# Changing complex sociotechnical infrastructures: the case of Air Traffic Management

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Paper presented in sub-theme 63: Thinking Infrastructures, 33rd EGOS Colloquium 'The Good Organization' in Copenhagen, Denmark, July 6-8, 2017

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**ABSTRACT**

The aim of this paper is to analyse the decision processes that are taken to implement a planned change in a complex ecosystem where decisions are identified as obligatory passage points of any change that affects the evolution and (in)visibility of infrastructures. In this work decision processes are not considered as discrete decisions but as patterns of knowledge exchange and information communication which reduce the equivocality of a problematic issue. In particular, we focus on a complex organizational system, namely Air Traffic Management (ATM), and analyse the decision processes carried out by experts in the system. We outline whether and to what extend different decision making practices come into play in the adoption of any ATM changes and in the construction of the correlated sociotechnical system, and how the infrastructure shapes decisions and changes over time to become somehow visible. As depicted in the literature, we take advantage of the case study analysis, which allows us to identity the main building blocks through which infrastructures change.

***Keywords**:* decision processes, infrastructure, (in)visibility, Air Traffic Management

## 1. Introduction

In this work, we analyse how infrastructures become visible and change in a complex organizational system. In particular we focus our analysis on the interplay between the infrastructure, its (in)visibility, and the decision processes carried out in a complex socio-technical system.

While scientific research about knowledge infrastructures have addressed both theoretical and methodological issues (Karasti, et al. 2016a; Karasti, et al. 2016b), we claim that the way in which decision processes shape infrastructures remains unexplored.

By using the literature of group decision-making, the aim of this paper is twofold; on the one hand, we describe the most significant elements and categories that characterize group decision processes; on the other, we investigate whether and to what extent these elements and categories contribute to make the infrastructure visible during a planned change (and therefore during a group decision process).

In particular, we analyse the changes implemented in a complex organizational system and its (in)visible infrastructure based on various elements such as actors, organizational culture, processes, technology, artefacts, etc. When a change occurs, the relationships between these elements become visible pushing actors to negotiate and take consequent decisions.

We study the decision processes used to implement changes in European Air Traffic Management (thereafter ATM). ATM is the complex infrastructure which assists the flight of an aircraft when departing, cruising, and landing at an airport. This is done through distinct activities such as air traffic control and air traffic flow management. ATM services are based on advanced technologies and require highly skilled human resources entailing significant investment in personnel, assets and training. ATM services are complex systems also because they are provided by different organizations all over Europe.

The analysis is conducted through the interpretation of semi-structured interviews and focus groups with experts from the sector. In our conclusion, we outline the dimensions of the decision-making practices that come into play when creating, maintaining or changing an infrastructure.

The paper is structured as follows. The second section describes the notion of infrastructure and its (in)visibility. The third section discusses group decision-making

while the fourth introduces the case study and the fifth describes the method of analysis. Sections six and seven analyse and discuss the results. Section eight concludes this work.

## 2. Infrastructures and (in)visibility

One definition of a sociotechnical infrastructure is that it is a robust network of people, artefacts, and institutions that generate, share and maintain specific knowledge about the human and natural worlds (Edwards, 2010). A large body of literature, from interactionism to the workplace studies about infrastructures, has stressed the important role played by the human elements of infrastructures such as work practices, individual habits, and the organizational culture (Star & Ruhleder, 1996; Bowker & Star, 1999; Heath & Luff, 2000; Edwards, 2003; Edward et al., 2009; Schmidt & Bannon, 2013; Mongili & Pellegrino, 2014). Two important characteristics of sociotechnical infrastructures are (Star & Ruhleder, 1996; Neumann & Star, 1996; Star, 2002; Bowker & Star, 1999; Bowker et al. 2010):

1. the infrastructure is the result of negotiation among heterogeneous actors
2. people are connected to activities, structures and cognitive elements embedded in an infrastructure.

Infrastructures pattern what and how actors understand and interpret their world through practices, routines and organizational cultures, informational and knowledge infrastructures. Infrastructures exist in the background, are invisible and are taken-for-granted by actors who perform routines and practices (e.g. Neumann & Star 1996; Star 2002; Bowker & Star, 1999; Star, 1999; Bowker et al. 2010).

