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Participatory Simulations: Experiment Results

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ITACA

INCENTIVISING TECHNOLOGY ADOPTION FOR ACCELERATING CHANGE IN ATM

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Abstract

The goal of ITACA is to accelerate the development, adoption and deployment of new technologies in ATM. ITACA achieves this objective by having developed a new set of methodologies and tools that enable the rigorous and comprehensive assessment of policies and regulations, which in turn amplify the uptake of new technologies within ATM. The project has developed an agent-based model of the R&I lifecycle allowing the representation of the complex decisions and interactions between ATM stakeholders and their impact on the implementation of new technologies. This deliverable, in particular, describes the validation of the ITACA agent-based simulation model of the ATM technology adoption and implementation process.

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1 Introduction

Air Traffic Management (ATM) is an umbrella term used in aviation for describing all systems that enable an aircraft to depart from an airport, transit the airspace and eventually land at the destination airport. Particularly in EU, ATM as a system was responsible for the safe and timely transportation of more than one billion passengers in 2019. Despite the major disruption due to COVID-19 crisis, this is a figure that is expected to grow and consequently the demands from ATM will also grow. It is therefore an area which depends heavily on technology, and is therefore required and expected to stay on top of the technological advancements and be an early adopter of technologies.

Nevertheless, technological change in ATM has historically developed at a slow pace. The reasons are multiple: the very demanding safety requirements, the coordination effort required to harmonise standards around the world, the interdependencies between ground and airborne technologies, the monopolistic nature of air navigation service provision and the relatively small size of the global ATM market compared to other technology markets are among the factors that explain, at least in part, why ATM technological modernisation has traditionally followed a slow, evolutionary path. In recent years, the need to accelerate ATM technological change has become more and more evident: growing traffic demand and new market entrants, such as commercial drone applications, are rapidly pushing the ATM system to its limits, calling for disruptive solutions that are able to boost the performance of ATM operations. Emerging technologies, especially digitisation 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 the implementation of such technologies. In other words, decisions that affect ATM as a whole are not just influenced by the technical and economic factors, but also by political, legal and social aspects [1].

1.1 ITACA Model

In order to identify the factors that hinder technology adoption in ATM and be able to tackle them, in WP3 of the project, an agent-based model (ABM) of the ATM technology deployment cycle was developed (See D3.1. ITACA simulation model) [2]. As a modelling method, ABM 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 [3]. The novelty of the model stems from the fact that scarcely any references, and hence relevant work, were identified in the field of ABM in ATM technology diffusion. The organisational point of view, i.e., stakeholders' level, the focus on policy testing and the inclusion of behavioural economics aspects, separately do not represent a new contribution; it is the first time though that such comprehensive approach, combining all these three aspects, is applied to the study of technology adoption.

The ABM is focused on reproducing the mechanisms that drive the adoption and implementation of new ATM technologies. The model includes a representation of all stakeholders identified as relevant for technology adoption in ATM; a non-exhaustive list includes air navigation service providers (ANSPs), airports, airlines, the network manager, aircraft manufacturers and ATM technology providers, labour unions and policy makers. The model represents the long-term evolution of the system (e.g., up to 2050), paying special attention to the coupling between slow and fast dynamics (i.e., how the cumulative effect of the system performance on short timescales ends up triggering long-term decisions, such as the decision to invest in new technologies), building on and extending approaches such as the one proposed by [4].

1.2 WP4 Aim

As with all models, development is just one phase towards having a model that can effectively be used in real-world decision making. Validation is the next phase that gives credibility to the model's results. The aim of this report is to describe the ABM validation framework developed for the ITACA project, which includes a behavioural analysis of agents and a participatory simulation experiment. The behavioural analysis examines the behaviour of actors in past and future scenarios, whereas the participatory simulation validates the model at an aggregated/system level and at an individual/agent level.

1.3 Document Overview

In Section 2, a literature review on ABM validation in general and with the use of gaming method in particular is conducted. In Section 3, a brief description of the ABM is provided; although, WP4 of ITACA project is about the validation of the ABM, a description of the ABM would provide an internal consistency and less need for regularly referencing the detailed report from WP3, i.e., D3.1. ITACA simulation model. In Section 4, the behavioural analysis is highlighted, including the results from the related interviews. In Section 5, the ABM validation framework is presented, including the results from the participatory experiments. Finally, in Section 6, the future work is illustrated and final remarks are made.

2 Background Work

This section presents a literature overview on ABM validation using, but not limited to, participatory methods. ABM validation, as shown in Figure **1**, generally consists of the three following steps:

- Knowledge validation: An ontology is the first step for developing an agent-based model [5] and the first things to study are the agents, their attributes and relationships. Therefore, the validation of ABM starts with the validation of the ontology [6].
- Process validation: The existing relationships between agents are not enough to define the interactions; the agent behaviour attributes and interactions must be modelled separately. At this stage, ABM agents mainly represent two components: behavioural attributes and interaction protocols.
- System validation: The third stage of the validation follows traditional procedure. The performance indicators of models are validated with hypothesis (in case of synthetic data) or real-world measurements of those indicators (in case of real data) [7].

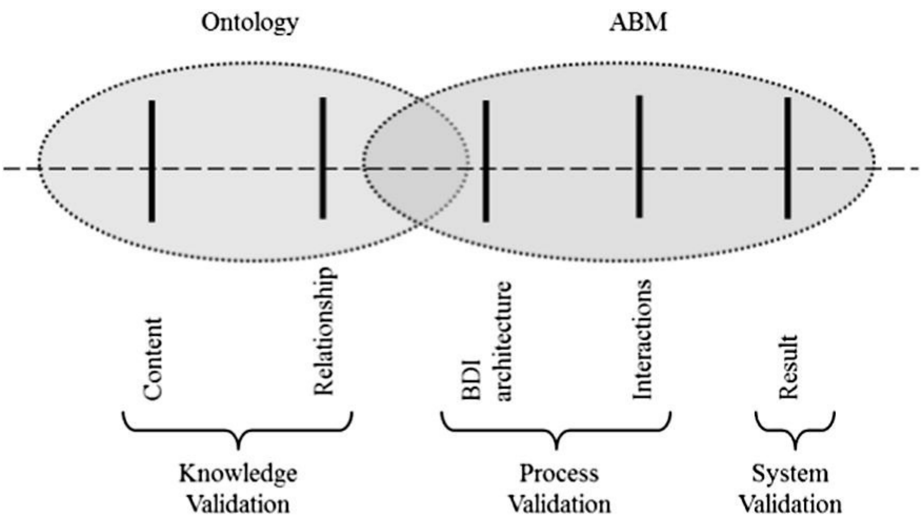

Figure 1: Stages of ABM validation

ABM validation is one of those areas that could benefit greatly from participatory methods but in which various quantitative methods can be, and have been, used with success as well.

2.1 Quantitative Methods

In general, a quantitative validation means that the results of the ABM are analysed with empirical data, where four aspects should be considered: *i.* the nature of the object under study (qualitative or quantitative), *ii.* the goal of the analysis (descriptive, forecasting, policy analysis etc.), *iii.* the modelling assumptions (e.g., size of the space of representation, time considerations etc.), and *iv.* the sensitivity of the results to different criteria (initial conditions, micro/macro parameters etc.) [8].

On the one hand, in ABM validation, traditional quantitative validation methods can be used. Some examples are the Temporal Variant - Invariant Analysis (TVIA) [9], the Analytical Hierarchy Process

[10], the Mean Square Error and Kappa Index of Agreement [11], as well as traditional statistical techniques [12]. On the other hand, validation frameworks specifically targeted at ABM have been proposed that provide an intuitive and comprehensive validation analysis, like VOMAS [13] and VALFRAM [14].

2.2 Participatory Methods

Participatory simulations are an effective, and alternative to the more traditional ones [15] method for gathering information about stakeholders, their interlocking behaviour, and their tacit knowledge [16]. Participants are placed in the dynamic environment of the ABM, so that their decision making is intertwined with each other. By joining an agent-based simulation model with human participants, an environment is created, using formal methods [17], where participants make decisions based on underlying rules that are consistent and coherent [18]. Results from the application of participatory simulations in ABM validation have shown qualitative and quantitative agreement between the decision-making of agents and the players [19][20].

