Science, Technology & Innovation Studies Vol. 2, Nov. 2006

ISSN: 1861-3675

STI Studies

www.sti-studies.de

Modes of Governance of Hybrid Systems. The Mid-Air Collision at Ueberlingen and the Impact of Smart Technology

Johannes Weyer (University Dortmund)

received 27 June 2006, received in revised form 30 October 2006, accepted 20 November 2006

Abstract

The paper deals with hybrid systems, where human actors and non-human agents meet and interact. Different from most of the literature on autonomous technology, which mainly deals with the question of agency of non-humans, the paper puts forward the assumption that the release of smart technology may lead to a deconstruction of order or even a regime change, thus raising the question of how order emerges in hybrid systems. Discussing different sociological concepts, the paper identifies two modes of governance: central control and decentralized self-organization. However, smart technology allows implementing different system's architectures, some of which may go beyond this traditional distinction. Referring to a case study on collision avoidance in aviation (and especially the mid-air collision at Ueberlingen in 2002), the paper shows that hybrid systems create new opportunities, but entail new risks as well. The release of smart technology seems to intensify well-known problems of automation, especially when systems get out of control. Aviation is one of the societal fields, where experiments with new modes of governance currently take place that combine features of central control and decentralized self-organization.

1 Introduction: The problem of (social) order

Modern knowledge societies find themselves in a situation that may turn out as the threshold of a new era, which is constituted by a new relationship of man and machine, of technology and society. Smart agents are now being released in large numbers into the real world, which are stupid compared to human beings, but can generate "intelligent" behaviour if they are interconnected to large networks. Smart technical agents meet human actors more and more frequently, and they interact and coordinate their actions. Artificial societies emerge and mingle with human societies. Hybrid systems come into being which are constituted of human and non-human decision makers.

Sociology has reacted to this phenomenon in different ways: Bruno Latour and others raised the question of agency of non-humans and proposed a symmetric ontology (cf. Latour 1998). However, the primary focus of Latour has always been the claim that non-humans have to be accepted as equal ranked co-players, disregarding the question of the specific features of the interaction of humans and (smart, autonomous) non-humans in distributed systems – and whether it differs from other types of interaction. Other researchers in the fields of "artificial societies" (cf. Epstein/Axtell 1996, Macy 1998) and "socionics" (cf. Malsch 1997, Kron 2002) have tried to utilize their knowledge of human societies and to transfer it analogously to artificial societies in order to create more realistic designs of multi-agent systems that – conversely – help to better understand how social order emerges out of the interaction of utility maximizing agents. Despite of many insights about the functioning and especially the dynamics of distributed systems, the obvious shortcoming of this kind of research has been that it is not suited to explore the interaction of real humans and artificial agents.

Thus the question remains unresolved, how orderly structures emerge in hybrid systems, which consist of human actors and non-human agents. Referring to *human* societies, the term "social order" typically implies

- the existence of various self-interested actors (thus establishing the need to regulate the processes of interaction and exchange by some kind of rule-set),
- a mechanism of the generation of mutual expectations and trust as a base of cooperation, and finally
- the sedimentation of proven patterns of interaction in the form of stable societal institutions which serve as constraints and generate a kind of momentum as well (cf. Esser 1993, Weyer 1993a, Schimank 2005).

If we refer to *hybrid* systems, many questions still are unresolved, e.g.

- how interaction works, if actors and agents are involved (and, besides, if we are allowed to apply the term "interaction" to these processes at all),
- how a certainty of expectation can be achieved, which is – referring to Uwe Schimank (1992) – an inevitable prerequisite for strategic action in modern societies, and finally
- how rules, norms and even institutions emerge in hybrid systems, that guarantee a certain amount of integration and stability and make possible the governance of this new type of systems – in a way that avoids risks and allows for a safe conduct of operations.

Referring mainly to the third item, the following paper will show that smart technology allows for creating hybrid systems, which offer the opportunity of a regime change (in aviation and in other large technical systems as well) by deconstructing the old order and establishing a new order that entails a new mode of governance. Additionally, hybrid systems seem to open up *differ-*

ent options to go beyond the traditional distinction of the two well-known governance modes: central control and decentralized self-organization. Hybrid systems create new opportunities, but entail new risks as well. Aviation is one of the societal fields, where experiments with new modes of governance currently take place.

1.1 Preview of chapters

Chapter 2 of the paper sketches the research on smart technology and hybrid systems and tries to identify different arguments in the analysis of the interaction of man and smart machines. One thesis that can frequently be found in literature is the assertion that the introduction of smart technology increases uncertainty and risk, leading to a *deconstruction* of traditional patterns of social order (chapter 2.1). These tendencies mostly are related to a new type of distributed systems, which are able to generate practical solutions by means of self-organization in decentralized networks, thus establishing a new kind of autonomous technology (chapter 2.2). This issue has been integrated into a sociological theory of distributed agency by Werner Rammert and Ingo Schulz-Schaeffer (chapter 2.3). However, they did not deal with the creation of order which is at the centre of this paper. In the work of Gene Rochlin some hints can be found concerning the management of complex systems, leading to a classification of types of order. Thus the question can be raised, whether smart technology facilitates the *construction* of new modes of governance of complex systems, which go beyond the traditional distinction of centralized control and decentralized self-organization (chapter 2.4).

Referring to this state of the art of research on smart technology chapter 3 presents a case study on the Traffic Alert and Collision Avoidance System (TCAS) – one of the first cases of a hybrid system that failed and contributed to a catastrophe in aviation in 2002. The invention and introduction of TCAS can be regarded as the transformation of the traditional, hierarchical system of air traffic control (ATC) and the creation of a new type of order in aviation. The paper presents insights into the operational logic of TCAS (chapter 3.1), especially into the interplay of human actors and non-human agents (chapter 3.2) and then analyses in a Perrow-like style the causes of the mid-air collision near Ueberlingen in 2002 (chapter 3.3).

Chapter 4 first asks, if the debate on "pervasive computing" may serve as a framework even for the analysis of TCAS (4.1), and then tries to answer the question of whether modern aviation can be regarded as a hybrid system of distributed agency (4.2). It then summarizes the argument of the change from the old regime of centralized control to the new regime of decentralized self-organization more systematically (4.3). Chapter 4.4 finally outlines the perspectives of future aviation that go beyond this distinction, leading to a short conclusion (chapter 5).

2 Smart technology and hybrid systems

2.1 Pervasive computing

In aviation, in road traffic as well as in many other sectors of society we can presently observe a new type of technology emerging which differs to some respect from the (automation) technology of past decades. It has been labelled "pervasive" or "ubiquitous computing". The visions of the engineers suggest that in future a large number of smart, embedded agents will monitor and control our actions and help us to manage our everyday life ("smart washing machine") or dangerous situations e.g. in traffic ("smart assistant systems"). These agents may become more and more autonomous, thus displacing the human decision maker.

