Identification of levers and barriers for the adoption of new ATM technologies

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Authoring & Approval

Authors of the document

Name/Beneficiary	Position/Title	Date
dr. Eef Delhaye (TML)	Project Team	08/02/2021
dr. Saskia Van der loo (TML)	Project Team	08/02/2021
dr. Christophe Heyndrickx (TML)	Project Team	08/02/2021
dr. Inge Mayeres (TML)	Project Team	08/02/2021
Danlin Zheng Zhang (CRIDA)	Project Team	08/02/2021
Adrián Fabio (CRIDA)	Project Team	08/02/2021

Reviewers internal to the project

Name/Beneficiary	Position/Title	Date
Ruben Alcolea (Nommon)	Project Coordinator	26/07/2021
Miguel Baena (Nommon)	Project Team	26/07/2021
Inge Mayeres (TML)	Project Team	26/07/2021

Approved for submission to the SJU By – Representatives of beneficiaries involved in the project

Name/Beneficiary	Position/Title	Date
Ricardo Herranz (Nommon)	General Assembly	27/07/2021
Eef Delhaye (TML)	General Assembly	27/07/2021
Sebastiaan Meijer (KTH)	General Assembly	27/07/2021
José Manuel Cordero (CRIDA)	General Assembly	27/07/2021

Rejected By – Representatives of beneficiaries involved in the project

Name/Beneficiary	Position/Title	Date
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ITACA

INCENTIVISING TECHNOLOGY ADOPTION FOR ACCELERATING CHANGE IN ATM

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Abstract

This deliverable analyses the main levers and barriers for the adoption of new technologies by the different ATM stakeholders. For this purpose, a mix of qualitative and quantitative methods are employed. The qualitative assessment is based on a review of literature and case studies, interviews with key players in the industry and a workshop. The case studies focussed on successful and unsuccessful experiences related to the uptake of new technologies. The primary focus of the case studies is on innovation in the aviation sector. It also includes the experience in other industries, especially in network industries such as rail, electricity and telecom. This combination of desk research and stakeholder consultation is used to identify the potential explanatory factors behind the experiences, helping us understand the reasons and conditions for the success or failure of the implementation of new technologies. This initial qualitative assessment also serves to depict several mechanisms linked to the adoption of new technologies. These are then investigated by means of quantitative economic modelling. The **first insight** from our analysis is that **regulation of navigation fees is necessary**, as without regulation the natural monopoly of ATM would allow prohibitively large charges on airlines. However, too tight an enforcement of the fee may stimy any real investment in technology as the ANSP may not recover its investment cost. **Regulation should therefore be flexible enough** to allow the ANSP to recover costs and make a small profit to allow for investment. The **second insight** is that the **market uptake of new technologies in a one-to-one setting is probably easier**. The **third and connected insight**, is that it is **not clear if increased competition between ANSPs will stimulate the uptake of new technologies**. Using a simple network analysis, we find that when airlines can choose multiple parallel routes managed by different ANSPs, the incentive of investing in technologies on the side of the airlines is reduced. The reason is that airlines lacking the necessary equipment will find alternative routes by ANSPs that do not make the necessary investments. In a serial network one ANSP may free-ride on the investment of another ANSP, while the overall benefit for airlines is reduced. This does not mean that pro-competitive policies on the side of ATM and airlines do not have other welfare benefits, but we find that in a more fractured market the investment incentives are reduced. The **fourth insight**- which is also supported by numerical analysis - is that an **overall technological mandate for a 'proven' technology can be a welfare improving solution.** This reduces the uncertainty that would be caused by a market-led uptake of the technology in a fractured and competitive market. **The conclusions of both the initial qualitative assessment and the economic modelling are then used within a multicriteria analysis to define a set of promising policy and regulatory measures. These are explored in more detail in subsequent stages of the project.**

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1 Introduction

1.1 Scope and objectives

The air transport industry is facing a host of new challenges. Airlines are going through an era of strong competition, while at the same time facing new restrictions related to climate change and a dwindling capacity for slots in airports. The SESAR Joint Undertaking leverages 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, virtualize, and enhance digital connectivity in air traffic management (ATM). However, despite all the efforts undertaken, the results have not lived up to the expectations.

Researchers and stakeholders alike [35] point to the high level of protection that surround ATM. The sector is still dominated by national monopolies and strong labour unions [12]. There is a general lack of customer awareness and competition. This is shown to affect the uptake of disruptive technologies [2], which has led some researchers [20] to propose regional forerunners to adopt new technologies and increase competition between providers. Other reasons for the slow pace in technology adoption are the very demanding safety requirements, the host and variety of the stakeholders, etc.

[32] acknowledged that the SES initiative addressed a clear need and has led to a greater culture of efficiency in ATM. They also concluded that the SES has failed in achieving the expected performance targets. Therefore, they recommended analysing a variety of alternative policy options. More recently, the same institution conducted a new audit to review the EU's intervention in the deployment phase of SESAR. It concluded that, while the SESAR concept of common projects promotes coordinated action and mitigates the so-called "last mover advantage", its first application –the Pilot Common Project (PCP) –suffered from several shortcomings and included projects for which EU funding was largely unnecessary, as they would likely have been financed without EU support [34]. In its reply to the report, [30] nuances some of the conclusions but recognises the need to facilitate the transition from the 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. Within this first deliverable of the ITACA project we first take a step back. We assess qualitatively the main barriers and levers, how these can be linked to policy measures, and what is the acceptability and applicability of these measures. This is based on a review of literature and case studies of successful and unsuccessful experiences with the uptake of new technologies, interviews and an online workshop. In the second part, we take a more quantitative approach with a theoretical analysis, which is illustrated with two numerical examples. The analysis uses elements of principal-agent modelling[1], game theory and transport economics. It focusses on two aspects which are not yet well understood:

- How do split incentives between the air navigation service providers (ANSP) and airlines may affect the outcome of regulations and policies to increase the uptake of new technologies?
- What is the influence of network effects when the benefits of the technology implemented depends on the uptake rate, a problem which is also called the "last mover advantage"?

The result of this qualitative and quantitative assessment is a list of policy measures which should be implementable in a relatively short time frame. These are then further assessed within the ITACA project using an agent-based model (ABM).

1.2 Structure of the document

The document is structured as follows:

- Section 2 provides the results of the qualitative analysis. This analysis is based on a literature review, interviews and the first ITACA workshop.
- Section 3 presents the economic modelling in which we quantitatively assess some of the barriers discussed in section 2.
- Based on section 2 and 3, Section 4 describes some of the potential policy measures, discusses a multicriteria analysis of these measures to come to a selection of policy measures which can be further assessed in the ITACA project.
- Section 5 summarizes the main results.

1.3 List of acronyms

Table 1 List of acronyms

Acronym	Definition
ABM	Agent Based Model(ling)
ACCHANGE	Accelerating Change by Regional Forerunners
ACL	ATC Clearances Service
ACM	ATC Communication Management Service
ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	Above Ground Level
AMC	ATC-Microphone Check Service
ANSP	air navigation service provider

[1] The Principle-Agent theory focusses on conflicts in priorities between a person or entity and the representative authorized to act on their behalf. The agent may act in a way that is contrary to the best interests of the principal.

ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATM	Air Traffic Management
AU	Airspace User
BEV	Battery Electric Vehicles
CAA	Civil Aviation Authority
CBA	Cost Benefit Analysis
CEF	Connecting Europe Facility
COMPAIR	Competition for Air Traffic Management
CONOPS	Concept of Operations
CPDLC	Controller Pilot Data Link Communication
DLIC	Data Link Initiation Capability
DLS	Data Link Service Implementation Rule
EASA	European Union Aviation Safety Agency
EATMA	European ATM Architecture
E-OCVM	European Operational Concept Validation Methodology
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
EU	European Union
FAA	Federal Aviation Authority
FAB	Functional Airspace Block
FIS	Flight Information Service
GPS	Global Positioning System
GSM-R	Global System for Mobile Communication-Railway
ICAO	International Civil Aviation Organization
ICE	Internal Combustion Engine
ICT	Information Communication Technology
ITACA	Incentivising Technology Adoption for Accelerating Change in ATM
KPI	Key Performance Indicators
LC	Legacy Carrier
LCC	Low Cost Carrier
MCA	Multi Criteria Analysis
NSA	National Safety Authority/Agency
OEM	Original Equipment Manufacturer

PCP	Pilot Common Project
PHEV	Plug in Hybrid Electric Vehicle
PM	Project Management
R&D	Research & Development
R&I	Research & Innovation
RES	Renewable Energy Sources
ROI	Return On Investment
RP	Reference Period
RTC	Remote Tower Centre
RTS	Remote Tower Service
SDM	SESAR Deployment Manager
SES	Single European Sky
SESAR	Single European Sky ATM Research
SJU	SESAR Joint Undertaken
SPI IR	Surveillance Performance and Interoperability Implementing Rule
TRL	Technology Readiness Level
V2G – G2V	Vehicle to Grid – Grid to Vehicle

2 Qualitative analysis

2.1 Introduction

There are several indications of underinvestment at ANSP level. The deadlines for the full deployment of the six functionalities of the Pilot Common Projects vary between 2018 and 2026 [14]. The European Court of Auditors estimated that by July 2018 only 23% of the Pilot Common Projects were completed, 47% were in progress, 17% were planned and 13% were not yet planned at all. Many of the projects which were already launched also faced delays in their implementation. Part of this can be explained when considering the yearly investments made by ANSPs. Within the first reference period (RP1) actual investments were about 25% lower than the planned investments and eight Member States even invested less than half of the planned amounts [15]. Despite overspending (spending more than planned) in the last two years of the second reference period, the Member States are still lagging by 404 M€ (-8%) compared to the total planned investments for reference period 2 (RP2) [59]. During the last two years of the RP2, capital expenditures were more than planned, indicating that ANSPs intended to catch up as they were underspending in all the years before. Note that this refers to the total figures and that there is a large difference between ANSPs where some ANSPs have invested more than planned (Sweden, UK), while others are still lagging far behind (e.g., Greece, Ireland...).

The reasons for this relatively slow pace are multiple and some of them are well known: the demanding safety requirements, the host and varied nature of the stakeholders, the monopolistic nature of the ANSPs, …

Withing this section we make a first qualitative assessment of the main barriers and levers of technology uptake within ATM. First, we review literature and case studies of successful and unsuccessful experiences related to the uptake of new technologies. The primary focus of the case studies is on innovation in the aviation sector, but also includes the experience in other industries, especially in network industries such as rail, electricity, and telecommunications. Secondly, personal interviews and an online workshop with different stakeholders is used to identify the potential explanatory factors behind the reviewed experiences, helping us understand the reasons and conditions (e.g., level of competition, product lifetime cycles, etc.) for the success or failure of the implementation of new technologies.

This initial qualitative assessment serves to depict several mechanisms linked to the adoption of new technologies, which are then investigated by means of quantitative economic methods.

2.2 Literature Review

Economic research focusing on ATM is not abundant. Even less research has investigated the drivers behind the uptake of ATM technologies and/or new concepts[2]. Technology uptake is researched within sociology, industrial economics [9] and organisation and management sciences. This research consists of descriptive analyses discussing the uptake of different technologies in different industries, empirical assessments of technology uptake and diffusion (using econometrics), economic models (industrial economics and game-theory) and behavioural and simulation models (Agent-Based Modelling). For example, [49] analyses the pricing and the technology investments by telecom providers using a game theoretical model while [51] empirically estimated the determinants of investments in mobile telecommunication markets in Africa. [73] on the other hand provide a more descriptive assessment of the diffusion and adoption of telecom innovations.

Research took off by the classic work of [66] and [6], which focused on the relationship between market structure and the incentives for Research and Development (R&D). Today, there is a consensus that this relationship has an inverted U-shape: perfect competition leaves no profit for innovation, while within a perfect monopoly there are no real incentives. This is particular relevant for ATM, with ANSPs being **monopolistic by nature** and an aviation market working in a more competitive environment. The seminal work of [62][63] not only discusses the incentives to innovate but also the diffusion of innovations within an industry/society. A growing body of information shows that human factors and organisational/environmental factors play a very significant role in determining the success or failure of technology transfer and commercialisation ventures [64] . Research focussing on ATM has identified some potential causes of the relatively slow technology uptake. Within the economic modelling of the WP-E ACCHANGE project (www.tmleuven.be/en/project/acchange), **fragmentation of the market, price regulation, home bias and the power of the unions** came out as important elements influencing the efficiency of ANSPs. The SESAR ER COMPAIR project [16] focused on the issue of national monopolies and the introduction of some forms of competition as the solution to encourage ANSPs to invest in technologies. The work of [53] does not focus on ATM but on the factors influencing technology diffusion. One of these factors is the technology itself. Within ATM many technologies are characterised by: (i) **network features**, in which the full benefits of upgrading a system are only realised if the whole network is upgraded leading to externalities and hence non-optimal investments; (ii) “**last mover advantage**”, in which stakeholders tend to postpone their investments knowing that benefits only arrive when all stakeholders are equipped with the new technology; and (iii) the need to take into account **the legacy technologies** used by other countries/partners, etc. [4]focuses on the role of the user consultation process in the decision-making by ANSPs. She states that this consultation process is hindered by: (i) the fact that the users are a very diverse group (small and large airlines, national and international, cargo, general aviation, etc), (ii) the free rider problem (the benefits are for all the users, irrespective of who invested time and resources in the consultation process) and (iii) the complexity of the technologies. As causes of the slow uptake of technologies, she also adds the element of safety and the fact that operational disruptions in the system are not possible.

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[2] We use “technology” in the remainder of the text, but this should be interpreted in the broadest sense. It could also stand for the uptake of a certain concept for which investments in technology may or may not be needed.

Hence, there is not a single reason for the slow uptake of technologies within ATM, but a combination of different, interactive factors. The next sections focus on some specific examples within ATM/aviation and in other industries to get a first flavour of which are the most important enablers and barriers.

2.2.1 ATM/Aviation

Three examples are discussed for ATM: datalink, the uptake of space-based Automatic Dependent Surveillance-Broadcast (ADS-B) and remote towers. Datalink refers to the digital air/ground communication between aircraft and ground systems. ADS-B is an air traffic surveillance technology that relies on aircraft broadcasting their identity, a precise Global Positioning System (GPS) position and other information derived from on-board systems. It is automatic as no work is required from the pilot or the Air Traffic Controller (ATCO). Space-based means that information is transmitted using satellite-to-satellite communication. Both are interesting examples as they require that ANSPs, aircrafts (and airports) are equipped, as the costs and benefits are different for the different stakeholders and as the experience is different between different regions. Remote tower service (RTS) is a system which allows aerodrome air traffic control (ATC) of flight information service (FIS) to be provided from a location other than the aerodrome whilst maintaining a level of operational safety which is equivalent to that achievable using a manned Tower at the aerodrome to oversee both air and ground movements [42]. It is an interesting example the potential benefits are large and even larger if the provision at more than one aerodrome would happen from one single remote location- also called Remote Tower Centre (RTC). It is an example where the investment costs are (usually) for the airports, which together with the airlines also have benefits from the investment – especially when the remote tower can be shared, while ANSPs lose revenue.

Datalink

Improvements in data links for the digital air/ground communications between aircraft and ground systems, have long been considered desirable. On the other hand, for automation, voice communications are inadequate to transmit detailed flight plan information [71]. Datalink provides a semi-automatic alternative by enabling the Controller-pilot datalink communications (CPDLC), which allows, by the time being, flight crews and air traffic controllers to exchange non-urgent ATC information by data messages instead of voice radio. The controller would still be in charge. It would replace some routine administrative tasks, but not the controller itself.

While everyone agreed that it is a good idea, the implementation is not obvious. According to the supplier Honeywell, replacing voice communications by data link using CPDLC technology could add 11% of sector capacity if the usage rate (number of flights or number of flight-hours) is about 75% [25]. Notable about this technology is that the deployment was not led by the ANSPs but by the International Civil Aviation Organization (ICAO) and aircraft producers (and hence the airlines). It is intended to meet a real need and uses a lot of the existing equipment, although some investments by airlines are still needed – besides the investments made by ANSPs. This example is of key interest as the implementation is very different regionally.

The United States started relatively early with considering the deployment of datalink. Initially, the idea was to expand datalink to all domestic centres by 2005, but the implementation itself was seriously slowed down by[3]

- The high costs for the ANSP.
- The budget constraints for the Federal Aviation Administration (FAA). Moreover, the budget of the FAA must be approved each year by US Congress, making the FAA focus on the Congress as customer and not the users.
- The fact that the main benefits were for the users and not the agency.
- Involvement of too many players with different objectives in which the airlines were mostly interested in the aircraft data and not in the data for ATC. There are potentially some savings in fuel and in delays, but these savings would be the same for all users and hence do not lead to a comparative advantage. In addition, there is a last mover advantage as the benefits only accrue if the use is widespread and the costs are expected to decrease over time.
- Concern about safety as there are some doubts if software can consider all possible options as you cannot test every possible situation (“envelope problem”).
- The reluctance to change a system that works.
- Technical issues. Early issues with VDLm2 (which is a means of sending information between aircraft and ground stations) reduced the stakeholders' confidence in the technology, even though the situation has improved today.

Today, due to COVID-19 the deployment has been halted completely. Currently only Indianapolis, Kansas City and Washington Centres are operating 24/7 with Controller Pilot Data Link Communications. Earlier plans for Atlanta, New York and Boston Centres have been put on hold.

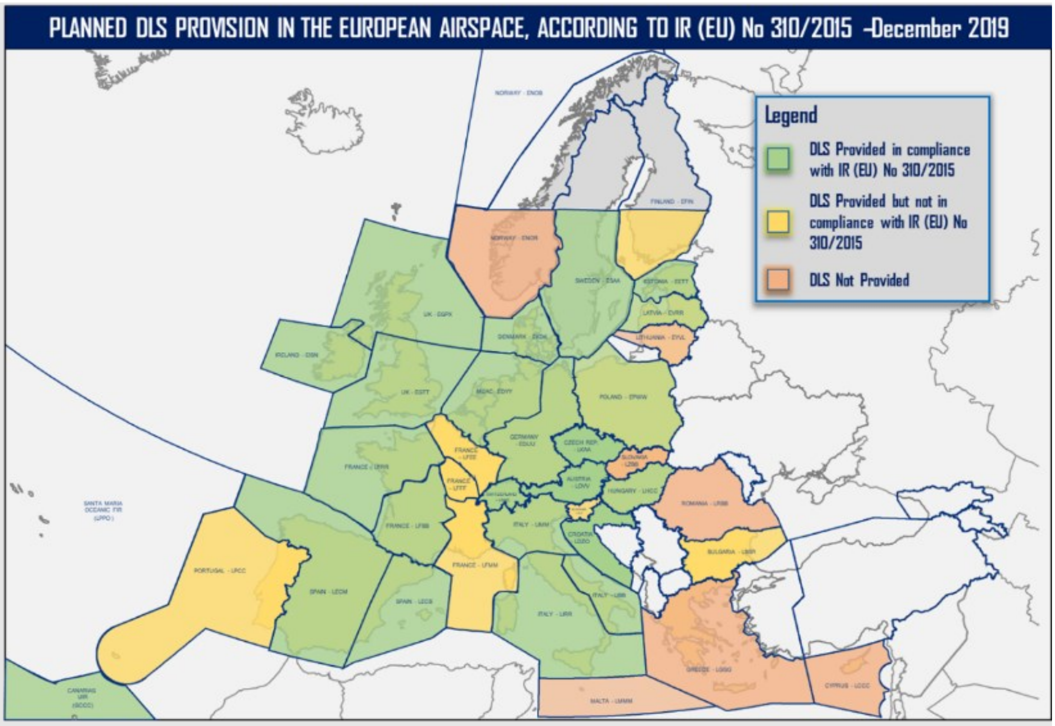
NAV CANADA, on the other hand, started real deployment in 2011 by gradually introducing datalink in its centres. In addition, it introduced a differentiated charge depending on the use of the system and not on the weight, encouraging the use of the data link technology. The result is that in Canada, the usage rate is up to 83% (2015). Planning and the development of a concept of operations, promoting and encouraging services and equipage, using a phased approach, coordination with users and the setting of realistic timings were seen by NAV CANADA as the key levers of obtaining this result.

In Europe, datalink was pushed forward by Eurocontrol, more corporatized ANSPs such as Skyguide and providers such as Honeywell. There is a mandate (EC Regulation (EU29/2009), referred to as the Data Link Service Implementation Rule (DLS IR), effective since February 2020), requiring the air navigation service providers (ANSPs) to offer four datalink services (Data Link Initiation Capability - DLIC, ATC Communication Management Service - ACM, ATC Clearances Service -ACL and ATC-Microphone Check Service- AMC) and the airspace operators to be capable (i.e. to have equipped aircraft and trained crews) to operate these services for all flights in the European airspace operating above Flight Level 285 [27]. However, today the different ANSPs are at different levels of maturity

[3] First three by [58], next three by [71], final one by anonymous reviewer.

(9/30 making use of a so called "white list" due to safety reasons and 6/30 only having limited operation). Figure below shows that 18 states declare that they provide DLS in compliance with the regulation, 5 states provide DLS but not in fully compliance and 7 states declared that they currently do not provide DLS.

Figure 1: Planned DLS provision in the European Airspace – December 2019



Source: Deliverable 11.1.1 Report on DLS Architecture and Deployment Strategy – Draft for SCP consultation (2019)

One of the reasons stated for the delay is that datalink was maybe rolled out too quickly (before having been validated and proven ready). Another reason is the fragmentation of the European airspace requiring more coordination efforts. In 2020 the number of flights capable (does not equal using) is around 66% in Europe [28].

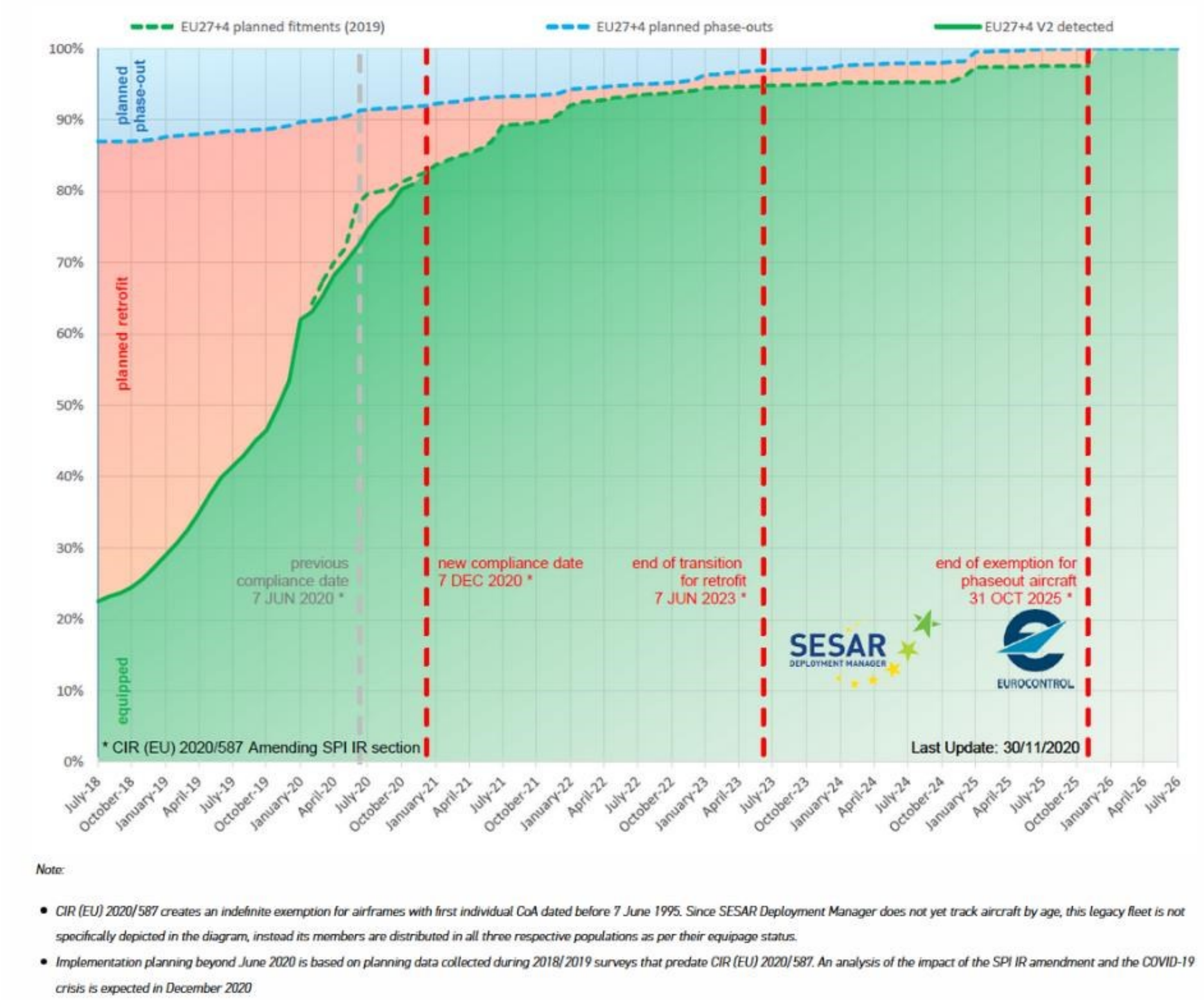
The uptake of Automatic Dependent Surveillance-Broadcast (ADS-B)

An ADS-B equipped aircraft automatically broadcast information once per second to receiving stations on the ground. This information includes (but is not limited to) a GPS-derived aircraft position, barometric pressure altitude and aircraft speed and direction. This information is used to display the aircraft on the controller's display. With space-based ADS-B (a variant of ADS-B using satellites, developed by Aireon), 100-percent global surveillance of air traffic is now possible, and updates are happening about six times faster than the traditional ground-based radar.

Given ADS-B potential, the European Commission requires aircraft operators to equip their aircraft with respective surveillance functions to pave the way towards the ADS-B availability. The mandate is known as the SPI IR, for Surveillance Performance and Interoperability Implementing Rule. The diagram below shows the continued evolution of the equipage. The diagram is based on airline planning data covering 60% of the EU-based, mandated fleet, responsible for at least 85 % of monthly

IFR movements. The evolution of the actual equipage (solid green curve) is monitored by EUROCONTROL. As the goal for the first compliance date was not met, an extension of six months was given.

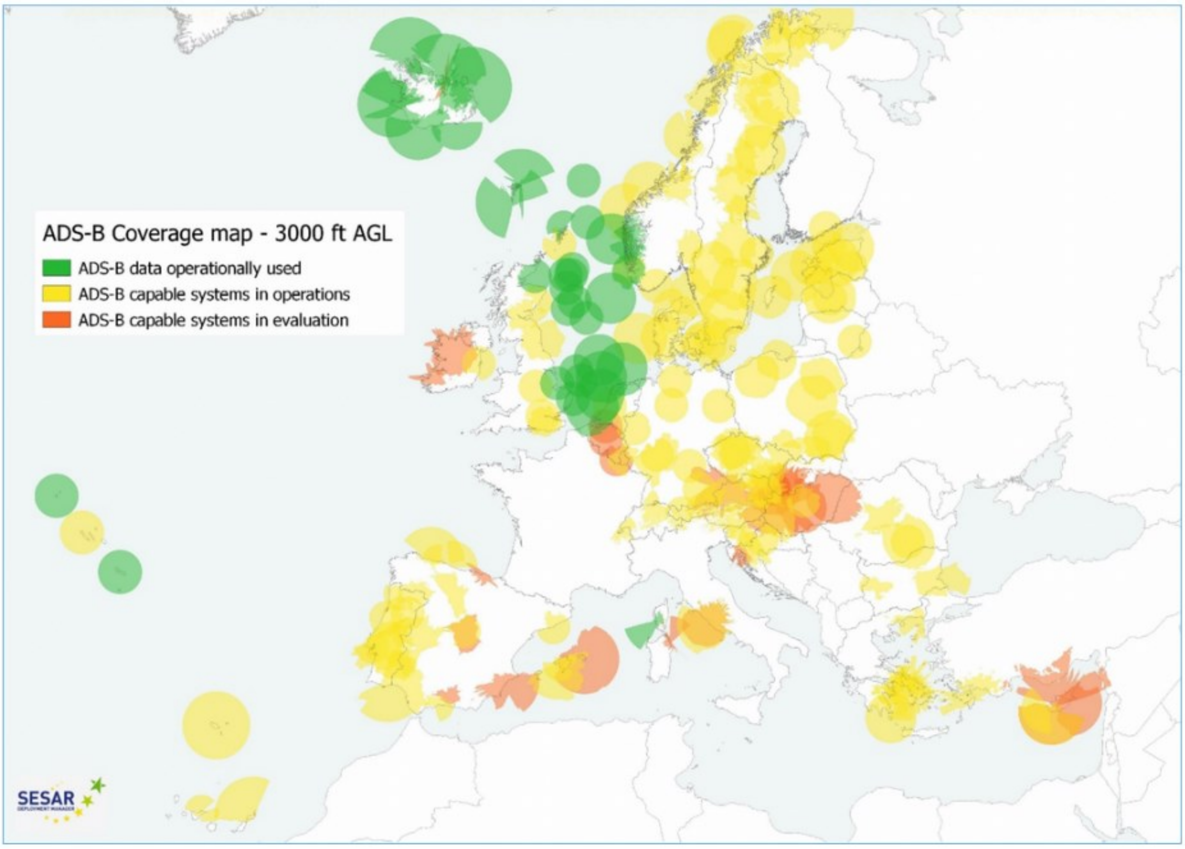
Figure 2: Evolution ADS-B equipped aircrafts – planned versus detected.



Source: https://ads-b-europe.eu/

With respect to the ground implementation, the uptake was much lower as can be seen from the map below showing the status of December 2019 at 3000 ft above ground level (AGL) (similar map for Flight Level 300 can be found at https://ads-b-europe.eu/).