In order to validate the behaviour of agents using participatory simulations, information about the representative participant's behavioural attributes is collected. An agent's decision-making mechanism follows the Belief-Desire-Intent architecture. An agent's belief is defined as the information it perceives about the state of the model's environment. In essence, the belief represents the agent's perception of the current state of the system. The agent's desire is then represented as a motivational state that the agent wants to achieve. Desires are, in fact, priorities for the agent's goals in different situations. Finally, the agent's intention is described as the final act that the agent performs, based on the beliefs and desires at the particular stage of the system [21].

Figure **2** depicts a schema for ABM validation using a participatory simulation. The left side represents the typical process for developing the agent's behaviour in the ABM, which for ITACA project would be the WPs up to and including WP3. The right side shows the process for collecting decision-making attributes from a participant using a participatory simulation [20], which for ITACA project would be WP4. Participatory simulations, as depicted in Figure 2, allow for the validation of an ABM from experts both from the domain the ABM is applied to as well as validation experts. Moreover, they give the ability to test the ABM in a real-world setting. Particularly in ITACA project, participatory simulations would enable the validation of the model, specifically focusing on the behaviour of the group called Adopters, which are defined in Section 3.

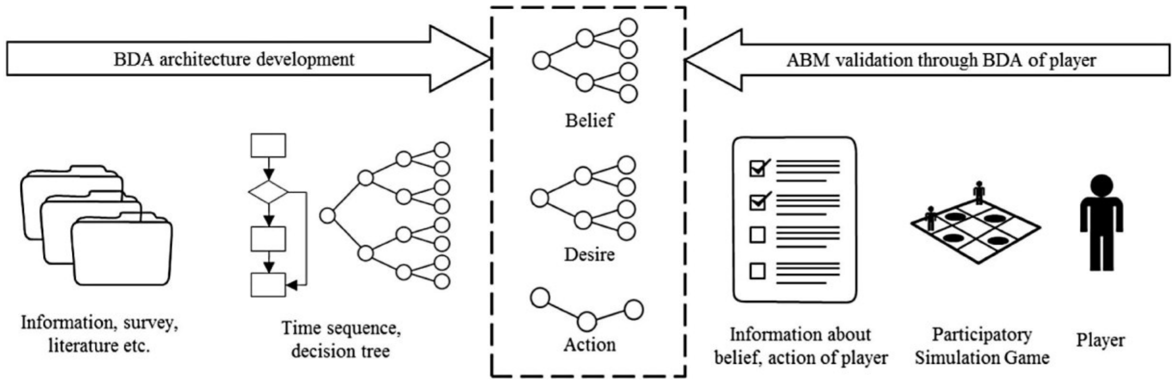

Figure 2: ABM validation using participatory simulations [20]

3 Description of the ABM

In this section, a brief introduction of the ABM is provided. The purpose of this section is not to give the full details and specification of the model, as those are described by Nommon in the document with title “D3.1 ITACA simulation model”, but to give the reader a general understanding of the model without necessarily the need to read any other report.

With this in mind, the aspects of the ABM mentioned in this report are *1.* the behavioural economic aspects incorporated in the model, *2.* the hypothesis and assumptions, *3.* the model definition, including the exogenous variables affecting the simulation, *4.* the agents’ definition, including their roles, decisions, and interactions, *5.* the decision-making process the model is going simulates, and *6.* the model outputs.

3.1 Behavioural Economics in ABM

ABM's primary difference from other modelling methods, for example system dynamics, is that the stakeholders of the system under study, i.e., the agents, are modelled individually and not as a group with similar characteristics. As a result, a whole new set of challenges arise, since modelling agents realistically would imply assigning agent's heterogeneous human-like behaviour. This is where theories from behavioural economics become applicable. The specific theories that are modelled in the ITACA ABM are *i.* bounded rationality, *ii.* prospect theory, *iii.* time dimension theories, like memory and hyperbolic discounting, and *iv.* social dimension theories, like herd behaviour.

3.1.1 Bounded Rationality and Information Asymmetry

Bounded rationality was first introduced by Simon [22], in which he posited that there are certain limits to humans' thinking capacity for a number of reasons, like limited information, cognitive capabilities of the human mind, and time restrictions. As with many systems, in ATM, some pieces of information are available to the public and accessible by all stakeholders, while other pieces are confidential and only accessible from certain agents. This information asymmetry has the potential to influence greatly the decision-making process and thus is modelled in each agent.

In addition, decisions should be categorized with regards to the time needed to make them. Strategic decisions usually have a long-term impact and depend on multiple factors, thus require more time to make. On the other hand, operational/tactical decisions might share some common characteristics with strategic ones, like impact, yet due to their nature, they usually require quick decision-making processes. In ATM, the adoption of a certain technology is considered a strategic decision, while an example of an operational decision is the commencement of a strike.

3.1.2 Prospect Theory

Prospect theory [23] is based on the idea that individuals think in terms of expected utility relative to a reference point rather than in terms of absolute outcomes. Outcomes are then compared to the reference point and classified as ‘gains’ if they are superior to the reference point and as ‘losses’ if they are inferior to the reference point. Prospect theory is based on a s-shaped value function representing gains and losses, as shown in Figure **3**.

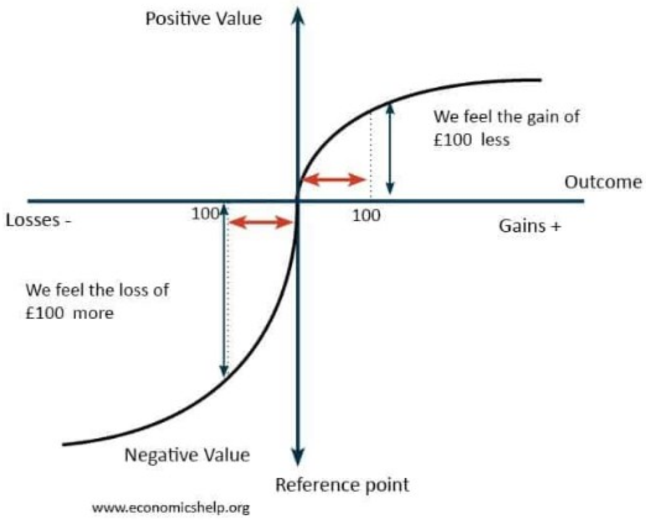

Figure 3: Graphical explanation of the concepts in prospect theory (www.economicshelp.org)

The underlying idea is that people dislike losses more than they like an equivalent gain. As a result, the function is much steeper for losses than for gains, which illustrates loss aversion behaviour. Since individuals dislike losses more than equivalent gains, they are more willing to take risks to avoid a loss. Prospect theory also describes how people have a greater willingness to overweight low probabilities and underweight high probabilities. This impact is well evidenced in a multitude of trading and valuation contexts.

3.1.3 Time Dimension

There are several ways in which time influences behaviour and decision making; some examples that are relevant to the proposed ABM are *i.* hyperbolic discounting [24], based on which present events are weighted more heavily than future ones, and *ii.* memory [25], based on which humans tend to overestimate the outcome of a future action and neglect the poor results of past activities. Hyperbolic discounting is implemented as a modification of the observed benefit by the company depending on the timespan of the reward. Memory is applied to the feedback loop of information on each time step.

3.1.4 Social Dimension

One of the basic assumptions of economic theory that behavioural economics disregards is that humans make decisions in isolation or to serve only their own interest. There are several reasons for abolishing this fundamental assumption of economics, with the most relevant for ABM in ATM being *i.* herd behaviour or as is known in game theory “information cascade” and *ii.* fairness. Information cascade is described as the tendency to adopt the decisions of others, especially when there is information asymmetry [26]; in the current ABM, it takes the form of a fashion effect similar to the ones investigated by Hamilton [27] in the energy supply industry. Fairness in behavioural economics has the same meaning as in all other aspects of life and people’s responses to positive actions are often kinder than a self-interest model would predict [28]; in the current ABM, this shift in reactions is applied to the relationship between organizations and labour unions.

3.2 Hypothesis and Assumptions

The first step towards specifying the ABM is formulating the assumptions that constitute the basis of the model. Assumptions are made for the model as a whole, the agents, the technology and the exogenous variables. With regards to the model as a whole, the focus of the study is on civil aviation, thus military aviation is not taken into account. Since military aviation usually ensures airspace security, this role is taken by each national government. Moreover, the adoption or rejection of a specific technology as a decision is made by the agents in each timeframe.

With regards to agents, the basic assumption is that they learn from previous experience as the simulation runs. Technology adoption by an agent can be partial; some examples to illustrate this concept are: *i.* an airline could adopt a certain technology only for certain routes, *ii.* an ANSP implements a technology only in a specific area control centre etc. In addition, the economic and business aspects of technology providers is not considered in the model, except price definition. Finally, airlines city pairs are fixed, thus limiting the competition between them.