Referring to Marc Weiser, who first outlined the vision of ubiquitous computing in 1991, Friedemann Mattern (2003) describes the vision of a world, which is inhabited by miniaturized, sensor-equipped devices that have the capability of context-awareness, i.e. they can observe their environment and can react to a change of certain parameters (such as light, temperature, speed, distance etc.). These smart devices are part of almost any object (desk, window, door, coffee machine etc.) and can communicate the collected data with other parts of the system (cf. TA-Swiss 2003b).

According to Mattern and others, a large number of pervasive smart objects will observe the movements and actions of all people involved and check them according to predefined patterns.[1] These smart devices are omnipresent, but they are disappearing at the same time – they become invisible to the user (cf. Weiser 1991). In future no human being will be forced to operate a computer interface any more (like a computer keyboard, a touch pad or any adjusting lever e.g. for the central heating), because all the smart objects around observe their environment and act according to pre-programmed routines, e.g. switching on the light when you enter the room.

However, many proponents of smart technology also have identified considerable *risks*, since smart objects allow for an identification and localisation of mobile objects and people, thus raising questions about data protection as well as about abuse of these systems for surveillance by totalitarian organizations (Mattern 2003: 14). This conflict seems to be irresolvable, because if you strengthen data protection by inhibiting the hidden exchange of data, the performance and the efficiency of the systems will diminish and vice versa.

Mattern points at a large number of unresolved questions, which – according to his opinion – have to be solved urgently, if modern societies want to exploit the potentials of the new technology. One cause of concern is the possible loss of control, if smart objects become disloyal. Another question is the degree of autonomy of smart objects. A further serious problem is the erosion of trust, which emerges for example by dynamic pricing in the internet or by the dynamic adjustment of the (mostly) virtual environment (cf. Skiera 2000, Mattern 2003, TA-Swiss 2003b).[2] Trust is a central feature of modern societies, because – as Uwe Schimank argues (1992) – strategic actors can only execute goal-oriented action if there is at least some sort of certainty of expectation, i.e. a (mutual) expectation that other actors will behave in a predictable way that has emerged as a result of previous actions and interactions. Furthermore said certainty of expectation allows for individual and organizational learning and thus is – in addition with goal-oriented action – one major precondition for societal development. In a world without trust social relations will erode and societal development will slow down or even grind to a halt.

In a world of smart, adaptive things the objects are no longer stable and resistant, but soft and fleeting (cf. Hubig 2003). This may result in a number of severe consequences for

[1] The basic underlying technology is Radio Frequency Identification (RFID), i.e. the equipment of people and objects with transponders that submit all relevant data needed to identify and to track a person; cf. Locquenghien 2006.

[2] Mattern (2003) and others such as Langheinrich (2003) discuss the option of a virtual memory which helps finding a path through the real world by providing information about the objects. If each object has its own website, the "identity" of the objects as well as the – virtual – reality we are living in, may change frequently and may be manipulated easily.

human action, because individual (as well as societal) learning is only possible, if you can fail when acting strategically. According to Hubig, in a smart world that constantly changes people are hindered to act strategically, because strategic action implies to take into consideration the boundary conditions of action (the world outside as well as the presumptive actions of other actors), to calculate the probability of success and failure, and subsequently, to adjust the strategy according to the result of the action.

Hubig and other critics of pervasive computing thus emphasize the deconstruction of the traditional order of social life, which has been triggered by the introduction of smart technology. Intelligent systems, as described above, prevent human actors from acting strategically and from learning that way because they try to avoid situations in which the individual can fail (and learn) – by presenting or rather constructing a "perfect" world that shows up according to the system's rules, the user does neither know nor understand.

2.2 Distributed systems

In order to grasp the capacity of smart systems it is necessary to understand the sources of their performance, which differ significantly from previous systems e.g. in automation technology insofar as agency is constituted by the cooperation of distributed components.

Smart systems typically consist of networks of embedded computers, which are equipped with sensors and communication devices in order to collect data and communicate them to other components of the system (cf. Mattern 2003). The singular components of these systems are not intelligent, at least when regarded from the point of view of traditional artificial intelligence (AI) research. They are rather stupid because of lacking computer power as well as missing capabilities to overview the whole situation. The single device doesn't have global information, but the network of "smart" object may develop a remarkable problem-solving capability.

In the last decades the traditional notion of intelligence which mainly focuses on the cognitive capacities and human-like properties of a machine has been replaced by a new concept of intelligence which focuses on the problem-solving capacities of computer systems or rather multi-agent systems ("practical intelligence"). This paradigm shift has among others been promoted by Rodney Brooks. In his book "Flesh and Machines" (2002) he describes his unsuccessful attempts to program a robot that could manoeuvre safely through a building, avoiding collisions with people and objects. All attempts to take into consideration, according to the model of anticipative planning, every possible situation and to supply the machine with a software-based routine to cope with these situations, failed as Brooks shows in his description. It is the simple changes of light and shadow during the course of the day that raise unsolvable problems to a robot of this type (Brooks 2002: 39pp., 52). Every conceivable constellation had to be put down in the memory of the central processor, and it would take several minutes to calculate one single step of the robot. In fact this device would be incapable of solving very simple tasks.

Therefore 20 years ago the idea came up to do without a central processor, to distribute "intelligence" among the different parts ("agents") of a machine and to combine these parts into a multi-agent system (MAS). The singular agents only have little computer power, but they can act autonomously according to their simple internal rules, and – the most innovative feature – they can monitor their environment and thus contribute to a behaviour of the entire system that can be described as adaptive. A MAS robot can very easily move through a building only complying with simple rules of movement and collision avoidance. It is rather the coupling of a number of simple, decentralized agents and not the superior "intelligence" of a centralized brain that makes these systems so powerful. "Intelligence" thus appears as an emergent feature of the network (and its coordinating activities) and not as a given property of the elements (also cf. Weiser 1991: 72). MAS systems can act in real time and they can adapt to their environment. Brooks created small insect-like machines which moved around with an astonishing agility and thus contributed to the emergence of the new research field of "Artifical life", because the behaviour of the machines resembled living organisms. Above all: The performance of MAS was much better than the performance of classical robots constructed by referring to the traditional, "cognitive" AI paradigm (also cf. Christaller 2001).

Since then the idea has gained ground in different sectors of society (e.g. transportation or aviation) that decentralized systems of distributed agents can perform better and help to avoid risks (cf. chapter 3).

2.3 The question of agency

Promoted by Brooks and others, during the last 20 years a new generation of technology has emerged, which can be categorized – according to Werner Rammert and Ingo Schulz-Schaeffer (2002) – as interactive, intelligent and adaptive. This results in implications for the interaction of man and machine, since the traditional instrumental notion of technology no longer applies, if technological devices gain the capability of autonomous decision making. Thus, from a sociological point of view the question of agency of objects arises.