An infrastructure is usually invisible or opaque in daily life and operates below the surface. It becomes visible in two main cases (Karasti, et al. 2016a):

1. when it breaks down (Bowker, et al, 2010; Star, 1999; Star & Ruhleder, 1996). For instance, when a server goes down, a bridge is washed out, or when a power blackout occurs, the infrastructure becomes very evident to the actors that use it. The safe management of such situations implies the creation and implementation of ex-ante and ex-post procedures, such as back-up mechanisms or other emergency procedures, which should fix breakdowns and bugs.
2. when it is analysed during meetings that aim to create, maintain or change an infrastructure (Star & Bowker, 2002; Karasti et al., 2010; Jackson, 2014).

Changing an infrastructure is an extremely complex venture. It is not an instantaneous process; it requires time and iterative development, involves multiple actors and implies various non-deterministic phases. Since the infrastructure supports and is, in turn, inhabited by social, political and technical elements, its creation or change cannot be analysed only from a technological point of view but rather from the result of the actors' negotiations on practices, routines, assets and the sociotechnical elements that make up the infrastructure itself. In this paper, we investigate the "planned changes", namely those specific changes which occur when a group of individuals in an official setting seek to change the infrastructure or a part of it. These planned changes involve a multitude of decisions about the interconnections between people, activities, structures and cognitive elements and in some cases implies complex negotiation processes. From an organizational point of view, decisions that have consequences on an entire ecosystem are usually made by groups (Huber, 1980; Robbins, 1992; Vroom & Jago, 1988). To better explore the role of decision in infrastructuring, the next section identifies the most significant elements that characterize group decision processes.

## 3. Group decision processes in complex organizations

Decision-making processes in complex organizations represent one of the most important management activities (Mintzberg, 2008; Simon, 1997) at any level of the organization (strategic level, operational level, etc.). In society, decisions are almost never individual; very often, the essence of organizations resides in coordinating different contributions and achieving a common goal that could not have been achieved by any of the working group members alone (Maznevski, 1994).

According to Beersma and De Dreu (2002), group work involves negotiation and the negotiation dynamics have a prominent role in decision making. Some of the most important contributions on group decisions in organizational theories are found in organizational psychology studies (Argyris, 1972; Maslow, 1943; Schein, 1980) where group decisions are strongly related to the knowledge of individuals, their ability to negotiate and the knowledge infrastructure of the group.

Various elements can be considered antecedents in a negotiation process; among others, skills, knowledge and competencies (Schermerhorn et al., 2011; Maznevski, 1994, Jackson, 1992); procedures, routines and rules (Neale and Bazerman, 1991);

and roles, power and social motives (Giebels et al., 2000; Mannix, 1993; De Dreu, et al., 2000). By analysing each of these elements in detail, the following emerges.

Group decision process can be analysed by first of all emphasizing the diversity that characterizes each group. Each group differs from any other in various ways, but one of the most significant difference for group decision process is role-related (Maznevski, 1994, Jackson, 1992). Decisions made by groups with diverse expertise and knowledge are of a higher quality than those made by homogeneous groups or by a single individual (Schermerhorn et al., 2011). For instance, Schermerhorn and colleagues (2011) analysed the interconnection between group composition and group performance whereas Maznevski and DiStefano (2000) focused their attention on decisions within multinational organizations, emphasizing the role played by the teams involved, as well as the diversity of roles, positions, skills and competencies.

The role played by these elements in the whole decision-making process is crucial and perhaps inevitable because in each organization a wide variety of skills, expertise and knowledge is held by actors working in different groups or teams. The importance of these element emerges even more forcefully when the organization is big and complex.

According to Mintzberg (1976), when faced with a complex and unplanned situation, the decision maker seeks to reduce the uncertainty by subdividing each decision/problem into sub-decisions/sub-problems and linking them to simpler, familiar and well organized elements. As often happens, procedures, rules and routines help individuals to take decisions in negotiation dynamics but the latter embed the invisible infrastructure in which individuals act.

In group negotiation a large variety of decision rules (procedural variables) may be analysed (Neale and Bazerman, 1991), but the two common rules are unanimity and majority rules (Neale and Bazerman, 1991). Unanimity rules imply that each group member has to support the agreement but at the same time has the ability to veto. Majority rules, instead, imply that a majority of the group members is enough to attain an agreement; it may happen that the majority forces the group to reach an agreement that yields high outcomes for the majority, but not for the minority.

Beersma and colleagues (2002) argue that group members will engage in more distributive behaviour in asymmetrical rather than in symmetrical negotiation tasks, and that the key mechanism that explains this effect is the group members' limited focus in asymmetrical negotiation tasks. Mannix (1993) and Giebels et al. (2000) found that in

a decision-making task group, imbalances in the power positions of the members lead them to focus on their individual outcome instead of on the group results.

