227
		Market share	SWIM	0.867	0.867	0.867	0.867	0.867	0.000	0.000
			Safedrone	0.000	0.000	0.000	0.000	0.000	0.000	#DIV/0!
			DAC	0.273	0.182	0.182	0.182	0.182	-0.091	-0.707
			i4D	1.000	1.000	1.000	1.000	1.000	0.000	#DIV/0!
	Economic	Social welfare		4.03E+11	4.06E+11	4.00E+11	3.93E+11	3.97E+11	-1.31E+10	-0.785
		En-route surplus		2.73E+08	1.14E+08	2.48E+08	1.58E+08	1.92E+08	-5.89E+07	-0.287
		Terminal surplus		2.18E+08	1.25E+08	2.19E+08	1.06E+08	1.79E+08	-4.89E+07	-0.297
		Airline surplus		1.93E+11	2.00E+11	1.99E+11	1.98E+11	2.06E+11	1.22E+10	0.823
		Airport Surplus		2.01E+11	1.97E+11	1.90E+11	1.83E+11	1.79E+11	-2.87E+10	-0.997
		Passenger surplus		2.24E+10	2.28E+10	2.37E+10	2.43E+10	2.48E+10	3.07E+09	0.991
	Operational	En-route throughput		64613	64328	64119	63434	63191	-1870	-0.981
		TMA throughput		37943	37798	37625	37325	37205	-975	-0.991
		En-route DUC		58.18	58.46	58.61	58.72	58.84	0.79	0.977
		Terminal DUC		568.14	567.96	567.64	568.35	567.93	-0.02	-0.026
		N flights		7551	7559	7618	7433	7510	-104	-0.480
		Load factor		0.911	0.908	0.907	0.908	0.906	-0.004	-0.754
		Airfare		99.84	105.79	111.72	121.52	130.70	38.73	0.993

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A.4 Policy parameter exploration data

Table 68: Cost plus pricing - unit rate margin parameter exploration

				Value							Slope	Correlation
				ref	0.1%	1%	5%	9%	13%	17%		
Indicators	Technology	Time for adoption	SWIM	728	764	767	767	767	767	769	0.18	0.765
			Safedrone	0	11	242	242	242	242	242	7.58	0.540
			DAC	19	109	198	198	198	198	198	2.92	0.540
			i4D	456	465	465	466	466	465	465	0.00	-0.060
		Market share	SWIM	0.867	0.867	0.867	0.867	0.867	0.867	0.867	0.000	0.000
			Safedrone	0.000	0.030	0.667	0.667	0.667	0.667	0.667	0.021	0.540
			DAC	0.182	0.636	1.000	1.000	1.000	1.000	1.000	0.012	0.540
			i4D	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	NA
	Economic	Social welfare		3.99E+11	4.01E+11	4.05E+11	4.19E+11	4.30E+11	4.45E+11	4.55E+11	3.22E+09	0.999
		En-route surplus		2.48E+08	3.91E+08	3.08E+09	1.44E+10	2.56E+10	3.67E+10	4.80E+10	2.81E+09	1.000
		Terminal surplus		2.19E+08	1.76E+08	1.05E+09	4.36E+09	7.62E+09	1.10E+10	1.43E+10	8.31E+08	1.000
		Airline surplus		1.99E+11	2.00E+11	2.00E+11	2.01E+11	1.99E+11	2.00E+11	1.98E+11	-1.39E+08	-0.767
		Airport Surplus		1.90E+11	1.91E+11	1.91E+11	1.90E+11	1.88E+11	1.87E+11	1.86E+11	-2.85E+08	-0.987
		Passenger surplus		2.37E+10	2.39E+10	2.39E+10	2.37E+10	2.36E+10	2.33E+10	2.28E+10	-5.91E+07	-0.973
	Operational	En-route throughput		64119	63996	64086	64104	64039	63903	63744	-16	-0.811
		TMA throughput		37625	37574	37594	37590	37506	37443	37377	-13	-0.955
		En-route DUC		58.61	58.69	58.67	58.69	58.70	58.73	58.69	0.002	0.511
		Terminal DUC		567.64	568.44	568.09	568.47	568.60	568.78	568.40	0.017	0.502
		N flights		7618	7481	7559	7526	7458	7390	7510	- 3.8920394	-0.442
		Load factor		0.907	0.909	0.909	0.907	0.909	0.909	0.909	0.000	0.117
		Airfare		111.72	112.29	114.43	114.45	114.38	114.89	113.97	0.06	0.450