Figure 3: ADS-B Coverage map – 3000 ft above ground level



Source: https://ads-b-europe.eu/

In the US the uptake of ADS-B was relatively slow as most airlines were hesitant to invest before 2020 deadline [58]. They wanted to see that the FAA trained the controllers and if the performance gain was big enough. In addition, the expectation was that it would become cheaper over time as production volumes would increase (creating a last mover advantage). It appears that investing in ADS-B was also more costly than in Europe. The reason for this is unknown. Recently, a sharp increase in the uptake was noticed with about 68% of the in-service turbine aircrafts registered in the US were ADS-B Out Compliant in February 2019 while this was only 24% in October 2016 [40]. This was due to the Federal Regulations 14.CFR 91.225 and 14 CFR 91.227 which mandated the equipment to be installed by 31st of December 2019 for most of the regulated airspace.

Regarding the future ADS-B provision, [8] focuses on the institutional framework influencing the uptake of space-based ADS-B. His work describes the role of regulation (e.g., price regulation and the difficulty of using licenses instead of owning equipment), the influence of being part of the public sector (which implies risk aversion, slow decision-making culture, etc.), the normative barriers (e.g., national entities and fragmentation) and the technological barriers (e.g., technological uncertainty, the current static and stringent standards). His idea is that disruptive technologies such as space-based ADS-B can facilitate institutional change and a move towards the use of more commercial market principles but that at the same time the implementation of such disruptive technologies is hindered by the current institutions.

Remote towers

With remote towers, instead of locating tall structures at each airport with controllers in a top-floor control room, a series of sensors can be installed at an airport, with the data transmitted to remote location staffed by ATC personnel. In theory this concept could be applied to very small as well as very large airports. At small airports with very little traffic, staffing could be shared with other small airports at a single remote facility. At very large airports it would help to cover more-distant runways, obviating the need to construct a second tower.

In the US, the FAA's research facility in Atlantic city conducted a successful demonstration in 2007 showing that controllers performed better, especially when there is low visibility. Since then, little progress has been made in the US. Controllers opposed as they were concerned about their job in low-activity towers making this a key example of failed adoption due to labour unions pressure.

In Europe, the Swedish ANSP, LFV, worked together with private-sector firms such as Saab-Sensis to develop and certify remote towers in 2009. By October 2014, the first approval was given, and the remote tower was in use by April 2015. A second is also operational and a third one has been approved [47]. In Germany there is one remote tower operational and planned for three other airports. The PJ05 Final project report states that remote towers are implemented at "several locations" in Europe and that the success of this case is in the fact that the initial concept is taken even further towards having one ATCO serving 2-3 airports. Note that the US foresaw this potential benefit already from the start, while in Europe there is opposition from the labour unions against the simultaneous operation as it is considered not safe. Main driver in Europe is the increased cost efficiency related to the increased ATCO productivity and the potential as a contingency service to cover any temporarily non-availability (London Heathrow, Hungary). The main issues in Europe are the complexity, the reluctance of the ATCO labour unions and the safety concerns.

Hence in summary, the result has been mixed. The initial concept of remote towers is implemented in Europe but not in the US. At the same time, the next phase – this is serving multiple airports with one remote tower – encountered much more opposition.

2.2.2 Other industries

Rail – European Rail Traffic Management System (ERTMS)

To increase the security, capacity and competitiveness of European Rail, the European Commission encourages the adoption of ERTMS, a commons railway signalling system. Its implementation has, however, been much more expensive and slower than anticipated. ERTMS has been in development since the nineties. The aim was to replace the 20 different systems with one common system which had been jointly developed by eight companies. ERTMS consists of two main parts: European Train Control System (ETCS) which is the main pillar and GSM-R which is the Global System for Mobile Communication-Railway. ETCS exists of two subsystems: the equipment of the track and the equipment on the train. These two subsystems need to exchange information constantly. Depending on how this happens there are two levels of control. Level 1 in which the information is exchanged via radio frequencies and Level 2 in which this is done using GSM-R frequencies. Over the years different versions of ETCS developed to adapt to the advances in technology but this gave rise to compatibility problems… [33] noted that between 2007-2020 about 4 billion euros were allocated towards ERTMS and that at the same time the development has been low and fragmented. This even if, in principle, the railway industry supported the idea, the timing was right (as several networks had to consider their control-command system especially due to the high-speed development) [48] and that already in 2002, the first technical specifications for ERTMS interoperability became legally binding. In 2009 a Deployment Plan with landmarks in 2015 and 2020 was set up and in 2012 ERTMS was obliged in all projects funded by the EU. This policy did not lead to the expected results as in 2017 only 11% of the Core network was equipped [31]. The reaction of the Commission was to move the deadline for 2015 to 2030. By the beginning of 2020, the % had modestly increased to 12% of the Core network [60]. [33] distinguishes three main reasons for this slow progress:

- Unwillingness of the infrastructure managers and railway companies due to the costs and feasibility issues. In general, the incentives were very low in Member States such as Germany where the national system functions well.
- The European Commission did not estimate the total cost of the introduction. Only in 2015 the Commission started to assess the costs, but this was limited to equipment and its installation costs and restricted to the core network corridors. In reality, the deployment of ERTMS (in combination with the associated works such as the costs of migration) proofed to be costly. The EU auditors estimated that the overall cost could be 80 billion euro by 2030 for the Core network or up to 190 billion by 2050 when the comprehensive network is expected to be equipped with ERTMS.
- The Member States opted to develop ERTMS at different stages or with tailored solutions which led to compatibility issues and increased the risk for the investors.

Two other issues are raised by [65]. Firstly, the ERTMS specifications were instable, written in informal language, non-consolidated and incomplete. Updates were postponed in anticipation of new updates leading the various ERTMS levels and different systems provided by different suppliers. This also led to costs which are higher than necessary as the EC allowed the industry to develop the product further to get more subsidies. Secondly, the deregulation led to an increase of the number of players and actors leading to issues for the implementation at the train side. [48] added to this the issue that operators came to see the migration towards ERTMS as an additional cost as long as there is not a whole network, as it is just another system to be added to the national ones.

[48] propose as a solution the "strategy of small networks" in which smaller networks implement the system and hope that the big ones follow, although the larger networks are more reluctant and even actively slow down the process. Hence stronger policy is needed which leads to a minimum number of km equipped which form a true network such that it is not perceived as an additional cost to the operators. Note that the EC cannot subsidise the operators to migrate (rule competition) and that operators might perceive the implementation of ERTMS as leading to more competition on their own home market.

Telecom -packet switching revolution (Internet)

The old telecom sector was organised in three different layers: an equipment layer, a network layer, and a service layer. Due to increasing returns to scale the second layer used to be characterised as a natural monopoly. In many countries (e.g., Japan, Britain, France, Germany) there was a close cooperation between the national network provider and the national equipment providers, which are not a natural monopoly per se. This quasi-vertical integration also meant that most R&D was done in house. This worked well due to non-market incentives for innovation such as the cooperative competition between national systems and the political pressure to improve the services for both residential and business customers. The technology providers were protected in their home countries but were forced to compete on the foreign market and hence were under some competitive pressure. But the system also had some drawbacks. Due to the closed innovation system, the high entry barriers, the limited amount of innovators, the fragmented knowledge base, relatively small markets and the strong focus on reliability, the innovation process was relatively slow and sequential [36].This type of close cooperation between the service level and the equipment level, in house development and sequential innovation can also be observed within ATC. Hence the evolution which happed within the telecom sector is highly relevant for the ATC sector.

In the mid-eighties, for different political and economic reasons Japan, the UK, US decided to end the national monopolies. The incumbent operators outsourced their non-core tasks and left the R&D to the equipment suppliers and were forced to open up their procurement. From the nineties on new entrants emerged which were aggressive in their competition. They were able to enter the market as there were no large technical barriers for new entrants, as they could turn to the technology suppliers for both technical and human resources and as the financial market facilitated the entry and initial growth of new entrants. Hence, they did not have to worry about old legacy technology. On the other hand, it was more difficult to have a unique advantage [36].

Around the same time the internet emerged as a commercial force, creating an alternative way for delivering the same and/or similar services to those provided over the conventional telecom network and delivering a host of new services. This was only possible due to a technical revolution. The initial goal of the internet was to connect computers. This was first done over the telephone lines which was costly due to monopoly pricing and the use of circuit switching which was not very well suited for this. “Package switching” allowed for a better dynamic allocation as it gave much more freedom for traffic to move (transmission is no longer synchronised). This technology was already possible in the sixties, but telecom engineers were reluctant to change as there was no real need for it at the time. The real change came with a group of outsiders, computer professionals, which had a fundamental different starting point. They demonstrated in 1972 that this concept worked and was not a mere theoretical concept. By 1978 already, virtually all new data networks were based on packet-switching [36]. This on its turn facilitated the break-up of the value chain and opened the door for more competition. The role of outsiders (IT, media, financial services) within technology uptake within the telecom industry is also emphasised by [11].

The internet changed the telecom industry completely creating an Information Communication Technology (ICT) instead of a telecom and IT industry [72]. In this industry, customers are demanding different levels of service quality and are willing to pay for better services/more reliability/…. In response to this the network providers developed a series of service levels and pricing plans which are both acceptable and competitive. This was not possible in the legacy network that provided pre-dominantly high-quality voice service. With the new technology there is much more freedom for traffic to move (transmission is no longer synchronised) and to separate the services from the network carriers (e.g., Google provides e-mail services) [37].

But having the technology is not enough. Telecom providers were able to do so as the service regulation was flexible enough while for voice transmission there was much more regulation (requiring cost pricing). This was not intended, but initially most of the revenues came from voice transmission and hence this was the main (regulatory) focus. Over time this flexibility remained as regulators wanted to boost the internet [18]. The flexibility enabled the offering of new services, pricing at incremental costs and still the revenues contributed to the entire network’s overhead [37]. It also helps that the normal interplay between costs and technology innovation does not hold. Normally one expects that over time the prices decrease for new technologies. As in ICT services can also become more complex this is not necessarily the case and prices do not necessarily decrease [72]. This is important as telecommunication is characterised by economies of scale and scope with large, fixed costs which cannot be attributed to individual services on a causal basis but still need to be recovered [18].

[76] on the other hand, focusses on the role of ownership on investments. Based on a statistical analysis on the number of patents filed within telecom, they find that mixed ownership (government and private) leads to less investments than if a firm is 100% government owned or 100% private. The main argument is that mixed ownership is associated with governance conflicts. In general, the investments in technology within telecom increase with size, R&D capital, and scientific capabilities. They decrease when foreign sales are higher, when profits are higher, when there are financial constrained and when the ownership is mixed. Hence, they conclude that when the decision for privatisation is made, the government should move, quickly, to a full privatisation. Within Europe there are two key examples of partially privatised ANSPS: NATS – where the government holds 49% of the shares and a golden share [52], and Skyguide – where the Swiss Confederation holds the majority share [69]. [3] did not focus on the uptake of technologies did found that public-private ownership form with stakeholder involvement achieves statistically significantly higher productive and cost efficient en-route levels compared to either a government corporation or a state agency. As there are no fully private ANSPs it could not be assessed if they would perform better or not.

Energy – Electric Vehicles and smart grid

This section focusses on two related concepts: the take-up of battery electric vehicles (BEV) and the smart grid which allows a Vehicle-To-Grid (V2G) and a Grid-To-Vehicle (G2V) relationship.

To reduce CO2 emissions, policy makers are looking at both the demand and the supply of energy. On the demand side much of the attention goes to battery electric vehicles (and heat pumps), on the supply side the focus goes to Renewable Energy Sources (RES) such as wind and waterpower but also to residential solar panels. Important is the potential synergy between them. An important disadvantage of RES is the volatility of the supply combined with the difficulty of storing energy. BEVs on the other hand could be seen as disconnected storage facility (G2V) where excess power could be stored, and even brought back to the network (V2G). However, in practice there are still many barriers to overcome.

At the demand side, it is clear that, except for Norway with 75% of all new passenger car registrations a BEV or Plug in Hybrid Electric Vehicle (PHEV), the uptake of electric vehicles is still relatively low. Although the share of electric vehicles in the European fleet increased from 3.6% in 2019 to 11.0% in 2020 [29]. [10], [39] and give an overview of the main drivers and barriers to the take-up of BEVs. They emphasise that one must look beyond the economic and technological dimensions to overcome the barriers and hence should also look at institutions, infrastructure, and society. The main barriers listed are

- Involvement of many different actors: automotive, supply chain firms, infrastructure providers, governments, finance providers, car drivers, …
- The technical limitations of current BEV technologies.
- High costs which only decrease by economies of scale, although the prices of batteries are decreasing and hence this might be a smaller issue soon.
- Consumer risk aversion for relatively new products – reluctance to change.

- Consumers short time frame asking a return in maximum 4 years. BEH are characterised by large upfront costs and usually, but not certain, lower running costs and the second-hand market value is largely unknown.
- Consumers do not take rational decisions when buying a car.
- Lack of vehicle choice.
- Shortage of energy supply infrastructures.
- Reluctance by Original Equipment Manufacturer (OEM) which have made significant investments in Internal Combustion Engine (ICE), this is the issue of large sunk costs. A complete new set of suppliers, assembly process, technologies requiring technical and human capital and large investments costs are needed to make the transition [70]. In addition, a loss in maintenance and repair revenue is expected as the BEV has fewer moving parts, lubricants, filters, etc.
- Variability, inconsistency, and time-limited nature of incentives/policy measures.
- Network externalities such as the value of fuel availability, learning by doing spill-overs (think of range anxiety), dependence on oil market, …

The stimulation of niche activities is seen as an important enabler by [10]. Tesla might be considered as a company which focussed on a very specific market making observers believe that it is more than a car company [41] but an identity. [39] on the other hand focusses mandates and subsidies to overcome the transition costs/network externalities. They also emphasise the need for a transition policy which balances the need to establish long term goals and the need to adapt policies as society learns about the progress of new technologies and the market's responses.

However, with a high uptake of BEVs, issues such as network congestion, three-phase voltage imbalance and frequency problems, system peaks and reduced power quality may arise. Hence the need to control EV charging to minimize the impact as BEVs. However, BEVs are also an opportunity in their potential use as energy storage and hence enabler to manage better the uncertain RES [7], increase the power quality and in regulating voltage/frequency [23] . This could also lower the costs of the BEV as the owner could be compensated for his vehicle to be used as a supplier in the peak and/or loaded in the off peak in a V2G setting [70] . However, the following barriers still stand in the way

- Potential battery degradation of the BEV if used as an energy storage system [7].
- as the battery of a BEV is relatively small, you need a lot of BEVs to make this work [7].
- Monopoly power of the oil market and incumbent OEMs which try to block transition. [70] gives the example of the California legislation which was pushed back with five years due to extensive lobbying.
- Reluctance of the electric suppliers as this would imply a shift away from centralised plants and be seen as competitors to traditional forms of electricity provision... [70]
- Reluctance of people and businesses to fully embrace the opportunity of own generation as this is not their expertise. Hence for V2G to succeed a sufficient level of automation, transparency and ease of use is required [70].

- (Cyber) security of the network [50].
- need for smart meters, which on its turn is hindered by issues around data privacy and security and the uncertainty around the additional costs they might impose [50] and the potential problems of accepting more complex pricing [17].
- Uncertainty on what is needed for a smarter grid, the technology is not yet clear, will the smart meters of the first generation be smart enough, timescale, location… [17]

Overall, the progress has been summed up as being small and far from completion [17]. As potential levers [70] sees a change in the R&D pathways away from focussing purely on costs and technological feasibility towards an integrated path including economic, behavioural, cultural, and infrastructural obstacles. This is confirmed by [17], who also argue that as there are many actors involved, a multi-actor approach focussing on acceptance is needed. [17] also lists the following enablers:

- A change in the current price regulation towards more dynamic pricing or real time pricing would help to overcome the reluctance of the traditional suppliers.
- Access of the market by new players should be possible.

2.2.3 Lessons from previous experiences

The three "ATM technologies" all had in common that their implementation level differs across regions. The table below summarizes the observed main drivers and barriers for the implementation of these three technologies. As the implementation of some of them is different in different regions it is possible that a certain policy is listed both as a barrier and a lever. For example, the efficiency of a mandate is correlated with the enforcement of the mandate.

Table 2: Levers and barriers ATM/Aviation technologies

Technology	Barriers	Levers
Data Link	High costs ANSPs/Budget constrains Principal-agent problem: main benefit for users – who do not bear the major share of the investment Stakeholders with different objectives Last mover advantage Safety concerns Reluctance to change Unrealistic timelines Fragmentation airspace Technical issues	Differentiated charges Promotion of technology Phased approach Realistic timelines Coordination efforts Mandate

ADS-B	Lack of enforcement Reluctance to change Fragmentation airspace Technology uncertainty Use of static and stringent standards Last mover advantage Costs for ANSPs	Mandates with strict enforcement Realistic timelines
Remote Tower Control	Opposition ATCOs Safety concerns Complexity	Large potential benefits Potential as contingency service Regional forerunners (starting at very small airports)

The next table shows the observed drivers and barriers from the technologies discussed in the other industries.

Table 3: Levers and barriers "other industries"

Technology	Barriers	Levers
ERTMS	Unstable specifications -> different systems -> compatibility issues Fragmentation network – network effect Lack of enforcement Reluctance to change Underestimation costs + gold-plating Large number of actors	Condition for receiving subsidies In some countries needed to be replaced anyway Regional forerunners (start with smaller networks) Stronger policy
Telecom – packet switching	Reluctance to change Price regulation (cost pricing) Reliability	Flexibility in regulation Competition with other providers Political pressure

	Human capital Mixed ownership	Liberalisation Financial market Separation technology – services Outsiders
Energy – BEV	Changing policy measures High costs Uncertainty on actual costs and benefits Risk aversion consumers Many actors involved Reluctance OEMs Technical limitations Lack of vehicle choice Shortage loading infrastructure Reluctance OEMs	Outsiders – niche markets (Tesla) Mandates Subsidies Adaptive policy
Energy – smart grid	Battery degradation Many BEV needed Reluctance electric suppliers Reluctance consumers Lobbying oil industry (Cyber) security Data protection issues Technological uncertainty	Real time pricing New players Multi-actor approach Integrated R&D pathway

Comparing the experiences in the other industries with the experiences in the aviation/ATM sectors we see that similar barriers arise. This is not unexpected as we focussed on other industries which shared some of the main characteristics (national monopolies, network industries, large number of actors…) with ATM. Hence in most of these experiences the uptake of technology was relatively slow. An important exception is the telecom industry which changed drastically over the last 30 years. From this experience, and most relevant for ATM, we learn the importance of

- The role of demonstration that something actual works (see data switching).
- The role of outsiders with a different viewpoint (computer specialists).
- The role of flexibility in (price) regulation – although unintentional at the start.
- The need for some competitive forces.

2.3 Interviews and ITACA workshop

This section describes the results of the interviews and the ITACA workshop. The goal of the interviews was to gain more insight into three elements: the main barriers and levers with respect to the uptake of technologies within ATM; the importance of several factors during the decision process and the decision flow mechanisms within the organisation of the interviewees. The main goal of the workshop was to collect further feedback on the identification of levers and barriers, to make the link between barriers and potential solutions and to receive some feedback on a first set of selected potential policy measures.

2.3.1 Set up of the interviews

The main purpose of the interviews was to collect feedback from different type of stakeholders about both operational and technical points of view of the life cycle (creation, evolution, and implementation) of innovative concepts/technologies to identify the main factors influencing the decision-making processes at different stages.

The interview is structured in three parts[4]:

1. Part I: Open questions regarding the main levers and barriers of the uptake of disruptive technologies and the individual perspectives of the role of each kind of stakeholders within the research and deployment cycle.
2. Part II: Classification of a set of proposed factors about their importance during the decision-making processes of the adoption and implementation of a new technology and whether they could be considered as a lever or barrier for the same objective.
3. Part III: A business case is presented to participants showing the main outcomes and impacts of a new technology at the end of the research phase. Participants are asked to define their organisation's decision-making process of both:
    - Internal decision processes of a specific organisation/stakeholder to the implementation of the technology.
    - Coordination flow needed to push the adoption between all stakeholders.

[4] A template of the interview structure is attached in Annex 1

2.3.2 Set up of the workshop

The workshop took place online on the 23rd of November 2020 with about 20 participants from outside the consortium. The workshop entailed three main parts: a general introduction of the project and the overall methodology, an interactive part focussing on the validation of the results of the interviews and a policy measure poll exercise.

2.3.3 Results

This section discusses the main results of both the interviews and the workshop.

2.3.3.1 Part I: Barriers and potential solutions

Perception of the stakeholder with respect of his company being a leader or a follower

The result of this question depends highly on the actual identity of the respondents. Hence, we only discuss the more general tendencies. Industry should be seen as leaders within the aviation sector. They develop products which their clients will buy only years later. The picture for airlines, airports and ANSPs is more mixed. Airlines are, overall, more to be considered as followers although regional differences exist, and the larger airlines can play a leading role. Airports are in general very interested in the R&D field but are less active in innovation on the air side. The business model and the financial state of the ANSP, as well as the type of technology, play a key role in whether an ANSP will be more of a leader than a follower. However, regional differences are present.

Agreement on slow uptake of technologies; extensive list of barriers identified

All interviewees agreed that the uptake of technologies within aviation was **slow to extremely slow**. Even up to the point that some technologies were obsolete by the time of implementation. This leads to some frustration as concepts with great potential are lagging. Some argue that the uptake of technologies should be slow due to the safety considerations, but that in any case it should go faster than the current pace. One respondent argued that if there is really a need, implementation can go fast – although this would not be the general case, while another respondent stated that this mainly depends on the technology itself.

A very long list of barriers was identified. Some of them were mentioned only once, others were discussed by most of the respondents – although sometimes with a slightly different focus/phrasing and some of the barriers overlap. The replies are the same over all stakeholders. Hence **it is not the case that some stakeholder groups focus more on certain barriers than others**. We distinguish three groups and list them in order of frequency:

- Barriers mentioned 6 times or more.
- Barriers mentioned 3-5 times.
- Barriers mentioned 1-2 times.

Barrier mentioned 6 times or more

1. It is a complex system with a **lot of stakeholders**, many different systems in use and a lot of interdependencies. In addition, there are large differences between stakeholders: airlines are completely market driven, ANSPs are national monopolies and airports are somewhere in

between. Even within one group of stakeholders such as the end users there can be large differences.

2. Culture of the sector, which is very **reluctant towards change**. Different reasons for this are mentioned such as the fact that ANSPs are national geographical monopolies, often state owned with little incentives to invest (no competitive advantage) and which attach great value to safety.

3. The **gap between research and actual implementation**. The prototype's maturity at the end of the research phase is not enough to start the deployment phase. Most of the results achieved in the research phase addresses nominal use cases (i.e., 80% of the total use cases), but the remaining 20% is out of research stage and thus, out of the validation, which impacts the deployment and implementation of new systems. Real demonstrations projects are needed to push the uptake of technologies and more communication and coordination between development and operation.

4. **Too much regulation** (including different national regulations due to the fragmentation of the European market) and procedures including the procurement rules which lead to a high administrative burden. The **bureaucracy** involved in (funded) research is also perceived as excessive.

5. Linked to the third point is **the safety environment** in which aviation operates. Due to the stringent safety regulation, it takes more time to develop and validate a new technology. Sometimes the development does not even start as there is the risk that the technology will not be approved by the safety agency.

6. **Difficulties of transition**. Aviation is a continuous business which cannot be stopped to replace one system by another. In addition, often different systems (legacy system and new system) must be used simultaneously as not all stakeholders invest simultaneously in all systems (e.g., ADS-B). It is difficult to build a business case when two systems must work next to each other.

Barriers mentioned 3-5 times

1. **Conflict of interest** between the (owner of the) ANSP and the client. Usually, the benefits are for the client, leaving little incentives for the ANSPs. In general, ANSPs almost only focus on technologies which increase performance.

2. **Limited human resources**. There is a shortage of operational staff, as the priority is to maintain the ATCO positions, so involvement in projects is lowest in priority. Especially as there is a shortage of ATCOs at EU level – In 2018 there was a shortage of ATCO-staff of 8% on average [22]. There is also a shortage of technical staff leading to the same experts being involved in many projects.

3. **Home bias** – especially by ANSPs- leading to a preference of inhouse development which on its turn hinders interoperability and the customer basis (see below).

4. There is a large difference between the cost benefit analysis done within SESAR and the one during the **real implementation**.

Barriers mentioned 1-2 times

1. **Budget constraints** as ANSPs are often government owned, and airlines operate with small margins. In addition, airlines work with relatively short pay back periods making large investments nearly impossible.
2. **Weak management and low pressure from the EU.** There is not enough regulation to homogenize the use of technologies and no real enforcement in the case of non-compliance with the performance targets.
3. **Lack of standards** (operational or technical) for ANSPs and National Safety Authorities (NSAs) to be followed. They have their own standards, which make it very diverse. Hence there is a lack of homogeneity of standards. Different standards of a same technology led to ambiguity and confusion (e.g., software standards). Although some claim that it would be difficult to set standards due to the different local needs.
4. **Chicken and egg problem**: different stakeholders wait until the other takes the first step.
5. For the industry, **ATM is not a large customer**. High investments are needed for few customers. Due to home bias, local needs and custom equipment, the number of potential customers even further decreases.
6. SESAR solutions do not take enough consideration to the **local needs.** If the innovative solution does not address local existing needs and the legacy system works properly, there is no willingness to develop and deploy other technologies, although that may bring benefits.
7. **Social pressure** – labour unions. ATM systems maintain a strong dependency on human resources, especially, engineers, technicians, operations staff. This dependency leads to the influence of social and organizational aspects on the development and deployment.
8. Aviation has always been working **isolated*;*** interchanges with other industries are not usual.
9. Lack of willingness **to exchange essential information**. This slows down the process as not all available and useful information is shared with the others.
10. **Military** is a big player and can sometimes hinder the implementation of new concepts. Although on a national level there are some improvements, but decisions between Member States are mostly politically driven.

Potential solutions according to the stakeholders

With respect to the potential solutions a distinction can be made between the different stakeholders, although, as with the barriers, there is quite some overlap. In general, introducing more incentives for both ANSPs and airlines is mentioned by all stakeholder groups. ANSPs focus a bit more on the need of standardisation and more validation and demonstration of solutions while airlines demand a stronger leadership and clear mandates. These solutions are in line with the findings of the literature study.

Three groups of potential solutions are listed according to their frequency.

Solutions mentioned 5 times or more

Only three solutions were mentioned five times or more:

1. Increase the credibility of new technologies by **increasing the validation efforts** (in a real environment, use of demonstration networks, close collaboration with operational staff) and increase the awareness of the potential benefits by making detailed, reliable, and credible cost-benefit analyses.

2. Create **incentives** for the adoption of new technologies. The respondents distinguish between two systems

   a) Performance based operations such as 'best equipped – best served' or 'best capable-best served'. This is often not accepted as it could lead to discrimination between users, but this is not necessarily the case. It would reward the early mover while not necessarily have a negative impact on the others. There are cases where there is also a benefit for the last movers.

   b) Monetary bonusses and penalties. For the users, this could take the form of a discount or surplus on the user charges. For the ANSPs this could be based on the performances or related to a Key Performance Indicators (KPI) linked to technology uptake (e.g., NAV Canada change in charges for increasing datalink uptake).

3. Make sure that there are **enough human and financial resources.** This includes monetary incentives for ATCOs to participate in research and development as their income decreases if they switch from being an 'active' ATCO to participating as an ATCO expert in R&D.

Solutions mentioned 3-4 times

1. Change in **business model/culture**

2. High **standardisation** levels

Solutions mentioned 1-2 times

1. No more additional bodies but **better coordination** between existing bodies. For example, by including the safety agency and authorities in the research phase.

2. Better leadership and governance including **clear mandates** with no extensions calculated upfront. This could take the form of a pan-European infrastructure manager with enough enforcement power.

3. **Increased virtualisation** which decreases the costs and increases the flexibility to take up new technologies.

4. Break down the system in small pieces to ease and speed up the adoption of technologies. Use **incremental steps** to facilitate the adoption.

5. **Public funding** such that businesses do not lose money in the event a solution is not accepted due to safety concerns.

6. **Bring in people from other industries** and increase the quality of project management in all stages of the process (research – development –industrialisation- implementation).

7. **Separate service provision and technology adoption**. Hence no inhouse development, but keep the customer involved enough such that the development meets the needs.

8. Make sure there is a **continuous research cycle** – from innovation to implementation.

9. **Start from a more general concepts** and leave the standards up to a much later phase.

10. **Start by setting standards** such that the solutions would certainly comply. Note that this contradicts the solution above.

Linking barriers with policy measures

In the workshop we asked the participants to link the policy measures to the most important barriers. In the following sections we discuss the main results for ten barriers.

1. Home bias in development

The home bias was mentioned 3-5 times in the interviews, but at the workshop the views were more mixed, and the question was raised if they are really a barrier.

This barrier **might not be relevant for airports** due to two main reasons: (1) the relatively small size of some airports, especially compared with other stakeholders (e.g., ANSPs), leads to outsourcing given the available resources and the reasons to develop a solution in house (except for the top ten larger airports); and (2) the lack of expertise developing complex systems in house.

Airlines usually avoid in-house developments: from the business case perspective, it is important to get higher levels of amortizations. Generally, purchasing the product to a supplier is cheaper than developing the solution in-house. On the other hand, there are some exceptions, especially in areas that impact on the know-how, confidential data, or safety requirements.

From the **Air Navigation Service Provider (ANSP) perspective**, in some cases, it might be quicker to implement a development if it is made in house. Besides, development of in-house solutions does not imply systems that do not comply with standards (i.e., in-house developments and adoption of standards are not incompatible). Moreover, by outsourcing, the equipment may not have a functionality that is required for specific tactical operations of the ANSP. Besides the previous considerations and depending on the nature of the technology to be developed, most ANSPs do not have either the capabilities to afford in-house developments (e.g., Virtual Centres) or the expertise in defining functional requirements (i.e., requirement language).

