ITACA

Incentivising Technology Adoption for Accelerating Change in ATM

State-of-the-art and Future Challenges

May 2021

NOMMON

CRIDA I+D+i - ATM

KTH VETENSKAP OCH KONST

TRANSPORT & MOBILITY LEUVEN

Contents

Executive summary

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 Air Traffic Management (ATM) is essential for shaping effective policies and regulations that aim a successful implementation of innovations.

This white paper presents an overview of the current status of the SESAR ITACA project. In this project we investigate 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 ultimate goal of ITACA is to support policy making decisions aimed at accelerating the development, adoption and deployment of new technologies in ATM. In order to achieve this general objective, **ITACA will develop 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. The specific objectives of the project are the following:

1. Identify the main drivers and barriers for technological change in ATM and devise a set of policy measures and regulatory changes.
2. Develop an agent-based model of the technology deployment cycle.
3. Validate the behavioural assumptions of the agent-based model through a set of participatory simulation experiments involving the direct participation of ATM stakeholders.
4. Demonstrate and evaluate the potential of the newly developed methods and tools through a set of policy assessment exercises.
5. Consolidate the methods, tools and lessons learnt delivered by the project into a coherent policy assessment framework and a set of policy recommendations.

1. Introduction

There is the concern that the decrement of revenues in the airspace sector due to the current COVID-19 crisis situation may slow down the already slow pace of the urgently needed adoption of technologies in the sector. However, there are also some voices stating that the crisis is an opportunity to implement the solutions (e.g., automation, virtualisation and trajectory-based operations) that have been proven to be able to make ATM more resilient to disruptions, by building in flexibility to shift capacity in line with demand, rather than managing demand to fit available capacity (SESAR JU, 2021).

Nevertheless, air traffic will resume in the end and new market entrants (e.g., Urban Air Mobility) will rapidly take the ATM system to its limits, calling for disruptive solutions able to boost the performance of ATM operations. Emerging technologies, especially digitalisation and automation, have the potential to facilitate this urgently needed technological upgrade. However, **technology evolution is a necessary but not sufficient condition**. Innovation is a complex phenomenon, which depends not only on the development of new technologies, but also on the **existence of regulation and institutions able to facilitate and foster their implementation**.

The need for both regulatory and technological developments that lead to the modernisation of the ATM system has since long been recognised by the European Commission. It is at the origin of the coordinated launch of the Single European Sky (SES) initiative and its technological pillar, SESAR. However, despite all the efforts undertaken under both initiatives, **the results have not lived up to the expectations**. The European Court of Auditors (2017), in its special report “Single European Sky: a changed culture but not a single sky”, acknowledged that the SES initiative addressed a clear need and has led to a greater culture of efficiency in ATM. But also concluded that the SES has failed in achieving the expected performance targets and recommended analysing a variety of alternative policy options. In its reply to the report, the European Commission (2019) 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 R&I lifecycle emerge as critical needs. ITACA aims to address these needs.

This document will introduce the state-of-the-art in technology adoption in Section 2, Agent-Based Models for the analysis of technology adoption in Section 3 and the use of gaming experiments for ABM calibration in Section 4. Finally, Section 5 describes our vision on how to assess new policy measures aimed at increasing the pace of technology adoption in ATM, i.e., the ITACA project.

2. Innovation and technology adoption and diffusion

Economic research focusing on ATM is not abundant. Even less research has investigated the drivers behind the uptake of ATM technologies. Technology uptake is researched from the perspectives of sociology, industrial economics (Belleflamme & Peitz, 2012) and organisation and management sciences. This research consists of empirical assessments of technology uptake and diffusion (using econometrics), economic models, game-theory and descriptive analyses discussing the uptake of different technologies in different industries. For example, Maillé (2012) analyses the pricing and the technology investments by telecom providers using a game theoretical model while Moshi and Mwakatumbula (2017) empirically estimated the determinants of investments in mobile markets in Africa. Tscerning & Dansgaard (2008) 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 Schumpeter (1943) and Arrow (1962). They focused on the relationship between market structure and the incentives for Research & Development. 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 of particular relevance for ATM, with ANSPs being **monopolistic by nature** and an aviation market working in a very competitive environment.