Table 69: Best equipped best served - charge reduction parameter exploration (charge penalty = 0.1%)

				Value						Slope	Correlation
				ref	-1%	0.1%	1%	5%	9%		
Indicators	Technology	Time for adoption	SWIM	728	673	689	251	351	377	-26.47	-0.547
			Safedrone	0	221	11	11	0	0	-13.10	-0.561
			DAC	19	165	94	18	0	0	-13.46	-0.767
			i4D	456	395	443	0	0	0	-39.76	-0.714
		Market share	SWIM	0.867	0.755	0.821	0.367	0.367	0.367	-0.040	-0.710
			Safedrone	0.000	0.667	0.030	0.030	0.000	0.000	-0.039	-0.557
			DAC	0.182	1.000	0.636	0.091	0.000	0.000	-0.084	-0.766
			i4D	1.000	0.844	0.955	0.000	0.000	0.000	-0.085	-0.713
	Economic	Social welfare		3.99E+11	4.05E+11	4.03E+11	3.95E+11	3.94E+11	3.94E+11	-1.05E+09	-0.784
		En-route surplus		2.48E+08	2.19E+09	1.78E+08	2.03E+08	1.91E+08	1.76E+08	-1.13E+08	-0.521
		Terminal surplus		2.19E+08	6.89E+08	1.53E+08	1.74E+08	1.76E+08	1.87E+08	-2.68E+07	-0.479
		Airline surplus		1.99E+11	2.01E+11	2.03E+11	1.97E+11	1.96E+11	1.96E+11	-5.77E+08	-0.774
		Airport Surplus		1.90E+11	1.91E+11	1.90E+11	1.88E+11	1.88E+11	1.88E+11	-2.79E+08	-0.728
		Passenger surplus		2.37E+10	2.38E+10	2.37E+10	2.30E+10	2.32E+10	2.31E+10	-6.04E+07	-0.688
	Operational	En-route throughput		64119	64021	64068	63450	63520	63505	-49.39	-0.670
		TMA throughput		37625	37556	37594	37388	37499	37457	-7.79	-0.397
		En-route DUC		58.61	58.72	58.77	58.86	58.81	58.81	0.01	0.467
		Terminal DUC		567.64	568.64	568.93	569.05	569.29	568.97	0.03	0.500
		N flights		7618	7496	7609	7513	7515	7527	-1.54	-0.143
		Load factor		0.907	0.909	0.907	0.910	0.907	0.908	0.000	-0.253
		Airfare		111.72	114.28	114.87	111.96	111.90	111.47	-0.29	-0.775

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Table 70: Best equipped best served - charge reduction parameter exploration (charge penalty = 1%)