Regardless of the approach for implementing a new technology, **Civil Aviation Authority** (CAA) focuses on evidence. Therefore, whoever produces and provides the system is transparent for them. Although, lack of standards and information which, in some cases, might be implied within the in-house developments, can disrupt the expectations of the system, and shift the focus to the **coordination and communication** between the stakeholder and the CAA. Because of this, generally, in-house developments may translate into longer acceptance and approval processes.

2. Lack of standards

When the SESAR programme was created, the ambition was twofold: to provide a blueprint for the future of ATM, addressing all aspects of ATM and to provide support to standardization. Therefore, the goal was to define the reference architecture (i.e., EATMA: European ATM Architecture).

When SESAR started, the ambitions slightly changed: the approach moved to a service-oriented architecture. Therefore, services could be standardized and provided by one system and used by others. Under these circumstances, the problems raised by in-house developments were tackled, especially for the ANSPs: they can adopt the SESAR architecture as a reference and add local solutions, which have been developed beforehand for other ANSPs, by integrating standardized services.

Nevertheless, ANSPs face the incompatibility between the current architecture and the service-oriented approach: legacy systems are not ready for integrating services, especially within the core. The issue, therefore, is not the development of new functionalities per se, but the **transition from the legacy systems to the new ones**, especially regarding the core and the **cost of upgrading the system**. Participants proposed the following **mitigation measures** to address the home-bias in development, the lack of standards and, in general, to speed up the adoption of new technologies:

- **To avoid vertical integration:** clearly differentiate between the data provider, the service provider, and the user.
- **Transition to service-oriented architecture**.
- **Stronger performance regulation to create market conditions**. This would foster competition and be a move away from monopolistic business models.
- **To incentivize the adoption of new technologies**, for example by rewarding early adopters.

3. Complex system with many interdependencies

To overcome the complexity of the system, the following measures are mentioned

- **High standardisation levels**: lack of standards is seen as a barrier- The telecommunication industry is mentioned as an industry where expansion has been triggered by high standardisation.
- **KPIs** at European level.
- **Avoiding in-house developments**. There is a need to have someone from outside the organisation as the different stakeholders can interfere with efficient development and hence there is a need for an outside player.

4. Gap between SESAR and Deployment

Increased virtualisation and increased validation effort are seen as the main solution. One must try to prevent the maturity gap by adding steps to the process making sure that the prototype is fit. Virtualisation will help to plan better and assess if a solution is fit. Other solutions include **high standardisation, better coordination, and governance**. As an additional mitigation measure an **independent agency** is proposed as there are too many conflicting interests between the stakeholders pushing solutions before they are ready. An independent agency would be more objective as today sometimes solutions pass the maturity gate while they are not ready and sometimes the information provided by SESAR is not the information needed by the stakeholders to decide.

5. Organisational and cultural limitations

The reluctance to change is often linked to the high workload within the organisation; ensuring there are enough resources would ease the pressure. Change of culture/business model is also seen as a potential solution.

6. **Extensive regulation and bureaucracy**

KPI's at EU level or better governance are seen as solutions. But more important is that respondents are not sure if there are too many regulations; **bureaucracy is more of a problem** and a larger barrier (a lot of agreement on this).

7. **Safety critical environment**

High standardisation levels, **balance between safety and flexibility** and the importance of **funding** and the use of **incremental steps** were appointed as possible mitigation measures for boosting the implementation of new technologies in a safety critical environment. An important remark is that the **CBA** in projects involving safety critical elements is most of the times negative, thus, an eventual funding or a reduction of safety certification costs are needed to make the implementation of such technologies appealing while increasing the level of safety.

8. **Limited human resources**

Regarding the **safety critical environment**, **limited human resources** and **operational difficulties for transition**, the **use of incremental steps** was proposed to be an effective way to solve these problems. The rationale behind this is the risk reduction when a modular approach is taken. For example, the time required for certification and training is split into shorter parts, which are easily addressed.

To **ensure that there are enough human and financial resources** was raised as another measure for tackling this problem. **Political commitment** should be the way to ensure these resources.

A need for **culture change** and **better communications with professional associations** was proposed to avoid false assumptions and division between management and professionals with consequent negative actions such as strikes of air traffic controllers.

9. **Conflict of interests between stakeholders**

A **reward system** was seen as a good measure to de-conflict the situation and move the unavoidable individual interests towards the common interest.

Some comments about the Functional Airspace Blocks (FAB) environment and the (lack of) willingness of states to enforce it suggests that **political interests** are sometimes against expert agreements. Some rules at European level regarding this matter should be set to avoid this interest barrier.

10. **Operational difficulties for transition**

This was seen as one of the most important barriers in ATM. To mitigate its effect, the **incentives for adoption of new technologies**, such as **monetary incentives**, are important. The use of **incremental steps** would reduce risks in operational deployment and therefore the difficulties, as asserted before.

Preference for performance related policies

There was a clear preference for measures which include some relationship with performance. When choosing between policy measures related to the monopolistic nature of ATM performance monitoring was chosen by most participants, followed by yardstick competition. Today there is already performance monitoring, which is not leading to the desired results. It was argued that performance monitoring is key, but it would be good to include some bonus-malus system within this performance monitoring process. Focussing on policy measures related to the principal agent problem, this is the main investor is not the main beneficiary, performance related payments were unanimously chosen as the preferred option. When considering only non-financial policies related to the principal agent problem, contract design was almost unanimously chosen as the preferred option. Mandatory implementation with strict enforcement was only chosen once and by one participant as the best solution and only when forced to choose between non-financial incentives. The main reasons for the reluctance towards this approach is that monitoring would be difficult (you monitor that it is implemented and not the outcome) and practically not possible (as there are more than 130 solutions). In addition, the organisation mandating might not choose the most optimal solutions.

2.3.3.2 Part II: Factors behind the decision process

List of proposed factors

Factors are split into two different phases, Research and Deployment, since some of them could be different in each stage of the cycle or have a different importance. The factors discussed during the interviews are listed in the following table:

Table 4: List of factors – part II

	Factors	*Description*
Research phase	**Stakeholders** Operational/Technological stakeholders' involvement	This means the involvement of the different stakeholders during the research phase
	SESAR ATM needs alignment Funding for research	This is more about the global purpose of SESAR and if the solutions proposed by SESAR are aligned with the real needs of ATM. Additionally, is it important to have (European) funding to commit to the research?
	Results Maturity level Research outcomes: positive/negative impacts on KPAs and requirements Dissemination to impacted stakeholders	We distinguish here between the results themselves (hence the results of the research phase with respect to maturity level, benefits, impact, requirements, …) and the dissemination of the results to the stakeholders. Does dissemination also play an important role in the uptake of a technology?
Deployment phase	**Stakeholders** Operational/Technological stakeholders' involvement Stakeholder's coordination	This is the involvement of the stakeholders during the deployment phase. In addition, we would like you to assess the importance of coordination between stakeholders. E.g., If there is central coordination, is a technology more likely to be implemented?
	Implementation requirements	This means the requirements which resulted from the research phase to implement the

	Operational: Human licensing and training Technological: technology development and implementation	solution (licensing, training, development of new technology, integration within existing technology…)
	Legal Framework Policies and regulations Funding/subsidies/charges Rewards/penalisations	We distinguish two main aspects: 1) which policies must be created/modified to support the solution and if the systems need to comply with existing policies. E.g., Platform to be equipped on board may need to comply with certain laws and regulations. 2) Incentives to adopt the technology either positively (by subsidies, discount on navigation charges, priority when equipped) or negatively (by higher charges, penalties).
	Business criteria Organisation Business model Willingness to change **Trade-off between revenues and costs**	The impact on the own company Individual cost benefit analysis (CBA) Impact can be different depending on business model-> which models are more willing to invest in new technologies Culture of the company – willingness to change

Aggregated results

Within the interviews, respondents were first asked to rate the importance of each factor by giving a score between 1 and 5 (for the figure this scoring was transformed to three categories: low – score 1 or 2, medium – score 3 or 4 and high – score 5). Secondly, they were asked to state whether the factor acted as a lever or a barrier or both and to give some comments. The following figure shows the results as stated by most of the participants. The colour (tone of blue) of the boxes depends on the percentage of the interviewees that contributed to this classification. This means that this reflects the opinion of most of the participants but still there are some individual opposite opinions. Sometimes there are differences between different types of stakeholders, but mostly the differences are related to individual perspectives and experiences.

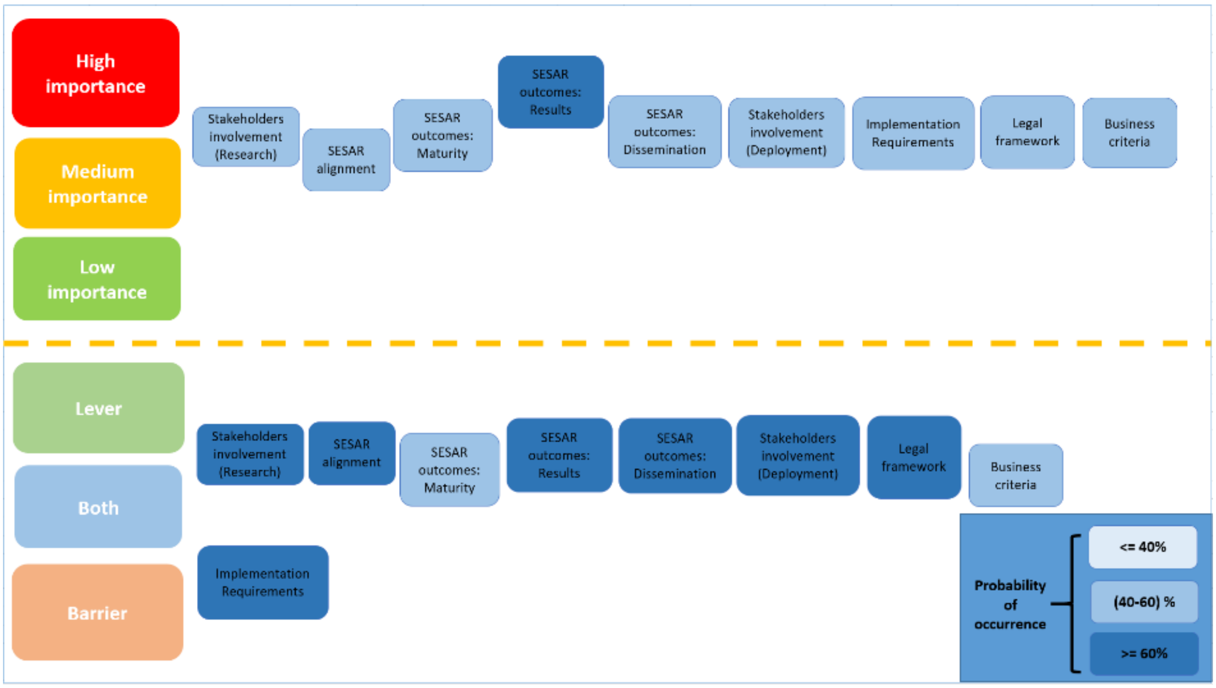


Figure 1 Factors' classification Part II (from interviews)

The main reasons or comments of this classification are listed below, separated into research and deployment phases. These are consolidated opinions of all participants, showing both sides (e.g. why some think a factor is important and other state the opposite):

Research phase:

1. Not all stakeholders' involvement **is at the same level**. E.g., airline involvement is low as they don't have the resources to have an ATM R&D department.
2. If ATM needs are aligned with SESAR Master Plan, it **incentives** the adoption of the technology in a short-term horizon. But it somehow **stops** the long-term research as long-term R&D should not be constrained by the current ATM needs and should give more room to disruptive and innovative ideas.
3. The **funding** is in general always welcome. However, if private entities are really interested in a certain technology, they will **fund the research themselves**.
4. The maturity of the technology is important in R&D phase since it related to the **gap between Research and Deployment**. Nowadays the maturity at the end of R&D phase is often **not enough** to be quickly implemented by the operational team. However, people also think that if the technology is very desirable and interesting for the community, then the level of maturity is not a big issue, which can be solved eventually.
5. Others think that maturity levels, and specifically the European Operational Concept Validation Methodology (E-OCVM), introduces **noise** to the R&D phase. Or at least, has a higher influence/importance than it should have.
6. The **administrative side** of the R&D projects is too complicated and impedes the involvement of some stakeholders.

7. The better the outcomes/benefits of the technology, the more likely it will be adopted by the operational side. This does not mean that technologies which have both positive and some negative impacts are not **acceptable**.

8. The **dissemination today is not good** as the message is not forwarded to the correct community. Dissemination should include the **operational teams** and the **decision makers.**

Deployment phase:

1. The need of involvement of certain stakeholders and the need for coordination between de different stakeholders depends on **the kind of technology** to be adopted. Technologies that do not need a common collaboration to be implemented, have a lower need . Specially airports need to align the use of equipment with the airspace user (AU) Airports also need standardised guidance from EUROCONTROL for most of the deployments.

2. The **stakeholders' interests** are not always aligned thus too much involvement could sometimes create noise instead of helping deployment forward.

3. The operational and technological requirements resulting from the research phase are necessary for the implementation. Although not all changes are not welcomed, they are necessary, and we must make people **aware of it and accept it**. Additionally, from airport perspective, the technological changes are more important than operational, while for the ANSPs, the staff training (ATCOs) is crucial.

4. The policies and regulations have two sides. The existing ones that the technology must **comply with** are barriers (specially for the industry) and the new ones that we create to **promote adoption** are levers.

5. Funding is always welcomed in both R&D and Deployment phases. Nevertheless, people also think that it is not that important to reward (early adopters) or penalise but to **promote the willingness to the change**. If people are interested in the technology and are willing to adopt it, this works better than giving them some economic (dis)advantages. This is especially true for the public entities; for the airlines, rewards/penalties could work better.

6. The business model of the company/organisation does not have a big influence on the Decision-Making process (although the larger the alignment, the larger the likelihood). it is more about the **willingness to change** for public entities (ANSPs) and the **CBA analysis** for the private entities (Airlines, Industry). However, there are benefits that are not considered in the CBA. Some benefits are not visible at the start and might only appear when the solution is implemented. In other words, **some operational benefits remain out of the CBA**.

7. Other people stress that most ANSPs are in a **monopoly situation,** while competitive private companies are more willing to innovate. Hence, the need for a **holistic business model approach.** This is the need to be aware of the different business models: Airborne and ground industries have very different business models. Airborne industry invests first and needs to wait for airline orders. Ground industry will not invest before they have at least one order from a service provider. Airborne industry needs to take more risks. In other words, to be a business that uses holistic techniques, it means that the entire organization is considered in its processes and policies, as opposed to focusing only on its specific components.

Workshop feedback

During the 1st ITACA Workshop, the results of this part were a bit different from the results of the interviews:

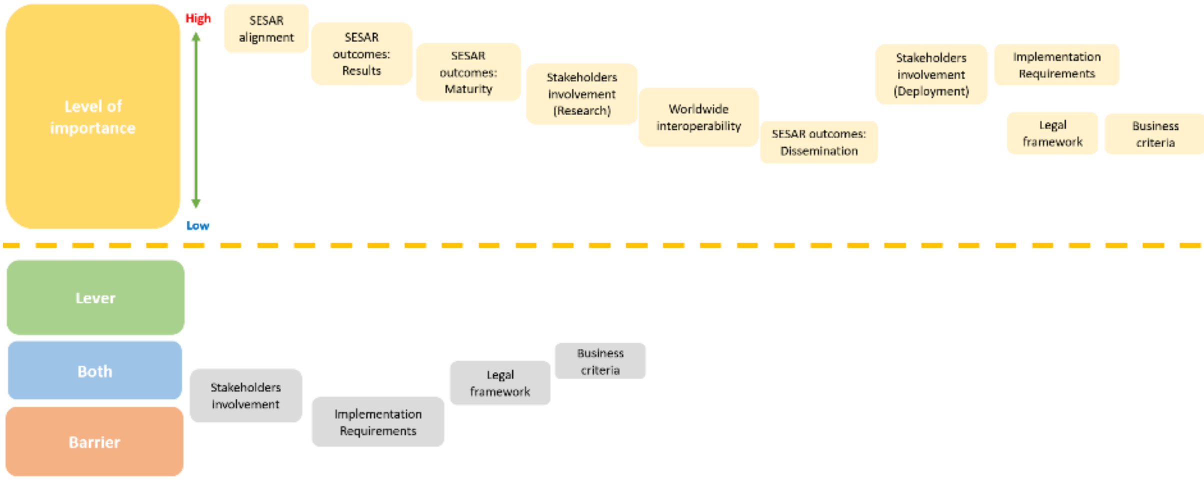


Figure 2 Factors' classification Part II (from Workshop)

Regarding the level of importance, the main difference is that the SESAR alignment seemed to be the most important factor when during the interviews they were considered not crucial for the uptake. A new factor came up about the worldwide interoperability between aircrafts. In the deployment phase, the stakeholders' involvement and implementation requirements were considered critical for the technology implementation. The legal framework and business criteria were equally important but slightly lower than the other two.

For the lever and barrier identification, only four factors were highlighted and discussed. The business criteria seemed to be the closest to a lever compared with other factors and the implementation requirements the closest to a barrier - this opinion was quite like the results of the interviews.

The main arguments for this ranking are described below:

Level of importance

- **SESAR alignment:** SESAR solutions fit the ATM needs. Besides, the different stakeholders are involved in their definition and decide which solution must be addressed.

- **SESAR outcomes: Performance.** From the ATM perspective, research programmes such as SESAR look for optimal solutions. SESAR is performance-driven but achieving very promising performances in areas that are not relevant for ATM is not the ambition.

- **SESAR outcomes: Maturity**. Maturity level is the indicator for measuring the readiness of the technology to be deployed. Therefore, maturity is essential for any stakeholder to support the decision-making process.

- **Stakeholder involvement (research).** During research, the stakeholders' involvement is also relevant since as long as they are involved in the solution definition, they will be keener to deploy it.

- **Worldwide interoperability (airborne industry).** Out of the European framework, airborne industry needs to be interoperable, which serve for the different airspace users from a worldwide perspective.

- **SESAR outcomes: Dissemination**. If the solution is aligned with ATM needs and reaches a high maturity level, dissemination is the easiest step. The reasons for the different stakeholders for implementing or embracing a new technology should be considered in both the performance and maturity of the SESAR outcomes.

- **Stakeholder involvement (deployment):** The main reason for scoring this item highly is the risk that the technology is not fit for the user. It was stated that the role that coordination bodies such as the European Commission take nowadays is limited to monitoring. This leads to a mismatch between expectations and promises. Therefore, it was suggested that more power and accountability of these bodies could improve the deployment process. Additionally, in practice, the funding from SESAR went to the bigger companies and small stakeholders (small ANSPs, small airlines) were not taken into enough consideration.

- **Implementation requirements:** Implementation requirements need to be known clearly and must be kept in mind, but it was also acknowledged that you are likely to have to adjust them. Some disenchantment with the European ATM roadmap was shown and trustful implementation expectations and timing are needed. In relation to the trust, more validation of implementations in different environments should be required. It is important to note the link between implementation requirements, business case and funding: a requirement not beneficial for you should be supported with monetary incentives to palliate the negative business case.

- **Legal framework:** This should be in place before the deployment phase starts. Regarding this aspect, it was highlighted that mandatory implementation must come with funding appropriately targeted at overcoming negative business criteria.

- **Business criteria:** Given that it drives the decision in the first place, it was placed at ‘low importance’ as, in the deployment phase, it should be already aligned with the business model. It was stated that individual benefits drive decisions in the first place and the accomplishment of goals at global, network level must be incentivised properly. Only if the business criteria are not positive, the other factors (especially the legal framework) must push forward the implementation of a new technology. It should be highlighted that the provision of ATM service is a must, regardless of negative business criteria.

Lever and barrier identification

- **Stakeholder involvement:** This was categorized as being both a lever and a barrier in practice while ideally it would be a lever. It was suggested that stakeholder’s involvement must be approached differently than today. In some cases, it was considered as a barrier since no clear coordinator has sufficient power and accountability to steer the actions of all stakeholders. An effective and efficient coordinator would make this factor a lever.

- **Implementation requirements:** Some categorized them as being both a lever and a barrier as it can both help as stand in the way if there are many hurdles. It was argued that the exact effect depended on the technology. Ideally it is used as a lever to show the usefulness of a technology. Other participants saw this as a barrier, since this factor is many times associated with the lack of benefit provided. Also, the timing for implementation and expectations are considered not aligned with reality by stakeholders.

- **Legal framework:** It was unanimously seen as the main barrier, as the legal requirements are what can block the implementation and is a time-consuming process. However, some participants found this factor as a lever, since it can counteract the effects of a negative business criteria.
- **Business criteria:** A link was made with the research phase. If the organization was involved in research, as is often the case for ANPs, this will not so much be a barrier. For stakeholders less or not involved in the research it could be a barrier. For example, for airlines this is the phase where they look at the business case as they are not so much involved in the research phase. It was also seen as a potential barrier due to lack of consistency in time and across stakeholders. However, others considered it as a clear lever, since a good business case makes the process advance smoothly. On the other hand, a bad business case is not necessarily a no-go factor.

2.3.3.3 Part III: Decision making

The interviewees were given the following three decision making approaches as a starting based.

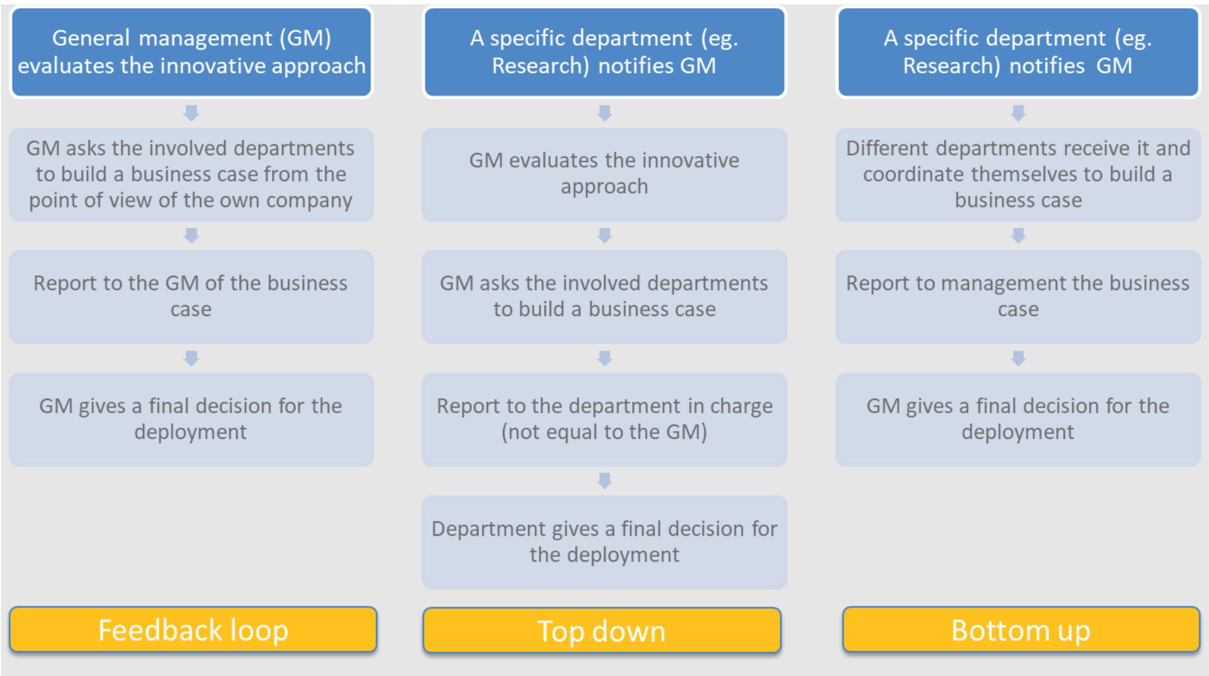


Figure 4. Decision-making approaches.

Based on this, two decision-making diagrams were defined based on the trigger that pushes the adoption of either a new technology or a new concept: on one hand, EC implements a regulation to move SESAR concepts into operations (e.g., Common Projects); on the other hand, an organisation decides on implementing a solution that addresses his own need.

Because of the relevant differences between both processes, two flow diagrams were outlined. Regardless of the trigger, a colour code is used to show the different aspects that influence the process:

- **Blue boxes** illustrate the type of company/stakeholder (e.g., airspace user).
- **Grey boxes** indicate the approach to the decision-making process. As discussed above, three kinds of procedures are considered: bottom-up approach, top-down approach, and feedback loop. Figure 4 depicts, from a general perspective, the steps define in all those processes. On the other hand, **boxes in white with a grey contour** collect some considerations about the approach to the decision-making process.
- **Green arrows and boxes** represent the relationships among the different stakeholders to move forward with the deployment process. **White colour and green contour boxes** gather the main considerations regarding the relationships between the stakeholders.
- **Orange arrows and boxes in white and orange contour** depict the main risks and issues that the different organisations may face during the deployment phase. As the green arrows represent the coordination to advance with the deployment; relationships among the organizations may come up because of the risks they face.

Decision making when adoption is triggered by an EC mandate

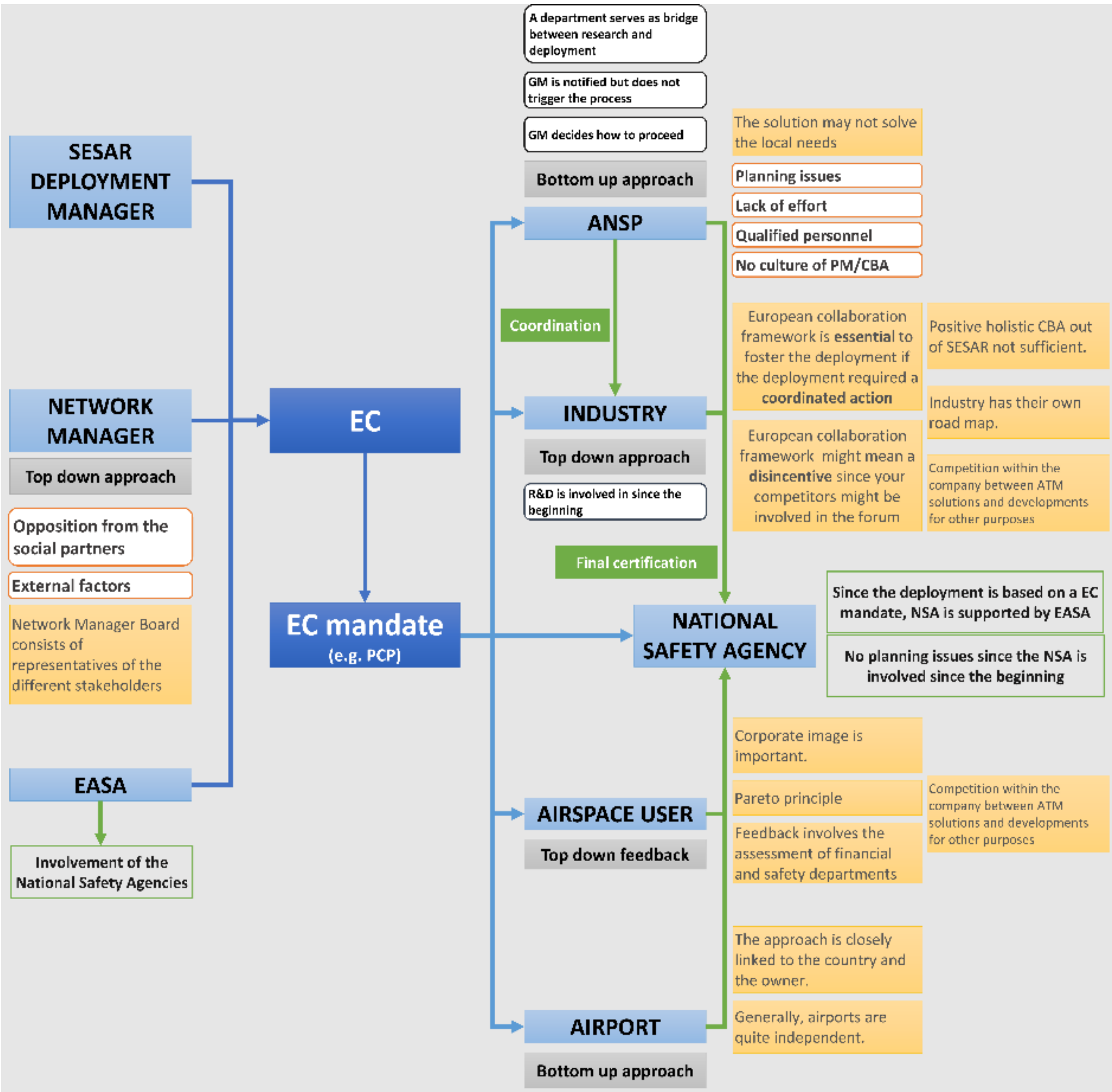


Figure 5. Diagram flow when the adoption is triggered by an EC mandate.

The process is triggered by the European Commission (EC) after conducting a large consultation with the different stakeholders. The EC produces a mandate that affects different stakeholders, depending on the solution to be deployed. The EC also initiates the coordination phase between, on one hand, ANSPs and industry, which could be applicable for all the stakeholders, and, on the other hand and most importantly, the certification stage.

Left side of Figure 5 represents the involvement of the stakeholders in the elaboration of the mandate and prior its release: European Commission, Network Manager, European Union Aviation Safety Agency (EASA) and SESAR Deployment Manager (SDM) coordinate among themselves in order to make a decision about what, when and how to deploy a new technology. From the workshop, four comments need to be considered:

- In theory, all stakeholders and organisations are involved in this first step since the Network Manager Board consists of representative of the different stakeholders.
- The adoption of the common projects (i.e., EC mandates) follow four steps: (i) setting the content, (ii) stakeholder consultation, (iii) endorsement and institutional consultation, and (iv) adoption. Therefore, prior to the release of the mandate, the EC first makes its own business case to decide if it is worth to deliver that mandate and, secondly, conducts a large consultation to ensure that the different stakeholders can comply with the content and the assigned deadlines.
- The involvement of EASA implies the participation of the national Safety Agencies.
- The SDM has two main roles: firstly, it is responsible for the management level (e.g., develop, maintain, and implement the deployment programme) and, secondly, the coordinator of the framework partnership (e.g., implement and monitor the action plans[5]).