Research focussing on ATM 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 (www.compair-project.eu) focused on the introduction of some forms of competition as the solution to encourage ANSPs take up of technologies. The project examined different options: performance regulation with variations in ownership and governance models, unbundling, tender of licenses for en-route air traffic services and flight centric, sector-less operations. It found out that the first one could be a candidate for implementation in the short-term, while the rest present institutional or technological barriers and would only be a candidate for medium- or long-term implementation. Baruta (2018) focuses on the institutional framework influencing the uptake of space-based ADS-B. This 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). Based on that, it provides recommendations on how to overcome the institutional barriers such as to promote the commercialisation of ANSPs, to achieve a more flexible regulatory framework or to foster competition. The work of Papazoglou (2018) 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 will 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. Arblaster (2012) 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 disruptions in the system are not possible.

Hence, there is not a single reason for the slow uptake of technologies within ATM, but a combination of different, interactive factors.

3. Agent-Based Modelling and technology adoption

Traditional models of innovation diffusion, such as the Bass model (1969), represent aggregated trends rather than individual decisions. These models are helpful to understand innovation diffusion, but they are not designed to answer what-if type questions. They also do not explicitly consider the variety of agents and the complex dynamics of the social processes that shape technology adoption. In addition, aggregated models are usually criticised for a lack of explanatory power, as they are not behaviourally based. To overcome these limitations, in recent years Agent-Based Modelling (ABM) has been increasingly adopted for the modelling of technology adoption and diffusion processes in different sectors, helping understand aspects such as the **role of network topologies, strong and weak ties, and network externalities** (Kiesling et al., 2012). The perspective of ABM is accompanied by the attempt to represent actors of economic systems in a more realistic fashion, where deviations from the assumed theoretical behaviour play an outstanding role. The inclusion of **Behavioural Economics** principles allows for **normative understanding, qualitative insights and theory generation** (Mueller, 2016).

ABM has been used, for example, to simulate the diffusion of agricultural innovations and water resource use in Chile and assess policy options in the context of the Mercosur agreement (Berger, 2001; Berger et al., 2007). In the transport sector, Zhang et al. (2011) investigated the factors that can speed up the diffusion of hybrid and electric vehicles in the US. Günther et al. (2011) simulated the diffusion of a second-generation biomass fuel in the Austrian market. Dugundji and Gulyás (2008) studied the effects of households' heterogeneity and interactions in the adoption of various transport modes. Innovations in energy and water consumption have been also investigated using ABM: Schwarz and Ernst (2009) modelled different types of households to simulate the diffusion of water-saving innovations in Southern Germany. Faber et al. (2010) studied the adoption of micro combined heat and power (micro-CHP) systems in the Netherlands. Rai and Robinson (2015) developed a model to study the adoption of residential solar photovoltaic.

In the field of aviation, ABM has been used in a number of research projects to better capture the mechanisms underlying the relationships between different stakeholders. The example most directly related to the research proposed in ITACA is that of the SESAR ER COMPAIR project (www.compair-project.eu), which developed an agent-based model to analyse the introduction of competition in the ATM market through the tendering of licenses to operate en-route air navigation services, explicitly modelling ANSPs' decisions to invest in new technologies, as part of their strategy to compete in a liberalised market (Torres et al., 2017).

4. Combination of ABM and gaming experiments

The validation of agent-based models implies assessing the extent to which the model, from assumptions to results, is capable of approximating reality. To this end, different methods have been proposed, but yet no widely accepted procedure has emerged (Le Pira et al., 2017). Gaming methods have been suggested as a way of validating agent-based models, but relatively little work has been done on actually implementing a useful combination in a rigorous way. The CIRAD institute (www.cirad.fr/en) has a long history of creating agent-based models for use within games and participatory simulations in management of natural resources, particularly in rural areas. In the Japanese community, the people around Arai and Degushi have developed hybrid games with agents and humans in meaningful social interaction (Arai et al., 2006). In the social simulation community, there have been attempts to validate ABM with games, and in the behavioural economics field the use of game-like experiments and parallel ABM is also well noted.