				Value						Slope	Correlation
				ref	-1	0.1	1	5	9		
Indicators	Technology	Time for adoption	SWIM	728	690	724	326	351	377	-31	-0.649
			Safedrone	0	242	209	196	196	196	-3	-0.641
			DAC	19	192	190	168	126	90	-11	-0.993
			i4D	456	436	471	72	0	0	-45	-0.785
		Market share	SWIM	0.867	0.771	0.821	0.503	0.367	0.367	-0.044	-0.840
			Safedrone	0.000	0.667	0.606	0.545	0.545	0.545	-0.009	-0.701
			DAC	0.182	1.000	1.000	1.000	0.636	0.455	-0.061	-0.980
			i4D	1.000	0.938	1.000	0.591	0.000	0.000	-0.108	-0.916
	Economic	Social welfare		3.99E+11	4.06E+11	4.02E+11	3.99E+11	4.00E+11	3.96E+11	-6.84E+08	-0.794
		En-route surplus		2.48E+08	3.62E+09	1.11E+09	1.04E+09	2.99E+08	-4.07E+07	-2.69E+08	-0.772
		Terminal surplus		2.19E+08	9.66E+08	2.78E+08	3.05E+08	2.76E+08	2.25E+08	-4.41E+07	-0.583
		Airline surplus		1.99E+11	1.99E+11	1.99E+11	1.99E+11	2.02E+11	1.99E+11	5.60E+07	0.188
		Airport Surplus		1.90E+11	1.92E+11	1.91E+11	1.88E+11	1.88E+11	1.88E+11	-3.46E+08	-0.776
		Passenger surplus		2.37E+10	2.40E+10	2.40E+10	2.34E+10	2.33E+10	2.31E+10	-8.49E+07	-0.853
	Operational	En-route throughput		64119	64199	64141	63721	63665	63682	-49	-0.761
		TMA throughput		37625	37639	37617	37511	37484	37477	-15	-0.824
		En-route DUC		58.61	58.68	58.67	58.85	59.04	59.64	0.09	0.971
		Terminal DUC		567.64	568.70	568.51	569.43	569.42	569.38	0.07	0.668
		N flights		7618	7464	7568	7513	7541	7542	4	0.425
		Load factor		0.9072	0.9070	0.9077	0.9081	0.9085	0.9079	0.0001	0.551
		Airfare		111.72	114.36	113.89	112.62	112.29	112.24	-0.19	-0.815

Table 71: Best equipped best served - charge reduction parameter exploration (charge penalty = 2%)

				Value						Slope	Correlation
				ref	-1	0.1	1	5	9		
Indicators	Technology	Time for adoption	SWIM	728	741	751	536	359	378	-40	-0.874
			Safedrone	0	242	242	242	242	242	0	NA
			DAC	19	198	198	198	198	180	-2	-0.836
			i4D	456	449	475	355	0	0	-54	-0.930
		Market share	SWIM	0.867	0.819	0.867	0.844	0.367	0.367	-0.058	-0.915
			Safedrone	0.000	0.667	0.667	0.667	0.667	0.667	0.000	NA
			DAC	0.182	1.000	1.000	1.000	1.000	0.909	-0.008	-0.836
			i4D	1.000	0.938	1.000	1.000	0.000	0.000	-0.119	-0.915
	Economic	Social welfare		3.99E+11	4.07E+11	4.01E+11	3.98E+11	4.02E+11	3.98E+11	-4.67E+08	-0.530
		En-route surplus		2.48E+08	4.85E+09	2.44E+09	1.04E+09	1.32E+09	5.24E+08	-3.07E+08	-0.736
		Terminal surplus		2.19E+08	1.21E+09	5.87E+08	5.68E+08	4.66E+08	4.45E+08	-5.09E+07	-0.668
		Airline surplus		1.99E+11	1.99E+11	1.98E+11	1.97E+11	2.03E+11	2.00E+11	3.03E+08	0.551
		Airport Surplus		1.90E+11	1.91E+11	1.90E+11	1.90E+11	1.88E+11	1.88E+11	-3.15E+08	-0.915
		Passenger surplus		2.37E+10	2.39E+10	2.39E+10	2.39E+10	2.36E+10	2.34E+10	-5.53E+07	-0.996
	Operational	En-route throughput		64119	64202	64069	64126	63814	63671	-53	-0.978
		TMA throughput		37625	37662	37568	37591	37590	37485	-13	-0.827
		En-route DUC		58.61	58.71	58.69	58.84	58.84	59.09	0.04	0.931
		Terminal DUC		567.64	568.34	568.85	569.35	569.32	569.40	0.08	0.730
		N flights		7618	7565	7547	7508	7543	7507	-4	-0.600
		Load factor		0.907	0.907	0.908	0.908	0.907	0.908	0.000	0.222
		Airfare		111.72	113.59	113.69	113.48	112.24	113.24	-0.08	-0.531

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Table 72: Best equipped best served - charge reduction parameter exploration (charge penalty = 5%)