The degree in which group members include everyone in the agreement depends on their social motives (motivational variables), such as the preferences for distributions of outcomes between oneself and interdependent others. Two main types of social motives related to the negotiation dynamics exist in the literature, namely prosocial and egoistic. Prosocial motives are aimed at seeking good outcomes for oneself as well as for other group members while egoistic motives are aimed at seeking good outcomes only for oneself (De Dreu et al., 2000).

According to Pruitt and Carnevale (1993), both types exist in a negotiation, but they may vary due to individual and organizational differences, or both. Prosocially motivated group members tend to value inclusiveness and equality in outcome distribution and, at the same time, they tend to negotiate, like in a collaborative game, in which fairness and joint welfare are key elements (Giebels et al., 2000). In contrast, egoistically motivated group members tend to ignore others' interests and to transform the negotiation into a competitive game in which the key elements are power and personal success (Giebels et al., 2000).

The elements illustrated above allow us to emphasize the socio-relational character of group decision-making. The influence of routines and procedures, power dynamics, variety of skills and competencies as well as social motives on decision making inevitably deal with complex dynamics.

In the next section, we will focus on a specific case study where we will analyse the ATM system and what elements affect planned decision-making processes.

## 4. The case study: from sectored to sectorless ATM

Air Traffic Management is the entire ecology of systems that assist the flight of an aircraft - departing, cruising, and landing at an airport (Duong et al., 2001). According to the European Organisation for the Safety of Air Navigation (EUROCONTROL), the international organisation which manages and controls air traffic across Europe, ATM is made up of three distinct activities:

- **Air Traffic Control:** the activity by which aircraft are safely separated in the sky as they fly en route and at the airports where they land and take off.
- **Air Traffic Flow Management:** the activity done before flights take place. Any

aircraft using air traffic control files a flight plan and sends it to a central repository. All flight plans for flight into, out of and around Europe are analysed and computed.

- **Aeronautical Information Services:** the services responsible for the compilation and distribution of all aeronautical information necessary for airspace users. This includes information on safety, navigation, technical, administrative and legal matters.

ATM is currently populated by a set of heterogeneous actors such as:

- air navigation service providers (e.g. DFS in Germany and ENAV in Italy)
- European Civil Aviation Conference member states
- civil and military experts in airspace design
- passengers and airspace users
- flight planner organisations
- relevant international bodies.

Since one of the main goals is the safety of flights, ATM and the interaction among actors is driven by strict national and international regulation that formalize the working procedures. This means that any change of the infrastructure is a complex endeavour that affects hundreds of national and international organizations, actors, procedures, assets and regulations. The effort made within the EU to change the ATM with a special focus on the ATC is described in the following section.

### 4.1. Background: willingness to make ATM more efficient in Europe

The current configuration of the European ATM is the result of the harmonization process in European countries carried out by the EU in the 1960s. The foundation of EUROCONTROL - the international organisation working on air traffic management across Europe - is the visible element of this effort.

Twenty years ago, the EU started the Single European Sky (SES) initiative with the aim of designing, managing and regulating a single coordinated airspace throughout the European Union. This was done by setting up the SES legislative framework consisting of four Basic Regulations (N° 549/2004, 550/2004, 551/2004 and 552/2004). The intention behind this project was to improve the operational efficiency of ATM. European airspace is one of the busiest in the world but the current system of air traffic management suffers from inefficiencies, such as using air traffic control boundaries that follow national borders, and having large areas of European airspace reserved for

military use when in fact they may not be needed. ATM relies on a number of new key features including better trajectory management, new aircraft separation modes and full integration of airport operations.

The full initiative is an EU collaborative research programme called Single European Sky ATM Research (SESAR) and it is intended to last several decades (SESAR, 2015). Since 2004 SESAR has developed and deployed radical innovations in ATM systems, sponsored the production of a new generation of technological systems and components, and supported the implementation of a new air traffic management infrastructure with fully harmonised and interoperable components to guarantee high performance air transport activities across Europe.

Considering the complexity of the project and the numerous initiatives underway, this paper focuses on only one of these issues, namely Air Traffic Control (thereafter ATC) activity aimed at assisting aircraft in the upper airspace. It is one of the most critical activities and is further described below.