Rammert and Schulz-Schaeffer have made an attempt to answer this question in a way that goes beyond the symmetrical ontology of Bruno Latour (1996, 1998). They raise the question of how technology studies shall deal with technical objects, which behave and interact in a way that resembles social interaction (Rammert/Schulz-Schaeffer 2002: 16).[3]

There are more and more technical systems where intelligent agents assist or substitute the human decision maker (e.g. in modern airplanes, trains or cars, cf. Timpe 2002). The behaviour of a car which brakes automatically in case of danger looks very similar to the behaviour of a car where the action has been taken by a human controller. In many instances we are unable (from an outside point of view) to distinguish human action from non-human action, because the system's behaviour is almost identical. It can only be said, the socio-technical system, consisting of the driver, the brake assistant and other devices, has performed in a way that usually is described as an action, which is based on a decision. Thus, people attribute a more or less strategic behaviour even to non-human agents and technical objects, if they behave in a way that resembles human action (cf. Brooks 2002: 56).

Rammert's and Schulz-Schaeffer's construct a model of "distributed agency between people and objects" (2002: 21), which distinguishes different levels of "agency" that can be achieved either by human actors or by technical agents (43-50):

- causality: the ability to trigger changes,
- contingency: the capability to act in a different way (i.e. choosing alternatives),
- intentionality: the ability to control and to give meaning to the given behaviour.

At the first level there are almost no differences between men and ma-

[3] Bruno Latour never dealt with smart objects, but with representatives of a technology that can also be understood by using the traditional instrumental notion of technology, such as key tags or speed bumps; cf. Rammert 2003.

chines. A dish washer can do its job at least as good as the well-behaved husband. However, to meet the decision which kind of dishes may be put into the dish washer (second level), requires some sort of advanced technology which can for example distinguish different material. Bid assistants at electronic market places or autopilots in modern planes obviously can be subsumed to this category.

The third level is the most complicated one. Rammert/Schulz-Schaeffer avoid a final statement (e.g. on ontological issues) and call for an observation of the societal practices of attribution of intentionality to either people or objects instead (47). They argue that intentionality is not a natural ingredient of human action, but mostly a product of processes of interpretation and attribution. Human beings are used to suppose that someone who acts in the way he acts, has done so because he intended to do so. But nobody really knows, if this assumption of rational decision making is true. The same could even apply to machines. Today we still are not used to assume that a brake assistant acts intentionally, but – according to Rammert/Schulz-Schaeffer – this is a societal practise we should reflect about and not a fixed ontological fact.

Rammert/Schulz-Schaeffer have sketched a new framework that helps to better understand the roles, actors and agents can play in hybrid systems. However, some questions remain. First they do not deal with the interaction of actors and agents as well as the emergence of social order out of this interaction. Their model just integrates non-humans into a framework of agency, which obviously is guided by the concept of equality in character of human actors and non-human agents. This implies that sociology can construct agent societies according to the rules of human societies, taking a similarity of actors and agents for granted.

Second – as a kind of consequence of the first issue – from their point of view the interaction of a human with other humans cannot systematically be differentiated from the interaction of a human with non-humans.[4] Rammert/Schulz-Schaeffer thus cannot put forward the question, if different types of systems and even new types of social order emerge from these different kinds of interaction. They confine themselves to the micro-level of agency, which is important without doubt. However, since they do not treat the problem of social order, they also do not deal with the question, if these new types of hybrid systems are feasible or even desirable.

Finally Rammert/Schulz-Schaeffer do not care about the consequences or risks of hybrid systems and their diffusion in society. Instead, they call for a new approach, which explores the broad variety of distributed agency open-mindedly. Their model thus can be regarded as a neutral point of view which does not care about possible societal risks of hybrid systems, as put forward by the authors quoted in chapter 2.1.

2.4 A new mode of governance?

A more sceptical, pessimistic view is taken by Gene Rochlin, who summarizes the experiences already made by implementing agent systems in different sectors of society. In his book "Trapped in the Net" (1998) Rochlin discusses the "unanticipated consequences of computerization" (subtitle of the book), which is – to start with the conclusion – a fundamental transformation of society. His argumenta-

[4] The still open question, if one should apply the terms "interaction" or "cooperation" even to machines, can be answered here, referring to Rammert (2003: 297), as follows: if technology can change its behaviour according to the given situation – which is level two of the scheme presented above – then it might appropriate to use this term. This concept differs deeply from Latour, who attributes agency to every kind of (technical or natural) object.

tion is based on a number of case studies on the informating of labour, the management of organizations, computer trading, the automatisation of high reliability systems and, finally, on different instances of the implementation of smart technology in the field of the military. His main argument is that in history we can observe a sequence of modes of management of organizations as follows (7p.):

- Hierarchical, centralized control and rational planning (core technology: mainframe computers, period of time: 1950s and 1960s),
- flexible, decentralized self-organization (core technology: personal computer, period of time: 1970s and 1980s),
- central control of decentralized structures by means of networking (core technology: networking of heterogeneous, distributed systems, e.g. via the internet, period of time: since the 1990s).[5]

Rochlin's book deals with the apparent paradox that in the third mode (mode C) the networking of autonomous elements eventually ends up with a total control and loss of autonomy. Road traffic is a good example to illustrate this recent paradigm shift (cf. Spehr 2006): in a first step the singular cars could improve their performance by adding electronic assistants such as the navigation system, which largely increased the autonomy of the drivers, e.g. in finding an alternative route in case of congestion (mode B). As soon as cars become "knots in the net" (TA-Swiss 2003a: 2) which communicate all relevant data bidirectional, a re-centralization and a redistribution of authority takes place (mode C), which in principal gives way even to visionary concepts of the remote control of road traffic, e.g. in order to avoid negative effects such as congestions (cf. TA-Swiss 2003a, Weyer 2006a). This would imply far-reaching interventions from outside and an almost total loss of control on the side of the drivers.

Referring to this partly foreseeable, partly even realized change of the system's architecture and its control logic, Rochlin uses the term "computer trap" (217) to point at the unintended and unpredicted consequences of the implementation of smart technical devices. His main concerns are the foreseeable risks of this development such as the deconstruction of social institutions (56, 208p.) and the growing vulnerability and dependency of society on a kind of technology which can hardly be controlled, but entails unpredictable risks (11, 14, 106, 186).