With regards to technology, the model focuses on deployment, hence disregarding the technical aspects of the previous phases, like research, development, certification and manufacturing. In other words, the technology is assumed to be developed and ready to be implemented. Yet, all these previous phases are considered in terms of time. For instance, a complex certification process will be emulated by providing a technology with a longer certification buffer time. Moreover, prices are set as constant a priori, but also enabling in the future to convert towards a dynamic pricing. In order to more realistically depict the influence of technology, certain technologies could have an impact on labour, like salary modification or even hiring or firing employees.

3.3 Model Definition

ATM is a complex system; the challenge therefore is to abstract it enough, rendering its complexity manageable, yet not too much as to invalidate the model's explanatory power. The complete model definition, shown in Figure **4**, incorporates three pillars: *I.* the model input, i.e., the scenario on which the ABM runs every time, which comprises of the policy measures, technology features, and exogenous variables; *II.* the ABM, which comprises primarily of the agents' definitions and their decision-making processes, and *III.* the model outputs, which are analysed based on a performance framework that includes metrics related to technology adoption, economics, and operational performance.

With regards to agents, the basic assumption is that they learn from previous experience as the simulation runs. For example, a decision to adopt a technology in a previous simulation will impact the decision-making process of agents, making them more reluctant to adopt a new technology. Technology adoption by an agent can also be partial; some examples to illustrate this concept are: *i.* an airline could adopt a certain technology only for certain aircrafts, *ii.* an ANSP implements a technology only in a specific area control centre etc. In addition, the economic and business aspects of technology providers is not considered in the model, except for the price definition. Finally, airlines city pairs are fixed, thus limiting the competition between them.

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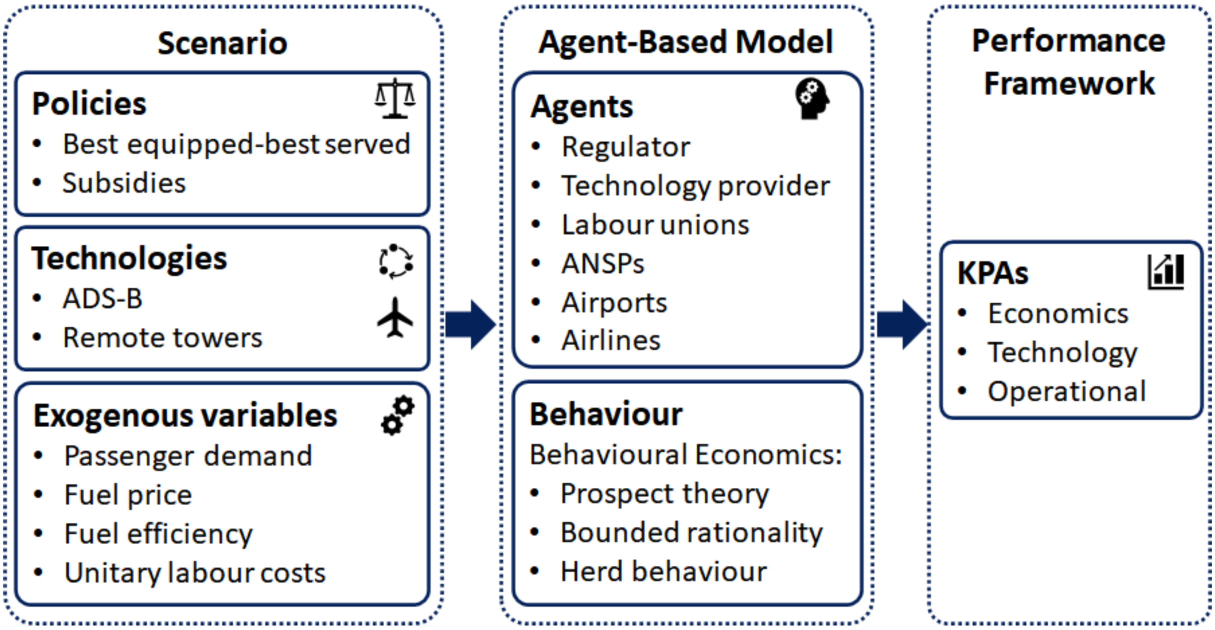

Figure 4: ITACA Model overview

3.4 Agents' Definition

ATM is a complex system that involves multiple agents in different hierarchical layers. Moreover, agents can be categorized in different groups according to their objectives and the decision they have to take in the process of technology adoption. The agents identified in ATM are ANSPs (en-route and terminal), airports, airlines, network manager, technology providers, aircraft manufacturers, policy makers, safety agencies, funding agencies (CEF and national funding agencies) and labour unions. The different groups with their objectives and common decisions are summarized in

Table 1. Aircraft manufacturers, safety agencies and any sort of national or European funding agencies are not modelled a priori, hence the tasks of the first are included in the technology provider agent, while the last two of those are grouped under the Regulators. Similarly, in this model, network managers act as a technology adopter ANSP and they possess a leader role, regarding technology adoption. Their monitoring and potential regulatory tasks are reflected in the policy maker agent. It should be finally noted that the primary objective of agents in the adopter's group is whether or not they will adopt a specific technology. As such, the primary focus of the validation process are the adopters, and particularly ANSPs, Airports, and Airlines, which are analysed below.

Table 1: Groups of agents with their objectives and decisions

Groups	Agents	Objectives	Decisions
Adopters	ANSPs, Airports, Airlines, Network Managers	Achieve an optimum result in their operational tasks while ensuring a minimum level as per industry standards (e.g., safety).	Technology adoption
Technology providers	Technology providers (ground/airborne, including aircraft manufacturers)	Provide a set of ATM technologies to the adopters	Set market prices
Regulators	Policy Makers, Safety Agencies, Funding Agencies	Monitor and execute the applicable policies in order to ensure the global welfare	Decisions derive from the policy in case and its compliance by the adopters
Labour unions	Labour unions	Lobby adopters in order to defend the labour conditions of their guild	Obstruct or support a deployment

3.4.1 Air Navigation Service Providers (ANSPs)

Considering the liberalisation process that recently happened in some European countries for the terminal ATC services (e.g., Spain, Sweden) we have differentiated between ANSPs dedicated to terminal or en-route ANS activities. They share many common features but they also have some distinct differences. The role of the former (ANSP en-route) is to manage air traffic, by primarily providing ATM services to the airspace users (mainly airlines). The role of the latter (ANSP terminal) is to provide air navigation services (ANS) specifically related to approach ANS (ascending and descending) and aerodrome ANS (landing, take-off and taxi operations). This distinction is important since terminal ANS have been partially or fully privatized to other certified entities in many countries.

Other than these differences, the objectives, decisions and interactions between the two types of ANSPs are almost identical:

- Their objective is to balance KPAs regarding the environment, airspace capacity (delay) and cost efficiency. Privately owned ANSPs have the additional objective of optimizing their profits while complying with minimum KPAs levels.
- The decision of adopting new ATM technologies, with better performances, will help them to comply with their goals. Other decisions are related to the capacity allocation, air traffic control charges and human resources aspects, like labour agreements and contracts.
- The interactions of ANSPs with the other agents in the model can be summarized as follows:
  - Airlines: ANSPs provide ATM services to airlines in exchange for navigation charges.
  - Other ANSPs: ANSPs coordinate with other ANSPs regarding the technology acquisition.

3.4.2 Airports

Airports are the interface between land and air traffic and the base for airlines. Airports offer several services (landing, aerodrome services, passenger services, parking, terminal use, etc.) the cost of which is included by airlines in the ticket price passengers pay for. Their objectives, decisions and interactions with other agents modelled in this study are:

- The objectives of an airport are to provide the best possible service and to maximize its profits, especially those managed by private companies.
- The main decisions, apart from deciding on technology adoption are to define the charging fees for the services it provides, to decide on tendering the tower ATC and to plan for any capacity increase, like a new runway.
- The interactions of airports with the other agents in the model can be summarized as follows:
    - Airlines: airports are the interface between airlines and their passengers. Landing charges are established for the use of an airport.

