

# SOCIOTECHNICAL ENVIRONMENTS

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## **Sociotechnical Environments**

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# Changing Complex Sociotechnical Infrastructures: The Case of ATM

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*The aim of the paper is to analyse the decision processes that are taken to implement a planned change, in a complex ecosystem. As described by various authors in the so called second-generation development of STS theory, decisions are obligatory passage points of any change that affects the evolution of infrastructures. In this work decisions processes are not discrete decisions, but are considered as patterns of exchange and communication which reduce the equivocality of a problematic issue. In particular, we analyse the decision processes carried on by experts in Air Traffic Management (ATM) system and we sketch out whether and to what extent different decision making practices come into play in the adoption of an ATM changes and in the construction of the correlated socio-technical system.*

*As depicted in literature, we take advantage of the case study analysis which allow us to identify the main building blocks through which infrastructures change.*

**Keywords:** Infrastructure; invisibility; decision processes

## Introduction

In this paper, we analyse decision processes used to implement changes in Air Traffic Management (ATM) systems. ATM systems are complex infrastructures aimed at assisting aircraft flights through distinct activities, such as air traffic control, air traffic flow management and other information services. Thanks to the ecological approach, we studied the complex interrelations among heterogeneous elements using both intra- and inter-organizational perspectives.

When a change needs to be implemented in the ATM, different and complex relationships occur and may underline some practices embedded in

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the socio–technical infrastructure shared by the actors. The relationships involved in decision processes affect the practices of actors making (in)visible ATM infrastructure that can be seen as an ecology constituted by interrelated elements that are continuously negotiated.

In this paper we analyse these relationships and their visibility. The analysis is conducted through the interpretation of semi–structured interviews with stakeholders involved in decision processes. In our conclusion, we sketch out whether and to what extent different decision making practices come into play in the adoption of an ATM change and in the construction of the correlated socio–technical system.

The paper is structured as such. The second section describes the notion of infrastructure and its (in)visibility. The third section discusses about invisibility and decision processes. The fourth section introduces the case study. The fifth sketches out some conclusions.

## **Infrastructures and (in)visibility**

Sociotechnical infrastructure might be defined as 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 spanning from interactionism to the workplace studies about infrastructures, emphasizes the importance of infrastructure’s human elements such as work practices, individual habits, and organizational culture (Bowker and Star, 1999; Edwards, 2003; Heath and Luff, 2000; Mongili and Pellegrino, 2014; Star and Ruhleder, 1996; Schmidt and Bannon, 2013). These elements stress on the importance of the relations in an infrastructure. Two important characteristics (Bowker and Star, 1999; Bowker et al. 2010; Neumann and Star, 1996; Star, 2002; Star and Ruhleder, 1996) of the socio–technical infrastructure should be underlined:

- The infrastructure is the result of negotiation among heterogeneous actors.
- Within an infrastructure, people are connected to activities, structures and cognitive elements.

Infrastructure is embedded in stable work practices and become visible when work within or across communities breaks down (Star, 1999; Star and Ruhleder, 1996). Therefore, various studies have analysed the evolution of socio–technical infrastructures. Among others, Edwards et al. (2009) focused on two moments that seem to mark the evolution of the largest infrastructures:

1. Transition: it is the moment in which technical, social innovations and policies previously separated, will bind together to form a new, larger and 'powerful network'.
2. Adjustment: it is the moment in which an infrastructure fits and remodels, without aggregating previously separated elements, but only 'adjusting' them according the organizational needs.

In this line, STS studies have analysed the infrastructure starting from the invisibility concept. This means that the infrastructures are typically embedded in practices, embodied in routines. Therefore, they exist in the background, are invisible and are taken-for-granted by actors who perform routines (e.g. Bowker and Star, 1999; Bowker et al. 2010; Neumann and Star 1996; Star, 1999, 2002).

Socio-technical infrastructure becomes visible when it breaks. For instance, when a server goes down, a bridge washes out, or when a power blackout occurs, the infrastructure becomes very evident for the actors that use it. Therefore, they attempt to create and implement ex-ante and ex-post procedures (such as back-up mechanisms or other emergency procedures) which tend to fix breaks and bugs (Star and Ruhleder, 1996). In very complex systems, it may happen that a change is required by an actor in the system. The actor may push the others to plan changes of their own practices and/or infrastructures according to this new aim. This 'planned change' makes the infrastructure visible allowing actors to take decisions about its evolution. In this paper, we focus our study on this latter situation, in which actors take decisions to change the current ATM complex systems.

## **(In)visibility and decision 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 and Jago, 1988). The essence of each organization is to coordinate diverse contributions and accomplish a goal that could not have been achieved by any of the group members working alone (Maznevski, 1994). A planned change of an infrastructure involves a multitude of decisions about:

1. the infrastructure as the result of negotiation among heterogeneous actors and
2. the interconnections among people, activities, structures and cognitive elements.