One would obviously misinterpret Rochlin, if one relates these negative impacts to the character of the technology and nothing else. Rochlin insists that it is the striving for a permanent improvement of efficiency (and the utilization of computer networks to achieve this objective) which causes a development that eventually ends up with a standardization of processes and a subordination of decentralized systems under a central plan (as e.g. in the case of inventory or data warehouse systems). The technological foundation of this type of systems, which operates in a mode of central, anticipative control, is the electronic networking and integration of numbers of elements in real time (mode C). Rochlin uses the term "micro-management" (149, cf. 63), to indicate a strategy of vertical coordination, which intervenes directly at any level by means of advanced IT devices, thus governing every process in the whole organization. Rochlin also hints at the risks of such a development, which are a loss of autonomy and "slack" (63, 213) – i.e. the ability to react to unexpected situations flexibly – as well as "the potential losses of social means for learning, social capacity for adaptation, and social space for innovation and creativity" (213).

[5] In the following the paper will refer to these three stages as "mode A", "mode B" and "mode C" (cf. chart 3 on page 144).

Rochlin apparently is a promoter of decentralized self-coordination (mode B). He argues that systems of this type are able to cope with unexpected situations, because the members of the organization are well-trained in crisis management (cf. Rochlin 1991, LaPorte/Consolini 1991, Krücken/Weyer 1999). Every measure that transfers the decision-making authority to a central control body therefore entails the risk of a fatal error, because the design of a centralized system may entail errors, which finally inhibit the participants to act according to the concrete operational needs in a given emergency situation.

To summarize Rochlin's argument: The new type of smart technology facilitates the emergence of a new mode of governance of complex systems, which goes beyond the well-known types of central control and decentralised self-coordination. "Intelligent" systems give rise to the capability to execute some kind of central control of decentralised systems (mode C), since smart devices can collect large amount of data about the world and the people and integrate them – by networking – into a unique control architecture.

2.5 Summary

If we compare the concept of Rammert/Schulz-Schaffer with the approach of Rochlin, the divergences are obvious. Rammert/Schulz-Schaeffer have constructed a model for an unbiased analysis of hybrid systems (with distributed agency) which still lacks empirical evidence and is open-minded concerning the results of future development. Rochlin, on the other hand, does not take much care of theoretical questions of agency, but has analysed a number of cases of the informating of society which give evidence to the assumption that networks of pervasive smart devices may lead to totalitarian systems of central control which eventually end up with a fundamental transformation of society.

Up to now the debate has been unresolved and the two approaches have not yet been conciliated. But we can take this controversy as a starting point for the analysis of the case study on TCAS (cf. chapter 3). This case shall help to discuss the issue of distributed agency on the one hand and the topic of governance of hybrid systems on the other. It will show that the traditional, hierarchical order of aviation (mode A) has been deconstructed by the implementation of innovative technological systems, leading to a reorganization of air traffic control and an introduction of another mode of governance (mode B), which, however, entails some previously unknown risks. Therefore the question will be discussed, if the new regime of decentralized self-organization in aviation, which is facilitated by TCAS, can guarantee the same level of safety as the old hierarchical system of centralized control. The following chapter 4 will take a look at future developments beyond TCAS that may lead to new combinations of governance modes (mode C).

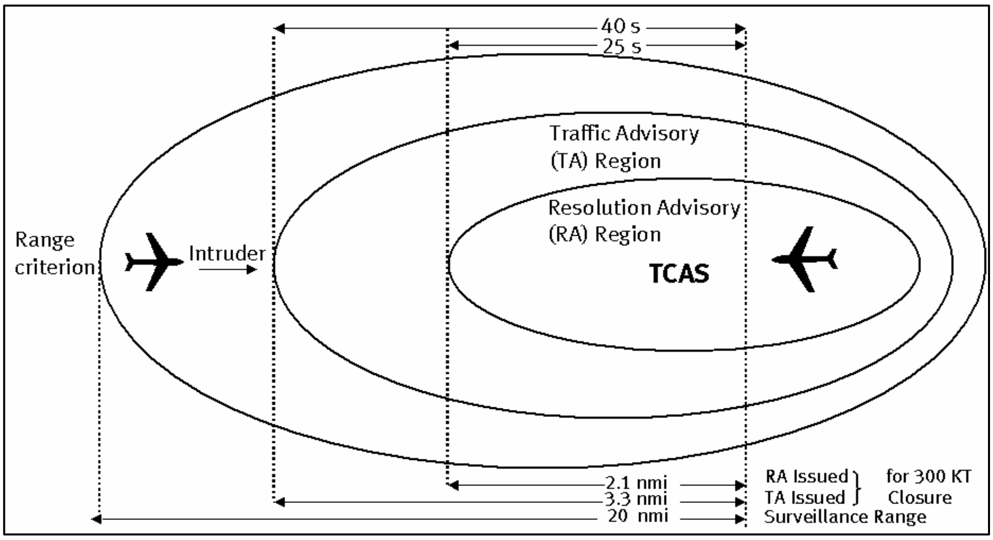
3 Case Study TCAS

In the following section a case study on the Traffic Alert and Collision Avoidance System (TCAS) will be presented, which explores the operational logic of a hybrid system, discusses the challenges and risks and raises some – tentative – questions about different control logics and system architectures. The experiences, which have been gathered with the interaction of human actors and non-human agents in TCAS guided aircraft during the last ten years, are being interpreted in the following as a part of the effort to create a new type of socio-technical order in hybrid systems.

3.1 History and operational logic of TCAS

TCAS is an airborne short-range collision avoidance system which is mandatory equipment of modern passenger aircraft in the U.S. since 1994 and in the European Union since 2000 (Denke 2001, Nordwall 2002). Its purpose is to prevent aircraft from midair collision by warning the pilot when another plane is in a predefined range of about six kilometres (which is about 40 seconds flight time, cf. chart 1). This is especially important at night or when weather conditions are bad.[6]

Chart 1: TCAS – Traffic Alert and Collision Avoidance System
(souce: Mensen 2004: 374)



If a TCAS system detects a conflict situation it warns the pilot ("traffic advisory") and some seconds later issues commands to climb or to descend ("resolution advisory"). If both aircraft which are part of the conflict are equipped with TCAS "they will communicate to avoid mirror-image manoeuvres" (Nordwall 2002).

TCAS thus can be regarded as a distributed system where two (or even three) agents "communicate intentions" (Nordwall 2002) and coordinate their actions autonomously. Even if the pilot finally takes the action, the proposal to act is generated by a set of communicating agents. TCAS is a "foolproof" system, and pilots "have a high regard" (Nordwall 2002) for this device (cf. also VC 1997). Nevertheless TCAS has been one cause among others in the midair collision of a Russian Tupolew Tu154M and a DHL cargo Boeing B757-200 on July 1, 2002 over the Bodensee in southern Germany, killing all 71 passengers aboard. Both aircraft had been equipped with the latest version of TCAS.[7]

Before describing the chain of events that led to the disaster, it is necessary to understand the role TCAS plays in the overall system of aviation safety.