3.4.3 Airlines

Airlines are the most well-known actor of ATM in the public. Airlines transport passengers and freight with safety and in time from their origin to their destination. They are the main users of the airspace. Their objectives, decisions and interactions with other agents modelled in this study are:

- The main objective of an airline is to maximize profits.
- Airlines main decisions revolve around three areas. First is the network planning, where decisions like the frequency of flights, the destination airports and other strategic decisions take place. Second is the adoption of technology with regards to aircrafts, like the acquisition of a new plane or the renewal of equipment in existing planes. Third is the routing, where the routes that planes follow are determined based on different factors like the ANSP charges and efficiency (e.g., expected delay) and fuel costs.
- The interactions of airlines with the other agents in the model can be summarized as follows:
    - ANSPs: provision of ATM services and payment of navigational charges.
    - Airports: airports are the interface between airlines and their passengers. Landing charges are established for the use of an airport.

3.5 Decision Making Process

There is a clear distinction in decision making theory between individual and organizational decision making. While this study is concerned with organizational decision making, since every agent represents a company with specific objectives and agenda, several aspects of individual decision making are also considered. The reason is that decisions in an organizational level are made from people (managers, policy makers etc.) [29]. This does not mean that the two areas of decision making are one and the same; it means that they are not two distinct and unrelated disciplines and that when contemplating organizational decision making, one cannot ignore aspects and insights from the individual decision-making field.

Considering therefore the argument above, several factors that affect decision making should be considered. There is a wide range of such factors and some examples are *i.* the heterogeneity within each type of agent, *ii.* aspects from the field of behavioural economics, which is analysed in more detail in 3.1, *iii.* situational factors unique to each case and scenario, *iv.* the characteristics of the technology developed, v. individual aspects, particularly those characterized as intrinsic, like leadership skill and innovativeness, and vi. exogenous variables.

It should finally be noted that the ITACA ABM is particularly concerned with modelling the decision-making process of adopters.

3.6 Model Output

The Single European Sky (SES) is a European Commission initiative that seeks to reform the European ATM system through a series of actions carried out in four different levels (institutional, operational, technological, and control and supervision) aiming to satisfy the needs of the European airspace in terms of capacity, safety, efficiency, and environmental impact. In turn, SES has defined several Key Performance Area (KPA) and Key Performance Indicator (KPI), whose ultimate goal is to reflect the overall performance of the European ATM system. The outputs of the model are aligned with SES's KPA as well as with several additional KPAs. These additional KPAs are captured through the outputs of the model attending both distributional and global effects. The qualitative insights that the model can provide are paramount for the objectives of this research. The goal is thus not to focus in the specific number of final adopters at the end of each simulation, but rather to obtain the effect of a given policy measure in both an aggregated/system and an individual/agent level.

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4 Behavioural Analysis

The aim of the behavioural analysis of the ITACA ABM is to validate and enable the fine-tuning of the conceptual model, meaning the assumptions made by the modellers while building the ABM and the behavioural aspects embedded in the ABM. In order to gather data for conducting the behavioural analysis, interviews with experts in the field of air traffic management were conducted.

4.1 Questionnaire Design

Interviews have been conducted with experts, the expertise of whom is represented in the model. In the beginning of the interview, interviewees have been informed about the assumptions based on which the behavioural experiment is built. Then, in the remaining of the interview, they filled out a questionnaire, which consisted of 3 parts.

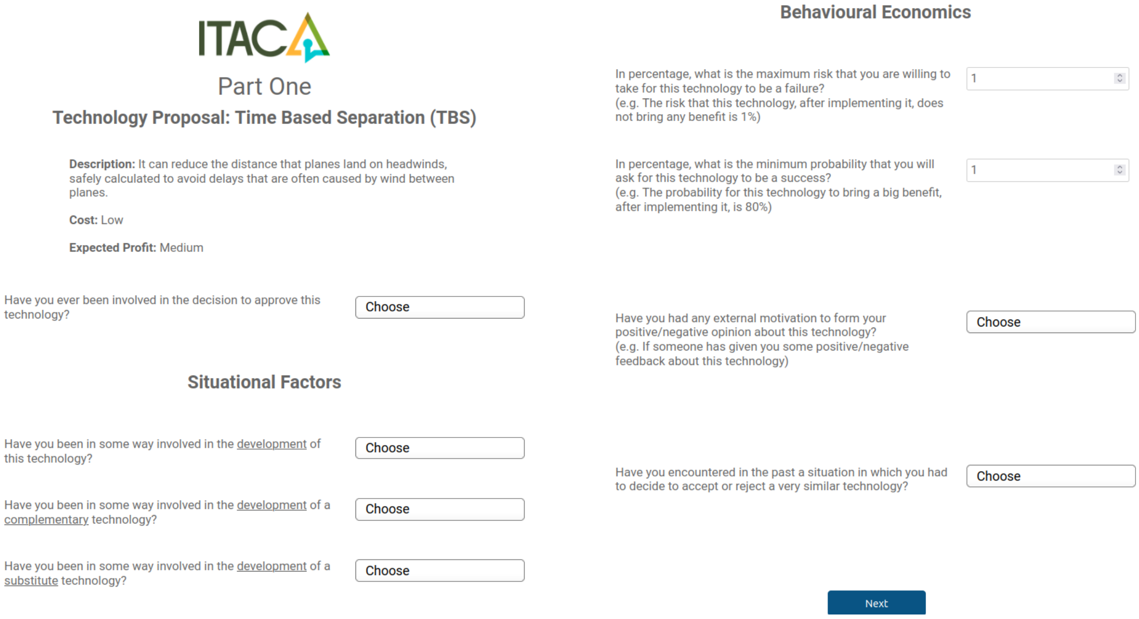
4.1.1 Questionnaire Part 1

Four different technology proposals are introduced. Two of the proposals concern technologies that have been introduced in the past in ATM, whereas the other two concern technologies that have future potentials. An overview of the proposal is shown in Table 2. The assignment of costs and benefits of the technologies listed are related to a preliminary CBA. Some of the technologies included here were finally discarded for the Participatory Experiments for lack of reliable CBAs.

Table 2: Description of the technologies in the behavioural experiment

Name	Description	Cost	Expected Profit	Time
A. Time Based Separation (TBS)	It can reduce the distance that planes land on headwinds, safely calculated to avoid delays that are often caused by wind between planes.	Low	Medium	Past
B. Automatic Dependent Surveillance–Broadcast (ADSB)	It is a system that monitors the live location of aircraft and allow controllers and other aircrafts to track them without the need of communication. This can give pilots and controllers more accurate and faster information about their position, which can reduce wait times for control.	High	High	Past
C. Unmanned Traffic Management (UTM)	A new way of control in which the humans are not in charge of the air traffic. A digital system can properly monitor and manage it.	High	High	Future
D. Flight Deck Interval Management (FIM)	A technology that allows controllers to manage the landing of aircraft more precisely, reducing the waiting times, the interval between planes, and thus the money on fuel and emissions.	High	Medium	Future

For each of these four technologies, the experts answer a series of questions. The first part of the questionnaire is shown in Figure **5**.



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Part One

Technology Proposal: Time Based Separation (TBS)

Description: It can reduce the distance that planes land on headwinds, safely calculated to avoid delays that are often caused by wind between planes.

Cost: Low

Expected Profit: Medium

Have you ever been involved in the decision to approve this technology? Choose

Situational Factors

Have you been in some way involved in the development of this technology? Choose

Have you been in some way involved in the development of a complementary technology? Choose

Have you been in some way involved in the development of a substitute technology? Choose

Behavioural Economics

In percentage, what is the maximum risk that you are willing to take for this technology to be a failure? (e.g. The risk that this technology, after implementing it, does not bring any benefit is 1%) 1

In percentage, what is the minimum probability that you will ask for this technology to be a success? (e.g. The probability for this technology to bring a big benefit, after implementing it, is 80%) 1

Have you had any external motivation to form your positive/negative opinion about this technology? (e.g. If someone has given you some positive/negative feedback about this technology) Choose

Have you encountered in the past a situation in which you had to decide to accept or reject a very similar technology? Choose

Next

Figure 5: Part 1 of the behavioural analysis questionnaire

4.1.2 Questionnaire Part 2

In the second part of the questionnaire, experts are asked to rank the technology proposals based on their likelihood to be accepted by the other agents. The objective of this part of the interview is to check the perspective that agents have about the other agents, and if the assumptions that have been considered about them match the vision that the people involved in ATM have. The second part of the questionnaire is shown in

Part Two

Ranking Technologies

You are now asked to rank the technologies based on their likelihood to be accepted by other stakeholders. Rank all the technologies from 1 to 4, in which 1 is the most probable to be accepted and 4 the least. Input the abbreviated name of each technology. For your reference, a quick overview of all four technologies is shown below.