Once the EC mandate has been released (i.e., adoption phase), the different stakeholders follow their own approach to include the deployment related to the mandate in their planning. It is important to highlight some comments considering the behaviour of the different stakeholders:

- **ANSP:**
    - The solution to be deployed may not solve the local needs, making ANSPs more reluctant to implement the mandate.
    - The fact of including a mandatory deployment in a tight planning results in planning issues leading to lack of effort and qualified personnel for addressing the deployment. Hence the importance of setting realistic timelines.
- **Industry**:
    - European collaboration framework is **essentia**l to foster the deployment if the deployment requires a **coordinated action.**
    - European collaboration framework might mean a **disincentive** since your competitors are also involved in the forum.
    - Positive holistic CBA out of SESAR is not sufficient as it does not consider the individual impacts.
    - Competition within the company between ATM solutions and developments for other purposes.

[5] The deployment programme refers to PCP or CP1 and the actions plans are purely related to the deployment of a solution in a specific country.

- **Airspace User:**
  - Corporate image is important.
  - Competition within the company between ATM solutions and developments for other purposes.
  - Pareto principle: 20% of the effort invested in a project addresses 80% of the project/use cases.
  - Feedback involves the assessment of financial and safety departments.
- **Airports:**
  - The approach is closely linked to the country and the owner.
  - Generally, airports are quite independent.
  - Coordination with other airports (if that happens, it is not in the first step).
  - Airports might look for collaborative frameworks for easing the deployment (e.g., Connecting Europe Facility (CEF) programme), after the request of the SDM.

Importantly, most stakeholders conduct an individual cost benefit analysis to particularise the net benefits from the research phase. The elaboration of an **own business case** lets companies prioritise the tasks (i.e., fit the solution in the tight planning) and design the process for achieving the deployment.

Finally, regarding the behaviour of the **National Safety Agencies**, which are responsible for the final certification of the solution, they count on the **support of EASA** and, therefore, issues related with planning and lack of resources do not come up.

Decision making when adoption is triggered by a local need

Under the term of **local need**, the own local demands of the stakeholders are considered. These solutions do not need a European framework to be either researched or deployed. Hence the development most likely happens in-house. Furthermore, local needs usual require lower budgets than within the large collaborative frameworks such as the SESAR programme.

According to the participants of the workshop the process for deciding and developing a solution that addresses a local need follows the steps below:

- **Minor coordination + Initial planning + Initial risk assessment:** This step consists basically of gathering the internal information (i.e., related exclusively to the own organisation) required to perform the business case.
- **Minor coordination for checking the available technology:** The catalogue of available technologies in the market is checked.
- **Business Case:** A Cost-Benefit Analysis (CBA) and a Return on Investment (ROI) analysis are performed to decide.
- **Local Needs Prioritisation.**

- **Planning:** The final plan for the deployment is elaborated and the steps to its achievement are discussed among the involved departments. It is worth mentioning that intermediate gates and milestones are essential for the design and adoption of the process design.

- **Certification.**

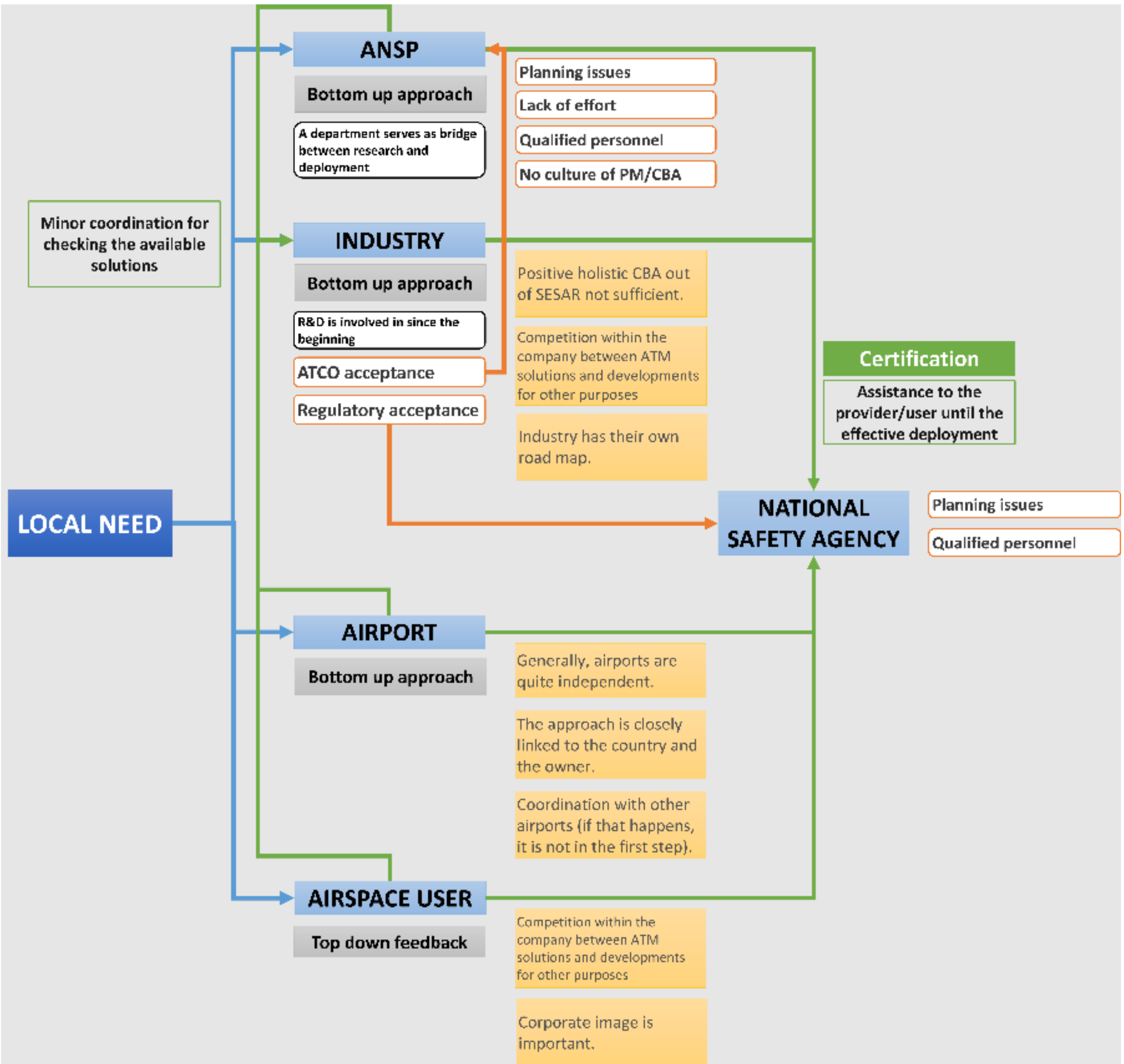


Figure 6. Diagram flow when the adoption is triggered by a local need.

Since the trigger is a local need the research, development and deployment cycle are quite independent from other stakeholders/organisations. However, a minor coordination of the stakeholders and industry must be considered: ATM organisations stay close to industry to check and be aware of new technologies and solutions that may apply to address their own needs. Because of the independence of the process, links among the stakeholders are not only the result of the coordination phase but the risks as well. On the one hand, industry deals with the risk of ATCO and regulatory acceptance through the research phase and, on the other hand, issues about planning and human resources come up because of the lack of coordination with the NSAs.

Figure 6 illustrates the relationships between stakeholders for deploying a local solution. In this case, the trigger, the local need itself, is not shared by the partners. It is important to highlight some comments considering the behaviour of the different stakeholders:

- **ANSP:**
  - Under the local need approach, ANSPs suffer from the same risks explained in the EC implementation: planning issues, lack of effort and qualified personnel.
  - An additional risk comes up due to the nature of the local need: the decision-making process within the ANSPs is not usually based on the results of a CBA. The difficulties of measuring and assessing the benefits, especially regarding operational necessities and solutions, is believed to distort the results of the CBA.
  - ANSPs usually maintain contact to keep abreast of changing technologies and solutions that might apply to their own context and needs.
- **Industry:**
  - As technology providers industry is not a source of local needs but, since they are involved in the research for a continuous improvement of the ATM, industry must be considered within the local need diagram. The fact of being part of the process, not working for their own purposes but providing technologies to solve other stakeholders' needs make them face two risk that link them to both the ANSPs and National Safety Agencies: on one hand, the ATCO acceptance and, ultimately, the acceptance from the ANSP itself and, on the other hand, the regulatory acceptance, linking industry with the local Safety Agency.
- **Airport:**
  - The approach is closely linked to the country and the owner.
  - Generally, airports are quite independent.
  - Regarding the coordination with other airports, if that happens, it is not in the first step.
- **Airspace user:**
  - Corporate image is important.
  - Competition within the company between ATM solutions and developments for other purposes.
  - Pareto principle.
  - Feedback involves the assessment of financial and safety departments.

The development of solutions for addressing local needs implies that **Safety Agencies** are not involved since the beginning and do not count on the support of EASA. This leads to both planning issues because of the short notice for the approval and lack of qualified personnel for the certification of the solution.

2.4 Conclusion qualitative analysis

The case studies related to the three "ATM technologies" all had in common that their implementation level differs across regions. This seems to indicate that the real issue is not the technology but that the institutional framework, including regulation and policy measures is more important. Based on the case studies the following "policy measures" (or the lack of them) played an important role

- Differentiated charging
- Promotion and demonstration of the technology
- Realistic timelines and phased approach
- Coordination efforts
- Mandates and credible enforcement
- Starting at a niche market

Comparing the experiences in the other industries with the experiences in the aviation/ATM sectors similar barriers arose. This is not unexpected as the chose industries shared some of the main characteristics (national monopolies, network industries, large number of actors…) with ATM. Hence in most of these experiences the uptake of technology was also perceived as relatively slow. An important exception is the telecom industry which changed drastically over the last 30 years. From these experiences in other industries, and most relevant for ATM, we learn the importance of

- The role of demonstration that something actual works (see data switching)
- The role of outsiders with a different viewpoint (computer specialists)
- The role of flexibility in (price) regulation – although unintentional at the start
- The need for some competitive forces
- Starting at a niche market
- Role of (conditional) subsidies and mandates
- Role of coordination.

Which are very similar to the "policy measures" drawn from the ATM experience.

Notable is the fact that most of these "policy measures" were also seen as levers in the interviews and the workshop. There is a strong agreement on the need for better dissemination and demonstration of technologies. Better coordination was also raised as a solution. Some flexibility within the pricing regulation – especially related to performance-based pricing or performance-based services- was also acceptable by the stakeholders. Although mandates could overcome some of the barriers leading to slow implementation, the appetite with the stakeholders was almost non-existent. The main reasons for the reluctance towards this approach is that monitoring would be difficult (you monitor that it is implemented and not the outcome) and practically not possible (as there are more than 130 solutions). In addition, the organisation mandating might not choose the most optimal solutions.

The interviews and the workshop also brought out valuable lessons about the barriers and levers during both the research and the deployment phase, and about the relationships between the different stakeholders.

From the interviews it was clear that the most important factor during research phase is the **outcomes (results) of the research project itself** (supported by more than 60% of the participants), in terms of performance/operational benefits, the expected impacts on the different Key Performance Areas (KPA) and the requirements to support the concept. The results are the key factor to lead to a successful implementation of the concept/technology. The more positive the benefits (economical and performance) of the concept/technology, the keener will be all affected stakeholders to adopt it. In line with this, when the negative impacts are bigger, the organisations are less motivated by this change. On the other hand, the other factors remain quite within the same level of importance.

Regarding the lever/barrier classification, in the interviews, almost all the factors are categorised between "lever" and "both" (but closer to "lever") without any remarkable difference. **"Implementation requirements"** is the exception and clearly identified as a barrier, although a minority believes that it could be "both" as the requirements are needed to support the implementation. With respect the workshop feedback on this same analysis, it should be highlighted that the most important factor there was the "**SESAR alignment**" since only with proper alignment with the ATM needs and with solutions addressing the current problems the interest and adoption of the solution by the different stakeholders will be triggered. For the lever and barrier analysis, the "**implementation requirements**" are also considered as a barrier as in the interviews and the "**business criteria**" the closest to a lever since if alignment is achieved it triggers the adoption but even if not aligned it should not be considered a no-go factor (the legal framework would make it mandatory if necessary).

Notwithstanding the difficulties of summarizing the particularities of the different stakeholders when deciding and deploying a solution, the differences between the cases analysed above i.e. EC mandate and local need lie in the role of the local Safety Agency. When there is an EC mandate the NSAs are involved since the beginning. In the case of addressing local needs, NSAs are not part of the process until the certification step what poses planning and resource issues on their side. Beyond the differences, the importance of elaborating an individual and specific business case to analyse the costs and potential benefits of the solution was highlighted. However, at the same time, the difficulties for assessing, especially, the benefits from operational solutions were commented and considered.

3 Economic modelling

3.1 Introduction

Economic research focusing on ATM is not abundant and even less is known about the barriers and drivers behind the uptake of new ATM technologies.

Researchers and stakeholders alike [2] point to the high level of protection that surround ATM management. The sector is still dominated by national monopolies and strong labour unions [3]. There is a general lack of customer awareness and competition. This is shown to affect the uptake of disruptive technologies [4], which has led some researchers [5] to propose regional forerunners to adopt new technologies and/or increase competition between providers [6]. Other reasons for the slow pace in technology adoption are the very demanding safety requirements and the host and variety of the stakeholders.

To tackle the new challenges created by increased demand, climate change and growing competition between airlines, to name just a few, new technologies are proposed to make ATM services more efficient and performant. As pointed out in previous sections, the uptake of these technologies remains disappointing. Several reasons for the slow uptake have been suggested, such as, the monopolistic nature of the ANSP and its strong labour unions, the stringent safety requirement inherent to the industry or the large number of stakeholders involved.

In this section we want to focus on the technologies itself and see whether certain characteristics displayed by ATM technologies could hinder their uptake. Indeed, ATM technologies possess some specific characteristics, namely: (i) often both the ANSP and the airlines need to make an investment, (ii) there is an imbalance in the allocation of benefits and costs as most of the investment costs are often born by the ANSP, while it is the airline that enjoys most of the benefits and (ii) ATM technologies often display network features, in which the full benefits of upgrading a system are only realised if the whole network is upgraded leading to externalities and hence non-optimal investments.

We develop a simple model to analyse the uptake of certain ATM-technologies based on the potential efficiency gains by both ANSP and airlines. We start from a simple set-up with a single ANSP and airline. We then enrich the model by allowing multiple types of airlines. This adds realism to the model as it introduces competition between airlines and allows us to gain insight in the difference in reaction of low-cost carriers (LCC) or legacy carriers (LC). In our last step we generalize the model even further considering two ANSPs, either in serial or in parallel connections on the same origin and destination. This is inspired by how transport network capacity decisions are reached. As the ANSPs will need to recuperate at least a part of the cost of the investment in new technologies, both the structure of the market and the possibility of an airline to reroute are considered in this model variant. Finally, we apply our model to two ATM technologies (Controller Pilot Data Link Communication (CPDLC) and Remote Towers) which exhibit different characteristics to illustrate how these affect the ease or difficulty to implement them.

3.2 Model components

3.2.1 Agents and interactions

We consider four economic agents (see Figure 7); the regulator, ANSPs, airlines and passengers. The regulator (e.g., EUROCONTROL) can impose policies and rules on the ANSPS and the airlines. These can be monetary incentives, such as subsidies, or certain mandates or price regulations such as caps on the navigational charges etc. The ANSPs provide ATM services to the airlines in return for navigational charges and finally, the airlines provide air kilometres to the passengers in return of ticket fares. The model could be modified to include airports instead of airlines but to keep the analysis as simple as possible we focus on the interaction between airlines and ANSPs.

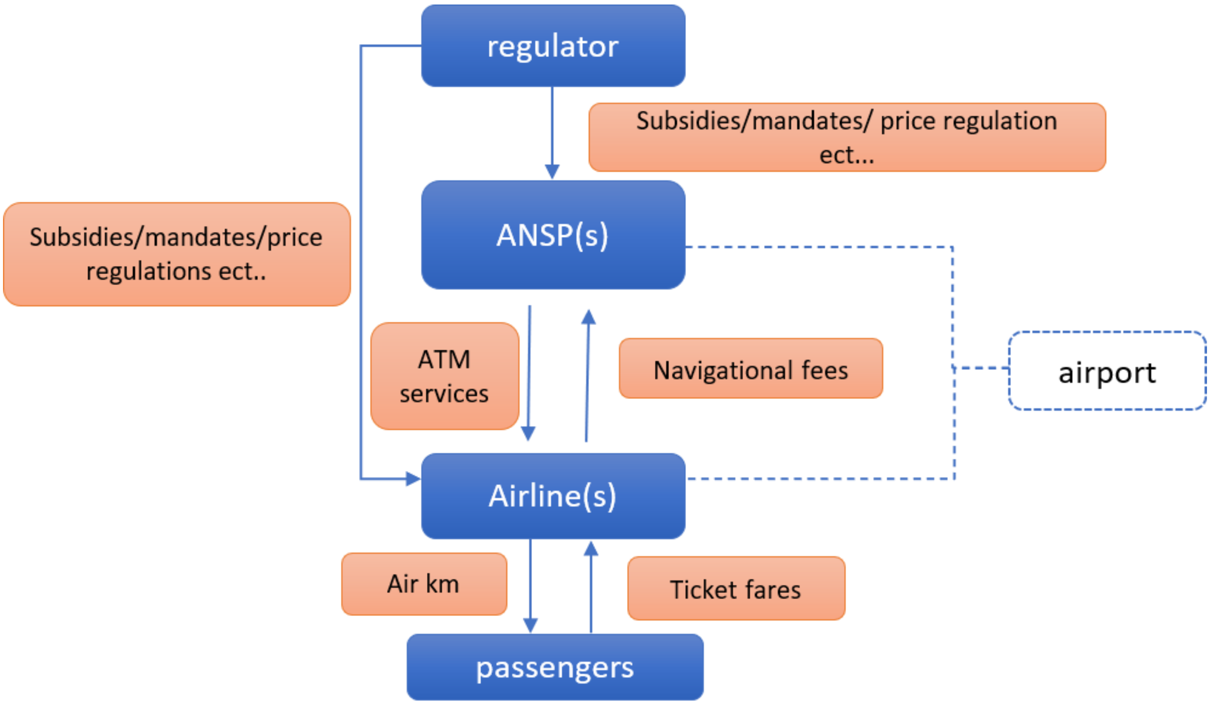


Figure 7: Agents and their interactions

Our model is set up within a two-stage game (see Figure 8). In a preliminary stage, the regulator sets the rules or policies. These are taken as exogenous to our model. In the first stage, the ANSPs set the navigational charges and decide whether to adopt the new technology or not. We consider several ways in which the service providers set its charges. One option is to assume the current situation where the ANSP is allowed to set its charges as to recover its costs. Another option is to impose a cap. Finally, we consider the possibility that there are no restrictions and the ANSP simply maximises its profits. In the second stage, airlines decide whether to invest in the new technology and choose the desired flows to maximise their profits. In the simplest set up of our model we consider only one ANSP and one airline, both will act as monopolistic entities. In the first extension, we allow multiple airlines to use the airspace of the ANSP. This allowd us to gain insight in the question whether competition between airlines could potentially make the uptake of technologies more or less likely. The next extension is to allow competition between ANSPs by considering multiple ANSPSs either in a parallel or serial network.

With a parallel network, in the second stage, the airlines not only set their flows but also choose their routes.

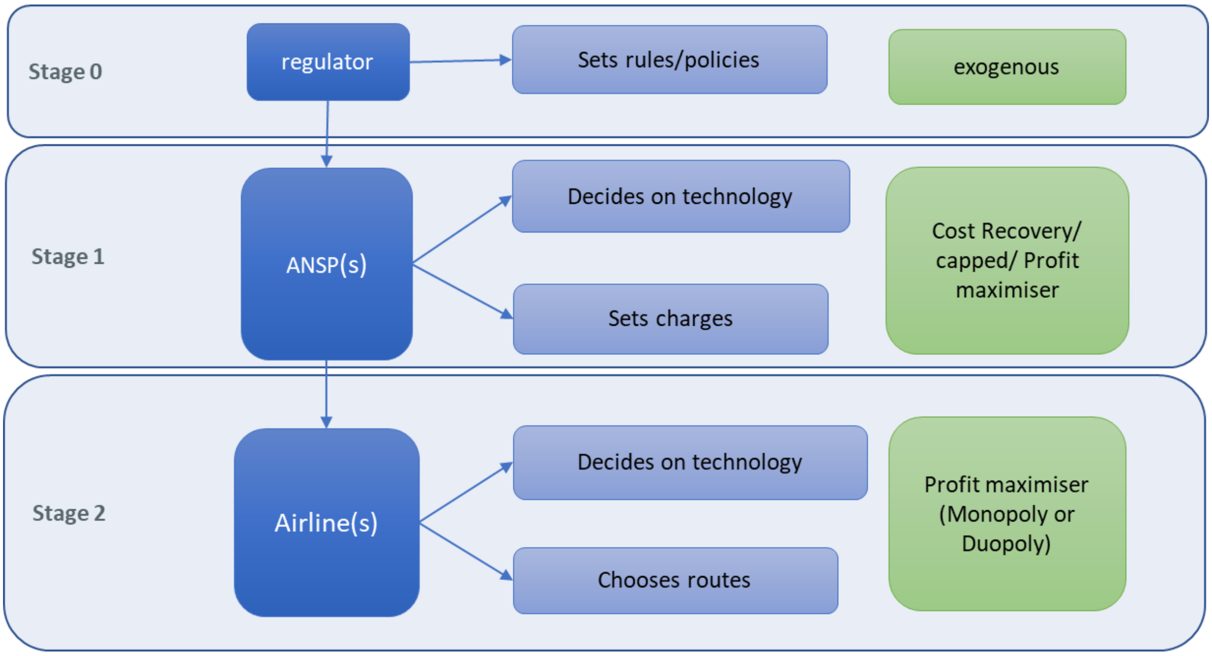


Figure 8: Two stage game and agent's decision tree

3.2.2 Demand and Cost Functions

We assume an airline (or multiple homogenous airlines) which serves a single market between a single origin-destination pair. For analytical purposes we assume linear demand and cost functions. The number of trips served by the airline is given by q. We assume a fixed load factor per flight and thus the number of flights is proportional to the number of passengers. Hence, we can express everything in terms of passenger km without loss of generality.

The airlines profit function (Π_A) is simply its revenues minus its total costs. The total costs (TC_A) consists of three categories; a variable cost, a fixed cost and a cost associated with congestion or delays. Variable costs are the sum of the direct operational costs (c_A) such as fuel, labour and maintenance and the navigational fee (τ) which the airline pays to the ANSP for the ATM services. Navigational fees make up to 10% of the variable costs [21]. The fixed costs are the non-operating costs (also called overhead costs) such as acquisition of aircraft or investment in infrastructure or technology. Fixed costs are typically high in the airline industry and can make up more than 50% of the total costs [74]. Finally, the delay or congestion costs increases the costs per flight proportional to the number of flights (or passengers) and depends on the available capacity. We assume a linear marginal congestion cost such that the total congestion costs are a quadratic function of the demand. This set-up was also used in [2]. The airlines revenue is determined by the demand times the average fare per km. Putting all this together we obtain the following expression for the profit of airline A (see also Figure 9):

$$\Pi_A = pq - [c_A + \tau]q - \frac{\phi}{2}q^2 - FC_A. \quad (1)$$

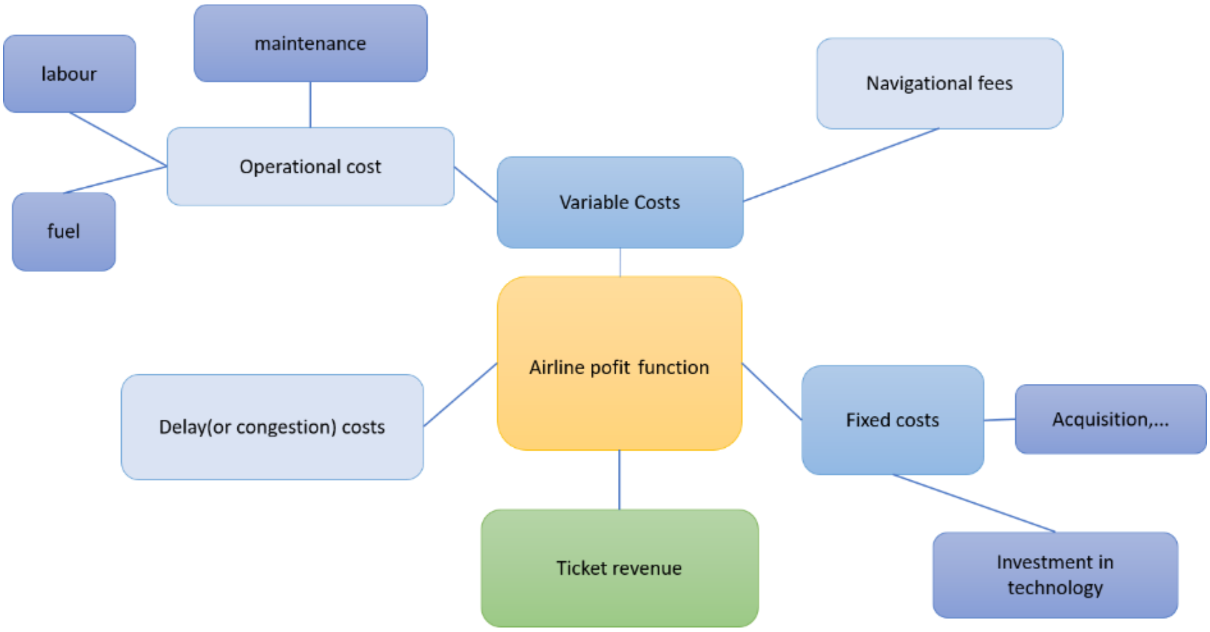


Figure 9: The airlines profit function

ANSPs are assumed to act as a monopoly. Indeed, their fixed costs, the national sovereignty, and the fact that there can only be one ANSP controlling a flight corridor makes them natural monopolies. Like the airline we assume a linear cost function for the ANSP being the sum of variable costs (c_G) such as labour and maintenance and a fixed cost (FC_G) that consists of the investment costs and other sunk costs. We assume here that the ANSP does not face costs of congestion on the airspace directly. However indirectly it leads to lower provision of airflight kilometres and hence impact its profits. Hence it is in the interest to reduce congestion for the ANSP. The ANSP has only one revenue resource which is the navigational charges collected from the airlines. The navigational charge (τ) depends on the number of kilometres flown and the weight of the aircraft [61] which is directly correlated with the size of the aircraft. Under the current regulations, ANSPs can recuperate part of its investment costs through higher charges, and these thus depend on the investment decision of the ANSP. The profits of the ANSP are the simply the revenues from the charges minus its operational costs and its fixed costs (see (2)):

$$\Pi_G = [\tau - c_G]q - FC_G \quad (2)$$

where q is the number of passenger km flown through the ASNPs airspace.