As such, the change of an infrastructure is a very complex set of processes, it implies various phases and involves many actors. In other words, it is not an instantaneous process, it requires time and reiterative development. Since the infrastructure supports and is, in turn, inhabited by social and technical elements and relationships, the changes cannot refer only to the technological sphere; rather, they are the result of actors' negotiations on practices, routines, and all the socio-technical elements that compose the infrastructure itself. Among others, Pava (1983) in a second-generation development of STS theory, argued that decision processes are patterns of negotiations used to reduce the uncertainty of a problematic issue. Moreover, decision processes are not individual activities and are not discrete decisions, they are embedded into a cyclic and continuous development.

This implies that the infrastructures tend to be aligned with the planned changes, new practices, culture, embedded knowledge, etc. (Hanseth and Lundberg, 2001).

In the specific case of planned changes, actors take decisions on their interpretations of the infrastructure. In order to do that, they first analyse the infrastructure they see/perceive; secondly, they foresee/plan a change and finally they crystallize the moment in which the individuals enact the direction and shape a change trajectory.

According to Corbin and Strauss (1988) the key elements of this decision process are enclosed in the concept of 'crystallization', which is defined as a process made of two stages. At the beginning actors identify the performances that are not achievable later (where the infrastructure brakes), then they design new practices/infrastructures (Neumann and Star, 1996).

The way in which the foreseen future can be realized depends on the characteristics that the decision process assumes. These can be human and non-human relationships intertwined among heterogeneous elements, and negotiation processes related to power, reputation and trust. In detail, the trajectories of practices and decisions converging to the crystallization point allow the identification and implementation of new changes (Neumann and Star, 1996).

In this work, our focus is to study how the infrastructure is made visible, changes are planned, and decision are taken, in the specific case study of the Air Traffic Management.

## **The case study: the sectorless Air Traffic Management**

Air Traffic Management (ATM) is the whole ecology of systems that assists the flight of an aircraft: departing, cruising, and landing at an airport (Duong et al., 2002). According to the European Organisation for the Safety of Air Navigation (EUROCONTROL) – the international organisation managing and controlling air traffic across Europe – ATM is made of three distinct activities:

- *Air Traffic Control*: the process by which aircrafts 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 to airspace users. These include information on safety, navigation, technical, administrative and legal matters.

Since it has to deal with flights safety, the ATM is driven by strict national and international regulation. Furthermore, technical competence of the actors plays a strong role in the sector, as security of flights must be guaranteed.

ATM is a complex ecology of actors such as:

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

Traditional air traffic control is based on geographical partition of the airspace, indeed control sectors. Each airspace passing through a sector is controlled by a specific organization. Figure 1 shows an example of the traditional sectorized control system applied to Germany (DFS, 2016).

In order to assess the feasibility of this concept, scholars have focused on several operative aspects of the sectorless scenario over the last decade, such as changes in the controllers' tasks, the procedures of aircrafts

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

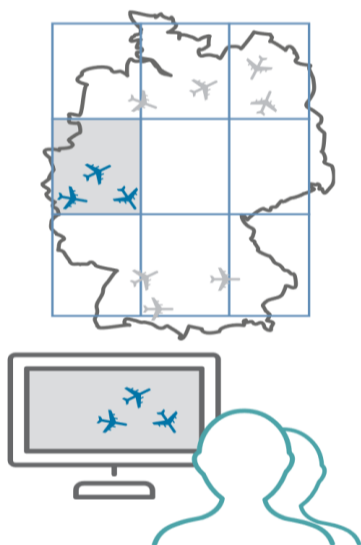


Figure 1 Sectorized control scenario  
(Source: DFS, 2016).

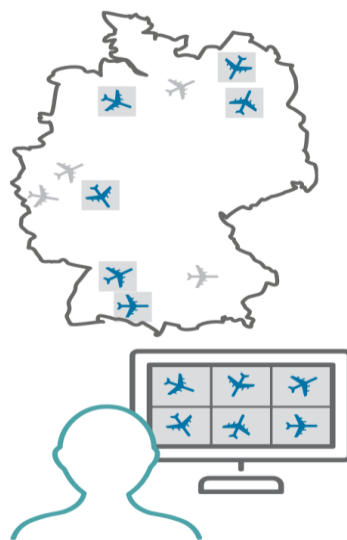


Figure 2 Sectorless control scenario  
(Source: DFS, 2016).

The sectorless scenario is said to offer significant improvements while addressing the main bottlenecks of the traditional sectorized approach. The main improvements are (Birkmeier, Tittel and Korn, 2016):

- Higher number of traffic. The system is able to control a bigger 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 flights meaning less fuel and less travel time.
- Single point of contact for pilots. When entering a sectorless area, pilots have a unique controller to talk with.

Since the sectorless scenario is a complex innovation, its implementation lasts for several years: its real implementation is set to become gradually operational from 2020/2021, meaning more ten years since the initial exploration of the notion by a national control provider. The technical and procedural innovations of the scenario bring many changes within the sector; in this sense, actors should take decisions in order to plan and

implement the changes of the infrastructure and its interconnected practices.

## Research method and discussion

To study the introduction of this change we performed semi-structured interviews and a workshop with international experts during Spring–Summer 2016 (PACAS, 2016):

- 1st phase: interview with 3 experts in May 2016;
- 2nd phase: workshop with 5 experts in July 2016.