3.2 ATC or TCAS?

The well established system whose task is to avoid accidents in aviation is the ground based air traffic control (ATC). ATC centres are equipped with modern devices – mostly redundant – to detect airplanes far away. They have

[6] For more details see VC 1997, BFU 2004.

[7] The recent midair collision in Brazil on September 29, 2006 might also partly be caused by a malfunctioning TCAS or a gap in the system which arises from the invisibility of a plane that has switched off its transponder; cf. Fiorino 2006.

global information of schedules and current traffic on different flight levels. Moreover they can communicate with the airplanes by radio telephony but also by asking the transponders of the planes to communicate all relevant data. So in an ideal situation the ATC has complete information. The ATC system is a typical example of a *hierarchical, centrally controlled system* which in principle is able – referring to Perrow (1984) – to guarantee a high degree of safety.

However, since the 1960s an alternative safety system has been developed which functions according to a very different logic, which is *decentralized coordination*. TCAS creates a communication link between two (or more) aircraft and so can avoid collisions independently of the ATC ground control. It is obvious that this system can only work reliable, if every aircraft is being equipped with (at least similar) TCAS devices. And it generates questions about the co-ordination of ATC and TCAS which can be answered in different ways – either replacing the ground control by an independent system or finding reliable ways of cooperation of the two systems. One cause of the Ueberlingen accident is the fact that different aviation communities had generated different answers to this question.

The U.S. Standard Operation Procedures (SOPs)

In the U.S. as well as in Europe TCAS is being regarded as an additional short-range "safety net" (VC 1997) that only issues warnings if the ATC systems already has failed (Nordwall 2002). Pilots are being trained to rely on TCAS and to obey its commands strictly in a case of emergency – especially concerning the fact that in these situations there remain only a very few seconds to react properly. U.S. pilots are used to ignore the commands of ground controllers, because they are aware of the fact that in such a critical situation the ATC has imperfect knowledge, since the (decentralised) TCAS systems are not designed to communicate their data to the ATC computer.

U.S. pilots rely on TCAS even if they know that this system has some shortcomings. In the U.S. TCAS had only been mandatory for passenger aircraft with more than 30 seats, whereas the European Union had put the limit to a weight of 15 metric tons.[8] Every pilot flying a TCAS-equipped aircraft therefore must be aware of the fact that there may be some other aircraft, e.g. military or small planes, in the vicinity which are invisible to him (VC 1997).

The Russian Standard Operation Procedures

The Russian SOPs concerning TCAS are very different, since they distrust the system because of its well-known limitations and pitfalls. The Russian logic to cope with situations of conflict between ATC and TCAS was very simple: "In Russia pilots will take ATC's orders *over* the instructions of *any* onboard navigational system." (Venik 2002, emphasis added) Besides the invisibility of some sort of aircraft the reason is, that ATC has "a complete picture of the sky" (ibd.) which is based on redundant systems (TCAS is not redundant). Obviously there is some confusion in the skies and a *conflict between different safety cultures*. This confusion is partly due to the fact, that the two safety systems are not interconnected. There is no feedback that informs the ground controller of the recommendations given by TCAS to the pilots. Such a feedback obviously would help to improve the system's performance and avoid opposing commands. In the current state the conflict must be resolved by the lonely pilot who has to decide – in a very short period of time – to ignore one of the two safety measures the original

---

[8] These rules have been changed and internationally harmonized in 2003 (17 metric tons) and again in 2005 (5.7 metric tons, cf. Mensen 2004: 375).

intention of which had been to increase air transportation safety (cf. Venik 2002). And he takes the full responsibility for his actions – a typical pitfall of automation which apparently cannot substitute for human decision making, but creates situations of human decision making which are much more difficult to solve than before.

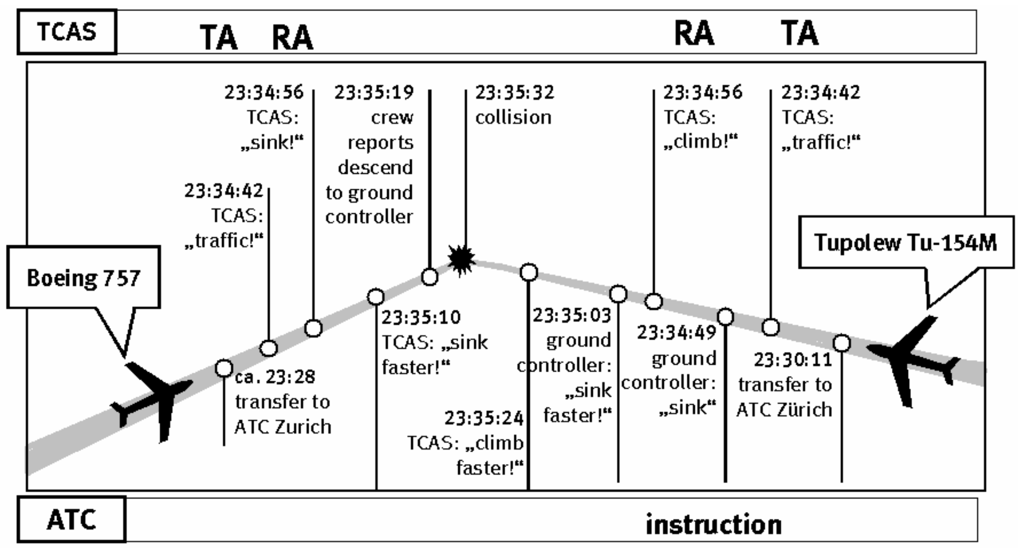
However, the confusion is also partly due to the incompatible operational logics of the two systems: Either you rely on central control and put the responsibility on the controller, who organizes the system's performance by hierarchical governance, or you rely on the problem-solving capacity of decentralized self-organization and distribute responsibility within the system. But you cannot do both at once. We'll come back to this question later.

Now it is easier to understand the Ueberlingen crash, because the crew of the DHL cargo Boeing followed the U.S. SOPs, to obey strictly TCAS, while the crew of the Russian Tupolew was divided on the question which procedure to follow and finally adopted the Russian way which urged them to rely on the ground controller and to neglect the recommendation of the TCAS, which unhappily was exactly the opposite. This conflict, however, could have been resolved, if there had not been an unfortunate concatenation of events which contributed to the dramatics of the situation.