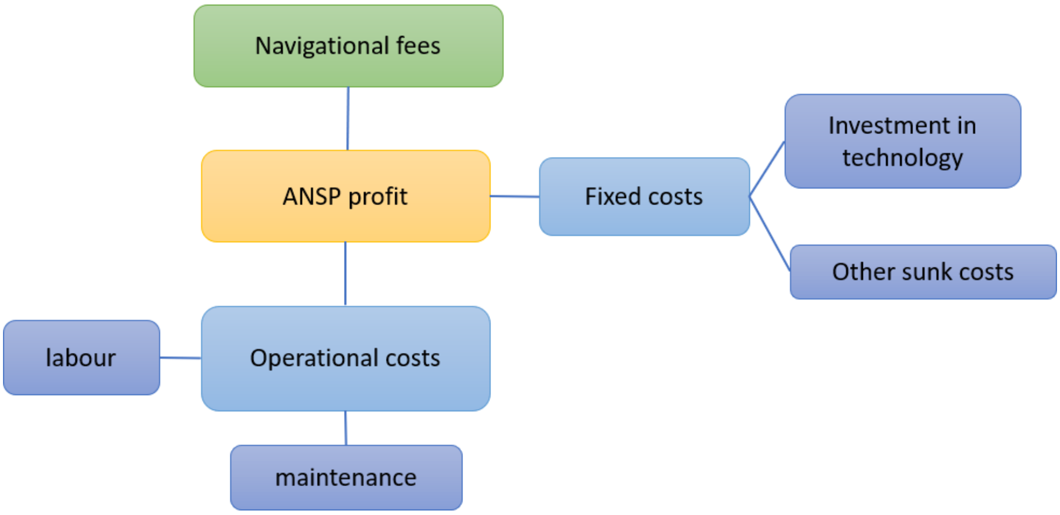


Figure 10: ANSPs profit function

3.2.3 ATM technologies and their impacts

To tackle the new challenges created by increased demand, climate change and growing competition between airlines, new technologies are proposed to make ATM services more efficient and performant. These ATM technologies display, however, certain characteristics which could hinder their uptake, namely: (i) both the ANSP and the airlines need to make an investment, (ii) there is an imbalance in the allocation of benefits and costs as most of the investment costs are often born by the ANSP, while it is the airline that enjoys most of the benefits and (ii) ATM technologies often display network features, in which the full benefits of upgrading a system are only realised if the whole network is upgraded leading to externalities and hence non-optimal investments. ATM technologies impact airlines and ANSPs cost functions in multiple ways. We examine the situation where a new technology is available and the ANSPS and airlines need to decide whether they want to invest in this technology or not. Their decision depends on the impacts on their profits. Potential impacts of a new technology are depicted in Figure 11. Denote k the decision variable for the airlines and K the decision variable of the ANSP so that $k = 0$ (or $K = 0$) if the airline (or ANSP) chooses not to invest and $k = 1$ (or $K = 1$) if the airline (or ANSP) does invest and uses the new technology. For the airlines there are multiple impacts: ATM technologies reduces fuel and delay costs whilst requires investing in new equipment and retrofitting aircrafts. The new technology also affects the costs of the ANSP: by increasing the efficiency of the air traffic controllers, operational costs can be reduced. On the other hand, fixed costs are increased. Under the current regulations, ANSPs can recuperate part of its investment costs through higher charges, and these thus depend on the investment decision of the ANSP. To incorporate these effects in the profit functions we rewrite eq(1) and eq(2) as functions of the relevant components as function of K and k:

$$\Pi_A(K,k) = pq - [c_A(K,k) + \tau(K)]q - \frac{\phi(K,k)}{2}q^2 - FC_A(k), \quad \textbf{(3)}$$

$$\Pi_G(K,k) = [\tau(K) - c_G(K,k)]q - FC_G(K) \quad \textbf{(4)}$$

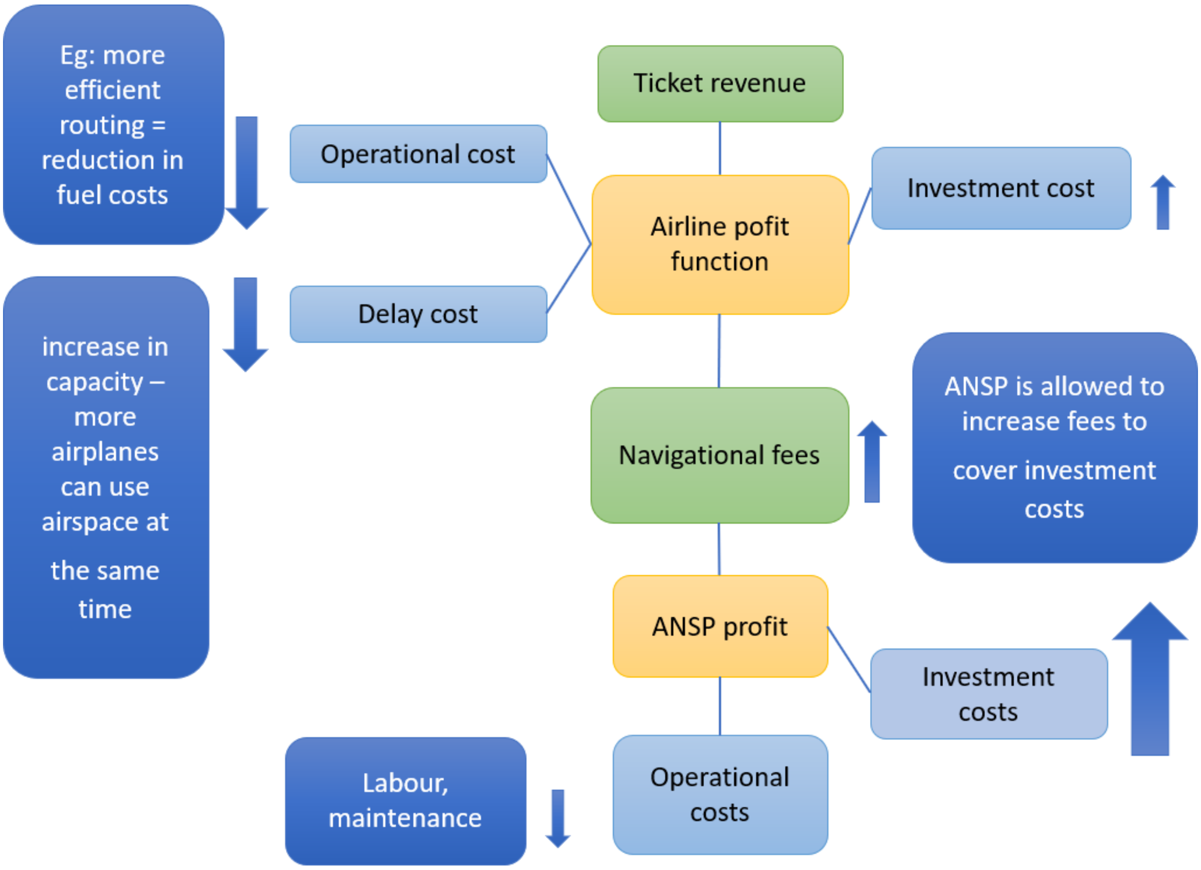


Figure 11: ATM technologies and their possible impacts

Only when an equipped airline uses the airspace of an ANSP that has adopted the new technology will certain impacts be accomplished. Operational costs and congestion or delay costs are reduced only when both parties have invested in the new technology. As soon as one agent invest in the new technology its fixed costs naturally increase. Finally, the navigational charges will reflect the investment costs of the ANSP and thus increase whenever the ANSP has adopted the new technology, regardless of whether airlines have. The impacts on the various parameters are depicted in Table 5.

ANSP uses new technology	YES		YES		NO		NO
Airline uses new technology	**YES**		**NO**		**YES**		**NO**
Airline operational costs $c_A(K,k)$	$c_A(1,1)$	<	$c_A(1,0)$	=	$c_A(0,1)$	=	$c_A(0,0)$
Airline Fixed costs $FC_A(k)$	$FC_A(1)$	>	$FC_A(0)$	<	$FC_A(1)$	>	$FC_A(0)$
Congestion / delay $\phi(K,k)$	$\phi(1,1)$	<	$\phi(1,0)$	=	$\phi(0,1)$	=	$\phi(0,0)$
ANSP operational cost $c_G(K,k)$	$c_G(1,1)$	<	$c_G(1,0)$	=	$c_G(0,1)$	=	$c_G(0,0)$
ANSP Fixed costs $FC_G(K)$	$FC_G(1)$	=	$FC_G(1)$	>	$FC_G(0)$	=	$FC_G(0)$
Navigational charge $\tau(K)$	$\tau(1)$	=	$\tau(1)$	>	$\tau(0)$	=	$\tau(0)$

Table 5: Possible impacts of the new ATM technology on the costs of the airlines and ANSPs

Notation can become quickly cumbersome when allowing for more than one airline or ANSPs. We also we see that, except for the fixed costs, the impact on the parameters only occurs when the ANSP has adopted the technology. Hence, we introduce the following notation: $c_A(1,1) = c_A^1$ while $c_A(0,k) = c_A^0$.

In the theoretical section, we consider technologies with these general characteristics. To illustrate the model, we apply the model to two use cases: Controller Pilot Data Link Communication (CPDLC) and Remote Towers.

The first technology, CPDLC exhibit all the features mentioned above. The CPDLC is a means of communication between aircraft and ground control using data link for ATC communication. It has the possibility to drastically increase efficiency of air traffic control, by standardizing operational control messages. CPDLP can offer a solution by increasing the effective capacity of the communication channel, the number of flights one controller can handle, and the cost efficiency of the ANSP. The main implications for the airlines are that they suffer less delay costs and rerouting is minimized. Airlines are then able to use their preferred route and will not incur extra fuel costs. The ultimate result being a reduction of the operational and delay costs for the airlines.

The second technology, Remote Towers, only exhibits a subset of the possible characteristics. With the latest concept of remote towers, instead of having ATCOs at each airport, they will be in a centralised remote tower centre. There they can control many airports and flight routes from a distance. This technology does not require investments on the side of the airlines but large investments from the ANSPs. The main benefits are cost savings for the ANSPs. A more efficient provision of ATM services could increase its capacity, albeit smaller than for CPDLC and as such have an indirect benefit to the airlines.

3.3 Simplest set up: one airline and one ANSP.

In this section we consider the situation where there is only one ANSP and a single airline using the airspace. We first consider the case where the agents have perfect knowledge about the benefits and costs for the other agents and where the ANSP can be considered as a first mover.

We assume one airline (or multiple homogenous airlines) serving a single market, i.e., using the airspace of a single ANSP between a single origin-destination pair. For analytical purposes we assume linear demand and cost functions. The inverse demand for trips is given by.

$$P = A - Bq \tag{5}$$

Where q is the number of trips served by the airline and both A and B are positive demand parameters. The airline profit is given in eq(3). The airline choose output (number of passenger kilometres or pkm) to maximise profits. The optimal number of pkm and optimal fares for the airline satisfies the first order condition ($\frac{\partial \Pi_A}{\partial q} = 0$) and are equal to:

$$q^*(K,k) = \frac{A - c_A(K,k) - \tau(K)}{2B + \phi(K,k))}, \qquad p^*(K,k) = \phi(K,k)\, q(K,k) + c_A(K,k) + \tau(K). \tag{6}$$

As expected, if the operational costs or the navigational charge decreases, prices decreases and output increases. In the presence of congestion costs ($\phi > 0$), the price will be higher, as the **monopolist**

airline absorbs the full congestion cost in the price. Hence there is no congestion externality in this case. If both the ANSP and the airline invest in the new technology, the operational costs decreases whereas the navigational charges increase. The relative importance of the two effects determines whether output increases or decreases and the airlines need to weigh up both effects. Whether the airline has an incentive to switch to the new technology depends on the overall benefits it can gain.

The ANSP can either use a cost recovery or profit maximisation strategy. In the case it sets its fee such to maximise its profits, the fee equals:

$$\tau^*(K) = \frac{A - c_A(K,k) + c_G(K,\kappa))}{2} \quad \textbf{(7)}$$

Note that airlines only operate if they can make a profit. The optimal navigational charge in this setting will however drive profits for the airline to zero. Indeed, substituting τ^* and q^*into the profits function of the airline yields $\Pi_A = 0$. To ensure that the airlines can make some profits, ANSPs needs to be regulated and charges need to be capped (another possibility is to impose performance targets):

$$\tau^{CR} = \frac{FC_G(K)}{q} + c_G(K,k), \quad \textbf{(8)}$$

The higher the total demand, and the lower the marginal cost, the lower the charge. The main driver of the ANSPs profit is the amount of traffic, the ANSP has therefore an incentive to maximise the traffic using its airspace and its capacity (or minimize the congestion). The more inelastic the demand, the lower the potential benefits for the ANSP.

We first want to analyse what happens when no policies (other than a cap) are in place. In the next section we analyse the different scenarios of investments and use game theory to see whether either the airline or the ANSP have the right incentives to adopt the new technology.

3.3.1 Investing with perfect information with ANSP as first mover

In the case of perfect information, we can consider two stage game where the ANSP moves first and decides to adopt the technology or not. Given this decision the airline then makes its decision. Firstly, if the ANSP does not adopt the technology, there is no incentive for the airline to invest. The more interesting question is when will the airline be interested to make the investment too. We illustrate this in the figure below:

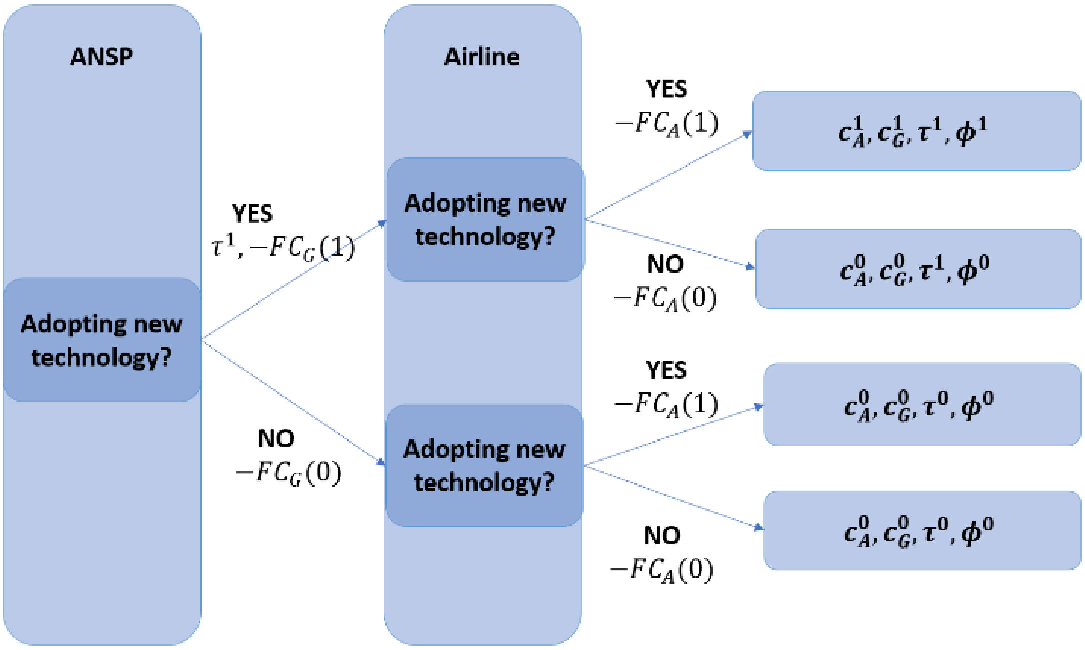


Figure 12: Two stage game with one ANSP and one Airline

We see that there are four possible outcomes. Only in the case when both airlines and ANSP invest the full benefits of the new technology are realised. To solve this problem, we need to determine the specific outcome of each case.

The impact on profits can be written as:

$$\Delta\Pi_A = \frac{(2A - c_A^0 - c_A^1 - 2\tau)}{(2B + \phi^1)}\Delta c_A + \frac{(A - c_A^0 - \tau_1)^2}{(2B + \phi^1)(2B + \phi^0)}\Delta\phi - \Delta FC_A > 0, \quad \textbf{(9)}$$

where an uppercase 1 respective 0 is used in the case the ANSP uses the new technology or not. The symbol Δ denotes the difference between situation with and without the new technology. If the technology reduces the operational costs and congestion cost substantially and the investment costs are not too high, **the airline will make the switch provided the ANSP has switched.** It can be shown that for every change in congestion ($\Delta\phi$) there corresponds exactly one positive reduction in operational costs Δc_A that, for a given investment costs, would make the change in profits positive.

We now turn to the ANSPs decision. The technology allows the ANSP to handle more traffic and reduce the operational costs. At the same time, the ANSP must charge more to recover its costs which reduces demand. If the airline does not adopt the technology, only the latter remains and the ANSP will see a drop in its profits. The ANSP will therefore only want to adopt the technology if the airline follows. The changes in profits

$$\Delta\Pi_G = q^1(\tau^1 - c_G^1) - q^0(\tau^0 - c_G^0) - \Delta FC_G > 0 \quad \textbf{(10)}$$

The ANSP balances difference in income with and without investing against the costs of investments. If the ANSP is not able to increase it navigation fee, it has only limited benefits in terms of reduced operation costs and of the additional margin it has on the increased demand. We illustrate the impacts of the technology on the airline and ANSP in Figure 13 (investment costs are omitted here).

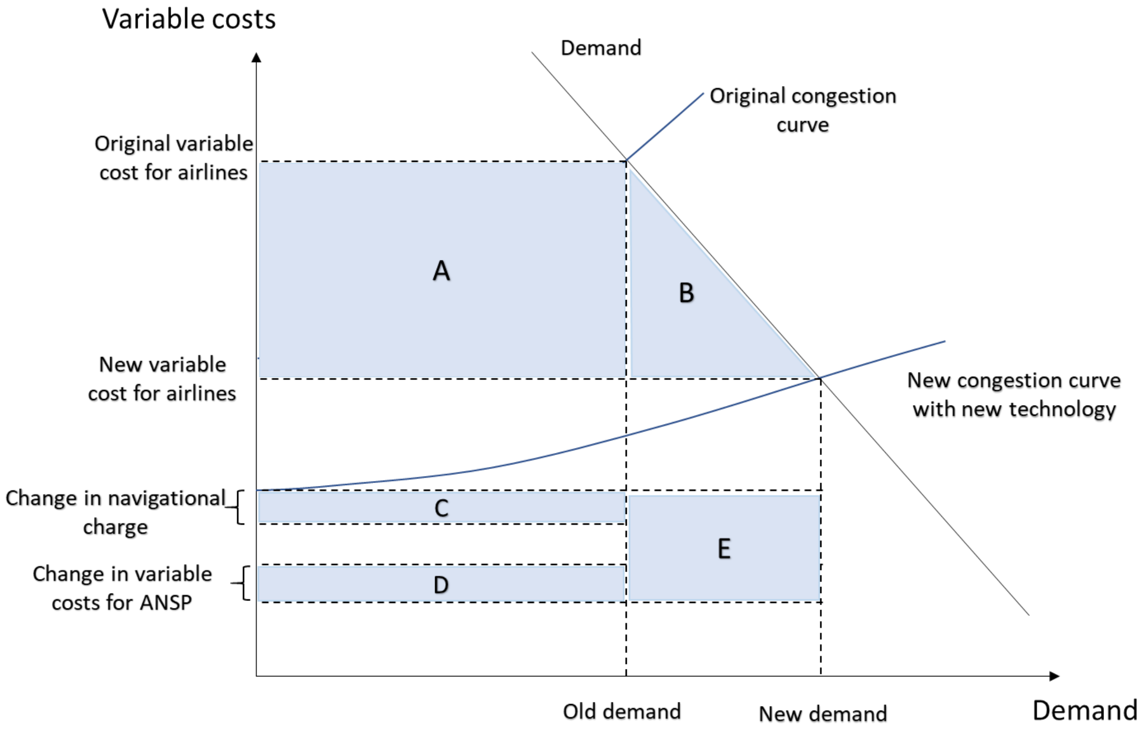


Figure 13: Impact on the airline and ANSP of a new technology

This figure combines the impact on the ANSP, the airline and passenger market. The change in consumer surplus can be calculated using the so-called triangle rule or as A + B indicated in the figure. Here A represents the benefit for existing market users (A) and the welfare benefit of the new users (B).

On the side of the ANSP there are three possible benefits. The first is the increased navigation fee for the existing users (C). The second is the reduction in the operational costs at the ANSP side (D). The last element is the margin of the ANSP on the new users (E). We see that if the ANSP is not able to increase its navigation fee (C=0) and has only limited benefits in terms of operation costs (D ≈ 0), the only way to recover the cost of investment is indirectly. Therefore, by the increased demand on the airline's side and the resulting additional margin (E). The more inelastic the demand, the more difficult it will be for the ANSP to generate any extra profits.

3.4 One ANSP, multiple airlines

3.4.1 Model specifications

In previous section we assumed there was only one airline who acted as a monopoly. Although useful to introduce the main ideas behind the model, it lacks realism. In most cases there are multiple airlines serving a same origin and destination. For this reason, we relax this assumption and assume n airlines. Only a fraction (κ) of these airlines decide to invest (airlines of type A). These airlines enjoy a reduction of their operational costs (assuming the ANSP has invested in the new technology). This reduction will depend on how many airlines have invested (network effect). The marginal operational costs (c_i) are taken to be linear and decreasing in κ for airlines of type A

$$c_A = c_A(\kappa) \quad \textbf{(11)}$$

For the airlines that do not invest (type B), the marginal costs remain unchanged: $c_B = c_B$. All airlines will face same navigational charge τ. In a similar way, the congestion reduction need not to be linear. Sometimes the full benefits of the technology are only achieved when the whole network uses the technology, when only a fraction (in this case one airline) of the airlines have invested then only a fraction $\gamma\Delta\phi$, with $\gamma < 1$ of the total potential benefits are achieved .

Following [68] the inverse demand function is a linear function and is given by:

$$P = A - \kappa B q_A - (n - \kappa) B q_B \quad \textbf{(12)}$$

The marginal cost per passenger is constant plus a congestion costs (ϕ) that is proportional to the total demand.

The cost and profit function are defined in the same way as in the monopolistic set up. As is customary in the aviation literature, we assume that the airlines engage in Cournot competition (this is, the airlines decide the supplied passenger kilometres simultaneously and independent from each other). We limit our attention to the Nash equilibrium, where airline of type *A* takes the output of the other airlines q_B as given. Solving the first order condition for airline *A* and *B* yield:

$$q_A^N = \frac{(A - 2c_A(\kappa) + c_B - \tau)}{3\kappa(2B + \phi(\kappa))}, \qquad q_B^N = \frac{(A - 2c_B + c_A(\kappa) - \tau)}{3(n - \kappa)(2B + \phi(\kappa))} \quad \textbf{(13)}$$

And the profits are

$$\Pi_A^{\mathrm{N}} = \frac{2(A - 2c_A + c_B - \tau)^2}{9\kappa(2B + \phi(\kappa))} - FC_A, \quad \textbf{(14)}$$

We can easily see that if a technology reduces the operational costs, this increases the demand for the investing airline. But it negatively affects the output of the competing airlines that have not invested. This implies that there will be more pressure for the other airlines to invest too to regain part of their market share. On the other hand, reduced congestion leads to an increase in demand for both airlines and there could be some free riding on the part of the non-investing airlines.

The assumptions for the ANSP are the same as in previous section. As previously we assume a constant marginal cost per passenger, which decreases if both the ANSP and the airlines can use the new technology. We assume that congestion does not enter the cost or profit function of the ANSP directly, but it will enter the profit through the demand. The operational costs for the ANSP decreases, as the more airlines use the new technology, the ANSP would like that as many airlines as possible would invest. Not only will its direct operational costs go down, but there will be an increase in demand which increases the profits of the ANSP.

3.4.2 Investment game with one ANSP and two airlines

Again, we consider a multiple stage game, where the ANSP decides to adopt the technology first and the airlines decide whether to invest. In this set up we consider the case where there are two types of airlines: type A and type B. We are thus in duopoly case for airlines and a controlled monopoly for the ANSP. We illustrate this in the figure below.

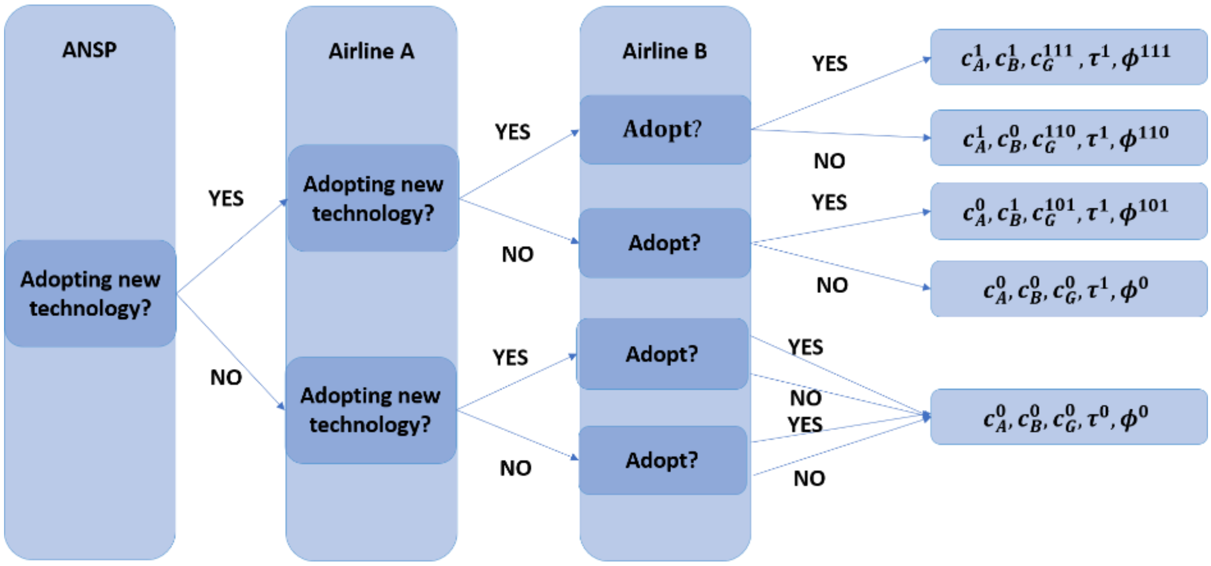


Figure 14: Investment game with 2 airlines and 1 ANSP – possible outcomes

Since the parameters ϕ and c_G now depend on the decisions of the two airlines, we need to generalise our notations. We introduce following notation: when $K = 1,\ X(K, k_A, k_B) = X^{Kk_Ak_B}$, eg. $\phi(1,0,1) = \phi^{101}$ is the congestion cost on the network when the ANSP and airline B uses the new technology, but not airline A.

The logic of the game above is as follows. The full benefit of the investment can only be attained if all players choose to invest. An outcome which can be seen as (1,1,1). In the figure above, this is indicated both the 'topmost' pathway. In principle there are 8 possible outcomes. However, four of these outcomes are essentially the same. If the ANSP chooses not to invest, the outcome is that the technology is not operational, even when airline A or B would have made an investment to use it. This fallback position is the same as the original baseline, since we can assume that even when the airlines would have invested, this would be treated as a sunk cost and have no influence on the price setting by the airline.

If the ANSP invests, but neither of the airlines choose to invest, the outcome is that ANSP increases its fee to recover the investment, but no airline follows through. This case is a worst-case scenario but is relatively unrealistic. More realistic are the partial and full uptake scenarios with the airlines either investing or partially free riding on the investment of the other airline.

This is a complex game and hard to solve analytically. We can simplify however, by assuming that both airlines **move simultaneously instead of sequentially**. This fits the overall modelling exercise as we already assumed that both airlines are in a Cournot equilibrium, where they decide the supplied passenger kilometres simultaneously and independent from each other. It is not such a big leap in the model to assume that they would also plan the investment in a similar fashion.

If we assume the ANSP has adopted the technology, there remain four different cases: (i) none of the airline has adopted the technology and profits for airline A are given by Π_A^{100}, (ii) only airline B has adopted the technology and profits for airline A are given by Π_A^{101}, (iii) only airline A has adopted the technology and profits for airline A are given by Π_A^{110} and (iv) both the airlines have adopted the technology and profits for airline A are given by Π_A^{111}. The profits are given below:

$$\Pi_A^{100} = \frac{2(A - 2c_A + c_B - \tau^1)^2}{9(2B + \phi^0)} - FC_A^0,$$

$$\Pi_A^{101} = \frac{2(A - 2c_A + c_B - \Delta c_B - \tau^1)^2}{9(2B + \phi^0 - \gamma\Delta\phi)} - FC_A^0 \ ,$$

(15)

$$\Pi_A^{110} = \frac{2(A - 2c_A + 2\Delta c_A + c_B - \tau^1)^2}{9(2B + \phi^0 - \gamma\Delta\phi)} - FC_A^1,$$

$$\Pi_A^{111} = \frac{2(A - 2c_A + 2\Delta c_A + c_B - \Delta c_B - \tau^1)^2}{9(2B + \phi^0 - \Delta\phi)} - FC_A^1.$$

If both airlines move simultaneously, they decide to invest only if they have sufficient merit from the investment based on the expected decision of the other airline. We look to the simplified case where the airlines are symmetrical so that $c_A = c_B$. Assuming the ANSP has adopted the new technology, we look to two cases: (i) if airline B has not invested – when is it a good idea for A to invest? And (ii) if B has already invested, when should A follow? Or stated differently when are the following statements true?

$$\text{(i)} \quad \Delta\Pi_A^{10} = \Pi_A^{110} - \Pi_A^{100} > 0$$

(16)

$$\text{(ii)} \quad \Delta\Pi_A^{11} = \Pi_A^{111} - \Pi_A^{101} > 0$$

The results hinges on the relatively importance of the reduction of operational costs and the network effects due to an increase of capacity. As was the case in the monopolistic set-up, for every impact on the congestion parameter ϕ, there is a corresponding reduction of the operation cost that will, for a given investment cost make the investment worthwhile. To illustrate this, we plot for a given investment cost and a given reduction in congestion, the corresponding operational cost reduction needed to ensure the airline A breaks even. We do this in the case where airline B is already using the new technology and when it does not. In Figure 15 we illustrate the case where $\gamma = 0.2$. This means that the benefit of both investing is larger than the sum of the individual benefits. The parameter values used are only for illustrative purposes and do not correspond to any technology.

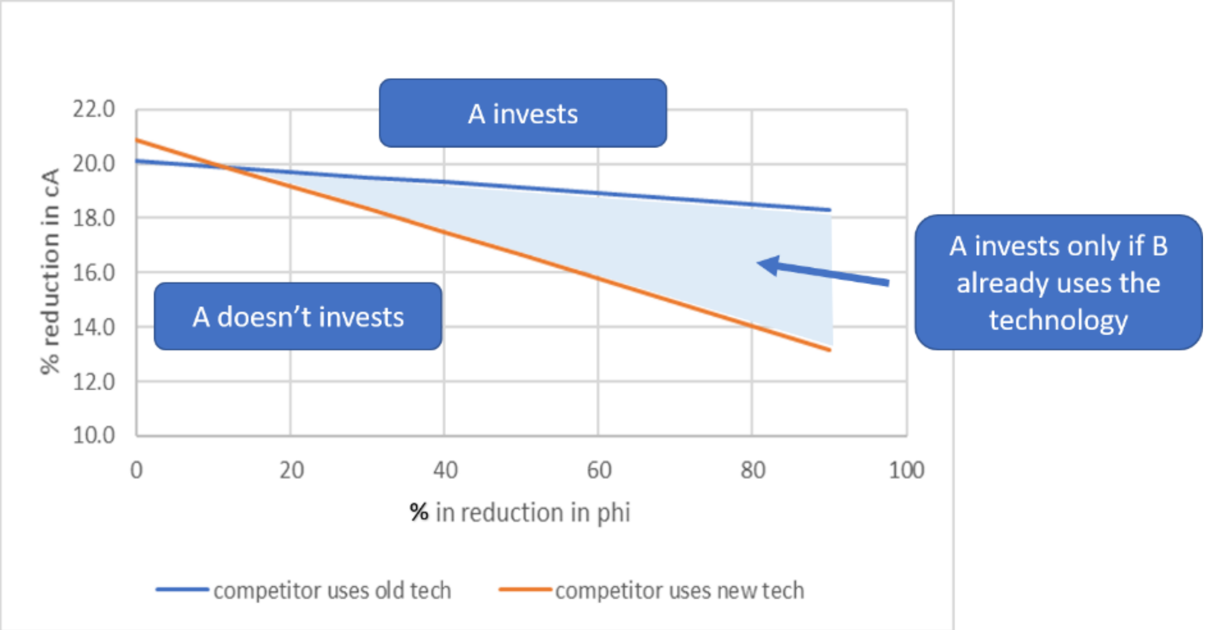


Figure 15: Investment decision for airline A depending on relative reduction of operational costs and congestion costs with strong network effects.