The goal of this activity was to identify the most important categories of an ATM decision process. The analysis of the interviews allowed us to identify four emergent categories:

1. the type of activities and information in decision process;
2. the actors involved;
3. how to solve conflicts during the decision processes;
4. the types of decisions.

In the following, we briefly describe the most interesting evidences for each category.

### *Evidence 1. Activities and information in decision processes*

The actors of the ATM face the need to clean the information from contaminations. In other words, the information should be represented and reported in the most objective and comprehensive way. The analysis of the interviews shows that this is necessary for three main reasons.

This excerpt of expert person n. 1 summarizes the most significant activities and type of information that characterize a decision process:

EP1: '[...] first of all the presentation of the problem. It must be presented in a way *as objective as possible*, because usually the problem comes *contaminated*. [...]'

First, knowledge has to be cleaned to clearly represent a problem or an issue at stake. Usually decision makers represent situations from their point of view. This might not represent or over-represent a problem issue.

Second, decontaminated information allow to better identify possible alternatives. Indeed, knowledge which is represented from one of the points of view of the decision makers, might not be useful to represent all available alternatives.

Third, objective information allows to better evaluate the impact of the alternatives on the infrastructure while preventing political games or interests to affect the decision.

### *Evidence 2. Actors in decision processes*

Interviewed persons state that the impact on all types of actors is being considered when taking decisions.

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

- the position they have within the ATM (are they actors directly involved in the decision process? Do they have a powerful position? Are they able to impose a choice to the others?);
- the situation they encounter while participating (are they actors indirectly involved in the decision process? Do they suffer the decision process?).

From our interviews it emerges that two types of actors are very relevant in any decision for ATM:

- Actors that are actively involved in the decision processes are also responsible for the changes of the infrastructure;
- Actors that are passively involved in the decision because they are affected by it (e.g. passengers).

Whenever actors make a change, they have to take into consideration the effects on all other actors.

### *Evidence 3. How to solve conflicts during decision processes*

Conflicts may happen during decision processes because of different reasons. A reason described by an interviewee is referring to the 'contaminated information' which may push actors working in an 'interested' way. As said, above, this may also shape the definition of alternatives and the evaluation of their impact. The conflicts may be solved in a political or operational manner. For instance, EP1 says that:

EP1: '[...] when you cannot act on the human being because he is stubborn, then *you must act on procedures* and then negotiate a common position.'

Interviewed persons state that, in case of conflict about a change, the decision makers have to consider various elements while reaching a common decision:

- the actors themselves: decisions may affect actors when this does not imply much conflict;

- the procedures: decisions may affect the flow of the procedures as a way to bypass conflict and force innovation;
- the artefacts: the design and choice of new artefacts may also be an option to minimize or bypass conflict.

#### ***Evidence 4. The types of decisions***

Information, actor and conflicts spread over various decision levels.

These are three:

- The operational level deals with the real management of any air traffic action, and decisions are made in real-time on an emergency basis.
- 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 an in depth technical and specialized knowledge shared in national and multinational projects.
- The strategic practices deal with the adoption of policies, norms and regulations at national and international levels.

The analysis of the decision processes allows us to understand how the infrastructural change spread all over the system by focusing on all the elements that compose the organization itself (human, non-human, environment and context). Furthermore, the analysis of the decision process allows reconstructing the role of different elements, object and actors in shaping the trajectory of the planned change.

## **Findings and future work**

The adoption of a sociotechnical approach has two main implications in terms of organizational change and decision process analysis. First, this approach allow us to understand the organizational change focusing on all the elements that compose the organization itself (human, non-human, environment and context). Second, the decision process could be analysed as a process by reconstructing the different trajectories among different elements, object and actors and focusing on the relationships among these elements (Star and Griesemer, 1989).

In particular, the analysis of the case study allowed us to identify that changes of an infrastructure are highly intertwined with decision processes. Changes, also, are discussed during the decision processes and the results are crystallized in facts that shape the change itself. Actors involved in the

decision processes, attempt to 'clean' the information from contaminations in order to share the most objective and comprehensive information which is crystallized in facts (Evidence 1).

Moreover, the relationships that forms the ecology of sociotechnical system emerges as a result of negotiations among actors and the role they play (even in term of power) in the decision processes (see Evidence 2 and Evidence 3). In the sectorless scenario, the innovation was initiated by DFS (Deutsche Flugsicherung GmbH), the German control provider and its real implementation is set to become gradually operational from 2020/2021. This imply the involvement of other actors that directly or indirectly take decisions in order to implement the innovation. Time is also required to reduce conflicts (Evidence 3).

Decisions about infrastructures go through three levels of decision (strategic, managerial, operational) that have different scopes (Evidence 4). As soon as an actor introduced the innovation and strategically shared the idea with other policy makers, managerial and operational levels get involved in decision processes and infrastructure changes.

Since the research project is still in progress, this work needs further improvements. Activities are in place in order to have a more in depth analysis of the interconnection between the infrastructure and each decision level; in particular, research is focusing on refining the insights about authority, influence and power on the decision levels.

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