3.3 The Mid-Air Collision at Ueberlingen

The two planes crashed at July 1, 2002 at 23:35:32 at flight level FL 360, which is a height of about 11.000 meters. Both planes had been guided by the ATC at Zurich (Switzerland) where only one controller was on active duty. He had taken over the two planes only a few minutes before, but did only realize the conflict 43 seconds before the collision. When he issued his warnings, the TCAS systems of the two aircraft had already automatically generated their recommendations (TAs and RAs), and the tragedy was that he urged the Russian crew to descend – which was exactly the contrary of the TCAS recommendation (cf. chart 2). Additionally an instructor, who was not familiar with the TCAS system, had taken over the role of the pilot in command (PIC) in the Russian plane, while the other pilot – in normal situations the commander – acted as the pilot flying (PF). After the contrary recommendations had been issued the crew was not only confused about the facts but also had to cope with author-

Chart 2: The Mid-Air Collision at Ueberlingen
(source: Frankfurter Allgemeine Zeitung 20.07.2002: 7)



ity and coordination problems, since the PIC demanded to comply with the commands issued by the ATC, while the PF insisted on relying on TCAS. The rearrangement of the crew (at a night flight!) and the missing comprehension of the TCAS system on part of the instructor were major causes of the subsequent mistake. So the question arises: Was it simply a human error?

Similar to other cases of highly automated systems, modern aircraft are also conducted by people, the main task of which is to monitor the system's operating in the routine mode, were nothing happens for hours and hours. Additionally modern technological systems are designed to prevent the emergency case, which mostly works very well – but with the consequence that unforeseen situations occur only very rarely and can hardly be trained systematically. As in other cases, the investigation of the Ueberlingen crash revealed that the operating procedures for TCAS, issued by the International Civil Aviation Organization (ICAO), were confusing and inconsistent (BFU 2004: 4, 7). At least the Russian crew was not familiar with the system and had only little experience with it.

However, if we take a look at the organization of Skyguide, the operator of the ATC Zurich, and the safety culture of this organization we will find some more factors which contributed to the disaster:

In that night there had been maintenance works at the ATC, which required to partially shut down the radar system. As a consequence the Short Term Conflict Alert (STCA) system – a ground based pendant to TCAS – which warns the controller of an upcoming conflict constellation, was only partly operating, i.e. it could not present the information optically on the screen. However, the controller was not aware of this. Generally, no one at Skyguide knew exactly which effects the maintenance works had on the overall performance of the ATC Zurich. For example the telephone line was out of duty for a few minutes. Evidently there was no awareness that this constellation with a coincide of uncommon events raises the risk and the probability of errors. One possible consequence might have been that the informal practise of a one-man-operation had been abandoned that night.

During the critical period of time (from 23:30 to 23:35) the attention of the unfortunate controller, who later was murdered by a relative of one Russian victim, was distracted by a third aircraft, approaching the nearby airport of Friedrichshafen, he had to guide, too, working at two desks simultaneously at different radio frequencies. A colleague at Karlsruhe airport who also observed the scene and had been alerted by his STCA, could not reach him by phone because the lines were out of duty exactly at that moment. (Remember: The STCA at Zurich airport could not issue an optical warning at that time.) Therefore the controller at Zurich only realized the conflict between the Boeing and the Tupolew a few seconds before the crash. He had to switch abruptly from the routine to the emergency mode (cf. LaPorte/Consolini 1991), but it was too late to find a proper solution because of the parallel working – above described – of two badly coordinated control systems working with opposite operation logics. He suddenly was heavily under pressure and made a number of mistakes: He didn't understand a radio message of the Boeing crew properly (partly because of several simultaneous messages at the two desks), and he didn't register the acoustic STCA warning.

Again: Was it a human error? Or organizational failure (at Skyguide as well as in the cockpit of the Tupolew)? Or was it a system's failure – a failure of a system that must fail because of complexity, of tight coupling, of lax safety cultures with a lacking awareness for risky constellations, and finally of unavoidable inattentiveness in boring night shifts in highly automated facilities and systems?

The following chapter will not deal with these questions in detail, because they can be treated in the framework of the traditional automation debate (cf. Weyer 1997). It will instead pitch on only one of the multitude of causes of the midair collision: the coexistence of two contradictory governance modes as well as the role of smart technology. Thus the question can be put forward, which governance mode is best suited to manage the risks of complex systems.

4 Creating order in hybrid systems

4.1 Smart systems

Modern aviation obviously is a good example for the omnipresence of embedded, sensor-equipped computers, which automatically and increasingly autonomously operate in the background, achieve a remarkable problem-solving capability by networking and generate solutions by the interaction of non-humans. Although it is only a quote from literature, the impression that TCAS systems "communicate *intentions*" (Nordwall 2002, emphasis added) refers to the fact that something is happening in aviation that comes close to the kind of relation we are used to attribute only to humans up to now. Many of the features of "pervasive computing" apply, even if the voluminous and costly TCAS system cannot be compared with a simple RFID chip, and well-trained professionals as e.g. pilots behave differently than non-trained people in everyday life.

However, the TCAS case showed that even in a professional environment smart technology may lead to some confusion and a loss of learning capability, since new uncertainties arise that cannot be solved by learned routines. Often it is difficult for pilots to really understand what happens, and it is equally difficult to learn by experience how TCAS works in an unforeseen situation. Steering a modern airplane means to totally rely on technical devices which construct a virtual picture of the sky that is hardly distinguishable from a computer game as e.g. "Flight Simulator" from Microsoft.[9] Aviation has gained a high level of safety, but with every innovative technology new, uncommon risks arise.

Finally attitudes have changed, since pilots' behaviour more and more can be described as adaptive rather than strategic (cf. Weyer 2006b): even though the pilot sees the intruder on the screen in advance, he is not forced to develop an evasion strategy (if he relies on TCAS), but he can calmly wait for the advisory automatically generated by the interacting TCAS systems. It is almost impossible to guess in advance if the recommendation will be "climb" or "sink", because this depends on a whole string of factors (among others the rank of the IDs of the communicating TCAS computers) the pilot can hardy determine let alone assess. The interaction of TCAS and the pilot thus resembles more a stimulus-response-model than the traditional concept of strategic (inter-)action.

As a result the debate on "pervasive computing" points out to be a valuable context for the analysis of modern aviation.

4.2 The risks of distributed agency

Aviation can also be regarded as a hybrid system of distributed agency. This applies to the meso-level of air traffic control as well as the micro-level of the cockpit. In the latter the (human) pilots and a number of (non-human) assistance systems such as TCAS work together in finding a solution to a given situation: TCAS takes the responsibility for the definition of the situation, the interaction with the other plane as well as the recommen-

[9] Personal communication Burkhard Kruse (Lufthansa) April 7, 2005.

dation of action to the pilot (in a human-like manner of oral speech), whereas the pilot is in charge for carrying out of the action and the supervising and evaluating the whole system (including the meta-decision to rely on TCAS). In many regards smart technology substitutes human actors and "acts" autonomously (e.g. in finding an agreement with the other plane – previously the task of the human controller), but the complete action to evade a critical situation is taken by a hybrid set of human actors and non-human agents, both of whom are responsible for different sequences of the action chain (cf. Rammert/Schulz-Schaeffer 2002).