Time Based Separation (TBS)	It can reduce the distance that planes land on headwinds, safely calculated to avoid delays that are often caused by wind between planes.
Automatic Dependent Surveillance–Broadcast (ADSB)	It is a system that monitors the live location of aircraft and allow controllers and other aircrafts to track them without the need of communication. This can give pilots and controllers more accurate and faster information about their position, which can reduce wait times for control.
Unmanned Traffic Management (UTM)	A new way of control in which the humans are not in charge of the air traffic. A digital system can properly monitor and manage it.
Flight Deck Interval Management (FIM)	A technology that allows controllers to manage the landing of aircraft more precisely, reducing the waiting times, the interval between planes, and thus the money on fuel and emissions.

By ANSPs

1	Choose
2	Choose
3	Choose
4	Choose

Figure 6.

4.1.3 Questionnaire Part 3

Finally, experts are asked whether they would change their answer knowing the answers of the other agents. The objective of this part of the interview is to check the social dimension among all the behavioural aspects. The third and last part of the questionnaire is shown in Figure **7**.

Part Two
Ranking Technologies

You are now asked to rank the technologies based on their likelihood to be accepted by other stakeholders. Rank all the technologies from 1 to 4, in which 1 is the most probable to be accepted and 4 the least. Input the abbreviated name of each technology. For your reference, a quick overview of all four technologies is shown below.

Time Based Separation (TBS)	It can reduce the distance that planes land on headwinds, safely calculated to avoid delays that are often caused by wind between planes.
Automatic Dependent Surveillance–Broadcast (ADSB)	It is a system that monitors the live location of aircraft and allow controllers and other aircrafts to track them without the need of communication. This can give pilots and controllers more accurate and faster information about their position, which can reduce wait times for control.
Unmanned Traffic Management (UTM)	A new way of control in which the humans are not in charge of the air traffic. A digital system can properly monitor and manage it.
Flight Deck Interval Management (FIM)	A technology that allows controllers to manage the landing of aircraft more precisely, reducing the waiting times, the interval between planes, and thus the money on fuel and emissions.

By ANSPs

1	Choose
2	Choose
3	Choose
4	Choose

Figure 6: Part 2 of the behavioural analysis questionnaire

Part Three
Social Dimension

You are now asked whether you would change your answers, regarding accepting or rejecting the technologies, knowing the answers of other stakeholders.

Time Based Separation (TBS)	Rejected by 40% of ANSPs.
Automatic Dependent Surveillance–Broadcast (ADSB)	Accepted by all other stakeholders.
Unmanned Traffic Management (UTM)	Accepted by 100% of Airlines.
Flight Deck Interval Management (FIM)	Accepted by 100% of Airlines and Airports.

After knowing their opinion, would you change your final decision of accepting or rejecting any of the technologies? (e.g. TBS: yes, I would change it and finally I would accept it)

Technology	Change?	Previous Answer
TBS	No	-
ADSB	No	-
UTM	No	-
FIM	No	-

Figure 7: Part 3 of the behavioural analysis questionnaire

4.2 Results

Eight ATM experts participated and completed the questionnaire, jointly representing ten different agents, due to double roles. The most interesting results which helped to fine-tune the ABM are the following (see also Figure 8 for first three results):

1. The acceptance rate was on average more than or equal to 80% for all technologies, with only TBS and UTM having individual acceptance less than 80%, from ANSPs and airports respectively. Given that in most cases technologies presented in such an advance stage are already vetted, such a percentage is plausible. If the technologies were not vetted, then the percentage could have been attributed to the fact that this was not a real decision-making situation.
2. Past technologies (i.e., TBS and ADSB) had a slightly higher, though not significantly, acceptance rate. This confirms to a small extent the time dimension of behavioural economics.
3. Airports and ANSPs were the most critical and resistant to accept new technologies, which is probably due to the fact that they are the stakeholders that usually bear the heaviest weight on the implementation of new technologies and enjoy less of the benefits.
4. 6 participants did not value the risk of failure and the prospect of success equally, confirming the Prospect Theory.
5. 3 participants had some kind of feedback which conditioned in some way their opinion about the technology.
6. Only 1 participant changed their answers when informed on the decisions of the other agents.

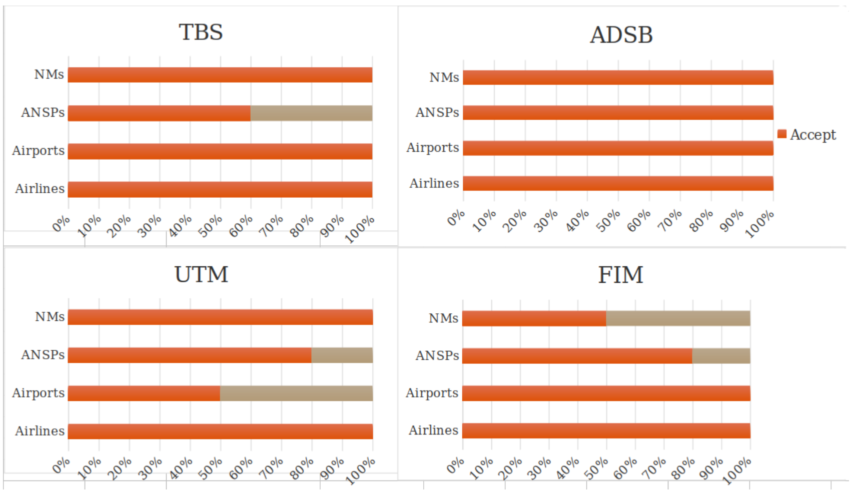

Figure 8: Results from the behavioural experiments

5 Participatory Experiments

The participatory simulations (PS) are going to be used to validate the operational model, or in other words the executable ABM. The PS's aim is to enable the validation of the ABM in an individual/agent level and in an aggregated/system level, using both formal and informal methods.

5.1 Formal and Informal Validation Methods

The combination of formal and informal validation methods allows for a more holistic approach to validation since the shortcomings of the former can be mitigated by the advantages of the latter and vice versa. Specifically, formal methods have the major advantage that their results are data-driven, hard evidences, but they also come with two significant disadvantages. On the other hand, informal methods, which by many are considered equally powerful as formal ones, are human-driven, i.e., rely almost exclusively on experts' opinion.

With regards to the disadvantages of formal methods, the first one is that validation can only be performed synchronously, which means that for validating the model or a component of the model, the model or the component should first be built, then all the necessary data should be gathered in order to run all the tests. This sequential process is time and resource intense and could cause unforeseen delays and expenses. This is where informal methods complement formal ones by allowing for both synchronous and asynchronous validation. An informal method can be applied before, during and after the design and implementation of the model or the component of the model, enabling an iterative process where improvements can be identified and implemented in a timely efficient manner.

The second disadvantage is that formal methods can only validate what is already known. The application of a formal method for validation requires specific criteria that need to be defined beforehand, which in turn means that if certain aspects of the model are not known during the design of the validation study, then a formal method would not be able to capture it. Again, this is where informal methods can be very handy because of their human-driven nature, which enables them to be able to capture relationships that had not been identified and account for them almost immediately. In other words, informal methods enable the validation of models beyond the defined KPIs.

5.2 Two Levels of Validation

The PS is implemented in such a way as to allow for the validation to occur in two different levels, in an individual/agent level and in an aggregated/system level. In order to accomplish that, participants are able to play in two different ways:

- *Playing in the model:* Participants assume the role of agents in the model. This gameplay enables participants to actually play the role of an agent, who is relevant to their experience, thus allowing for the validation of the agents' behaviour (individual/agent level).
- *Playing with the model:* Participants tweak the parameters of the model. This gameplay enables participants to play around with the model changing parameters not necessarily

directly related to their expertise, thus allowing for the validation of the model as a whole (aggregated/system level).

5.3 Two Modes of Play

The PS, which is in the form of a game, is developed as an online interface with the capability of interacting with the ABM. The game was initially planned to have two modes of play, both of which could accommodate the validation of the ABM in both levels, i.e., agent and system as described above. The two modes of play are single player and multi-player.

Playing in the model, in the single player mode, allows a single participant to take over an agent, while the remaining agents are run by the model itself. *Playing with the model,* in the single player mode, allows a single participant to tweak the parameters of the model in order to see how the model reacts.