In this example, if the technology has a large impact on the capacity, airline A will be more likely to invest if its competitor uses the technology (it needs less compensation in the form of operational cost reduction to break even). For technologies that hardly have any impact on the capacity, the opposite is true.

The slope of the "isoprofits" depends on the strength of the network effect. Indeed, if we assume that the first airline to invest has a larger impact on the capacity than the second ($\gamma = 0.8$), we get a situation where airline A is more likely to invest when the competitor keeps the old technology as it can reap more of the benefits regardless of the decision of the other airline. This is illustrated in Figure 16.

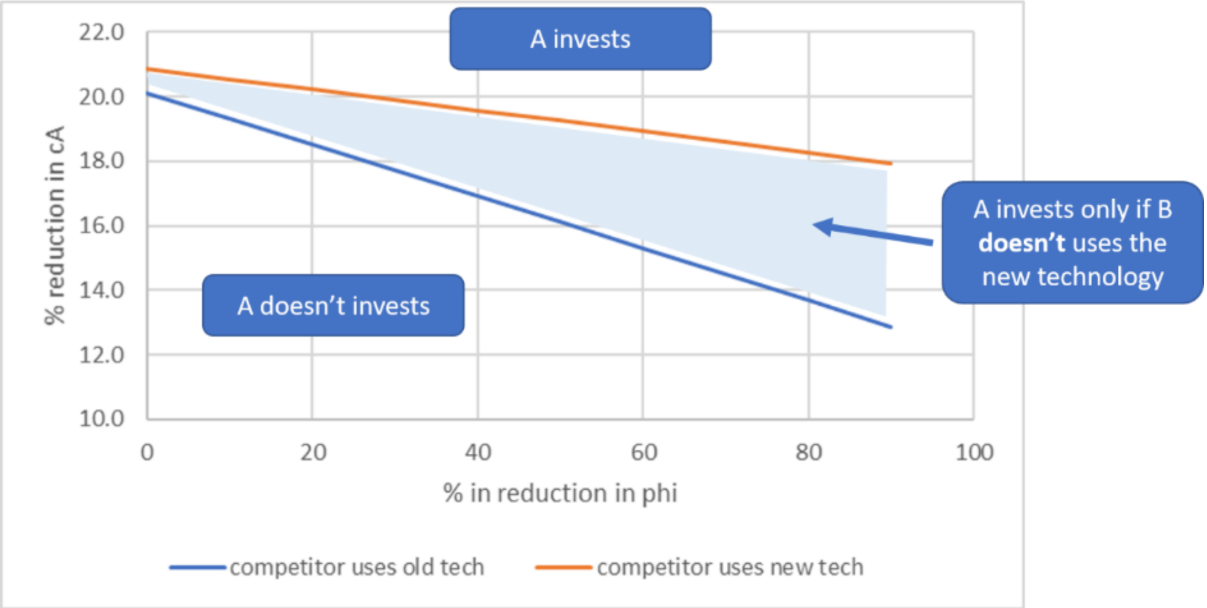


Figure 16: Investment decision for airline A depending on relative reduction of operational costs and congestion costs with little network effects.

This illustrates how the **incentives for the uptake of new technologies will be dependent on the characteristics of the technology itself**.

Compared to the monopolistic setting, airlines will not consider the full impact of the technology on the network delay cost, only the impact on their share of the market. This will limit the benefits of any technology whose benefits are mainly network based and have only limited benefits on the operational costs of the airlines. If the operational benefit or competitive benefit of the technology is large enough and outweighs possible network improvements, the uptake of the technology will be stimulated in a competitive environment compared to the monopolistic one. Vice versa: **if the benefit of the technology is strongly network based and only has a limited benefit on the operation cost of airlines, the uptake of the technology in a fractured and more competitive market may be hindered**. This is illustrated in Figure 17. We assume the investment cost to be higher for the monopolist than for the duopolist as it serves the whole market instead of only a fraction of it. The important feature here is the slope. A monopolist exhibits a steeper slope which implies that the more the technology has an impact on the capacity of the airspace, the more incline the monopolist will be to invest, i.e., needs less monetary compensation to break even.

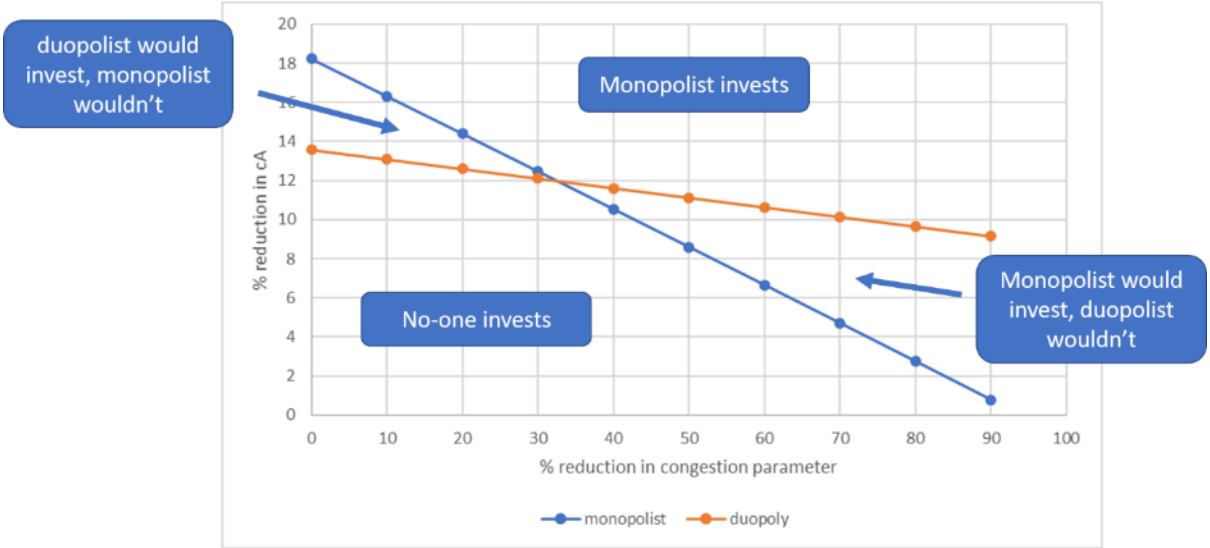


Figure 17: Investment decision of monopoly vs duopoly

One way to encourage the airlines to adopt the technology is to give them some form of compensation. This could be either a monetary compensation such as a reduction in the navigational charge, but it could also be in the form of a better service by given them priority over the airlines without the new technology.

What in the case of asymmetric airlines?

The model is essentially the same, but both operational and network level dynamics may be different for the two airlines. In the numerical analysis we distinguish a low-cost airline (LCC) and a legacy carrier (LC). In general, we expect relatively little difference between the symmetric case and the asymmetric case (legacy/low cost) except that **a legacy carrier will internalize more of the network delay cost** compared to a low-cost airline, as it behaves more monopolistically, has less flexibility to reroute and generally still has a large market share. This means that it **responds more to technologies that have an impact on congestion**. In addition, the **legacy carrier cares more for service cost than navigation fees set by the ANSP**. This means that it will be more responsive to 'best-equipped, best-served" policies by the ANSP. Since, the low-cost airlines generally do not own their fleet and invest less in staff training it could mean that retrofitting additional technology may be less obvious. On the other hand, **low-cost airlines will be more responsive if the technology leads to an obvious competitive advantage and reduced variable (also fuel) cost**.

3.5 More than one ANSP

3.5.1 Set-up of the model

Until now we have considered a single origin destination pair linked by a single arc that is controlled by a single ANSP. The European airspace is, however, very fragmented. It is very likely that airlines need to cross several airspaces controlled by different ANSPs or that they can choose between different routes. To study the interactions between ANSPs we focus on two very simplified networks. The first case is a parallel network consisting of two parallel links between a departure and arrival airport. Each link is controlled by a different ANSP. (e.g., airlines flying from London airport to South-Easter Europe have a choice between flying over Belgium (Belgocontrol) or the Netherlands (LVNL)). The second case is a serial network consisting of one link where the first part of the link is controlled by another ANSP than the last part.

In the parallel case the ANSPs will be in competition and the two routes are substitutes. This kind of network has been studied in [2]. It was shown that a price decrease on one route will lead to a price decrease on the other link. In terms of technology uptake, we will analyse whether ANSPs are now more willing to invest in new technology to be able to offer better service and increase the traffic in their airspace. We would also expect that if one of the ANSPs invest, this will force the other to decrease its prices.

We use a set-up that follows very closely the one used in [19]. The difference is that the users are non-atomistic, implying that each account for a non-negligible proportion of the total demand and thus enjoys some market power.

3.5.2 Parallel case with 1 airline and two ANSP

We consider one single OD and two routes connecting the origin and destination. The two routes cross two different airspaces (M and N), controlled by two different ANSPs. An airline deserving this origin destination pair can now choose between two routes. Air traffic in airspace $I = M, N$ is denoted by $q_{M,A}$ or $q_{N,A}$ and $q_A = q_{M,A} + q_{N,A}$. The two routes are perceived as perfect substitutes to the airline. We model the market for air transport in a similar way as previously with a linear demand like eq(5) and cost function. The total cost (TC_A) for any airline A using either route M and/or N is now the sum of the cost of using airspace M and N times the number of airkm flown in the airspace M or N respectively:

$$TC_A = (\tau_M + c_{M,A})q_{M,A} + + \frac{\phi_M}{2} q_{M,A}^2 + (\tau_N + c_{N,A})q_{N,A} + \frac{\phi_N}{2} q_{N,A}^2 \quad \textbf{(17)}$$

When deciding on its route, the transit airline will take the volumes of competitors as given. We need to make some market assumptions about the airline. **Suppose we have only one airline, which is in a monopoly position**. Working this case out is relatively simple. Let $\alpha_k = \alpha$ be the share of traffic that goes through airspace of ANSP N and $(1 - \alpha)$ the share through the airspace of ANSP M. For now, we will assume that $c_{A,M} = c_{A,N} = c_A^0$.

We have that:

$$\begin{aligned} \Pi_A = \Big(A - \alpha\big(c_{A,M} + \tau_M\big) + (1 - \alpha)\big(c_{A,N} + \tau_N\big)\Big)\, q_A \\ - 2(B + \alpha^2\phi_M + (1 - \alpha^2)\phi_N)q_A^2 \end{aligned} \quad \textbf{(18)}$$

The optimal amount of flight passenger kilometres produced by A is:

$$q_A^* = \frac{A - \alpha\big(c_{A,M} + \tau_M\big) - (1 - \alpha)\big(c_{A,N} + \tau_N\big)}{2B + \alpha\phi_M + (1 - \alpha)\phi_N} \quad \textbf{(19)}$$

3.5.3 Investment game with parallel ANSP

We can treat an investment game as an adaptation of the one we used in the previous section. As before we assume that the airline moves last. The ANSPs therefore bases its investment on whether the airline will invest or not. At the side of the ANSPs, we will assume they move simultaneously, so taking the behaviour of the other ANSP as given. This makes it easier to solve this relatively complex investment model.

The ANSP are assumed to control perfectly similar airspaces (equal in terms of complexity, size and length) a relaxation of this assumption is explored in the numerical exercise where one airspace is assumed to be more prone to congestion. The only element that can thus vary is whether the ANSP will invest or not.

We first solve for the decision of the airline in different cases. We adapt the expression from the section on a single ANSP and a monopoly airline and using superscript ($k = 0{,}1$) to indicate whether either ANSP M or N has invested in the technology.

$$\Delta\Pi_A = \frac{1}{2}\left(\frac{\left(A - \alpha\left(c_M^k + \tau_M^k\right) - (1-\alpha)\left(c_N^k + \tau_N^k\right)\right)^2}{2B + \alpha\phi_M^k + (1-\alpha)\phi_N^k} - \frac{\left(A - \alpha(c_M^0 + \tau_M^0) - (1-\alpha)(c_N^0 + \tau_N^0)\right)^2}{2B + \alpha\phi_M^0 + (1-\alpha)\phi_N^0}\right) - \Delta FC_A \tag{20}$$

For ANSP M we have (similar expression for N):

$$\Delta\Pi_M = \alpha^1 q_A^1\left(\tau_M^1 - c_{A,M}^1\right) - \alpha^0 q_A^0\left(\tau_M^0 - c_{A,M}^0\right) - \Delta FC_M \tag{21}$$

$$\Delta\Pi_N = (1-\alpha^1) q_A^1\left(\tau_M^1 - c_{A,M}^1\right) - (1-\alpha^0) q_A^0\left(\tau_M^0 - c_{A,M}^0\right) - \Delta FC_N \tag{22}$$

This model can be solved in a similar fashion as in the section above, by assigning probabilities that either no, one or both ANSP will invest, based on the uptake of the technology on the side of the airline.

There are two critical differences between the model presented here and the previous one. The first is that the **parallel routing reduces the incentive for the airline to invest**. This can be seen directly from the profit function. In this version of the game there is a possibility that only one ANSP will invest.

Suppose only ANSP M invests. When the airline uses the corridor of M, while investing in the new technology it will have an operational cost $c_M^1 < c_M^0$ and a benefit in the congestion cost $\phi_M^1 < \phi_M^0$. However, the **benefits of this investment are not fully attributed to this corridor in this case**. The **airline will use the airspace of M (increasing α), but only until the benefit of using this corridor** (lower operational cost, larger capacity) is **compensated by the higher cost** (increased navigation fee, increased congestion by increase in demand).

Let us assume that the impact on the share of airspace usage can be expressed in terms of α where we define the investment decision of ANSP M, N and A as $\alpha^{M,N}$ taking a value of 1 if an ANSP invests while also the airline A follows. The value α^0 is taken as the baseline and all cases where the airline A does not invest. In this case we have $\alpha^0 = \alpha^{11} < \alpha^{10} \leq 1$. Which means that **ANSP M may gain a competitive advantage when investing alone.**

For the airline however, **the benefit of investment will apply mainly to a certain percentage (say $\alpha^{0} < \alpha^{10} \leq 1$) when ANSP M chooses to invest alone. Possibly with some spill over of the congestion benefit to corridor N.**

We can thus conclude that the parallel case could reduce the incentive for airlines to invest, as they may only use the new technology on a part of their flying routes. From the ANSPs perspective, the decision to invest could give it a competitive advantage. As such the ANSP's incentives may not be the dominant hindrance.

3.5.4 Serial case with 1 airline and two ANSP

In the serial cast the airline needs to use a combination of both airspaces to get from origin to destination. This is critical difference. Let us retake the expression on the total cost of the airline and assume (like in the parallel case) that the airspace of each ANSP is equally large. We normalize the total distance travelled to 1, such that an airline travels half of the distance in each airspace. This gives:

$$\Pi_A = (A - Bq_A)q_A - \frac{1}{2}\left[(\tau_M + c_M)q_A + \frac{\phi_M}{2}(q_A)^2\right] - \frac{1}{2}\left[(\tau_N + c_N)q_A + \frac{\phi_N}{2}(q_A)^2\right] \quad \textbf{(23)}$$

Using similar techniques as in the previous section we can derive that:

The optimal amount of flight passenger kilometres produced by A is:

$$q_A^* = \frac{\left(A - \frac{\left(\tau_M + c_M^A + \tau_N + c_N^A\right)}{2}\right)}{\left(2B + \frac{(\phi_M + \phi_N)}{2}\right)} \quad \textbf{(24)}$$

3.5.5 Investment game with serial ANSP

Using the same reasoning as in the previous sections we can now also solve the investment game. Just as before we solve for a situation where ANSP M makes the decision to invest, independently from N. This decision, as before is **made based on the assumption that airline A will invest or not, given that M has invested.**

The impact on profits of airline A is:

$$\Delta\Pi_A = \frac{1}{2}\left(\frac{\left(A - \frac{1}{2}\left(c_M^k + \tau_M^k\right) - \frac{1}{2}\left(c_N^k + \tau_N^k\right)\right)^2}{2B + \frac{1}{2}\phi_M^k + \frac{1}{2}\phi_N^k} - \frac{\left(A - \frac{1}{2}(c_M^0 + \tau_M^0) + \frac{1}{2}(c_N^0 + \tau_N^0)\right)^2}{2B + \frac{1}{2}\phi_M^0 + \frac{1}{2}\phi_N^0}\right) - \Delta FC_A \quad \textbf{(25)}$$

For ANSP M counts that (similar expression for N).

$$\Delta\Pi_M = q_A^1\left(\tau_M^1 - c_{A,M}^1\right) - q_A^0\left(\tau_M^0 - c_{A,M}^0\right) - \Delta FC_M \quad \textbf{(26)}$$

As we can see this expression is very similar as the one of the parallel case but lacks a variable (α) as a means to divert traffic to another route.

Unlike in the parallel case, the decision of M to invest does not lead to a competitive advantage of $\boldsymbol{M}$ over $\boldsymbol{N}$. On the contrary. In the serial case, N may profit from an increase in flight kilometres (reduced cost on airspace M). This means that the ANSP that keeps using the old technology may 'freeride' on the investment of its competitor.

For the airline, compared to a situation **with a single ANSP the decision to invest or not, is still significantly reduced.** The reason is that the potential reduction in cost may only be realized for half of the territory used by the airline. The **main difference here is that there is no 'alternative route' available where the airline could avoid a possible increase in navigation fee after investment by ANSP M**. So, all air traffic will still need to go through M and then N to arrive at a destination.

In the serial case therefore, it is (under ceteris paribus conditions) more likely that the investment will happen than in the parallel case. This, however, depends on the parameters of the specific use cases and on the relative strength of a possible 'free-riding' effect for the non-investing ANSP in the serial network versus the possible competitive advantage in the parallel case (absent in the serial one).

3.5.6 Cases with multiple ANSP and airlines

These cases are not worked out theoretically in this document due to their complexity. We refer to the numerical analysis for final conclusions. We can however hint at a few conclusions based on the analysis above.

If two ANSPs on parallel routes are combined with a duopoly (or oligopoly) the **competitive advantage of an airline investing in new technology may be seriously diluted**. The reason is that the **non-investing airline may capitalize on a non-investing ANSP**. This creates a situation even worse than the case we considered above with only 1 airline operating on the airspace of two parallel ANSPs. Since gaining a competitive advantage (or avoiding one) is a serious element in the decision of the airline to invest or not, this may lead to a situation where no investments are made. So, a combined lack of interest by both airline and ANSP

In the case of serially linked ANSP, this problem may not occur, as the airline may still gain a competitive advantage on a part of the airspace (which the competition cannot avoid).

3.6 Numerical illustration

The aim of this section is to numerically illustrate the importance of the identified in the theoretical section. The numerical exercise performed here should not be viewed as a proper CBA of the technologies but as an illustration of the theory. The purpose is to gain insight into how the characteristics of ATM technologies might hinder the innovation in ATM provision. The focus lies in the comparison between the different set-ups rather than the absolute values of the obtained outputs.

3.6.1 Data inputs

To concentrate on the relation between ANSPs and airlines we make some simplifying assumption about the European airspace. We first assume that all ANSPs are fully integrated in one ANSP that controls the whole airspace. The total amount of flights controlled by this fictious ANSP is then 10.8 M flights with a total distance of 12,288 Mkm [54] (all data are on year basis). Using a load factor of 150 passengers per aircraft [2] this amounts to a total demand of 1,833,840 M passkm. For the price elasticity for air travel, a range of estimates have been estimated in the literature ranging between -0.6 and -2.34 [45] to be consistent with our demand and cost data we use an elasticity of -2.

Input	Amount	Unit
Passenger demand	1 833 840	M passkm
Average fare	120	Euro
Price elasticity	-2	
load factor	150	Pass/flight

Table 6: Demand parameter values

For the costs of the ANSP we use the Europe wide figures from [54]. These are summarised in the table below. We classified deprecation cost and cost of capital as fixed cost (1234 M euros). The variable costs consist of the staff and non-staff operating costs and the costs for exceptional items which amounts to 5360 M euros. The average navigational charge in Europe is equal to 0.64 euro/flightkm.

Input	Amount	Unit
ANSP Variable cost	5360	M euro
ANSP Fixed costs	1234	M euro
Average navigational charge	0.64	Euro/flightkm

Table 7: ANSP parameter values

In the first step of this illustration, we assume there is only one airline using the airspace. This is of course a radical simplification of reality. Our main objective is, however, to gain insight in the interaction between the ANSPs and the airlines and we will enrich this setting later. For the cases where two ANSPs are present, we adjust the parameter values so that congestion is kept equal in each of the ANSPs.

For the airlines we take figures used in [2] for the Cost per Available Seat Kilometre. In [2] they do not, however differentiate between variable and fixed costs which is needed in our setting. Based on the airline cost structure given in [CBA2018], we classify 60% of the total costs as variable. According to [54] [24], the total delay minutes in 2018 was 24.81 M minutes, using a cost per minute of 83.64 (own computations based on figures used in [2]) this amounts to a total delay cost of 2075 M euros.

Input	Amount	Unit
Airline Variable Cost	0.0468	Euro/pkm
Airline Fixed Cost	0.0312	Euro/pkm
Total Delay cost	2075	M euro

Table 8: Airline parameter values

When we consider the competition between Low-cost carriers and legacy carriers, we make some assumptions about the relative costs of the two types of carriers. The low-cost carriers (LCC), has a lower variable costs due to lower staff costs and higher load factors, and lower fixed costs due to a higher percentage of their fleet being leased. We assume a 25% reduction. Another distinction between low cost and legacy carriers is the fare they ask their passengers; we here assume that the legacy carrier is twice as expensive.

Outputs: consumer surplus and social welfare

In addition to the usual costs and benefits for the airlines and ANSPs we compute the consumer surplus and the social welfare to reflect the costs or benefits to the passengers and society. The consumer surplus is the difference between the price that the consumer actual pays and the price it is willing to pay and reflects the gain (or loss) of the passengers when airlines and/or ANSPs switches to the new technology. The social welfare is the sum of all the costs and benefits for all agents involved and is thus the sum of the profits of the airlines and the ANSPs and the consumer surplus.

Application 1: CPDLP

The first technology we focus on is CPDLP. The characteristic of the technology is that, if adopted by both the airline and the ANSP, it brings benefits to both parties by reducing the operational (or variable) costs and as it will increase the capacity of the airspace, there will be less congestions. Note that total delay costs could still increase due to an increase of overall traffic. As it is difficult to find accurate data about the exact costs and benefits of CPDLP we make some assumptions[6]. Fundamental to the model is that technology is such that the benefits are larger for the airlines compared to the benefits for the ANSP, while the ANSP incur a much larger investment cost. These are summarised in the table below.

[6] Based on experts' input.

Reduction in operational **costs for the airline**	-20%
Reduction in operational **costs for the ANSP**	-10%
Increase in capacity	+20%
Increase in fixed costs for the airlines	+1%
Increase in fixed costs for ANSPs	+10%

Table 9: impact of CPDLP on model parameters

Application 2: Remote Towers

The second application are the Remote Towers. Unlike the previous technology, this technology only requires an investment from the ANSPs, and the benefits are a reduction in operational cost for the ANSP. We will, however, assume that there is an indirect effect on the capacity of the ANSPs airspace due to the enhanced efficiency. The impact on the capacity will, however, be less pronounced than in the case of CPDLP. For the investment costs, the airlines have no investment costs, while the ANSPs' investment cost is assumed larger than the costs for CPDLP. Due to lack of available data, this should be taken as illustrative.

Reduction in variable costs for the airline	0%
Reduction in variable costs for the ANSP	-10%
Increase in capacity	+10%
Investment cost for airlines	0%
Investment cost for ANSP	+15%

Table 10: Impact of Remote Towers on model parameters

3.6.2 Application 1 CPDLP: Results

3.6.2.1 One ANSP and a monopolistic airline

A first result is that we see in the table below that the constraint on the navigation charge to just recover its costs gives the ANSP no incentive to make any investment as he cannot enjoy the benefits generated by these. **In all tables the lighter blue shade means that this actor does not invest, while the darker blue shade means that this actor invests.**

Invest?	AIR/ANSP	REF	YES/NO	NO/YES	YES/YES
	Demand [M pkm]	1 849 718	0.0%	0.0%	9.3%
Airline	Profits [M €]	42 643	-1.3%	-0.3%	43.3%
ANSP	Profits [M €]	0	0.0%	0%	-8.1%
Regulator	Welfare [M €]	287 323	-0.2%	0.0%	12.6%

Table 11: Impact of CPDLP with one Airline, one ANSP under cost recovery regulation

The impact of the current navigational charge is small compared to the variable costs of the airline. This implies that when the ANSP invests in the new technology and increases its charges this has little effect on the airline. Together with the relatively small investment costs for the airline, it would seem there is little risks for the airline not to invest even if it is not sure about the decision of the ANSP.

If the ANSP does choose to adopt the new technology, the airline would have a clear incentive to take advantage by investing in the technology itself as the benefits (decrease in operational and delay costs) can be substantial. The decrease in delay costs is less than the decrease in operational costs as the decrease in costs will generate additional traffic which annihilates some of the congestion reduction. But even then, the airline could potentially increase its profits. It is also clear that the overall welfare changes are positive when both parties adopt the new technology.

As previously mentioned, the cost recovery constraint is hindering the ANSP to make the decision to invest. For this reason, it is interesting to see what happens when this is relaxed. We will consider the case where the ANSP can set its fee 10% above the cost recovery charge (**relaxation price cap)** and increase with an additional 5% (**reward ANSP)** if it adopts the new technology. Results for this scenario as depicted in the Table 12.

Invest?	AIR/ANSP	REF	YES/NO	NO/YES	YES/YES
	Demand [M pkm]	1 832 780	0.0	-0.2	8.9
Airline	Profits [M €]	42 035	-1.4	-0.9	41.4
ANSP	Profits [M €]	599	0.0	39.9	173.3
Regulator	Welfare [M €]	285 522	-0.2	-0.2	12.4

Table 12: Impact of CPDLP with one airline and one ANSP with relaxed pricing rule

In this case we see that **if the ANSP can ask a higher charge, it will have an incentive to adopt the new technology** as the decrease in variable cost (see Table 22 Annex 2 for details[7]) and delay costs will

[7] The calibration of the demand, using the data found in the literature, yields slightly higher profit margins for the airlines than found in the literature (e.g. [43]). To achieve profit margins of 10%, we end up with different

allow more traffic to use its airspace and generate more income. **The airline would in this scenario also still be willing to invest as the increase in navigational charge is compensated by the reduction in delays and operational costs**. The potential benefits for the airlines are still substantial.

The regulator wishes to optimise the social welfare and the **best outcome will be achieved if both agents adopt the technology.** As already said, allowing the ANSP to be able to **charge above costs recovery charge** is one way to achieve this. If this is not feasible or acceptable, **subsidies** given to the ANSP in the case it invests could give the right incentives for the ANSP to invest. As these are a one-shot lump sum transfer whilst the higher charges would give the ANSP a steady stream of income, they would be less effective. Another possibility is to **impose a mandate on the ANSPs possibly together with some relaxation on the level of the navigational charges** to increase the probability of compliance. In this setting with a monopolistic airline, there is no need for any policy for the airlines to increase the incentives to invest as they are willing to do so without.

The setting of a monopolistic airline and ANSP is, however, very simplified. In the following sections we show how conclusions might alter when considering more complex and realistic settings.

3.6.2.2 One ANSP and two airlines (duopoly)

In our first generalisation of the model more than one airline uses the airspace of the ANSP. As detailed in the theoretical section, we assume that the airlines can be grouped in two categories (A= invest, B = does not invest) and that they act as a duopoly. At first, we consider the symmetric case, where both airlines are identical and thus share the market equally. After, we consider the case where one of the airlines has lower variable costs and is cheaper (LCC versus LC). The results for the symmetric case are depicted in the Table 13 (for more details see Table 23 in Annex 2).

Invest?	Air_A/Air_B/ANSP	N/N/N	Y/N/Y	N/N/Y	Y/Y/Y
Airline A	Demand	1 224 111	17.3	-0.2	8.9
	Profits	15 627	104.0	-1.0	49.5
Airline B	Demand	1 224 110	-8.6	-0.2	8.9
	Profits	15 627	-47.2	-1.0	49.5
ANSP	Profits	725	121.2	46.6	187.3
Regulator	Welfare	377 962	5.9	-0.1	11.5

Table 13: Impact of CPDLP with two airlines and one ANSP

From a social welfare point of view, the more parties that adopt the technology, the better. With a duopoly, total demand will be higher, and the profit margins of the airlines will be inferior to that of a

demand data. As, ultimately, it is the difference between the scenarios that interests us, this will not alter the overall conclusions, but some caution needs to be applied when interpreting the percentage changes.

monopolist. As for the incentives for the airlines to adopt the technology, the situation remains largely unchanged. According to our parameter values, they would both gain by using the new technology provided that the ANSP has done the necessary investments (in this symmetric setting, the benefits are shared equally among the two airlines if both invest). When one airline adopts the new technology, it will gain market share and the combination of an increase of revenues and a decrease of operational costs, means it will see its profits increase. Due to the increase in traffic, its delay costs will, however, remain similar. The competitor will be heavily penalised for keeping the old technology and will have a big incentive to make the switch himself. For the ANSP, with our assumptions, it will benefit from the technology even if the airlines do not adopt it. This is due to the increase in navigational charges we allow the ANSP to carry out. As the navigational charge is only a small percentage of the total operational costs of the airlines, the increase will not so much impact the total demand and the relatively small decrease in demand is largely compensated by the increase in the charge. This result might not hold if the ANSP cannot increase its charges as modelled. A result that remains is that the more airlines adopt the technology, the better for the ANSP.