Significantly less work has been done to address the complexity of policy making processes. The many dimensions at hand cannot all be modelled through ABM due to reasons of dimensionality and to the fact that certain factors might be unknown to the modellers but emergent at play. Tykhonov et al. (2008) studied the cultural dimensions of trade interactions in supply chains. In their model, the behavioural dimensions that were theoretically known were modelled, and in terms of logic, actions and pay-off structures, an economically rational behaving human was assumed. Then the model was enriched with value-sensitive parameters, for which very simple interactions were formulated. These parameters were analogous to the game options in the human simulations, so that the ABM and game sessions were comparable from the overall output. What was not done in their work was to create ABM and games through which the trajectory of the human decision-making could be captured. This problem is addressed by Anand et al. (2016) for model validation purposes, and by Flötteröd and Meijer (2012) for the purpose of maximising the human experience in a dynamic game. What has not been done so far is to explicitly model the technological dimensions of policy options into an agent-based model and into a game that has structurally the same concept. This to compare the higher-ordering reasoning of stakeholders on technology options with the parameter configurations of the model.

Within ATM, the PACAS project (www.sesarju.eu/projects/pacas) built a model language and an agent-based model of ATM stakeholders, with a gamification layer added. But this has lacked play in which the behaviour of the players is considered a valid part of the simulation model, and therefore the rigour to be able to base policy options on it.

5. The ITACA project

ITACA (www.itaca-h2020.eu) is a research project within SESAR Exploratory Research. It aims to shed light on the drivers and barriers for the adoption of new technologies in ATM. The ultimate goal is to support the identification, formulation and implementation of policies and regulations that accelerate ATM modernisation. To this end, the project brings together the wide body of theory on technology adoption developed in the field of industrial organisation with the state-of-the-art in computational behavioural economics and participatory simulation. This combination provides a rich, multifaceted analysis, able to capture the complexity of the ATM R&D lifecycle.

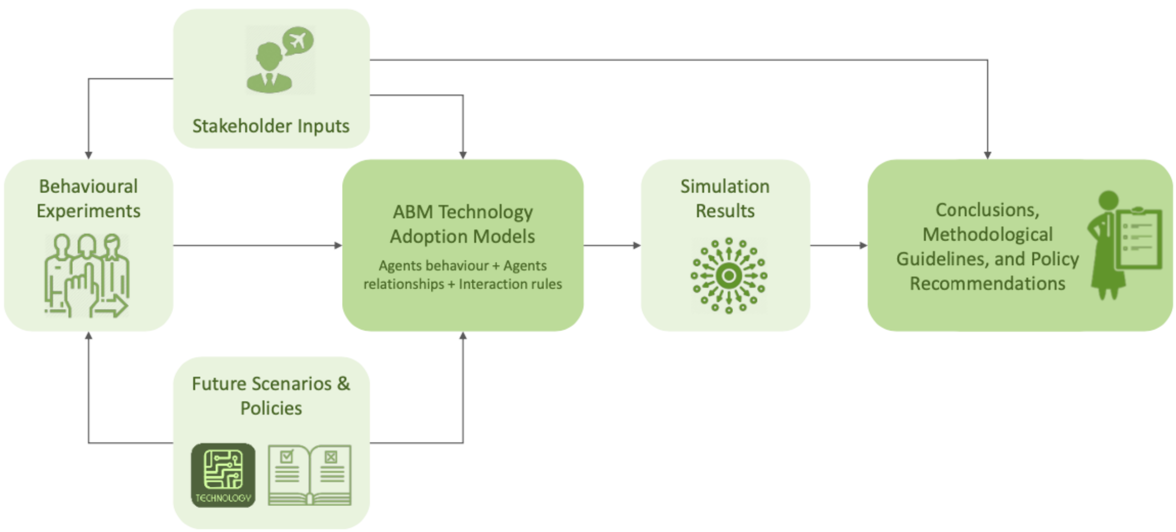

Figure 1. Overall project concept

5.1 Project objectives

The ultimate goal of the project is to accelerate the development, adoption and deployment of new technologies in ATM. In order to achieve this general objective, ITACA will develop 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.