Playing in the model, in the multi-player mode, allows multiple participants to take over several or even all agents; if not all agents are taken over by the participants, the remaining agents are run by the model itself. *Playing with the model,* in the multi-player mode, allows multiple participants to tweak parameters in the model at the same time, although this is a very challenging as it is explained below.

While it seems more realistic and intuitive to have only a multi-player mode, since the ABM has multiple agents, it comes with certain challenges that the single player mode can overcome. The challenges of having all agents, or even several of them, played by human participants at the same time are the following:

1. It is a logistical nightmare to coordinate 10+ very busy professionals to participate at the same time. The single player mode allows them to play at their own time, when it is convenient for them.
2. Given that it is very difficult to coordinate multiple participants at the same time, in that occasion, the best-case scenario will be to conduct 2 or maybe 3 game sessions with each having 5 or 6 variations. These would result in maximum 20 distinct exercises, which although not entirely bad, it still is weak with regards to establishing statistical significance.
3. Particularly when *Playing with the model*, having multiple players tweaking more than a few parameters at the same time would most probably yield results very difficult to analyse. It would be very challenging to interpret the effects of tweaking a certain parameter when 10 or even more other parameters were tweaked at the same time. The concept of tweaking a single parameter in order to observe its effects to the whole is known in economics as ceteris paribus and the single player mode could in several occasions accomplish it.
4. From the design and implementation point of view, it is much more complicated and time consuming to build an interface for a multi-player game. When a player tweaks one parameter or takes any action within the game, the change of state should be immediately communicated to the other players; this is one of the most challenging tasks with regards to software development. By all means, this would not be a problem in a board game or any non-digital game.

For the above reasons, it was finally decided to only develop the single-player mode of the game and conduct the participatory experiment with one participant at a time.

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5.4 Participatory Simulation Design

The PS starts with an introductory page (see Figure 9) asking the participants personal information that determines the agent they are going to control, like the company the work for and the position they have.

Figure 9: Introductory page of the participatory simulation

A disclaimer indicates some of the assumptions of the model and practical information that the participant should note:

- The agents you play, while share similar characteristics with the real ones, they differ in some aspects from reality.
- Only intra-Europe routes have been considered in the model.
- The results will not be published stating the name of your, or any other, organization. Instead, results will be anonymised (e.g., ALN01, ALN02, ...). The names are only for gaming purposes.

In the next step, they are asked some basic information regarding the agent they control that is used throughout all scenarios. An example for the agent Airline is shown in Figure 10.

Then, the main part of the simulation starts, which consists of 3 scenarios, 2 past scenarios (1 successful and 1 failed, attending to level and/or rate of adoption of the technology) and 1 future scenario. For each scenario, the design is identical, where participants are first presented with the specific technology to be adopted and the policy with which it is aimed to improve the adoption rate. Following that, the next page (see Figure 11) asks questions that are scenario-specific and are intended to validate the model in an individual/agent level, i.e., playing in the model. Whereas, the next 2 pages, showed together in Figure 12, ask questions regarding macroeconomic variables that intend to validate the model in an aggregated/system level.

After iterating the abovementioned pages for all 3 scenarios and having gathered all the required information, the ABM runs based on the participants' input. Once the ABM finishes, participants are presented with various graphs, based on which they decide whether or not they would adopt each technology and more importantly, why. An example of the Results' page is shown in Figure 13, in which particular case, four graphs are presented to the participant, two concern the penetration of a certain technology in the en-route ANSP market, by showing the market share and the number of agents that have adopted the technology. The other two graphs show the penetration of the technology in total. This is merely an example, since in each agent different, more relevant, graphs are presented.

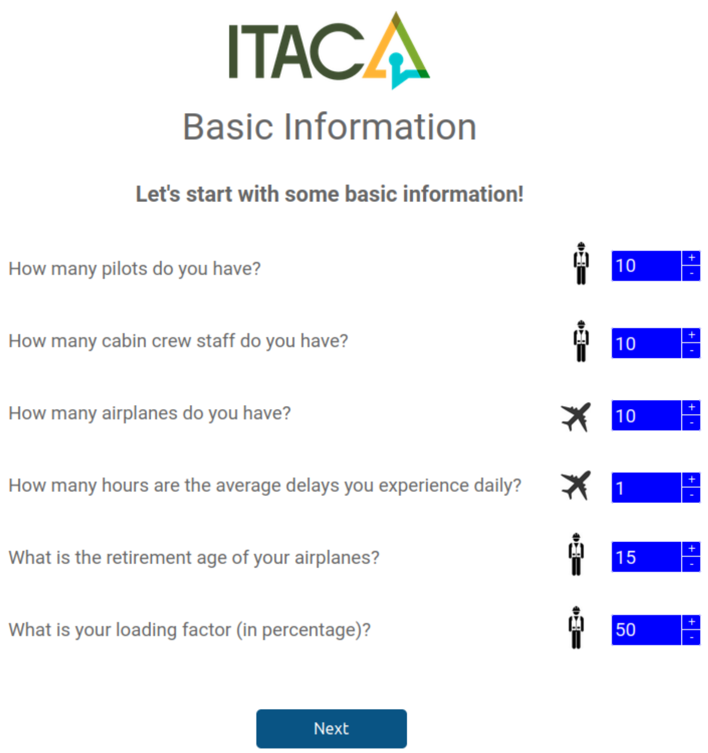

Figure 10: Basic information asked on the agent Airline

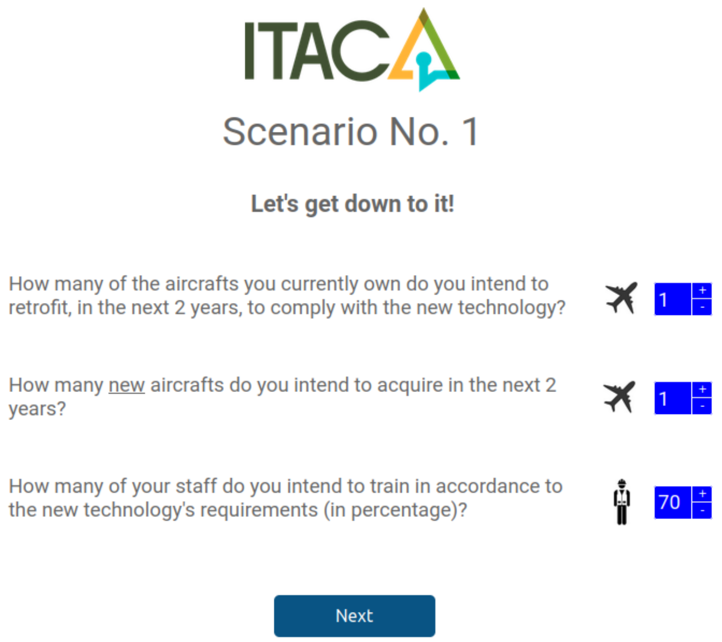

Figure 11: Playing in the model (agent level)

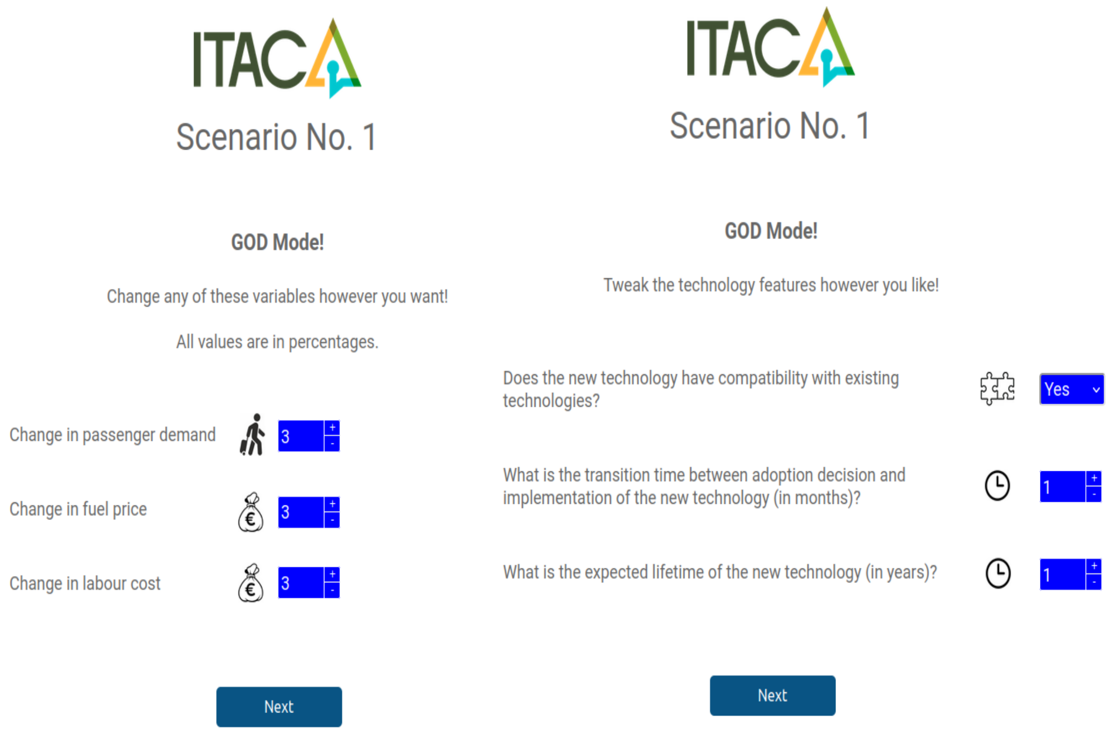

Figure 12: Playing in the model (system level)

Technology

Plan and co-ordinate the implementation of operational air-ground data link services for Air Traffic Management (ATM) in the core area of Europe.