### 4.2. The starting point: sectored air traffic control

The duty of ATC is to organize the air traffic flow, to prevent collisions between aircraft and to provide pilots with information. Controllers apply separation rules to keep aircraft at a safe distance from each other to reduce the risk of collisions or other types of accidents (e.g. wake turbulence) and move all aircraft safely and efficiently through their assigned sector of airspace as well as on the ground. Managing the traffic flow, balancing the demand and capacity of the airspace, and preventing collisions is a complex service involving organizational, cognitive, structural and technological issues. One of the most important issues is the management of complexity. Diverse organizational, technological and structural solutions have been adopted to manage complexity when controlling aircraft. One of the most important solutions adopted for ATC in Europe is the partitioning of the airspace into geographical sectors. Each airspace passing through a sector is controlled by a specific organization or air control centre (ACC). In each sector, a pool of controllers perform different activities:

- take care of and interact with pilots of the aircraft flying within the sector
- coordinate with controllers of other sectors to define the specific paths to bridge sectors.

Figure 1 shows an example of the traditional sectored control system applied to

Germany (DFS, 2016).

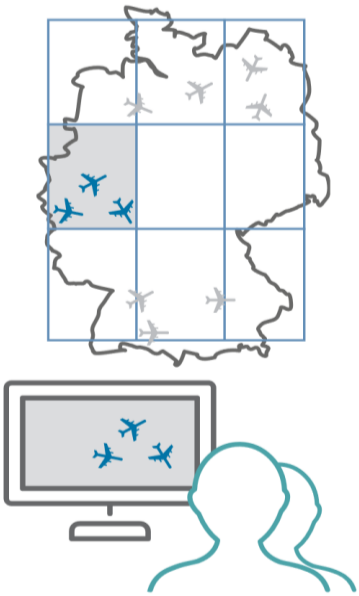

*Figure 1. Sectored control scenario. (Source: DFS, 2016)*

One of the main limitations of this type of work setting is that an increase in the air traffic flow means an increase of the workload for the air traffic controllers. In particular, the coordination efforts between sectors increase significantly (Birkmeier et al. 2016). A common practice used to reduce this workload excess has been to decrease the size of the sectors thus creating more sectors. Unfortunately, such practice displays limitations:

- a smaller sector means that controllers may exert less tactical and strategic control on aircraft
- partitioning the airspace cannot be done indefinitely. Physical limitations do not allow partitioning the airspace indefinitely. This problem is already present in some European countries (DFS, 2016).

Over the last two decades, different solutions have been proposed and explored to overcome the limitations of the traditional sector-based control system; one of the most explored is the sectorless scenario.

### 4.3. The proposed change: the sectorless scenario

International bodies, practitioners and scholars in the sector have started discussing an innovative approach to controlling airspace: the sectorless scenario (Riviere, 2004). The sectorless scenario envisages air traffic control without the conventional

geography-based sectors. This new approach means that several aircraft are assigned to a single controller regardless of their location. Each single controller will guide the aircraft during their entire flight in upper airspace (figure 2).

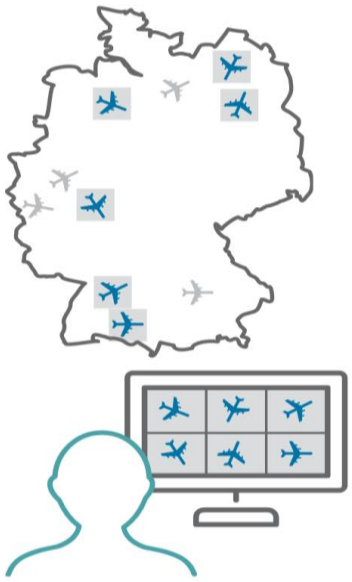

*Figure 2. Sectorless control scenario (Source: DFS, 2016)*

The sectorless scenario is said to offer significant improvements while addressing the main bottlenecks of the traditional sectored approach. The main foreseen improvements might be summarized as (Birkmeier et al. 2016):

- higher number of air traffic flights: the system is able to control a greater number of flights.
- less workload: controllers face less workload and also less handovers.
- efficiency in terms of costs and time: sectorless allows for more linear trajectories meaning less fuel and less travel time for each flight.
- single point of contact for pilots: when entering a sectorless area pilots have a sole controller to talk to.

In other words, this new job organization promises a significant increase in fight capacity and controller efficiency, and fewer costs for society in term of pollution and fuel consumption.