The specific objectives of the project are the following:

1. Identify the main drivers and barriers for technological change in ATM and devise a set of policy measures and regulatory changes.
2. Develop an agent-based model of the technology deployment cycle.
3. Validate the behavioural assumptions of the agent-based model through a set of participatory simulation experiments involving the direct participation of ATM stakeholders.
4. Demonstrate and evaluate the potential of the newly developed methods and tools through a set of policy assessment exercises.
5. Consolidate the methods, tools and lessons learnt delivered by the project into a coherent policy assessment framework and a set of policy recommendations.

5.2 Approach

The project follows 5 main stages: (i) identification of levers and barriers, (ii) ABM of ATM technology adoption, (iii) behavioural experiments, (iv) policy assessment case studies and (v) guidelines and recommendations. Each of the beforementioned steps are interconnected as illustrated in **Figure 1**, noting that both the creation of the case studies and the gathering of simulation results are included in the policy assessment step. All of them are described as follows:

Identification of levers and barriers

The first stage of the ITACA research methodology deals with the analysis of the main levers and barriers for the adoption of new technologies by the different ATM stakeholders. On one side, a qualitative assessment, based on a review of literature, case studies of successful and unsuccessful experiences related to the uptake of new technologies, was employed. Interviews with different stakeholders and a consultation workshop have been used to identify potential explanatory factors. Additionally, we make use of economic models within the field of industrial organization as a first quantitative assessment. The output of both the qualitative and quantitative analyses have been used to define a set of promising policy and regulatory measures, as described in ITACA's public deliverable D2.1 Levers and Barriers for the Adoption of New Technologies in ATM: Policy Approaches.

Agent-based model of ATM technology adoption

The analysis conducted in the previous stage serves as a starting point for the development of an ABM of the ATM technology deployment cycle. Agent-based modelling offers several features that make it particularly interesting for the study of innovation processes, such as the possibility to model agents' heterogeneity, the explicit representation of the agents' interactions, the possibility to endow the agents with non-rational behaviours and behavioural biases (e.g., loss aversion), and the ability to model learning processes, evolutionary behaviour and path dependence. Once the different model components are implemented, the agents´ behavioural rules will be refined and validated based on the results of the behavioural experiments.

Behavioural experiments

Within the project, relevant representatives from ATM stakeholders are asked to take over the decision-making roles of certain agents in the agent-based model. This will be designed as a playful interaction in which the participants are allowed to explain choices and their consequences, and also to reason about the real-world complexity around their choices. This phase will result in calibrated and validated models.

At a second level, we organise group sessions in which stakeholders can play with the model configurations to jointly determine the system-level validity and policy consequences of the work developed.

Policy assessment case studies

The ABM developed is then used to simulate the policies and regulatory changes proposed during the first stage of the project. A set of case studies will be defined including different policy measures or different scenarios. A variety of key performance indicators will be computed and analysed: pace of technology adoption, disaggregated distributional effects of different stakeholders or the aggregated social welfare among others.

Guidelines and recommendations

Finally, the conclusions extracted from the case studies will be consolidated into a set of lessons learnt, guidelines and recommendations, at two levels: on a policy level, we will derive recommendations extracted from the simulation experiments; and on a methodological level, we will discuss the strengths and limitations of the tools and methods carried out in the project and derive guidelines for the future maintenance, evolution and use of the ITACA policy assessment framework.

5.3 Progress beyond the State of the Art

ITACA will advance the state-of-the-art in ATM economics by delivering an **enhanced assessment of technology adoption processes**. Unlike existing descriptive work, we go beyond the measurement of technology uptake and study the **underlying drivers and mechanisms of technology adoption and diffusion in ATM**. To achieve the goals of the project, ITACA builds on two main methodological developments that also constitute, in themselves, an advance with respect to the state-of-the-art:

1. **Integrated modelling of stakeholder decision-making processes**. ITACA economic models will integrate the objectives of the different stakeholders who bear the costs and the benefits of the investments in ATM technologies. They take into account the institutional and regulatory framework and the characteristics of the technologies. We validate the stakeholder behavioural assumptions in both standard economic modelling and agent-based modelling. To the best of our knowledge, this is the first time that such comprehensive approach is applied to the study of technology adoption.
2. **Validation of an agent-based model through gaming experiments**. The combination of an explicitly modelled set of technological policy options into an agent-based model and a participatory game that are based on the same conceptual structure is a relevant methodological contribution. While some examples of economic behaviour have been approached in this way, there is little work on higher-ordering reasoning of stakeholders on technology options. Approaching this with an agent-based model is already on the cutting edge, but the combination with a game as a different, but also valid simulation method, is truly beyond the state-of-the-art. The validation of the two approaches against each other is a challenging problem, and is another main contribution of ITACA.

5.4 Expected impact

The project is expected to render a number of **benefits for the European ATM sector**:

1. **Better understanding of change and barriers of change in ATM**: ITACA will identify the main drivers and barriers for technology uptake within ATM using a combination of literature review, case studies, stakeholder consultation and economic modelling. Particular attention is paid to behavioural aspects of technology adoption and to the role played by the network and the interactions between stakeholders. These aspects are then explicitly modelled by means of an agent-based model, in order to develop a more structured knowledge of the mechanisms and conditions that accelerate or slow down the investment in new technologies. The behavioural assumptions of the model are tested and refined through a set of gaming experiments with ATM stakeholders. The three-fold perspective offered by the combination of economic modelling, agent-based modelling and behavioural

experiments allow us to develop a better understanding of the mechanisms to accelerate change in ATM.

2. **Provision of recommendations on how to facilitate change in ATM**: Based on the initial qualitative assessment and the economic modelling, ITACA will provide a first set of promising policies. These policies are assessed in detail using the agent-based model, which allows us to observe the behaviour that emerges from different possible reactions of the ATM stakeholders to the proposed policies. The gaming experiments help us assess which of these reactions are more prone to happen. While the agent-based model enables the exploration of a wider variety of scenarios for sensitivity analysis, in order to quantify the expected benefits and the possible unintended consequences of the proposed policies. The conclusions extracted from these experiments will allow us to provide the SESAR JU and the EC with evidence-based advice on the most adequate policy approaches to facilitate technology uptake.
3. **Accelerating development and deployment of new technologies better fitting stakeholder needs:** ITACA contributes to accelerating the development and deployment of new technologies in several ways: (i) the modelling of the technology adoption process takes into account the role played by the characteristics of the technology itself, which helps identify which innovative technologies are more likely to be promptly adopted; (ii) the explicit representation of the different ATM stakeholders and their behavioural drivers is inherent to the agent-based modelling approach adopted by ITACA, which allow us to understand the technologies that better fit the needs of different stakeholders, as well as to identify the required conditions to get the buy-in of each of the stakeholders concerned with the implementation of a particular technology; (iii) finally, the understanding of the stakeholders' behavioural drivers and the mechanisms behind technology adoption allow us to assess how the stakeholder behaviour is influenced by a certain policy. This allows us to derive guidelines on the effectiveness of different policies aimed at accelerating the development and employment of new technologies.
4. **Accelerating the achievement of the ATM Master Plan performance ambition enabled by SESAR solutions**: By providing guidance on the policies and/or the changes in the current regulations/institutional frameworks that can accelerate technology uptake, ITACA contributes to facilitating the adoption and use of SESAR solutions. This in turn contributes to the achievement of the ATM Master Plan ambitions.
5. **Impact on innovation and competitiveness**: ITACA intends to enhance innovation capacity, thus creating new market opportunities, strengthening the competitiveness of the European ATM section, and encouraging the creation and growth of technology companies.
6. **Environmental impact**: ITACA wants to accelerate the use of technologies that may have a positive impact on climate change and the local environment.
7. **Scientific impact**: The project has a number of tangible outputs that are likely to impact different academic fields, including transport economics, operations research and transport engineering. The research is disseminated through published papers, academic conferences and workshops, thereby ensuring that the results and methodology are available for further development.

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This project has received funding from the SESAR Joint Undertaking (JU) under grant agreement No 893443. The JU receives support from the European Union's Horizon 2020 research and innovation programme and the SESAR JU members other than the Union.

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