				Value						Slope	Correlation
				ref	-1	0.1	1	5	9		
Indicators	Technology	Time for adoption	SWIM	728	755	760	571	372	390	-41	-0.890
			Safedrone	0	242	242	242	242	242	0	NA
			DAC	19	198	198	198	198	198	0	NA
			i4D	456	466	475	374	0	0	-55	-0.933
		Market share	SWIM	0.867	0.819	0.867	0.867	0.367	0.367	-0.059	-0.910
			Safedrone	0.000	0.667	0.667	0.667	0.667	0.667	0.000	NA
			DAC	0.182	1.000	1.000	1.000	1.000	1.000	0.000	NA
			i4D	1.000	0.969	1.000	1.000	0.000	0.000	-0.121	-0.920
	Economic	Social welfare		3.99E+11	4.11E+11	4.06E+11	4.06E+11	4.08E+11	4.05E+11	-3.34E+08	-0.600
		En-route surplus		2.48E+08	8.59E+09	5.96E+09	4.41E+09	4.92E+09	3.98E+09	-3.18E+08	-0.714
		Terminal surplus		2.19E+08	1.94E+09	1.26E+09	1.24E+09	1.17E+09	1.08E+09	-5.67E+07	-0.684
		Airline surplus		1.99E+11	2.00E+11	1.98E+11	2.00E+11	2.03E+11	2.01E+11	3.06E+08	0.681
		Airport Surplus		1.90E+11	1.90E+11	1.91E+11	1.89E+11	1.88E+11	1.88E+11	-2.09E+08	-0.892
		Passenger surplus		2.37E+10	2.39E+10	2.39E+10	2.39E+10	2.34E+10	2.35E+10	-5.68E+07	-0.907
	Operational	En-route throughput		64119	64074	64039	64061	63801	63777	-34	-0.945
		TMA throughput		37625	37578	37570	37557	37553	37552	-2	-0.810
		En-route DUC		58.61	58.72	58.74	58.68	58.85	58.85	0.016	0.846
		Terminal DUC		567.64	568.65	568.59	569.78	569.26	569.13	0.036	0.302
		N flights		7618	7495	7514	7480	7511	7592	9	0.852
		Load factor		0.907	0.908	0.908	0.909	0.907	0.907	-0.0001	-0.640
		Airfare		111.72	114.17	113.52	113.40	113.06	112.06	-0.18	-0.962

Table 73: Best equipped best served - charge reduction parameter exploration (charge penalty = 9%)

				Value						Slope	Correlation
				ref	-1	0.1	1	5	9		
Indicators	Technology	Time for adoption	SWIM	728	774	760	604	434	477	-33	-0.862
			Safedrone	0	242	242	242	242	242	0	NA
			DAC	19	198	198	198	198	198	0	NA
			i4D	456	468	478	378	108	0	-52	-0.978
		Market share	SWIM	0.867	0.834	0.867	0.867	0.617	0.467	-0.042	-0.970
			Safedrone	0.000	0.667	0.667	0.667	0.667	0.667	0.000	NA
			DAC	0.182	1.000	1.000	1.000	1.000	1.000	0.000	NA
			i4D	1.000	0.969	1.000	1.000	1.000	0.000	-0.089	-0.826
	Economic	Social welfare		3.99E+11	4.14E+11	4.11E+11	4.08E+11	4.11E+11	4.08E+11	-3.49E+08	-0.580
		En-route surplus		2.48E+08	1.36E+10	1.08E+10	9.23E+09	9.14E+09	8.82E+09	-3.46E+08	-0.723
		Terminal surplus		2.19E+08	2.86E+09	2.19E+09	2.13E+09	2.01E+09	2.00E+09	-5.92E+07	-0.680
		Airline surplus		1.99E+11	1.98E+11	1.98E+11	1.97E+11	2.03E+11	2.01E+11	4.26E+08	0.739
		Airport Surplus		1.90E+11	1.90E+11	1.90E+11	1.90E+11	1.88E+11	1.86E+11	-3.85E+08	-0.997
		Passenger surplus		2.37E+10	2.39E+10	2.41E+10	2.41E+10	2.36E+10	2.35E+10	-6.08E+07	-0.841
	Operational	En-route throughput		64119	64168	64232	64150	63767	63808	-47	-0.893
		TMA throughput		37625	37635	37672	37625	37541	37553	-12	-0.858
		En-route DUC		58.61	58.70	58.73	58.63	58.89	58.87	0.02	0.806
		Terminal DUC		567.64	568.36	568.69	569.05	569.58	569.49	0.11	0.874
		N flights		7618	7569	7527	7526	7447	7499	-7	-0.683
		Load factor		0.907	0.907	0.907	0.908	0.907	0.908	0.000	0.873
		Airfare		111.72	114.28	112.93	113.23	112.30	111.86	-0.20	-0.892