In order to assess the feasibility of this concept, over the last decade scholars have focused on several operative aspects of the sectorless scenario including issues such as the change in controllers' tasks, the assignment procedures of aircraft, the priority

rules and the safety assessments routines (Korn et al. 2009; Biella, et al. 2011; Birkmeier & Korn, 2014).

Since the sectorless scenario is a complex innovation, its implementation will last for several years: its real implementation is set to become gradually operational over the next ten years, meaning that it is more than a decade since the initial exploration of the concept. The technical, organizational, economic and procedural innovations of the scenario imply numerous changes within the sector as a result of decisions to plan and implement changes of the infrastructure and its interconnected practices.

In the next sections, we investigate some of the decision processes that have advanced the adoption of sectorless ATM and how the infrastructure has been changed and made visible.

## 5. Research method

The goal of identifying the categories that shape the (in)visibility of the infrastructures was pursued by means of a qualitative research approach within a two-year European research project. The study started in spring 2016 and is still ongoing. As an exploratory research project, data collection and analysis were performed over time as a recursive process. Data collection and data analysis included three main methods:

1) Semi-structured interviews: 3 ATM experts were interviewed to identify the most important decision process categories that affect changes in ATM. The interviews were recorded and then transcribed. The first goal of the interviews was explorative, namely to identify the most significant elements and phases of the decision processes about change and innovation of the ATM infrastructure and of flight control systems. A second goal was to identify the emerging categories (Miller and Glassner, 2016) that characterize decisions about changes.
2) Two focus groups: one-day focus groups took place in June 2016 and March 2017. Table 1 briefly describes the experts' roles and competences. The goal of the focus groups was to better explore and understand the complex participatory processes involved in the decision to change the various aspects (theological, organizational, etc.) of the ATM domain. The categories identified during the preliminary interviews were also further investigated and verified (Wilkinson, 2016).

3) The analysis of the documentation centred around official ATM provider documentation and papers describing innovation and changes to ATM and, more specifically, to the air traffic control systems. The goal of this analysis was to compare the findings of the first two methods with official information available in documents.

After the identification and sharpening/validation of the categories, the focus of the analysis shifted to understand whether these emerging categories contribute to make the ATM infrastructure visible. The authors performed the analysis as follows: first, the authors analysed all the material independently; then the results of such analyses were triangulated between them.

*Table 1: Expertise of the experts participating in the focus groups*

| | |
|---|---|
| ATM Security Expert | • supports national service providers, state authorities and the industry with respect to ATM security<br>• works for an international organization providing ATM services |
| Senior Enterprise Architect | • supports the strategic development of Air Traffic Management<br>• works for a European National Service Provider |
| ATM Safety Expert | • expert on human resource within ATM<br>• works for a European National Service Provider |
| ATM Safety and Security | • expert in security and safety<br>• works for a European National Service Provider |
| Manager of an ATM R&D team | • expert in process reorganization and innovation in the ATM system<br>• works for a European National Service Provider |
| Head of the research unit | • expert in Innovative Systems<br>• works for a European National Service Provider |
| Senior Researcher | • expert in communication, navigation and surveillance<br>• works for a research unit of a European National Service Provider |

## 6. Data Analysis

In our analysis we have identified five of the most significant key elements that characterize decision processes within ATM systems and which may influence the infrastructure (in)visibility.

The key elements that affect the decision processes in ATM are related to:

1. the actors involved
2. dealing with the problem/issue that is the subject of the decision
3. solving the conflicts during a decision process
4. drive the decision process
5. the type of decisions.

Each of these elements has been analysed in depth and various analytical categories have been unveiled.

In the following part of this section, we describe each of these elements and then outline whether and to what extend these elements affect the (in)visibility of the ATM infrastructure.

### 6.1. The actors involved

Within any ATM system a huge number of practitioners (actors) interact; they usually act in very different roles requiring different competences, knowledge, and skills.

As explicated during the interviews, actors play different roles while dealing with decision-making processes. Consequently, ***"playing a role"*** can be considered a category, in particular when a decision is taken.

All the actors play a role in the decision process depending on:

- the position they have within ATM. (Are they actors directly involved in the decision process? Do they have a powerful position? Are they able to impose a choice on the others?).
- the situation they encounter while participating. (Are they actors indirectly involved in the decision process? Are they affected by others' decisions?).

In the last interviews, it emerged that conflict may occur between the ATM experts and the coordination role of each company. For instance, when a strategic decision that affects the sector is taken by experts, the actors playing the role of company officials or responsible coordinators should authorize the taken action.