Next, we allow the two airlines to differ and consider competition between a low-cost carrier and a legacy type of carrier. Summarised results are depicted in Table 14, detailed results can be found in Table 24 in Annex 2.

Invest?	Air_A/Air_B/ANSP	N/N/N	Y/N/Y	N/Y/Y	Y/Y/Y
Airline A (low cost)	Demand	1 532 984	12.6	-7.7	6.5
	Profits	14 907	88.2	-45.9	41.1
Airline B (legacy)	Demand	1 089 698	-5.9	14.6	7.4
	Profits	42 603	-14.3	33.7	16.8
ANSP	Profits	865	118.0	91.4	161.4
	Welfare	424 286	5.0	3.4	8.5

Table 14: Impact of CPDLP with LC vs LCC and one ANSP

From Table 14 we see that **both airlines will have an incentive to adopt the technology once the ANSP has.** The profits of both airlines have the potential to increase by 18-23%. The low-cost carrier will be more heavily penalised if it is the only one not adopting the technology. The reason why the gains are comparable is that the LCC, although it has less to gain from an investment as its variable cost are already lower (so proportionally its gain from the technology will be less important), it serves a larger market share and small changes will have more impact on the carrier. For the legacy carrier, the opposite is true; the technology will have more impact on the operational cost per passenger km, but as its market share is smaller the total impact turns out to be like those of the LCC. In terms of delay costs, the carrier adopting the new technology will proportionally gain less from the reduction. The reason is that the new technology, decreases its costs and increases its market share which will fill up the airspace capacity again. The competitor sees its market share decrease and thus its total delay costs (less passengers delayed), in addition in can free ride on the increased airspace capacity thanks to the investment of the competitor. This will compensate some of its revenue losses but in our setting, this is not enough to offset all of it and profits will decrease. The drop in profits of the airline that keep using the old technology should be enough for it to decide to follow suit, implying that it is enough for the ANSP to make sure one airline will invest, to make the investment worth.

A way to encourage one of the airlines to make the switch to the new technology could be to give them a reduction on the navigational charge if it uses the new technology, this is also known as **best-equipped-best-served charging regime.** If we apply this to our illustration, we see that this will have a larger effect on the LCC than for the LC. For the **LC it is not clear that this will make any big difference**. The reason is that the navigational charge is only a small fraction of the variable costs of the LC and a slight reduction will not make much of an impact.

3.6.2.3 Parallel network

Invest?	AirA/AirB/ANSP_M/ANSP_ N	N/N/N/N	Y/N/Y/N	Y/Y/Y/N	Y/Y/Y/Y
Airline A	Demand	1 221 879	15.2	7.1	8.9
	Profits	15 466	97.6	44.3	49.8
Airline B	Demand	1 221 878	-7.6	7.1	8.9
	Profits	15 466	-39.7	44.3	49.8
ANSP M	Profits	605	180.1	436.7	117.8
ANSP N	Profits	609	-51.1	-200.7	117.1
	Welfare	377 577	5.5	9.6	11.5

Table 15: impact of CPDLP with on parallel network

With the charging regime we consider, the ANSP can increase its profits substantially by adopting the technology and **risks to lose much of its profits if it does not, but its competitor does**. In this symmetric case, if they both use the new technology, profits are shared between them. In this symmetric case, not much changes for the airlines in the case both ANSPs have invested. When only one airline uses the technology, the incentives for the competitor to invest too is reduced compared to the duopoly using the airspace of one single ANSP. With this technology, the benefits for the airline using the technology are such that it will choose to use only the airspace of ANSPs that have invested, and we are thus in a corner solution (the reason is that the benefits of the reduction of operational costs outweigh the increase in congestion and navigational charges). The airline which has not invested will still use both but traffic in the airspace in an ANSP that uses the old technology will be reduced, leading to losses to this ANSP. The competition between the ANSPs will induce ANSP to follow the example of the ANSPs that uses the technology. **If, however, domestic traffic is more important than transit, the losses due to diverted traffic could be less severe**.

Reducing the charges to the airlines will increase profits margins for the airlines but to the detriment of the ANSPs. Giving a reduction to the airlines who can use the new technology, also known as **best-equipped-best-served charging**, will increase the profit margins of the airlines that have invested, while making the competition fiercer for those who did not. The impact of the navigational charge on the airline's profit remains, however, marginal. If airlines that have invested are charged the 'old' navigational charge, profit gains of around 0.2% can be expected with our data. This also assumes that the ANSP is allowed to charge above the cost recovery fee for the none complying airlines.

If the ANSPs do not belief that the airlines will carry out the investments needed they will play safe and prefer the status quo. This will be even more the case if there is a reluctance to change. We saw that the **best-equipped-best-served charging regime could help to increase the airlines incentives** although it is not clear whether this will always be enough.

We could ask ourselves what would happen **if one of the ANSPs has a less congested airspace or is able to handle more aircrafts**. In the next exercise we consider the case where in the reference situation where everyone still uses the old technology, the ANSPs delay costs are half of those of its competitor. The **main insights remain but the effects are more accentuated.**

Another asymmetry could occur when one ANSP charges lower navigational fees but with similar levels of congestion. The biggest difference will be the increase in profits for the ANSP that charges lower fees if it chooses to adopt the new technology and at least one airline does the same. The combination of lower fees and increased capacity will attract a lot of traffic to its airspace (up to 50%) and generate revenue. The delay costs, however become worse due to this increase in traffic. Only if both ANSPs invest can the delay costs be reduced. If the reduction of congestion is the focus of the regulator, having asymmetric charging (all other factors equal) is not a good strategy. The best-equipped-best-served charging regime will have similar effect. Note that these results do depend on the elasticity of demand and with more inelastic demands, the attraction of new demand could be less important.

3.6.2.4 Serial network

In this section we turn our attention to the case where airlines need to cross the airspace of two ANSPs consecutively.

Invest?	AirA/AirB/ANSP_M/ANSP_ N	N/N/N/N	Y/N/Y/N	Y/Y/Y/N	Y/Y/Y/Y
Airline A	Demand	1 176 685	17.9	9.0	18.1
	Profits	12 266	127.1	59.7	127.1
Airline B	Demand	1 176 687	-9.1	9.0	18.1
	Profits	12 266	-58.0	59.7	127.1
ANSP M	Profits	1 736	54.7	82.5	101.0
ANSP N	Profits	1 736	6.0	12.2	101.0
	Welfare	362 197	6.1	11.9	24.4

Table 16: Impact of CPDLP on serial network

In this situation we see that **the airlines have again a greater incentive to adopt the technology as they cannot divert their traffic** to counterbalance an increase in congestion in one of the airspaces. The main lesson here is that a **free riding problem** may occur in such a setting; **the ANSP that does not adopt the technology, will still profit from the investment of the other ANSP.** Although it can increase its profits by investing, it might choose not to and settle with a less pronounced increase of the profits. This could be the case if other factors come to play that are not modelled here, such as company culture or a reluctance to change.

A serial network setting will make investments less easy to implement although the welfare gains are more important and regulatory intervention will likely be necessary. The added difficulty with a serial network is that **all** ANSPs need to be given the right incentives.

3.6.3 Application 2 Remote Tower: Results

The results for the Remote Tower are summarised in Table 17 (for detailed results can be find in Annex 2).

Who invests?	Market structure	Change in Profits Airline A (%)	Airline B (%)	ANSP M (%)	ANSP N (%)
One Airline and One ANSP	**Monopoly**	-0.4	N/A	122	N/A
	Duopoly (symmetric)	-0.7	-0.7	89	N/A
	Parallel symmetric	-0.4	-0.4	50	4
	Serial	-0.9	-0.9	85	-0.2
All airlines only one ANSP	**Monopoly**	N/A	N/A	N/A	N/A
	Duopoly	N/A	N/A	N/A	N/A
	Parallel symmetric	-0.2	-0.2	87.6	-1.2
	Serial	-0.8	-0.8	130	-0.1
Everyone invests	**Monopoly**	-0.4	N/A	122	N/A
	Duopoly	-0.4	-0.4	140	N/A
	Parallel	-0.5	-0.5	85.8	85.8
	Serial	-1.5	-1.5	130	130

Table 17: Impact on demand and profits of the Remote Tower technology for various scenarios

Since the airlines do not get any benefits from this technology, it will only feel the impact of increased navigational charges, but these remain quite modest. The most interesting result here is the fact that now there is a **free-riding problem in the parallel network**. The reason is that as now the airlines do not enjoy any benefits from the technology, they will avoid the airspace of ANSPs that use Remote Towers, this increases the revenues of the competing ANSP. In the serial network, the opposite is true: if one ANSP invests, the total cost of the journey will increase for the airlines and demand will decrease. This will lead to a loss in revenues for the non-investing ANSP, while with the CPDLP technology he could free-ride on the investment of its competitor and reap the benefits of the increased demand. In this situation it is **important to give incentives to the airline to use the airspace of the ANSP that uses the new technology.** This could be in the form of subsidies or decreased charges.

3.7 Conclusions

The economic modelling started with a very simple case – one ANSP and one airline – and applied it to two technologies: CDPLP and Remote Towers. We added more complexity from there on and kept the examples of *CPDLP* and *Remote Towers*. However, the model could be applied to any (similar) technology.

In the case of **one ANSP and one airline** we see that the ANSP has no incentive to invest in any costly technology if it cannot charge a navigational charge above the pure cost recovery**. If it can charge a higher navigational charge** (+10% above the cost coverage), then it will have a clear incentive to invest. For technologies such as CDPLD the **airline will have enough incentives to follow**.

When there is **one ANSP and multiple airlines** there is **still an incentive for everyone** to adopt the new technology IF the ANSP is allowed to charge more than pure cost recovery. Under pure cost recovery there is no incentive for the ANSP to invest. A price cap is however still necessary. This result does not change in the asymmetric case with one low-cost carrier and one legacy carrier.

Next, we added a **simple network** – either parallel or serial. In the parallel network, airlines can choose between two routes, each controlled by a different ANSP. In the serial network, airlines need to cross two separate ANSPs to arrive at destination. In the **parallel network** the **incentives for the airlines are reduced** as both will reroute their traffic and in equilibrium the overall changes are smaller. The reason is that if ANSP 1 and airline 1 adopt the new technology, airline 1 will increase the number of flights using the ANSP 1's services to take advantage of the reduction in operational costs. This, however, increases the delay costs. The same happens for airline 2, that now avoids route 1 due to the higher delay costs and so increasing the congestion in that airspace. In equilibrium, both will more or less cancel each other out. **Reducing the charges** to the airlines will increase profits margins for the airlines but to the detriment of the ANSPs. Giving a reduction to the airlines who can use the new technology, also known as **best-equipped-best-served charging**, will increase the profit margins of the airlines that have invested, while making the competition fiercer for those who did not. The impact of the navigational charge on the airline's profit remains, however, marginal. **The competition between ANSPs will incite ANSPs to adopt the new technology as soon as another ANSP has done so** as otherwise transit traffic will divert their flying routes. **If domestic traffic is dominant this incentive might be less strong.** Asymmetric ANSPs do not change much the conclusions; it only makes effects larger/smaller. An additional problem occurs for technologies with little or no benefits to the airlines. In this case there can be some free riding on the side of non-investing ANSPs. As airlines cannot benefit from the technology, they will avoid the airspace of ANSPs that uses the new technologies due to increased charges to recover the investment costs (in the short run). A competing ANSP that holds on to the old technology is then able to benefit from the increased demand in its airspace. Although on the long run, the ANSP with the newer technology will be able to decrease charges thanks to the decreased operating costs, a short sighted ANSP might want to delay investments.

In the **serial network**, the **airlines again have an incentive to invest as they cannot divert their traffic**, but a **free riding effect** occurs as the ANSP that does not invest will not lose and will even gain very slightly. Although it can increase its profits by investing, it might choose not to and settle with a less pronounced increase of the profits. This could be the case if other factors come to play that are not modelled here, such as company culture or a reluctance to change. A serial network setting will make investments less easy to implement although the welfare gains are more important and regulatory intervention will likely be necessary. The added difficulty with a serial network is that all ANSPs need to be given the right incentives.

4 Towards policy instruments

4.1 Introduction

In this section we will use the conclusions of both the initial qualitative assessment and the economic modelling to define a set of promising policy and regulatory measures. This list of promising measures is evaluated using a qualitative multicriteria assessment including elements such as expected efficiency, effectiveness, acceptability, etc. Given these results, a selection will be further explored in more detail in subsequent stages of the project by means of agent-based simulations and gaming experiments.

4.2 Long list of policy instruments

In the table below we summarize the policy instruments which could be of interest to be investigated further. This table indicates the source (literature, stakeholder consultation or economic modelling), a short description of the policy measure and the issue it tries to solve. Some policy measures are discussed at several locations hence multiple ‘'sources” are possible. The policy options are listed from 'harder economic' policies to 'softer' policies.

Table 18: Long list policy measures

Source	**Policy measure**	**Related issue**
Case studies ATM Case studies other industries Economic modelling	*Direct subsidies for ANSPs (by preference conditional on implementation)*	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)
Case studies ATM Economic modelling	*Best equipped-Best Served/lower charged*	Overcome last-mover advantage for technologies with network effects and/or decreasing costs with scale
Case studies ATM Economic modelling	*Mandates (with strict and credible enforcement)*	Overcome current charging regulation which creates low incentives Overcome reluctance to change, opposition social partners,
Case studies other industries Economic modelling	*Flexible charge regulation, this means that – as in the illustration – the ANSP can recover its costs and*	Overcome current charging regulation which creates low incentives

	add a margin to its charge if it implements a certain technology.	
Case studies other industries	*Unbundling. This is removing all services from ATC which are not monopolistic in nature. Think for example of weather forecasts.*	Break up monopoly power by unbundling services which are not monopolistic in nature Could create more competition in service provision to ANSPs and hence driver for R&I Could lead to involvement of “"outsiders” which positively correlate with innovation Overcome need for tailored made solutions
Case studies other industries Stakeholder consultation	*Standardisation*	Overcome tailor made solutions Could increase competition if multiple suppliers possible Overcome safety concern
Case studies ATM Case studies other industries	*Regional forerunners*	Overcome network externalities Overcome fragmented network
Case studies ATM Case studies other industries Stakeholder consultation	*Phased approach/adaptive policy*	Break up large investment costs Overcome budget constraints Overcome inherent reluctance to change, opposition social partners, safety concerns Shorten strategy onlook time such that more in line with companies' investment timelines
Case studies ATM Stakeholder consultation	*Demonstration projects, Increased validation efforts, visualisation, dissemination*	Overcome inherent reluctance to change, opposition social partners, safety concerns Showing the benefits and hence decreasing uncertainty
Case studies ATM	*Realistic timelines, with this we mean that the timeframe to implement certain technologies should be set realistically instead of postponing deadlines as (unrealistic*	Overcome inherent reluctance to change, opposition social partners

	or overoptimistic) targets are not reached.	
Case studies ATM	*Coordination*	Overcome inherent reluctance to change, opposition social partners Decreasing uncertainty Overcome issue of large number of actors involved
Stakeholder consultation	*Increase matureness technologies*	Overcome gap between TRL4 and deployment Overcome reluctance to change Overcome human resource shortage at ANSPs
Stakeholder consultation	*Involvement of the safety agent in the research phase*	Overcome safety concerns
Stakeholder consultation	*Increase human resources at ANSPs*	Overcome lack of human resources (ATCOs and Tech)

4.3 Multi Criteria Analysis (MCA)

In practice a combination of different policy measures will be needed as there is not one policy measure which can tackle all potential problems for all technologies. In the table below we assess the policy measures listed above on their

1. Technological feasibility measured by
    a. Is the technology there to realise it? We could think of policy measures, such as competition between ANSPs on origin-destination level and hence within the same airspace, which are only possible if certain technologies are implemented.
    b. Time scale necessary for implementation of the policy
2. Economic feasibility
    a. Cost of introduction of policy implementation
    b. Efficiency, defined as increasing the likelihood of adopting 'a technology"
3. Regulatory feasibility, this is, how easy is the policy to be implemented
4. Acceptability
    a. By ATCO''s
    b. By ANSPs

c. By airlines

d. By Nations

5. Assessment possible in ABM (although we will also set the weight of this criteria at zero)

In the table below we score the different policies on these aspects (score between 1=positive and 4= negative; hence the lower the score the better). The scoring is based on the case studies, the stakeholder consultation, the economic modelling, and expert judgement (eg., for criteria 5)

Table 19: Scoring policy measures on five different criteria

	Technical		**Economical**		**Reg**	**Acceptability**				**ABM**
Policy measure	**1a**	**1b**	**2a**	**2b**	**3**	**4a**	**4b**	**4c**	**4d**	**5**
Subsidies for ANSPs	1	2	3	1	1	1	1	2	3	1
Best equipped-Best Served/lower charged	2	2	1	2-3	1	1	1	2-3	1	1
Mandates (with strict enforcement)	1	2	3	1	2	2	3	3	1	1
Flexible charge regulation	1	1	1	1	1	1	1	2	1	1
Unbundling	1	2	2	2	2	2	3	1	3	2
Standardisation	2	2	2	2	2	3	3	2	2	2
Regional forerunners	3	3	2	2	3	3	3	1	3	2
Phased approach/adaptive policy	2	2	1	3	1	2	2	2	2	2
Demonstration projects, Increased validation efforts, visualisation, dissemination	1	1	2	3	1	1	1	1	2	2
Realistic timelines	1	1	1	2	2	1	1	1	2	4
Coordination	2	2	2	3	2	2	2	2	2	4
Increase matureness technologies	1	2	2	1	2	1	1	1	1	4
Involvement of the safety agent in the research phase	1	1	1	3	1	1	1	1	2	4
Increase human resources at ANSPs	2	2	2	2	2	1	1	3	2	3

The ranking of the policy measures depends on the weights which are given to the different criteria. Assuming a relatively even distribution where each criterion gets a weight of two and sub criteria are even divided (this is, acceptability by ANSP gets a weight of 0.5), we can make weighted averages from the scores. The best performing policy (this is, scoring 1 on all criteria) would get a score of 10, the worst 40. We find that the following policy measures get the best (= lowest) scores

- Flexible charging regulation
- Best equipped – best served
- Subsidies for ANPS
- Demonstration projects

The worst assessed policies in the MCA are

- Coordination
- Increase the matureness of technologies
- Regional forerunners.

The reason for the lower score of policies such as increased coordination and increased matureness is that they do not overcome some of the inherent problems governing the incentives for ANSPs to take up new technologies.

If all subcriteria get an equal weight, which means that acceptability gets the highest weight and regulatory feasibility and assessment using ABM get the lowest weight, the order changes. We now have

- Flexible charging regulation
- Best equipped-best served
- Demonstration projects
- Involvement of the safety agency
- Realistic timelines – this is probably most relevant in combination with a mandate, although mandates score very low with respect to acceptability.
- Subsidies for ANSPs

The worst assessed policies remain the same.

One could argue that criteria 5 should get a lower weight as the feasibility to model something via ABM should not limit the policy instruments which are of most interest. Using the first weighing but setting the weight for criteria 5 at zero does, however, makes that 'softer' policy measures such as 'involvement of the SA" or having "realistic timelines" and "increasing the matureness" receive a higher score.

4.4 Selection of policy instruments for further research

For the further assessment we propose to consider the measures which scored – overall – the best in the MCA (even when changing the weights). This means the following list of policies

- Flexible charging regulation
- Best equipped-best served
- Demonstration projects
- Involvement of the safety agency
- Realistic timelines
- Subsidies for ANSPs

In addition, even though scoring lower than the instruments above, we add the 'increasing maturity level technology" as this was deemed very important by the stakeholders and its lower score was mainly related to the feasibility of ABM.

5 Conclusions

Innovation is a complex phenomenon. It depends not only on the development of new technologies, but also on the **existence of regulation and institutions able to facilitate and foster the implementation** of such technologies. A sound understanding of the economical, behavioural, and societal factors that influence the uptake of new technologies in ATM is essential for shaping effective policies and regulations that aim a successful implementation of innovations.

The **SESAR ITACA project** investigates the technology uptake pace in the ATM system. We use a combination of methodologies: qualitative assessment, economic modelling, agent based modelling and serious games.

The goal of ITACA is to support policy making decisions aimed at accelerating the development, adoption, and deployment of new technologies in ATM. To achieve this general objective, **ITACA develops a new set of methodologies and tools** enabling the rigorous and comprehensive **assessment of policies and regulations** aimed at amplifying the uptake of new technologies within ATM. Within this first deliverable of the ITACA project we first take a step back. We assess qualitatively the main barriers and levers, how these can be linked to policy measures, and what is the acceptability and applicability of these measures. This is based on a review of literature and case studies of successful and unsuccessful experiences with the uptake of new technologies, interviews, and an online workshop. In the second part, we take a more quantitative approach with a theoretical analysis, which is illustrated with two numerical examples. The analysis uses elements of principal-agent modelling[8], game theory and transport economics.

More concretely, we focus within this Deliverable on three questions

1. **How is the interaction between the different stakeholders when considering the uptake of a new technology?**
2. **What are the main barriers and levers for the uptake of technologies within ATM (or even aviation)?**
3. **What are possible policy options to stimulate technology uptake in the ATM sector and what is their potential?**

The answers to these questions provide input for the Agent Based Modelling (ABM), the behavioural experiments and the case studies which will take place in the next stages of the ITACA project.

To answer the first question relating to the interaction between stakeholders when considering the uptake of a new technology, interviews were carried out with different types of stakeholders and an interactive workshop was organised. During the workshop a difference was made between an EC

[8] The Principal-Agent theory focusses on conflicts in priorities between a person or entity and the representative authorized to act on their behalf. The agent may act in a way that is contrary to the best interests of the principal.

mandate and a technology developed to overcome a local need. The resulting interlinkages and the potential issues are summarized in two diagrams (Figure 5 and Figure 6). Notwithstanding the particularities of the different stakeholders when deciding and deploying a solution, the main difference lie in the **role of the National Safety Agency (NSA)**. When there is an EC mandate the NSAs are involved since the beginning. In the case of addressing local needs, NSAs are not part of the process until the certification step which poses planning and resource issues on their side thus risking the proposed technology not meeting the security and compliance standards.

The last two questions were answered via the literature review, the interviews and the workshop and the development of an appropriate economic model.

Three examples of "ATM technologies" are discussed: *Datalink*, *ADS-B* and *Remote Towers*. These technologies all have in common that their implementation level differs across regions. This seems to indicate that the real issue is not the technology but that the **institutional framework, including regulation and policy measures, is more important**.

The most important barriers hindering the implementation of the technologies, were identified from the case studies (of ATM and of other industries) and through stakeholder consultation:

- Relatively high costs of investment of new technologies while budgets are constrained
- Principal agent problem: the main benefits are not for the actor who carries the highest investment costs.
- Last mover advantage: this occurs when the benefit of a technology depends on the number of users and/or if costs are expected to decrease with the number of users
- The involvement of different stakeholders, all with their own objective, including active social partners.
- A culture which is reluctant to change. This is related to the importance of the overall safety of the system and the difficulty of transition as the system needs to remain operable at all times
- Fragmentation of the market
- Unrealistic timelines combined with lack of strict enforcement creating a laissez-faire attitude
- Gap between research and development

On the solution side, within the stakeholder consultation, there is a strong agreement on the need **for better dissemination and demonstration of technologies**. In addition, **more incentives to invest** should be offered. Some flexibility within the pricing regulation – especially related **to performance-based pricing or performance-based services**- was also acceptable by the stakeholders. Monetary incentives such as **subsidies** could also help. Although **mandates** could overcome some of the barriers leading to slow implementation, the **appetite with the stakeholders was almost non-existent**. The main reasons for the reluctance towards this approach is that monitoring would be difficult (the monitoring is usually focussing on the fact whether the technology implemented or not than on whether the implementation had the desired effect) and practically not possible (as there are more than 130 solutions). In addition, the organisation mandating might not choose the most optimal solutions.

We develop a simple model to analyse the uptake of certain ATM-technologies based on the potential efficiency gains by both ANSP and airlines. We start from a simple set-up with a single ANSP and airline. We then enrich the model by allowing multiple types of airlines. This adds realism to the model as it introduces competition between airlines and allows us to gain insight in the difference in reaction of low-cost carriers (LCC) or legacy carriers (LC). In our last step we generalize the model even further considering two ANSPs, either in serial or in parallel connections on the same origin and destination. This is inspired by how transport network capacity decisions are reached. As the ANSPs will need to recuperate at least a part of the cost of the investment in new technologies, both the structure of the market and the possibility of an airline to reroute are considered in this model variant. Finally, we apply our model to two ATM technologies (Controller Pilot Data Link Communication (CPDLC) and Remote Towers) which exhibit different characteristics to illustrate how these affect the ease or difficulty to implement them.

The first insight from our analysis is that **regulation of navigation fees is necessary**, as without regulation the natural monopoly of ATM management would allow prohibitively large charges on airlines. On the other hand, too tight an enforcement of the fee may hinder any real investment in technology as the ANSP may not recover its investment cost. Regulation should therefore be tight, but not too tight to allow the ANSP to recover costs and make a small profit to allow for investment. This is very apparent in the one airline - one ANSP setting but remains true for the other settings. Whether the airline will be willing to adopt the new technology will depend on whether the benefits outweigh the costs.

The second insight is that the market uptake of new technologies that have strong network based and have a big impact on congestion or delay costs will be more probable in a one-to-one setting. A (close-to) monopolistic airline internalises the benefits of lower delay costs in the airspace, while the ANSP is more certain about the uptake of the airline and the potential efficiency benefits. This may explain why the uptake of CPDLP technologies in the Canadian airspace (which has a single ANSP and a more limited number of competing airlines) was more successful than in the EU or the US. Moreover, if the technology has a significant impact on the capacity of the airspace as soon as some airlines are equipped, the remaining airlines can free ride, reducing their incentive to adopt the technology too. **If the operational benefit or competitive benefit of the technology is large enough and outweighs possible network improvements, the uptake of the technology will be stimulated in a competitive environment compared to the monopolistic one**. This has implications when considering Low-cost carriers (LCC) and Legacy carriers (LC). As **a** legacy carrier will internalize more of the network delay cost compared to a low-cost airline, as it behaves more monopolistically, has less flexibility to reroute and generally still has a large market share. This means that it responds more to technologies that have an impact on congestion. In addition, the **legacy carrier** cares more for service cost than navigation fees set by the ANSP. This means that it will **be more responsive to 'best-equipped, best-served" policies** by the ANSP. Since, the low-cost airlines generally do not own their fleet and invest less in staff training it could mean that retrofitting additional technology may be less obvious. On the other hand**, low-cost airlines will be more responsive if the technology leads to an obvious competitive advantage and reduced variable (also fuel) cost.**

The third insight is that it is not clear if increased competition between ANSPs stimulates the uptake of new technologies or not for the ANSPs. A lot of different effects are at play here. First, for the airlines to enjoy the full benefits of their investment, both ANSPs need to use the technology. Indeed, if only one ANSP has adopted the technology the airline will increase the number of flights using this airspace but only until the benefit of using this corridor (lower operational cost, lower contestability) is compensated by the higher cost (increased navigation fee, increased congestion by increase in demand). It will, therefor still use the corridor which uses the old technology and as such the benefits will only apply to a share of its total flights. The fact that the **airline needs both ANSPs to use the new technology, increases the uncertainty and reduces its expected potential benefits of the technology making it less prone to make the investment**. The free riding effect highlighted in the setting with one ANSP, moreover remains. If the ANSPs do not belief that the airlines will carry out the investments needed they will play safe and prefer the status quo. Secondly, **for ANSPs that have a large proportion of transit traffic** (as opposed to domestic air traffic that cannot divert its flight routes to avoid the ANSPs airspace), if a competing ANSP adopts a new technology that has strong operational benefits to the airlines (as is the case for CPDLP), and many airlines choose to adopt the new technology this traffic is diverted implying considerable losses to the ANSP. In this case there is a **strong first mover advantage and the uptake of these technologies could be facilitated in a more competitive environment**. For **technologies with little or no benefits to the airlines** (e.g., Remote Towers), the opposite can occur there can be some **free riding on the side of non-investing ANSPs**. As airlines cannot benefit from the technology, they will avoid the airspace of ANSPs that uses the new technologies due to increase charges to recover the investment costs. A competing ANSP that holds on to the old technology will be able to benefit from the increased demand in its airspace. Although on the long run, the ANSP with the newer technology will be able to decrease charges thanks to the decreased operating costs, a short sighted ANSP might want to delay investments. **In a serial network one ANSP may free ride on the investment of another ANSP which reduces the eagerness to switch to new technologies**. This does not mean that pro-competitive policies on the side of ATM and airlines do not have other welfare benefits, but we find that in a more fractured market the investment incentives are reduced.

The fourth insight is that an overall technological mandate for a ‘proven’ technology can be a welfare improving solution. This reduces the uncertainty that would be caused by a market-led uptake of the technology in a fractured and competitive market.