Policy

Subsidies: Provide ANSPs with incentives and therefore help for a faster deployment of the technology.

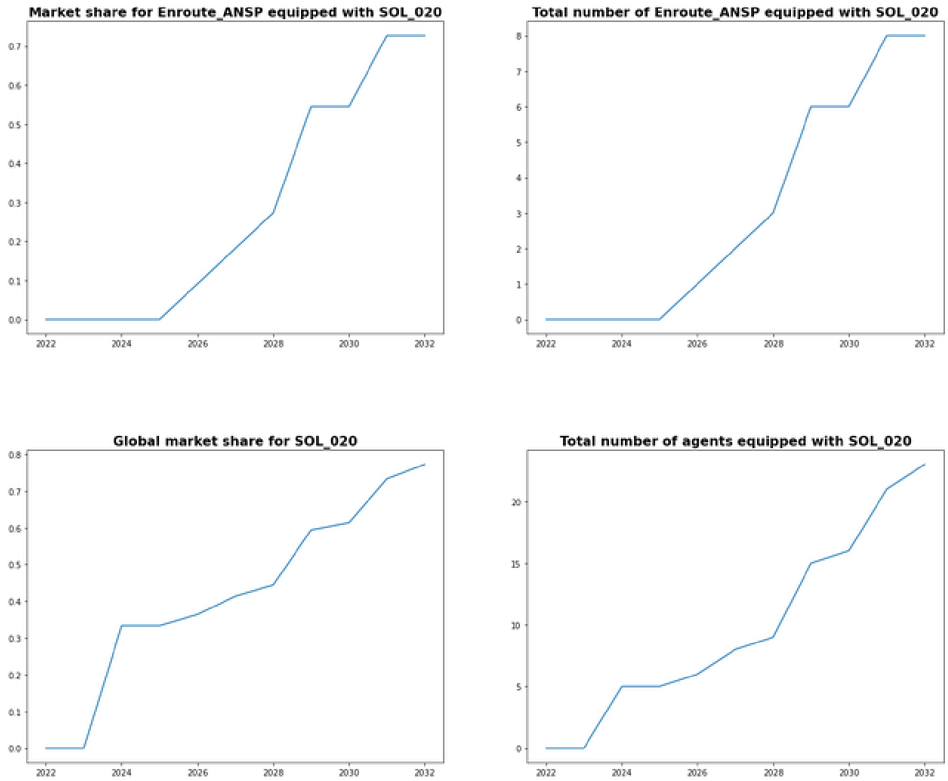

Figure 13: Playing in the model (results)

5.5 Validation methodology

The validation methodology consists of two phases. In the first phase, four sessions were conducted. One session was conducted with an airline representative, one session with an ANSP representative, and two sessions with representatives from airports. Due to privacy, the personal information of the participants cannot be revealed but what can be acknowledged is that the airline is a large European airline, the ANSP is public, and the airports are one large and one small.

In the second phase of the validation, a team of 3 model validation experts from KTH evaluated the results of the model, which were based on the input of the participants from the first phase. None of the validation experts were involved in the model design or implementation, thus providing an unbiased and objective assessment. Given that the technologies, in order to be adopted, were enhanced with specific policies targeted at increasing the adoption rate, the results from the sessions were not only judged purely on their numerical nature but the effects and influence of the accompanied policies were also considered.

5.6 Results

A first strong indication of the model's validity is the fact that the results are plausible. In other words, a face validation was first conducted in the model. Face validation is not enough to declare the model valid, especially in an individual/agent level, but it is a good first step and it increases the confidence with regards to the model's validity.

After judging the plausibility of the results, the next step would be to identify whether the adoption of each technology, with and without the application of the accompanied policy, within the model is valid, thus allowing us to evaluate both the adoption rate as well as the effect of the policies. For ease of reference, Table 3, 4, and 5 show the technologies and policies for each agent and scenario.

5.6.1 Airline

The airline agent appears to behave in a manner that corresponds to the historical data. More precisely, in scenario 1 and 2, which refer to past technologies, the agent rejects the technology proposed in scenario 2, while in scenario 1 it accepts the technology after 4 years. In both these cases, that was the intended outcome. Moreover, when participants tweaked the macroeconomic variables (passenger demand, fuel price, and labour cost) the model behaved well, taking into account the changes, which in some cases were significant (e.g., >100% increase in passenger demand), hence showing that the model can cope with extreme values and still give plausible and credible results. Despite the positive behaviour of the model in the extreme case, which could be considered a possibly unrealistic scenario, this analysis cannot guarantee that the model will behave in a valid way in any form of overestimated input parameters by participants. In scenario 3, which is a future scenario and thus without any historical data to compare it against, the model again appears to behave as intended. The new technology is finally adopted 6 years before the end of the simulation, i.e., year 2035, which upon examining the KPIs, like average profit, average airfare etc., is fully justifiable and the most rational decision.

Table 3: Technologies and Policies for each scenario affecting the airlines

Scenario	Technology & Purpose	Policy
1	**EUROCONTROL Link 2000+ Programme (Datalink)**: Plan and co-ordinate the implementation of operational air-ground data link services for Air Traffic Management (ATM) in the core area of Europe.	**Mandates:** Mandates with strict and credible enforcement. Force Airports or Airlines to adopt certain technologies with stricter regulations, in order to increase the technology adoption rate. Refusing to adopt a certain technology would result in a penalty of 2% of the company's revenues.
2	**Automatic Dependent Surveillance – Broadcast (ADS-B)**: Aircraft operating techniques enabled by airspace design, instrument procedure design and facilitated by air traffic control (ATC). CCO and CDO allow aircraft to follow a flexible and optimum flight path that delivers major environmental and economic benefits - reduced fuel burn, gaseous emissions, noise and fuel costs - without any adverse effect on safety.	**Best equipped-best served:** Consists of ANSPs giving priority to airlines that have the technology implemented.
3	**System-Wide Information Management**: It facilitates the exchange of data between applications. The SWIM Purple is a specification of the technical architecture and functions that are required to achieve full interoperability between air and ground SWIM segments.	**Demonstration projects:** Increased validation efforts, using visualizations or targeted dissemination practices in order to stimulate broader deployment and implementation. Furthermore, demonstration projects can be used for effectively addressing public problems but also in a social sense as an opportunity for justifying public action and power within a particular area in the name of public values [30].

5.6.2 Airport

As with the airline agent, the airport agent appears to behave in a manner that corresponds to the historical data. More precisely, in both scenarios 1 and 2, which refer to past technologies, the agent accepts the technology proposed, which was the intended outcome. Moreover, when participants tweaked the macroeconomic variables, the model captured the changes gave plausible and credible results. In scenario 3, which is a future scenario and thus without any historical data to compare it against, the model again appears to behave as intended. The new technology is adopted after the first year of the simulation, i.e., year 2023, which upon examining the KPIs, like average profit, average airport charges per pax etc., is fully justifiable and the most rational decision. The particularity of the airport agent was that it was not possible to test a failed technology because there were not any relevant historical data of such a technology.