The role played by each actor during any decision-making process is inevitably influenced by his or her motivation and level of engagement. Therefore, the second category which emerged is that of ***"actor engaging"***.

From our interviews, two types of actors are key players in any decision:

- actors who are actively engaged in the decision processes are also responsible for the changes in the infrastructure.
- actors who are passively engaged in the decision because they are affected by it (e.g. passengers).

The role played and the type of engagement are, however, closely related to the type of existing organizational culture within the ATM system. In other words, this means "***doing culture"*** and that whenever actors take a decision, they have to take into consideration the effects on all other actors. This is evident when reading one of the interviewees' words.

*"There must be a proactive debate among the various actors around the table and there must be no hypersensitivity. This is part of a culture, which means creating a solid organizational culture […]"*

Actors belonging to different organizations take decisions on the basis of various set of skills, personalities and knowledge, procedures, and organizational culture. As a consequence, to attain a common decision, actors need to compare their ideas, negotiate, and express their power.

### 6.2. Dealing with the problem/issue

The problem/issue that is the subject of decision-making often appears as a set of unresolved secondary and often subjective issues that contaminate the real problem of the decision. For this reason, a decision process can be done in a very long term, and should involve various actors with different views and approaches. If the problem is too complex, it should be subdivided into smaller problems. According to an interviewee, before making any decision, the problem/issue must be "objectivized".

The category ***"objectifying the problem"*** can be well represented by referring to the words of an interviewee:

*"[…] first of all the presentation of the problem. It must be presented in as objective a way as possible, because usually the problem comes contaminated. […]"*

Again, as revealed in the interviews, knowledge has to be cleaned to clearly represent a problem or an issue at stake. In other words, the problem is usually described according to the expert's point of view, but in order to make a more objective decision, involving various actors, the problem should be clearly described using common language and common values.

From the interviewee language, the problem now is "decontaminated information" that allows decision makers to better identify the best among all the alternatives. Objective information allows better evaluation of the impact of the alternatives on the infrastructure while preventing political games or interests to influence the decision.

Only in the case where specific knowledge is required to better understand the consequences of the decisions can it be taken into consideration; in some cases, specific knowledge is required to better represent the whole organizational and inter-organizational system.

For instance, if the decision concerns the security system, but the whole system is affected by any other perspective, expectation and political power, it should be "cleaned up". This can be done by eliminating or underestimating the non-relevant information and connection, thus focusing only on security as the main object of the decision processes.

### 6.3. Solving the conflicts

Conflicts may occur during decision processes for different reasons such as conflicting interests and motivations, and gaps in the process. According to one interviewee, a common reason for conflicts is having "contaminated information" which may bias actors working in favour of a specific interest. In an objectivised problem, actors are forced to deal mainly with their own expertise. The conflicts may be solved through negotiation at various levels of abstraction; a political level (more strategic) or operational manner (more connected to procedures). One interviewee stated:

*"[…] when you cannot act on the human being because he is stubborn, then you must act on procedures and then negotiate a common position. […]"*

Variables that affect negotiation have been studied by Beersma et al. (2002) who defined:

- structural variables which refer to the configuration of the negotiation task
- procedural variables which refer to the rules that determine the course of actions in the negotiation dynamics
- motivational variables which refer to emotions and incentives that lead negotiators towards a certain course of action.

These variables can also be detected in the interviews. An interviewee stated that, in case of conflict about a change, the decision makers have to consider various elements while reaching a common decision:

- the actors themselves (motivational variable): decisions may affect actors when this does not imply much conflict
- the procedures (procedural variables): decisions may affect the flow of the procedures as a way to bypass conflict and force innovation
- the artefacts (structural variables): the design and choice of new artefacts may also be an option to minimize or bypass conflict.

*"[…] organizations, as long as they are small [...] are simple enough, right? One person had the role of [...] administrator ... As it grew [...] the interactions became complicated, but [...] there is always the possibility of simplifying the model [...]"*

Within the ATM system there are heterogeneous actors involved in different organizations and when a decision has to be made, a situation where different powers and roles conflict can be created. When it is impossible to have a dialectic process and the conflict among organizations cannot be solved, the presence of a neutral actor that drives the whole decision is needed.