Next, the results of the case studies, interviews and workshop, and the economic modelling were used to come to a selection of policy measures which would be of interest to invest further within the ITACA project. 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 resulted in this short list of policy measures shown in Table 20. **This set of promising policy and regulatory measures will be explored and assessed in more detail in subsequent stages of the ITACA project and is an important first step towards a faster uptake of ATM technologies.**

Table 20: Selected policy measures

Source	Policy measure	Related issue
Case studies ATM Case studies other industries Economic modelling	*Direct subsidies for ANSPs (by preference conditional on implementation)*	Overcome the discord between high costs and goal to lower ANSP charges Overcome strict budget constraints Overcome principle agent problem (main investor is not main beneficiary)
Case studies ATM Economic modelling	*Best equipped-Best Served/lower charged*	Overcome last-mover advantage for technologies with network effects and/or decreasing costs with scale
Case studies ATM Economic modelling	*Flexible charging*	Overcome last-mover advantage for technologies with network effects and/or decreasing costs with scale
Case studies ATM Stakeholder consultation	*Demonstration projects, Increased validation efforts, visualisation, dissemination*	Overcome inherent reluctance to change, opposition social partners, safety concerns Showing the benefits and hence decreasing uncertainty
Case studies ATM	*Realistic timelines, with this we mean that the timeframe to implement certain technologies should be set realistically instead of postponing deadlines as (unrealistic or overoptimistic) targets are not reached.*	Overcome inherent reluctance to change, opposition social partners
Stakeholder consultation	*Increase matureness technologies*[9]	Overcome gap between TRL4 and deployment Overcome reluctance to change Overcome human resource shortage at ANSPs
Stakeholder consultation	*Involvement of the safety agent in the research phase*	Overcome safety concerns

[9] Increasing maturity level technology" was added to the result of the MCA as this was deemed very important by the stakeholders and its lower score was mainly related to the feasibility of ABM as it is rather a policy goal than a policy instrument.

6 Reference and applicable documents

[1] ACCHANGE, https://www.tmleuven.be/en/project/acchange
[2] Adler N., Hanany E., Proost S., (2015), Managing change in European air traffic control provision, Proceedings of the 11the USA/Europe Air Traffic Management Research and Development Seminar, ATM 2015
[3] Adler, N., Delhaye, E., Kivel, A., Proost, S. (2020), Motivating air navigation service provider performance, Transportation Research Part A: Policy and Practice, Vol. 132, 1053-1069
[4] Arblaster, M. (2012), Comparing consultation on investment and technology decisions in air traffic management in Australia and the UK, Journal of Air Transport Management Vol. 22, 36-44
[5] Arblaster, M. (2018), Air Traffic Management: Economics, Regulation and Governance
[6] Arrow, K.J. (1962), Economic Welfare and the Allocation of Resources for Invention, Chapter in NBER (1962), The Rate and Direction of Inventive Activity: Economic and Social Factors http://www.nber.org/books/univ62-1
[7] Asaad, M., Zamora, R., Tjing Lie, T. (2020), Integration of Electric Vehicles in the Distribution Network: A Review of PV Based Electric Vehicle Modelling, Energies Vol 13, 4541
[8] Baruta, I. (2018), Disruptive Innovation in an Institutionalized Environment: Space-based ADS-B in the Air Traffic Management Industry, Transportation Research Procedia 35: 176-189
[9] Belleflamme, P. & M. Peitz, (2012), Industrial Organization: Markets and Strategies, Cambridge University Press.
[10] Berkeley, N. et al (2017), Assessing the transition towards Battery Electric Vehicles: A Multi-Level Perspective on drivers of, and barriers to, take up.
[11] Berkhout, A.J & P.A. van der Duin (2007), New ways of innovation; an application of the cyclic innovation model to the mobile phone industry, International Journal of Technology Management, Vol 40 (4)
[12] Blondiau T., Glazer A., Proost S., (2018), Air traffic control regulation with union bargaining in Europe, Economics of Transportation, Vol 13, 48-60 doi: 10.1016/j.ecotra.2017.12.002
[13] Brueckner, J. and K. Van Dender (2007), Atomistic Congestion Tolls at Concentrated Airports? Seeking A Unified View in the Internalization Debate, CESIFO Working Paper 2033, Category 1: Public Finance
[14] Commission Implementation Regulation (EU) No 716/2014
[15] Commission Staff Working Document (2018) on the ex-post evaluation of the SES Performance and Charging Schemes in Reference Period 1 and the first year of Reference Period 2.
[16] COMPAIR , https://www.compair-project.eu/
[17] Connor, P. & F-R Oscar (2019) Chapter 14 The socio-economic challenges of smart grids in Tascikaraoglu, A. & Erdinç, O (eds.), Pathways to a Smarter Power System, Elsevier
[18] Davies, G., Hardt, M., Kelly, F. (2004), Come the revolution – network dimensioning, service costing and pricing in a packet swithched environment, Telecommunication Policy 28, 391-412
[19] De Borger B., Dunkerley F. And Proost S. (2007), Strategic Investment and Pricing Decisions in a Congested Transport Corridor, Journal of Urban Economics, Vol 62(2), 294-316
[20] Delhaye, E; Blondiau, T; Proost, S; Adler, N; 2014. ACCHANGE: Building economic models for understanding ATC performance. SIDs 2014 - Proceedings of the SESAR Innovation Days; 2014
[21] Dempsey-Brench, Z. & N.Volta (2018), A Cost-Efficiency Analysis of European Air Navigation Service Providers, Transportation Research Part A: Policy and Practice, Vol. 111, 11-23

[22] Dhondt, S., Oprins, E, Zon,R; van der Plaat, A. (2021), Study on Air Traffic Controller (ATCO) and Engineering Staff (ATSEP) social issues and working conditions, Report for EC, DG Transport https://op.europa.eu/en/publication-detail/-/publication/4e578c40-8b8a-11eb-b85c-01aa75ed71a1

[23] Erenoglu, A.K, Erdinç, O. Tascikaraoglu, A. (2019) Chapter 1, History of Electricity in Tascikaraoglu, A. & Erdinç, O (eds.), Pathways to a Smarter Power System, Elsevier

[24] Eurocontrol (2018). Standard inputs for cost-benefit analysis.

[25] Eurocontrol, Regulation (EC) No 29/2009, slide shown in EASA (2017), Commission Regulation (EC) No 29/2009 – Data Link Services Exemptions, Version 1.3 and https://www.eurocontrol.int/sites/default/files/2019-05/skyway70.pdf

[26] Eurocontrol (2017), Regulation (EC) No 29/2009, slide shown in EASA (2017), Commission Regulation (EC) No 29/2009 – Data Link Services Exemptions, Version 1.3 and https://www.eurocontrol.int/sites/default/files/2019-05/skyway70.pdf

[27] Eurocontrol (2021), https://www.eurocontrol.int/function/datalink

[28] Eurocontrol (2021) https://ext.eurocontrol.int/WikiLink/images/b/b8/2020-12_DL_Status_December_2020.pdf

[29] European Alternative Fuels Observatory (2021), On the electrification path: Europe's progress towards clean transportation

[30] European Commission (2019), Replies of the Commission to the special report of the European Court of Auditors "The EU's Regulation for the modernisation of air traffic management has added value – but the funding was largely unnecessary, COM (2019) 306 Final.

[31] European Commission 2020, COM (2020)433, Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Progress report on implementation of the TEN-T network in 2016-2017.

[32] European Court of Auditors (2017) Single European Sky: a changed culture but not a single sky

[33] European Court of Auditors (2017), Special Report No13: "A single European rail traffic management system: will the political choice ever become reality?" pursuant to Article 287(4), second subparagraph, TFEU.

[34] European Court of Auditors (2019), Special Report: The EU's regulation for the modernisation of air traffic management has added value- but the funding was largely unnecessary,

[35] Florence School of Regulation Transport AREA, 2016

[36] Fransman, M. (2003) Evolution of the telecommunication industry into the internet age. Published in Madden,G., The International Handbook on Telecommunication Economics, Edward Elgar Publishing

[37] Glass V. et al (2018), Unbundling reliability: lessons from the telecom industry, The Electricity Journal 31, 1-7

[38] Goeree, J.K, Holt, Ch.A. and T. R. Palfrey, (2018), "Stochastic Game Theory for Social Science: A Primer on Quantal Response Equilibrium" in Handbook of Experimental Game Theory.

[39] Greene, D.L., Park, S., Liu, C. (2014) Analyzing the transition to electric drive vehicles in the US, Futures 58, 34-52

[40] https://www.ainonline.com/aviation-news/business-aviation/2019-03-12/flightaware-tracking-ads-b-out-compliance

[41] https://www.businessinsider.com/teslas-influence-on-the-auto-industry-2018-2?r=US&IR=T

[42] https://www.skybrary.aero/index.php/Remote_Tower_Service

[43] IAG, Leading Sustainable Aviation, Annual Report and account, 2019

[44] IATA (2007). Airline cost performance: IATA Economics Briefing N°5. Retrieved from: http://www.iata.org/whatwedo/Documents/economics/airline_cost_performance.pdf
[45] IATA (2007), Estimating Air Travel Demand Elasticities, Final Report
[46] IATA (2008). Air travel demand: IATA economic briefing N°9. Measuring the responsiveness of air travel demand to changes in prices and incomes.
[47] IFATCA (2021), Remote Towers, https://www.ifatca.org/remote-towers-guidance/ (last visited 30/03/2021)
[48] Larocche, F. & L. Guihéry (2013), European Rail Traffic Management System (ERTMS): Supporting competition on the European rail network, Paper written on behalf of Innosutra Consortium, EU FP7 Research ProgramMoshi and Mwakatumbula (2017)
[49] Maillé, P., Reichl, P. and B. Tuffin (2012), Competition among Telecommunication Providers in A.M Hadjiantonis and B. Stiller (Eds): Telecommunication Economics, LNCS, 179-187
[50] Martins, J. et al (2019) Chapter 4 Smart Meters and Advanced Metering Infrastructure in Tascikaraoglu, A. & Erdinç, O (eds.), Pathways to a Smarter Power System, Elsevier
[51] Moshi, G. and H.J. Mwakatumbula (2017), Effects of political stability and sector regulations on investments in African mobile markets
[52] NATS (2021) https://www.nats.aero/about-us/what-we-do/our-ownership-2014/ (last checked 30/03/2021)
[53] Papazoglou, M.E, Spanos, Y.E (2018) Bridging distant technological domains: A longitudinal study of the determinants of breadth of innovation diffusion, Research Policy 47, 1713-1728
[54] Performance Review Body (2018). ATM Cost-Effectiveness (ACE) 2018 Benchmarking Report
[55] Performance Review Commission (2012). Performance Review Report: An assessment of air traffic management in Europe during the calendar year 2011.
[56] Performance Review Committee. US / Europe comparisons of ATM operational and economic performance. Eurocontrol/FAA, 2013.
[57] Performance Review Unit of Eurocontrol. (2013). ATM cost-effectiveness 2011 Benchmarking Report with outlook 2012-2016.
[58] Poole, RW. (2014), Organization and Innovation in Air Traffic Control, HUDSON Institute, Policy Study 431
[59] PRB 2019 report https://ec.europa.eu/transport/sites/transport/files/amr-2019-main-report.pdf
[60] PWC & INECO (2020), Deployment of ERTMS on Core and Comprehensive networks: On-Board and Infrastructure deployment strategies, report for the European Commission, DG Move, Directorate B Unit C4.
[61] Raffarin M., Congestion in European Airspace: a pricing solution? Journal of Transport Economics and Policy, University of Bath, 2004, 38 (1), pp 109-125. Hal-01021572
[62] Rogers E.M. (2010), Diffusion of innovation, fourth edition, Simon & Schuster
[63] Rogers E.M. (1962), Diffusion of innovation, first edition, New York: Free Press of Glencoe OCLC 254636
[64] Roupas, P. (2008), Human and Organisational Factors Affecting Technology uptake by Industry, Innovation 10(1), 4-28, DOI: 10.5172/impp.453.10.1.4.
[65] Schuitemakers, K. & M. Rajabalinejad (2017), ERTMS Challenges for a Safe and Interoperable European Railway System, PESARO 2017: Seventh International Conference on Performance, Safety and Robustness in Complex Systems and Applications
[66] Schumpeter, J.A. (1943) Capitalism, Socialism and Democracy, London: Unwin.

[67] Sherry L. & Dohonue G., 2013. “A micro-Economic Model of Airline Choice of Airfare and Aircraft Size in the Presence of Changing Energy Costs.” Conference Paper, DOI: 10.2514/6.2013-4225

[68] Silva, H.E. & E. T. Verhoef, 2011. "Optimal Pricing of Flights and Passengers at Congested Airports: The Efficiency of Atomistic Charges," Tinbergen Institute Discussion Papers 11-179/3, Tinbergen Institute, revised 28 Mar 2013.

[69] Skyguide (2021), https://www.skyguide.ch/en/company/about-us/ (last checked 30/03/2021)

[70] Sovacool, B.K, Hirsh, R.F. (2008), Beyond batteries: An examination of the benefits and barriers to plug-in electric vehicles (PHEVs) and a vehicle-to-grid (V2G) transition, Energy Policy 37, 1095-1103

[71] Spinardi, G. (2014), Up in the air: Barriers to greener air traffic control and infrastructure lock-in in a complex socio-technical system

[72] Stone, M. (2015) The Evolution of the telecommunication industry – What can we learn from it. Opinion Piece, Journal of Direct, Data and Digital Marketing Practice, Vol 16, 157-165

[73] Tscherning, H. & J. Damsgaard (2008), Understanding the diffusion and adoption of telecommunication innovations: what we know and what we don’t know. IFIP International Federation for Information Processing , 287 , 39-60.

[74] Vasigh, B., Fleming, K., Tacker, T. (2013), Introduction to Air Transport Economics: from theory to application. Second Edition, Routledge

[75] Violin, A.; M. Labbe and Castellim “En route charges for ANSP revenue maximization”,...

[76] Wehrheim, D. et al (2020), How mixed ownership affects decision making in turbulent times: Evidence from the digital revolution in telecommunications, Journal of Corporate Finance 64, 101626

7 Annex 1

This annex includes the document used during the interview as guidance and to collect feedback from interviewees. The part III of the interview is carried out using a presentation to better show the business case and build the decision-making flows. We created four different business cases for different type of stakeholders (ANSPs, Industry, Airlines and Airports) with slight differences to emphasize their involvement during the research phase and the impact of the technology on their organisation once deployment phase.

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The categories of stakeholders that were represented in the interviews can be found in the following table:

ID	Category	Percentage of representation
01	ANSP	35%
02	AU	14%
03	Industry	14%
04	Airport	23%
05	Safety Agency	7%
06	NM	7%

Table 21 Percentage of representation by stakeholders in the interviews

8 Annex 2

A.1 Detailed results for CPDLP

In the tables below you can find the more detailed results; these include the change in demand, revenues, variable costs (sum of operational costs and navigational charges) and profits for the airlines and the change in revenues, variable costs, and profits for the ANSP. In addition, the change in overall welfare is given. The first column corresponds with the reference scenario, where none of the agents has invested in the technology.

In the tables the results for the situation where there is one ANSP controlling the whole of the European airspace and one airline using the airspace. The first column depicts the reference situation when all agents are using the old technology. In the second column we compare the reference scenario with the case where the airline has adopted the technology but not the ANSP (YES/NO). In the third column the airline does not adopt the technology, but the ANSP does (NO/YES). Finally, we look at the case where both the ANSP and the airline adopt the new technology (YES/YES) and again compare this with the reference scenario. Changes are depicted in percentage change with respect to the reference scenario.

Invest?	AIR/ANSP	REF (Meuro)	YES/NO (%)	NO/YES (%)	YES/YES (%)
Airline	Demand	1 832 780	0.0	-0.2	8.9
	Revenues	194 349	0.0	-0.1	4.1
	Variable Cost	93 105	0.0	0.2	-10.7
	Delay cost	2 073	0.0	-0.4	-5.1
	Profits	42 035	-1.4	-0.9	41.4
ANSP	Revenues	7 332	0.0	4.8	14.4
	Variable Cost	5 498	0.0	-0.2	-2.0
	Profits	599	0.0	39.9	173.3
	Welfare	285 522	-0.2	-0.2	12.4

Table 22: Impact of CPDLP with one airline and one ANSP

Invest?	Air_A/Air_B/ANSP	N/N/N (Meuro)	Y/N/Y (%)	N/N/Y (%)	Y/Y/Y (%)
Airline A	Demand	1 224 111	17.3	-0.2	8.9
	Revenues	108 024	13.2	0.0	1.1
	Variable Cost	61 940	-3.9	0.2	-10.8
	Delay cost	1 849	10.2	-0.4	-5.1
	Profits	15 627	104.0	-1.0	49.5
Airline B	Demand	1 224 110	-8.6	-0.2	8.9
	Revenues	108 024	-11.8	0.0	1.1
	Variable Cost	61 940	-8.3	0.2	-10.8
	Delay cost	1 849	-14.2	-0.4	-5.1
	Profits	15 627	-47.2	-1.0	49.5
ANSP	Revenues	9 304	9.6	4.8	14.4
	Variable Cost	7 345	-1.5	-0.2	-2.0
	Profits	725	121.2	46.6	187.3
	Welfare	377 962	5.9	-0.1	11.5

Table 23: Symmetric duopoly, one ANSP

Invest?	Air1/Air2/ANSP	N/N/N	Y/N/Y	N/Y/Y	Y/Y/Y
Airline 1	Demand	1 532 984	12.6	-7.7	6.5
(Low cost)	Revenues	90 114	10.9	-12.3	-0.3
	Variable Cost	53 654	-6.9	-7.2	-11.9
	Delay cost	2 481	6.3	-15.6	-8.9
	Profits	14 907	88.2	-45.9	41.1
Airline 2	Demand	1 089 698	-5.9	14.6	7.4
(legacy)	Revenues	128 112	-7.3	8.8	0.5
	Variable Cost	55 139	-5.5	-6.2	-12.0
	Delay cost	1 764	-11.1	4.7	-8.1
	Profits	42 603	-14.3	33.7	16.8
ANSP	Revenues	9 967	10.1	6.7	12.3
	Variable Cost	7 868	-1.7	-3.2	-3.8
	Profits	865	118.0	91.4	161.4
	Welfare	424 286	5.0	3.4	8.5

Table 24: Low cost versus Legacy carrier

Invest?	Air_A/Air_B/ANSP_M /ANSP_N	N/N/N/N (Meuro)	Y/N/Y/N (%)	Y/Y/Y/N (%)	Y/Y/Y/Y (%)
Airline A	Demand	1 221 879	15.2	7.1	8.9
	Revenues	107 988	11.7	1.0	1.2
	Variable Cost	62 071	-5.6	-12.2	-10.7
	Delay cost	1 843	37.9	83.5	-5.1
	Profits	15 466	97.6	44.3	49.8
Airline B	Demand	1 221 878	-7.6	7.1	8.9
	Revenues	107 988	-10.4	1.0	1.2
	Variable Cost	62 071	-7.5	-12.2	-10.7
	Delay cost	1 843	-23.0	83.5	-5.1
	Profits	15 466	-39.7	44.3	49.8
ANSP M	Demand	1 222 212	33.1	114.2	8.9
	Revenues	4 889	39.7	124.9	14.4
	Variable Cost	3 667	21.5	92.8	-2.0
	Delay	1 844	59.3	267.0	-5.1
	Profits	605	180.1	436.7	117.8
ANSP N	Demand	1 222 545	-25.4	-99.9	8.9
	Revenues	4 890	-25.4	-99.9	14.4
	Variable Cost	3 665	-25.5	-100.0	-2.0
	Delay	1 845	-44.4	-100.0	-5.1
	Profits	609	-51.1	-200.7	117.1
	Welfare	377 577	5.5	9.6	11.5

Table 25: Parallel network, symmetric case

Invest?	Air_A/Air_B/ANSP_M /ANSP_N	N/N/N/N (Meuro)	Y/N/Y/N (%)	Y/Y/Y/N (%)	Y/Y/Y/Y (%)
Airline A	Demand	1 230 455	16.5	8.2	8.8
	Revenues	108 136	12.7	1.0	1.0
	Variable Cost	62 507	-4.5	-11.3	-10.8
	Delay cost	1 246	23.6	40.3	-5.4
	Profits	15 775	100.9	46.9	48.8
Airline B	Demand	1 230 455	-8.3	8.2	8.8
	Revenues	108 136	-11.4	1.0	1.0
	Variable Cost	62 507	-8.2	-11.3	-10.8
	Delay cost	1 246	-17.8	40.3	-5.4
	Profits	15 775	-44.2	46.9	48.8
ANSP M	Demand	1 641 046	17.9	62.2	8.8
	Revenues	6 564	23.7	70.3	14.2
	Variable Cost	4 923	9.1	46.0	-2.1
	Delay	1 662	25.0	110.5	-5.4
	Profits	1 024	102.4	223.6	95.2
ANSP N	Demand	820 864	-23.4	-99.9	8.8
	Revenues	3 283	-23.4	-99.9	14.2
	Variable Cost	2 460	-23.4	-100.0	-2.1
	Delay	832	-41.3	-100.0	-5.4
	Profits	207	-92.7	-396.3	220.6
	Welfare	380 332	5.7	10.7	11.3

Table 26: Parallel network with ANSP M has larger capacity

Invest?	Air_A/Air_B/ANSP_M /ANSP_N	N/N/N/N (Meuro)	Y/N/Y/N (%)	Y/Y/Y/N (%)	Y/Y/Y/Y (%)
Airline A	Demand	1 176 685	17.9	9.0	18.1
	Revenues	107 064	14.0	1.7	2.1
	Variable Cost	64 482	-1.8	-9.2	-21.4
	Delay cost	1 709	16.9	7.0	11.5
	Profits	12 266	127.1	59.7	127.1
Airline B	Demand	1 176 687	-9.1	9.0	18.1
	Revenues	107 065	-12.1	1.7	2.1
	Variable Cost	64 482	-8.7	-9.2	-21.4
	Delay cost	1 709	-9.8	7.0	11.5
	Profits	12 266	-58.0	59.7	127.1
ANSP M	Demand	2 353 372	4.4	9.0	18.1
	Revenues	9 413	9.6	14.5	24.0
	Variable Cost	7 060	-7.4	-12.8	-5.5
	Delay	1 709	-1.9	-4.9	11.5
	Profits	1 736	78.7	126.9	149.0
ANSP N	Demand	2 353 372	4.4	9.0	18.1
	Revenues	9 413	4.4	9.0	24.0
	Variable Cost	7 060	4.4	9.0	-5.5
	Delay	1 709	9.0	18.8	11.5
	Profits	1 736	6.0	12.2	149.0
	Welfare	362 197	6.1	11.9	24.4

Table 27: Serial network

A.2 Detailed results for Remote Towers

In the tables below you can find the more detailed results; these include the change in demand, revenues, variable costs (sum of operational costs and navigational charges) and profits for the airlines and the change in revenues, variable costs, and profits for the ANSP. In addition, the change in overall welfare is given. The first column corresponds with the reference scenario, where none of the agents has invested in the technology.

In the tables the results for the situation where there is one ANSP controlling the whole of the European airspace and one airline using the airspace. The first column depicts the reference situation when all agents are using the old technology. In the second column we compare the reference scenario with the case where the airline has adopted the technology but not the ANSP (YES/NO). In the third column the airline does not adopt the technology, but the ANSP does (NO/YES). Finally, we look at the case where both the ANSP and the airline adopt the new technology (YES/YES) and again compare this with the reference scenario. Changes are depicted in percentage change with respect to the refence scenario.

Invest?	AIR/ANSP	REF (Meuro)	YES/NO (%)	NO/YES (%)	YES/YES (%)
Airline	Demand	1 832 780	0.0	-0.2	0.0
	Revenues	194 349	0.0	-0.1	0.0
	Variable Cost	93 105	0.0	0.2	0.4
	Delay cost	2 073	0.0	-0.4	-10.0
	Profits	42 035	0.0	-0.9	-0.4
ANSP	Revenues	7 332	0.0	4.8	5.0
	Variable Cost	5 498	0.0	-0.2	-10.0
	Profits	599	0.0	29.6	122.2
	Welfare	285 522	0.0	-0.2	0.2

Table 28: Impact of Remote Towers with one airline and one ANSP

Invest?	Air_A/Air_B/ANSP	N/N/N (Meuro)	Y/N/Y (%)	N/N/Y (%)	Y/Y/Y (%)
Airline A	Demand	1 224 111	-0.1	-0.2	0.0
	Revenues	108 024	0.0	0.0	0.0
	Variable Cost	61 940	0.3	0.2	0.4
	Delay cost	1 849	-5.1	-0.4	-9.9
	Profits	15 627	-0.7	-1.0	-0.4
Airline B	Demand	1 224 110	-0.1	-0.2	0.0
	Revenues	108 024	0.0	0.0	0.0
	Variable Cost	61 940	0.3	0.2	0.4
	Delay cost	1 849	-5.1	-0.4	-9.9
	Profits	15 627	-0.7	-1.0	-0.4
ANSP	Revenues	9 304	4.9	4.8	5.0
	Variable Cost	7 345	-5.1	-0.2	-10.0
	Profits	725	89.0	38.0	140.1
	Welfare	377 962	0.1	-0.1	0.3

Table 29: Symmetric duopoly, one ANSP

Invest?	Air1/Air2/ANSP	N/N/N	Y/N/Y	N/Y/Y	Y/Y/Y
Airline 1	Demand	1 532 984	-0.1	-0.1	0.1
(Low cost)	Revenues	90 114	0.0	0.0	0.1
	Variable Cost	53 654	0.5	0.5	0.7
	Delay cost	2 481	-5.1	-5.1	-9.8
	Profits	14 907	-1.0	-1.0	-0.3
Airline 2	Demand	1 089 698	0.0	0.0	0.0
(legacy)	Revenues	128 112	0.0	0.0	0.0
	Variable Cost	55 139	0.3	0.3	0.4
	Delay cost	1 764	-5.1	-5.1	-10.0
	Profits	42 603	-0.2	-0.2	-0.2
ANSP	Revenues	9 967	4.9	4.9	5.1
	Variable Cost	7 868	-5.9	-4.2	-9.9
	Profits	865	89.2	73.8	127.5
	Welfare	424 286	0.1	0.1	0.3

Table 30: Low cost versus Legacy carrier

Invest?	Air_A/Air_B/ANSP_M /ANSP_N	N/N/N/N (Meuro)	Y/N/Y/N (%)	Y/Y/Y/N (%)	Y/Y/Y/Y (%)
Airline A	Demand	1 221 879	0.0	0.0	0.0
	Revenues	107 988	0.0	0.0	0.0
	Variable Cost	62 071	0.2	0.2	0.4
	Delay cost	1 843	-2.4	-5.0	-10.0
	Profits	15 466	-0.4	-0.2	-0.5
Airline B	Demand	1 221 878	0.0	0.0	0.0
	Revenues	107 988	0.0	0.0	0.0
	Variable Cost	62 071	0.2	0.2	0.4
	Delay cost	1 843	-2.4	-5.0	-10.0
	Profits	15 466	-0.4	-0.2	-0.5
ANSP M	Demand	1 222 212	-2.0	0.6	0.0
	Revenues	4 889	2.9	5.7	5.0
	Variable Cost	3 667	-6.9	-9.4	-10.0
	Delay	1 844	-8.8	-8.9	-10.0
	Profits	605	49.9	87.6	85.8
ANSP N	Demand	1 222 545	1.9	-0.6	0.0
	Revenues	4 890	1.9	-0.6	5.0
	Variable Cost	3 665	1.9	-0.6	-10.0
	Delay	1 845	3.9	-1.2	-10.0
	Profits	609	3.9	-1.2	85.3
	Welfare	377 577	0.0	0.1	0.3

Table 31: Parallel network, symmetric case

Invest?	Air_A/Air_B/ANSP_M /ANSP_N	N/N/N/N (Meuro)	Y/N/Y/N (%)	Y/Y/Y/N (%)	Y/Y/Y/Y (%)
Airline A	Demand	1 230 455	-0.1	0.0	0.0
	Revenues	108 136	0.0	0.0	0.0
	Variable Cost	62 507	0.2	0.2	0.3
	Delay cost	1 246	-3.1	-6.6	-10.1
	Profits	15 775	-0.6	-0.4	-0.6
Airline B	Demand	1 230 455	-0.1	0.0	0.0
	Revenues	108 136	0.0	0.0	0.0
	Variable Cost	62 507	0.2	0.2	0.3
	Delay cost	1 246	-3.1	-6.6	-10.1
	Profits	15 775	-0.6	-0.4	-0.6
ANSP M	Demand	1 641 046	-2.8	-1.1	0.0
	Revenues	6 564	2.0	3.8	5.0
	Variable Cost	4 923	-7.7	-11.0	-10.0
	Delay	1 662	-10.3	-12.0	-10.1
	Profits	1 024	40.9	68.4	71.0
ANSP N	Demand	820 864	5.5	2.2	0.0
	Revenues	3 283	5.5	2.2	5.0
	Variable Cost	2 460	5.5	2.2	-10.0
	Delay	832	11.2	4.4	-10.1
	Profits	207	21.7	8.5	153.3
	Welfare	380 332	0.0	0.1	0.2

Table 32: Parallel network with ANSP M has larger capacity

Invest?	Air_A/Air_B/ANSP_M /ANSP_N	N/N/N/N (Meuro)	Y/N/Y/N (%)	Y/Y/Y/N (%)	Y/Y/Y/Y (%)
Airline A	Demand	1 185 719	-0.1	-0.1	-0.1
	Revenues	107 267	0.0	0.0	0.0
	Variable Cost	64 029	0.2	0.3	0.5
	Delay cost	1 735	-2.7	-5.1	-10.2
	Profits	12 896	-0.9	-0.8	-1.5
Airline B	Demand	1 185 720	-0.1	-0.1	-0.1
	Revenues	107 267	0.0	0.0	0.0
	Variable Cost	64 029	0.2	0.3	0.5
	Delay cost	1 735	-2.7	-5.1	-10.2
	Profits	12 896	-0.9	-0.8	-1.5
ANSP M	Demand	2 371 439	-0.1	-0.1	-0.1
	Revenues	8 537	4.9	4.9	4.9
	Variable Cost	7 114	-5.1	-10.1	-10.1
	Delay	1 735	-5.2	-10.1	-10.2
	Profits	806	85.3	129.6	129.3
ANSP N	Demand	2 371 439	-0.1	-0.1	-0.1
	Revenues	8 537	-0.1	-0.1	4.9
	Variable Cost	7 114	-0.1	-0.1	-10.1
	Delay	1 735	-0.2	-0.1	-10.2
	Profits	806	-0.2	-0.1	129.3
	Welfare	363 852	0.0	0.2	0.4

Table 33: Serial network