Table 4: Technologies and Policies for each scenario affecting the airports

Scenario	Technology & Purpose	Policy
1	**Microwave Landing System (MLS)**: An all-weather, precision radio guidance system intended to be installed at large airports to assist aircraft in landing, including 'blind landings'. It enables an approaching aircraft to determine when it is aligned with the destination runway and on the correct glidepath for a safe landing.	**Mandates:** Mandates with strict and credible enforcement. Force Airports or Airlines to adopt certain technologies with stricter regulations, in order to increase the technology adoption rate. Refusing to adopt a certain technology would result in a penalty of 2% of the company's revenues.
2	**Airport Collaborative Decision Making (A-CDM)**: Improve the efficiency and resilience of airport operations by optimising the use of resources and improving the predictability of air traffic.	**Flexible charging regulation:** With this regulation ANSP can recover its costs and add a margin to its charge if it implements a certain technology.
3	**System-Wide Information Management**: It facilitates the exchange of data between applications. The yellow profile services for flexible/affordable ground/ground data communications, while the blue profile services for fast/secure/reliable ground/ground data communications. In addition, the SWIM TI Blue Profile is an alternative specification to the SWIM TI Yellow Profile focused on real time communications requiring extremely high availability. On the other hand, SWIM Purple is a specification of the technical architecture and functions that are required to achieve full interoperability between air and ground SWIM segments.	**Realistic timelines:** The timeframe to implement certain technologies should be set realistically instead of postponing deadlines as (unrealistic or overoptimistic) targets are not reached.

5.6.3 ANSP

As with the other two agents, the ANSP agent appears to behave in a manner that corresponds to the historical data. More precisely, in scenario 1 and 2, which refer to past technologies, the agent rejects the technology proposed in scenario 2, while in scenario 1 it accepts the technology after 4 years. In both these cases, that was the intended outcome. Moreover, when participants tweaked the macroeconomic variables, the model captured the changes gave plausible and credible results. In scenario 3, which is a future scenario and thus without any historical data to compare it against, the model again appears to behave as intended. The new technology starts to gradually be adopted after the first year, i.e., year 2023, and it is finally fully adopted in the last year of the simulation, i.e., year 2040, which upon examining the KPIs, like the unit rate etc., is fully justifiable and the most rational decision.

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Table 5: Technologies and Policies for each scenario affecting the ANSPs

Scenario	Technology & Purpose	Policy
1	**EUROCONTROL Link 2000+ Programme (Datalink)**: Plan and co-ordinate the implementation of operational air-ground data link services for Air Traffic Management (ATM) in the core area of Europe.	**Subsidies:** Provide ANSPs with incentives and therefore help for a faster deployment of the technology.
2	**Continuous Descent Operations (CDO) & Continuous Climb Operations (CCO)**: A surveillance technology in which an aircraft determines its position via satellite navigation or other sensors and periodically broadcasts it, enabling it to be tracked, without requiring any pilot or external input.	**Flexible charging regulation:** With this regulation ANSP can recover its costs and add a margin to its charge if it implements a certain technology.
3	**Dynamic Airspace Configuration (DAC)**: It is a new operational paradigm that proposes to migrate from the current structured, static airspace to a dynamic airspace capable of adapting to user demand while meeting changing constraints of weather, traffic congestion and complexity, as well as a highly diverse aircraft fleet.	**Involvement of the safety agency:** Carried out in the research phase and helps to reduce uncertainty on implementation times as it reduces time for certifications.

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6 Conclusion & Future Work

The aim of this Deliverable 4.1 is to present a validation of the ITACA Simulation Model and the behavioural assumptions built into the model. In the previous chapters, this validation has been presented, as well as the steps leading towards the validation. This includes the design, implementation, and sessions of the behavioural experiment and participatory simulation, aimed at validating the ABM, which was built at WP3. Participatory simulation was chosen as the validation method because it enables the acquisition of data from an environment closely related to a real-world setting. In the sessions, experts representing the main adopters' agents (i.e., airlines, airports, ANSPs) participated, giving answers that allowed three independent validation experts from KTH to further assess the validation.

The final results showed that the model behaves in a very realistic manner, from the perspective of all three agents, even when faced with extreme values and outliers. Apart from the positive final results, ITACA in general and WP4 in particular have proposed a novel methodology for ABM design and validation not just concerning the aviation sector but also applicable in other domains. In other words, the achievements of WP4 are i. the validation of the ITACA ABM for the purpose for which it is built, ii. the development of a validation methodology that is able to capture the nuances of the ITACA ABM and is also able, with minor or major changes depending on the case, to be utilized in different studies not necessarily in the aviation sector.

As with any studies, the results from WP4 do have certain limitations. The most important limitation is that the model has only been validated for three agents/adopters and not for any other participating agent, like labour unions, manufacturers, technology providers etc. Another limitation is the combination of technologies and policies forming the scenarios, in which case while chosen from domain experts, it is not possible to exclude the possibility of producing biased datasets and enabling the overfitting of the model. Both of these limitations by no means undermine the study and they could serve as a guide for improving the model.

When validating, the key question as discussed above is the validation for which purpose. The WP4 validation as reported here has been carried out with the use case in mind that the ITACA ABM will be used by stakeholders, or within the SESAR programme, to predict ex-ante what the impact of a policy for technology adoption will be. The validation shows a degree of validity of the ABM that would enable explicit outcomes to be generated by the model. However, it also shows that the outputs are highly dependent on the stated preferences and choices by the stakeholders as input to the model. It is therefore recommendable to start a future use of the ITACA ABM with a critical assessment of the input parameters by experienced stakeholders to even validate the model input during the use phase.

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Appendix A List of Abbreviations

Acronym	Definition
ABM	Agent Based Model
ACC	Area Control Centre
A-CDM	Airport Collaborative Decision Making
ACE	ATM Cost Effectiveness
ADS-B	Automatic Dependent Surveillance–Broadcast
AENA	Aeropuertos Españoles y Navegación Aérea
AFV	Alternative Fuel Vehicle
AIS	Aeronautical Information Service
ANS	Air Navigation Service
ANSP	Air Navigation Service Provider
API	Application Programming Interface
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
AU	Airspace User
BAU	Business as Usual
BAW	British Airways
BE	Behavioural Economics
BPMN	Business Process Model and Notation
CAA	Civil Aviation Authority
CAS	Complex Adaptive System
CCO	Continuous Climb Operations
CEF	Connecting Europe Facility
CNMC	Comisión Nacional de los Mercados y la Competencia
CNS	Communications, Navigation and Surveillance
COMPAIR	Competition for Air Traffic Management
COVID-19	Coronavirus disease
CSV	Comma Separated Values

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Acronym	Definition
DAC	Dynamic Airspace Configuration
DBF	dBase database file
DLH	Lufthansa Group
DG MOVE	EU Commission's department for mobility and transport
DMP	Data Management Plan
DUC	Determined Unit Cost
EASA	European Union Aviation Safety Agency
EATMA	European Air Traffic Management. Architecture
EC	European Commission
ECAC	European Civil Aviation Conference
EIA	U.S. Energy Information Administration
EIN	Aer Lingus
EPO	European Patent Office
EU	European Union
EUROCONTROL	European Organisation for the Safety of Air Navigation
EUROSTAT	Statistical Office of the European Communities.
EZY	EasyJet
FAB	Functional Airspace Block
FIM	Flight Deck Interval Management
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
GIS	Geographic Information System
GUI	Graphic User Interface
IAG	IAG group
IATA	International Air Transport Association
IBE	Iberia
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ITACA	Incentivising Technology Adoption for accelerating Change in ATM
KLM	KLM airline
KPA	Key Performance Area

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Acronym	Definition
KPI	Key Performance Indicator
LCC	Low-Cost Carrier
MET	Meteorology
MIT	Massachusetts Institute of Technology
MUAC	Maastricht Upper Area Control Centre
NMOC	Network Manager Operations Centre
OD	Origin-destination
ODE	Ordinary Differential Equation
OS	Operating System
PDF	Portable Document Format
PI	Performance Indicator
RYR	Ryanair
SA	Safety Agency
SAR	Search and Rescue
SD	System Dynamics
SDM	SESAR Deployment Manager
SES	Single European Sky
SESAR	Single European Sky ATM Research
SJU	SESAR Joint Undertaken
SU	Service Unit
SWIM	System Wide Information Management
TBS	Time Based Separation
TMA	Terminal Manoeuvring Area
TXT	TXT file extension
UK	United Kingdom
US	United States
USPTO	United States Patent and Trademark Office
UTM	Unmanned Traffic Management
VLG	Vueling
WHL	Wheel file extension
WP	Work Package

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