*"[…] There must be the master in command. When an unforeseen problem occurs that has an effect on a decision or obstacle. […]"*

### 6.4. Drive the decision process

As described above, ATM is a complex system, populated by actors from various organizations, with different interests at the political, managerial, and even operational level. A decision may affect the balance within the system and favour the interests of one side or another. In this complex system, the above-mentioned elements are entangled with power, interests and social motives and drive decision processes.

In the decision-making process we have identified various elements, the first being "***exercising power and motivating socially"***.

Power can be exercised in different ways. As mentioned by Thompson (1967), a coalition of power pressurizes an organization to take a specific decision. Therefore, an organization is forced to adopt a solution instead of another because the coalition of power provides or omits information.

*"[…] high-level managers, who [...] maybe out of interest, do not want to pass on that information rather than something else. […]"*

The upper levels of an organization take a decision that the other subalterns should accept. However, social motives seem to play a prominent role, especially related to the themes of reputation, confidence and trust within any hierarchical structure.

For this reason, another category identified is ***motivating socially***.

*"[…] We say that making a decision involves a responsibility. So anyway, if it is a decision that has positive effects, which is chosen and accepted as a right decision, it also creates you a reputation ... That is, it is the basis for creating a better reputation […]"*

When a decision-maker takes a decision within a social group, he/she inevitably builds a reputation. This can be positive or negative depending on whether the decision taken was right or wrong. However, to assign the final decision to a subject (whether it be an organization or a single individual), you must have confidence in it.

*"[...] confidence and trust, let's say. These are very important elements. [...] on*

*the airplane because you have confidence and trust in the company because it has a history, [...] also in the pilot who somehow [...] because you have confidence and trust in that person. […]"*

### 6.5. Type of decisions

The analysis of the collected data allowed us to highlight three levels in which decisions are made, namely operational, managerial and strategic.

- The operational level deals with the daily management of any air traffic action, and decisions are made in real-time on an emergency basis. The category identified is defined as ***managing the emergencies***.

> *"[...] When an adverse event occurs, the reaction must be measured, attentive and politically well-addressed and managed. On the other hand however [...] the first thing that generally happens in the service providers is that immediately the core business, that is who handles the operations, feels blamed [...] what to do is say <<look what we identified [...] a problem. Actually you should put this kind of action into play so that this event does not happen again>> […]"*

Emergency management should therefore be proactive, while in most cases the management culminates with the guilt of the single individual leader in the area where the event occurred. The managerial level deals with all the technical changes that may occur during a revision of ATM procedures, such as the introduction of new technologies, protocols etc. The changes are usually planned and are based on in depth technical and specialized knowledge shared in national and multinational projects. Thus, we identified a category called ***changing procedures***.

> *"[...] choosing an implementation rather than another, impacts some stakeholders rather than others. And then [...] it's clear that this is a decision that needs to be taken into account for the community, and for all partners. There is an impact, ... then they will eventually make decisions by considering all these aspects and will make a decision that could also be a policy, i.e. not just based on the economic aspect […]".*

Changes in complex organizational systems must necessarily take into account a

variety of aspects; those linked to the actors involved (particularly stakeholders), those related to the economics and, no less important, those linked to the political elements.

*"[…] If I need to change a procedure at an airport, I have to start the process according to the safety management system I have created, where on top there are many actors who do not have an active role and yet are there to evaluate what you say. […]"*

Often changes, even those planned, involve people at the top of the organizational hierarchy who, although without an active role, nonetheless evaluate the whole change.

The complexity of any change within ATM entails the involvement of different skills, roles and powers.

The strategic practices deal with the adoption of policies, norms and regulations at national and international levels. The category identified in this level is ***crossing the boundaries***.

ATM is a system that must necessarily overcome the boundaries because, to put it in the words of an interviewee,

*"[…] you can start from a two kilometre track and go everywhere [...]"*

For this reason, every decision must necessarily take into account different contexts across national and international boundaries.

*"Especially in a context like ATM, I cannot, in my opinion, make a decision only for national boundaries, because the space user is international. There Ryanair, British Airways, Europe ... ones from around the world, so surely must be the result of international harmonization, and so the decision is obviously gained with campaigns, with studies, with international research. So then, to be sure that everyone goes the same way, the decision is fixed by international laws."*

## 7. Discussion on infrastructure (in)visibility

After illustrating the key elements of decision making within the ATM system, we

identified five types of key evidence that in our view affect the (in)visibility of the infrastructure; these are described below.

### 7.1. Evidence 1: The actors involved

The actors directly involved in the decision process have a major role in making the infrastructure visible because, through the negotiation of interests, power and strategies, they reveal the infrastructure underlying the entire ATM system and, more specifically, at the basis of the planned change.