As far as that goes hybrid systems with distributed agency are a continuation of the well-known path of automation, and they share the risks of many other highly automated systems. At the same time the participation of autonomous technology in decision-making processes contributes to an *intensification* of problems and risks. Operating a plane is routine work with boring monitoring duties that leads to a low level of attention and awareness of risks – especially in systems regarded as self-controlling and inherently safe. In those rare cases of emergency, which mostly take the operators by surprise, an unexpected interaction of system's components produces a situation which is only partly understood and which can only hardly be managed – especially under time pressure, as the Ueberlingen case showed.

However, in an emergency situation the operators suddenly find themselves in a situation where they have to take the responsibility to control the facility (including a number of smart devices). This implies to make very difficult decisions, which emerge because of unfamiliar and previously unknown uncertainties. To some regard we can talk of a dramatization of the well-known automation paradox: the re-entry of the human decision maker, which had been excluded from making first-order-decisions (steering the plane on a climbing or descending path) and now has to make second-order-decisions, i.e. determine if the automation device gives the correct advice or not and if he can rely on its recommendation to climb or to descend.

Hybrid systems of distributed agency tend to intensify the over-reliance on technology, which increases risks solely by the invisibility of the processes and the enormous time pressure. Additionally hybrid systems, which allow for autonomous action of technology and aim at a "perfect" control of the world, run the risk of a loss of competence on the part of the operators, since they try to avoid situations in which the operator can gain experience and learn from experience. Distributed systems of the given type thus have an inherent tendency to turn into completely automated systems – with the human functioning only as a stopgap.

4.3 A new mode of governance

Moreover the case study has shown that the introduction of TCAS has triggered the deconstruction of the established order in aviation, leading to some confusion and irritation not only about the functioning of the device, but also about the rules which hold in the system. It is still an ongoing process of social learning and experimentation which uncovers the limits and pitfalls of the new system architecture. As in other cases of the introduction of a radically new technology, usually an experimentation period of some years is needed, until measures will have been generated to cope with unforeseen situations (cf. Krohn/Weyer 1994, Weyer 1997). However this process must also include the construction of new institutions, i.e. new modes of governance of hybrid systems, which will probably need a longer period of time.

The implementation of TCAS thus can be regarded not only as the introduction of a new device, but as a first step in a *regime change*, which may lead to a fundamental transformation of aviation, since pilots now are able to resolve conflicts in the mode of decentralized self-organization (cf. Deuten 2003). The next step will be a completely self-coordination of the aircraft during the *entire* flight ("free-flight"), including autonomous routing and navigation, which has been developed in the U.S. as a successor of TCAS and is currently tested in daily flight operations in Australia (cf. Hughes/Mecham 2004).

At the moment pilots find themselves in a contradictory situation: their autonomy, i.e. their freedom to act towards the controller has grown, whereas their autonomy to fly the plane has diminished because of the substitution of many actions by smart technology. Despite these uncertainties and only partly determined role conflicts, the introduction of TCAS has started to establish a new order in aviation and a new mode of the governance as well (mode B), which coexists beside the traditional mode of central control (mode A). This may be a cause of hardy resolvable conflicts, as the Ueberlingen case shows, because both modes follow a different operational logic:

Centralized control

In densely coupled traffic systems such as aviation or railway transportation the safety architecture mostly is based on the principle of *global optimisation* (cf. TA-Swiss 2003a). The governance structures are shaped by the top objective of overall system's safety, which is – for instance in civil aviation – realized by giving strict orders to the participants they have to obey. The control architecture intends to guarantee the system's performance and efficiency (with a load factor as high as possible) as well as the safety of operations (with an accident rate as low as possible). Social order thus is superimposed in a top-down-manner by actors which have superior knowledge and are conducted by the goal of maintaining public welfare. Technology serves as an instrument to monitor and to steer the participants of the system.

Decentralized self-organization

On the contrary the concept of decentralized self-organization argues that endogenous processes within a given system lead to good and stable solutions, which mostly cannot be attained by central control, since the external controller doesn't have the knowledge that the participants have. Modern technology such as TCAS enables the user to create solutions for current problems (such as optimizing the course or avoiding collisions) which are doubtlessly superior to the user who operates in a conventional manner. The basic logic here is *local optimisation*, since the singular user mostly doesn't have global information and doesn't take care of the external effects of his actions, but optimises his performance regardless of the consequences for other users as well as for the global system. Social order finally emerges in a bottom-up-manner as the unintended product of the interaction of selfish actors. So this kind of local optimization doesn't need to end with a global maximum (cf. Epstein/ Axtell 1996: 13).

However, if safety is at stake, the argument of the unpredictable emergence of order can also be read from the opposite. Emergence also can imply unforeseeable, undesirable behaviour, especially in the case of smart systems which are designed to act and evolve autonomously (cf. Resnick 1995, Richter/Rost 2004). Air traffic controllers for example are reluctant to accept the new system architecture, because they do not believe that in the future system architecture of "free-flight" a number of ten or more self-coordinating pilots will be able to generate solutions with the same level of safety as in the traditional system, where one person is in charge of the control of the entire system (Hughes/Mecham 2004: 50). This may indicate that we have only little knowledge what happens if self-organized systems get out of control.

The "double trap"

In the present transition period between the old and the new regime, where two modes of governance co-exist, a "double trap" appears:

- On the one hand self-organizing systems are able to create innovative solutions by own means and to generate emergent effects – a performance which hardly can be produced by centralized systems. However, these effects are – according to the concept of unintended consequences (cf. Vanberg 1975, Esser 1991) – unpredictable, which sometimes might also imply: undesirable and uncontrollable. Self-organizing systems may get out of control – with irreversible consequences –, and societies, which rely on them, do not have measures to recapture them.[10]
- On the other hand a central control can integrate the system's elements and coordinate their behaviour in order to avoid or even eliminate undesirable or unintended effects of self-organization and to achieve a global optimum (e.g. safety and reliability). However, according to Rochlin (1998), this kind of control network may be inflexible and even endanger the sources of self-organization and social learning.

Thus, referring again to Rochlin's idea of a third mode, the question arises if other options exist which combine the advantages of those two modes (and help to avoid their shortcomings). Smart technology allows for different options and different combinations to be explored in future. These options will be discussed in the final paragraph of this chapter.

4.4 Paths to future aviation

The future of aviation – here locked upon as a sector, where hybrid systems advance – can be shaped in different ways, extending or restricting the capabilities of human actors and non-human agents, thus constructing different combinations and constellations of hybrid systems (cf. chart 3).