Table 74: Demonstration projects - percentage of risk perception reduction

				Value						Slope	Correlation
				ref	5%	10%	15%	20%	25%		
Indicators	Technology	Time for adoption	SWIM	728	728	730	719	718	724	-0.40	-0.595
			Safedrone	0	0	0	0	0	0	0.00	NA
			DAC	19	19	19	18	18	18	-0.06	-0.866
			i4D	456	453	453	453	454	452	-0.02	-0.224
		Market share	SWIM	0.867	0.867	0.867	0.867	0.844	0.867	-0.0005	-0.354
			Safedrone	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	NA
			DAC	0.182	0.182	0.182	0.091	0.091	0.091	-0.0055	-0.866
			i4D	1.000	1.000	1.000	1.000	1.000	1.000	0.0000	NA
	Economic	Social welfare		3.99E+11	4.00E+11	4.00E+11	4.08E+11	3.99E+11	3.98E+11	-8.78E+07	-0.174
		En-route surplus		2.48E+08	2.39E+08	2.44E+08	2.64E+08	1.40E+08	2.02E+08	-3.57E+06	-0.578
		Terminal surplus		2.19E+08	2.02E+08	2.15E+08	1.86E+08	1.54E+08	1.65E+08	-2.69E+06	-0.844
		Airline surplus		1.99E+11	1.99E+11	1.99E+11	2.07E+11	1.99E+11	1.99E+11	-3.80E+07	-0.090
		Airport Surplus		1.90E+11	1.90E+11	1.89E+11	1.90E+11	1.89E+11	1.89E+11	-4.70E+07	-0.529
		Passenger surplus		2.37E+10	2.37E+10	2.37E+10	2.37E+10	2.38E+10	2.38E+10	2.75E+06	0.623
	Operational	En-route throughput		64119	64130	64131	64140	64026	64110	-3	-0.489
		TMA throughput		37625	37631	37632	37567	37583	37629	-1	-0.264
		En-route DUC		58.61	58.61	58.61	58.04	58.68	58.65	0.003	0.087
		Terminal DUC		567.64	567.59	567.53	568.13	568.37	568.10	0.037	0.801
		N flights		7618	7636	7647	7570	7477	7557	-7	-0.756
		Load factor		0.907	0.907	0.907	0.907	0.909	0.908	0.000	0.582
		Airfare		111.72	112.16	112.19	112.09	113.03	112.91	0.05	0.814

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Table 75: Subsidies - percentage of implementation costs subsidised exploration