The element that mitigates this process of negotiation is the organizational culture; when various actors share the same organizational culture, the infrastructure is less visible and changes are usually less radical. On the contrary, when each of the actors involved in the decision process takes into account the interests and opinions of the others, their organizational culture will facilitate the visibility of the infrastructure.

A less relevant role is covered by passive actors, who are only indirectly involved in the decision process because, while not participating in the negotiation, they are affected by the changes (e.g. because the infrastructure change makes the flight faster).

### 7.2. Evidence 2: Dealing with the problem/issue

Objectifying the problem/issue underlying the decision means to make the interpretations of the problem by the various actors involved in decision process, as well as the interests that guide the different interpretations, no longer "transparent" or "taken for granted", but visible. This objectification will also make the infrastructure visible.

In a complex system, the process of objectification is always tricky. In most of the cases, designers tend to force actors to use a common, unique language, which represents a unique point of view. As described by the interviewees during the second workshop, the actors involved in the decision process need to use their own language and knowledge representation in order to better understand their inner needs. As a result, the language is coherent with the infrastructure underlying the expert decisions.

In order to obtain a common decision, boundary languages and artefacts are shared among actors: the latter can be considered building blocks of a common infrastructure.

### 7.3. Evidence 3: Solving the conflicts

The dynamics of resolving conflicts during a decision-making process seem to affect the visibility of the infrastructure at least in two ways:

- the interests of individual decision makers sitting at the table during negotiation emerge and become visible.
- if any action cannot be imposed on the actors to reduce the positions and interests of each, then action can be levied on the physical world and therefore on procedures and individual artefacts.

Common procedures imposed on actors usually reveal the discrepancies in the new/shared procedure and the existing infrastructure, making it more visible.

### 7.4. Evidence 4: drive the decision process

Exercising power and relying on strong social motives encourage individual stakeholders to make a decision and choose one solution rather than another. In other words, these drivers affect the changes making the infrastructure visible by highlighting the limits and potential benefits of change for individual subjects and for the entire ATM system. Furthermore, the power exercised and the social motives play an important role in the definition and articulation of the future infrastructure because, once powers and social motives become invisible since they are taken for granted, the infrastructure will also become invisible and taken for granted.

### 7.5. Evidence 5: the type of decisions

Depending on the type of decision, the visibility of the infrastructure will emerge during a planned change.

Operational decisions do not affect visibility because they concern unplanned changes which often emerge from unforeseen situations.

Strategic and managerial decisions, on the other hand, help to make the infrastructure visible because they concern two key elements of the infrastructure itself:

- procedural changes
- crossing the boundaries and thus the role of standards and national and international rules.

## 8. Conclusions and future work

The focus on decision-making processes as units of analysis has two main implications in terms of both infrastructural changes and (in)visibility. First of all, this approach allows us to understand the organizational change based on the elements that make up the organization itself (personnel, artefacts, environment and context). Secondly, the decision process could be considered a building block for reconstructing the different trajectories among different elements, objects and actors, and for focusing on the relationships between them (Star & Griesemer, 1989).

In particular, the analysis of the case study allowed us to discover that changes in an infrastructure are highly intertwined with the decision processes. Changes are negotiated during the decision processes and the resulting agreements are crystallized in facts/objects that shape the infrastructural changes. Actors involved in the decision processes attempt to “clean” the information from contamination in order to share the most objective and comprehensive information, to encourage negotiation, and the agreement on facts which will be crystallized (Evidence 1 and 2). Moreover, the relationships that forms the ecology of the sociotechnical system emerges as a result of negotiations among actors and the role they play (even in terms of power) in the decision processes (Evidence 3). This implies the involvement of other actors that directly or indirectly take decisions in order to implement the innovation (Evidence 4).

Decisions about infrastructures go through three levels of decision making (strategic, managerial, and operational) that have different goals (Evidence 5). As soon as an actor introduced the innovation and strategically shared their ideas with policy makers, managerial and operational levels get involved in the decision processes and the infrastructural changes.

Since the research project is still in progress, this work needs further improvements. Activities are in place to gain a more in depth understanding of the interconnections between the infrastructure and each decision level by focusing on refining the insights on authority, influence, and power.

**Acknowledgments**

This work has received funding from the SESAR Joint Undertaking under grant agreement No. 699306 under European Union Horizon 2020 research and innovation programme.

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