				Value						Slope	Correlation
				ref	10%	30%	50%	70%	90%		
Indicators	Technology	Time for adoption	SWIM	728	790	850	943	950	952	2.1	0.912
			Safedrone	0	0	31	118	242	407	5.1	0.970
			DAC	19	97	157	184	198	198	1.2	0.905
			i4D	456	467	469	472	474	476	0.1	0.997
		Market share	SWIM	0.867	0.867	0.950	1.000	1.000	1.000	0.002	0.860
			Safedrone	0.000	0.000	0.091	0.333	0.667	1.000	0.013	0.981
			DAC	0.182	0.636	0.909	1.000	1.000	1.000	0.004	0.822
			i4D	1.000	1.000	1.000	1.000	1.000	1.000	0.000	NA
	Economic	Social welfare		3.99E+11	3.98E+11	3.99E+11	4.01E+11	3.98E+11	3.99E+11	1.04E+07	0.288
		En-route surplus		2.48E+08	8.61E+08	2.83E+09	5.12E+09	7.28E+09	9.29E+09	1.07E+08	1.000
		Terminal surplus		2.19E+08	4.61E+08	1.18E+09	1.93E+09	3.20E+09	4.06E+09	4.61E+07	0.994
		Airline surplus		1.99E+11	1.98E+11	1.99E+11	2.00E+11	1.99E+11	2.00E+11	2.22E+07	0.733
		Airport Surplus		1.90E+11	1.89E+11	1.89E+11	1.90E+11	1.88E+11	1.89E+11	-1.00E+07	-0.618
		Passenger surplus		2.37E+10	2.39E+10	2.40E+10	2.41E+10	2.42E+10	2.41E+10	3.04E+06	0.786
	Operational	En-route throughput		64119	64038	64155	64231	64289	64216	2.4	0.812
		TMA throughput		37625	37590	37617	37573	37715	37661	1.2	0.662
		En-route DUC		58.61	58.69	58.67	58.07	58.66	58.65	-0.0004	-0.048
		Terminal DUC		567.64	568.47	568.11	568.15	568.18	568.05	-0.0039	-0.746
		N flights		7618	7501	7519	7532	7588	7628	2	0.967
		Load factor		0.907	0.908	0.908	0.908	0.907	0.907	0.000	-0.845
		Airfare		111.72	112.93	112.51	112.20	112.14	112.73	-0.004	-0.354

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Table 76: Mandates - percentage of revenues subtracted with the fines

				Value						Slope	Correlation
				ref	0.01%	0.1%	1%	2%	3%		
Indicators	Technology	Time for adoption	SWIM	728	910	942	954	954	954	10	0.685
			Safedrone	0	53	176	407	407	407	105	0.810
			DAC	19	26	111	198	198	198	47	0.777
			i4D	456	471	486	486	486	486	3	0.530
		Market share	SWIM	0.867	1.000	1.000	1.000	1.000	1.000	0.000	NA
			Safedrone	0.000	0.111	0.364	1.000	1.000	1.000	0.274	0.820
			DAC	0.182	0.273	0.727	1.000	1.000	1.000	0.181	0.731
			i4D	1.000	1.000	1.000	1.000	1.000	1.000	0.000	NA
	Economic	Social welfare		3.99E+11	4.00E+11	3.97E+11	4.01E+11	3.98E+11	4.01E+11	7.36E+08	0.506
		En-route surplus		2.48E+08	1.30E+08	2.07E+08	3.57E+08	4.20E+08	7.33E+08	1.77E+08	0.971
		Terminal surplus		2.19E+08	1.31E+08	1.31E+08	1.62E+08	1.73E+08	2.89E+08	4.67E+07	0.919
		Airline surplus		1.99E+11	2.01E+11	1.99E+11	1.99E+11	1.95E+11	1.96E+11	-1.62E+09	-0.808
		Airport Surplus		1.90E+11	1.88E+11	1.87E+11	1.88E+11	1.88E+11	1.87E+11	-1.98E+07	-0.042
		Passenger surplus		2.37E+10	2.37E+10	2.40E+10	2.42E+10	2.41E+10	2.38E+10	1.79E+07	0.106
	Operational	En-route throughput		64119	63996	64260	64189	64102	64045	-26	-0.308
		TMA throughput		37625	37593	37699	37668	37575	37549	-35	-0.695
		En-route DUC		58.61	58.65	58.74	59.23	59.86	60.40	0.59	1.000
		Terminal DUC		567.64	568.35	568.54	571.70	575.20	578.84	3.52	1.000
		N flights		7618	7519	7607	7526	7498	7508	-21	-0.612
		Load factor		0.907	0.909	0.907	0.908	0.909	0.909	0.0006	0.706
		Airfare		111.72	111.71	111.79	111.86	112.17	112.38	0.22	0.985

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