Complete decentralization

One obvious option might be the complete decentralization of aviation, based on a high level of electronic equipment on board of each plane, thus allowing for a decentralized self-coordination in every phase of the flight – as well as a complete dissolution of ATC. (This is actually the "purest" version of mode B.) When TCAS was invented in the 1970s this detachment of the old system had indeed been the guiding vision of many engineers (Venik 2002). Experiments with "free-flight" now carried out in lowly frequented areas in Australia show that this might be one path into the future of aviation. The single planes must be able to locate themselves precisely (via GPS) and communicate all relevant data to the ground station (via ADS-B[11]), but they do so simultaneously to other aircraft in a radius of 250 km, thus allowing for a far-reaching autonomous coordination without intervention of the controller (cf. Hughes/Mecham 2004, Hughes 2005). The first time in the history of aviation the pilot has a complete picture of the sky. The task of ATC thus shifts from control to management and monitoring, while the pilot receives responsibility for navigation, coordination and separation – similar to the situation in the early days of aviation, but now on a high level of electronic assistance.

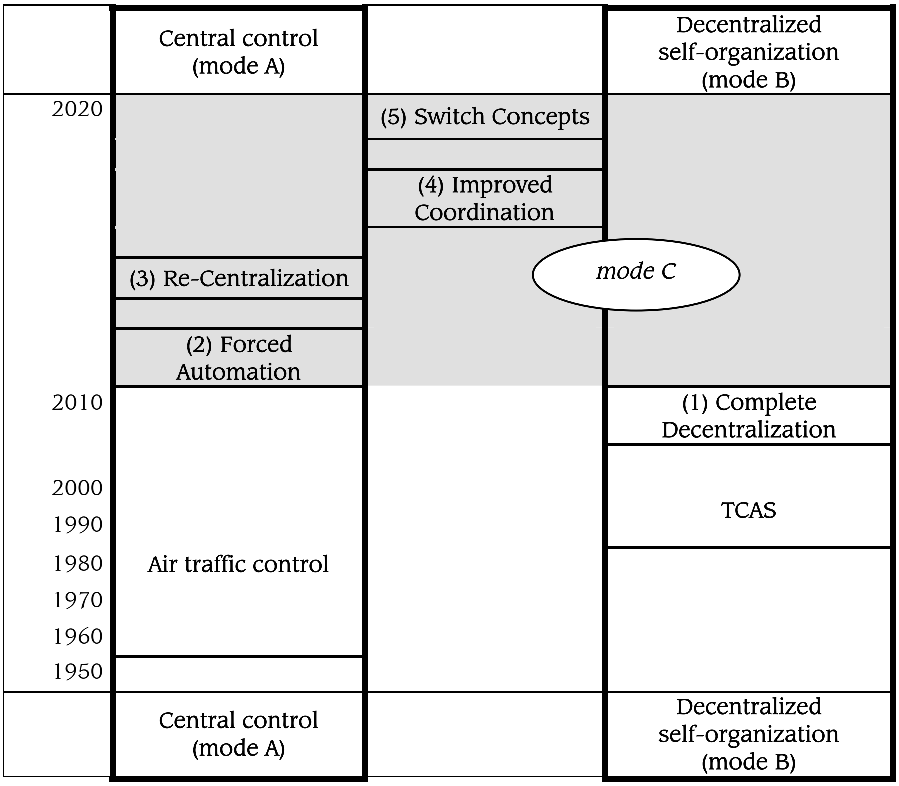
[10] This may be partly due to the lacking theoretical understanding of the mechanisms of self-organization, cf. Greshoff/ Schimank 2003, Richter/Rost 2004.

[11] Automated Dependent Surveillance – Broadcast.

Forced automation

However, a high level of equipment with smart devices could also lead to the complete displacement of the human decision maker in the cockpit (which stands for a major step towards mode C). In the early days of TCAS, the intention had been to directly transmit its commands to the autopilot, but these plans were dropped because of technical problems and a still low performance of TCAS (Venik 2002). The present solution is a half-hearted compromise that leaves room to error, as the Ueberlingen case shows. Thus the next step could be to establish a direct link between TCAS and the autopilot in order to automatically navigate and avoid collisions without human intervention. Even if actually nobody in civil aviation puts forward this proposal, the unstoppable advance of unmanned aerial vehicles (UAVs) in military aviation indicates that this second path is also on the agenda today (cf. Friese/Hein 2004).[12] Experts believe that at least in cargo transport we will have unmanned planes in about ten years, and the cockpit crew of passenger planes will be reduced to only one pilot, who will work as an observer of a completely automated system.[13]

Chart 3: Paths to Future Aviation



However this strategy of automation totally relies on the autonomous action of smart systems as well as their capabilities of decentralized coordination. This is a risk-taking strategy, because the extension of the area of automated decision making only implies that the borderline between humans and machines is being moved. Especially in the case of mode selection someone has to identify, in which

[12] The implementation of unmanned transportation systems e.g. in the field of passenger subways is another indication of this trend (cf. Wille 2004).

[13] Personal communication Karsten H. Severin (Bundesstelle für Flugunfalluntersuchung - German Federal Bureau of Aircraft Accidents Investigation) Oct. 20, 2005.

kind of situation (e.g. landing approach versus cruising) the system is currently operating, and take the decision to select the appropriate control mode. In partly automated systems the pilot is the decision maker, whereas in completely automated systems the decisions have been incorporated into the system's architecture (e.g. software). In this case software engineers have to anticipate critical states in which the system shifts automatically to another mode. However, they are unable to check if this solution is appropriate to the given situation, unless they learn from experience, namely by incidents or accidents.[14] Even in completely automated systems human error is possible and even unavoidable – especially if we take into consideration that the decision maker now is a person with no practical experience in flying planes (cf. Gras 1994, Weyer 1997).

Re-centralization

To avoid these risks described, the strategy of forced automation in many cases is accompanied by a closer networking of the elements and a subsequent recentralization of authority – which marks another path to future aviation. As Rochlin warningly argues, there may be a novel option of the central control of decentralized systems (mode C, cf. chapter 2.4). This can be regarded as a *combination* of the two well-known modes of governance, since it relies on the problem-solving capabilities of self-organization, and simultaneously highly profits from the advantages of central control. Thus it promises to achieve a combination of flexibility and efficacy. Paradoxically autonomous systems, which are effectively interconnected via networks, would allow for a recentralization, i.e. a centralized remote control. Referring to the case of German railways one could easily image all aircraft to be guided by one control centre – while the pilot on board would only monitor the system and manage those emergency cases which cannot be handled by the ground control.

This scenario requires an effective means of self-control of the vehicle (via smart technology) and of self-coordination within the system (e.g. for the purpose of collision avoidance) as well as real-time data communication with the centre, allowing also for effective intervention from outside. In this scenario the human operator would lose a great deal of his decision autonomy, whereas the control centre would gain force and the capacity to control the entire system. At the same time the control architecture described here decreases the capability of on-site crisis management by the operator, whose freedom to act is not only substituted by smart technical devices but also by the new governance mode of central control of a decentralized, networked system.

However, even in this case the problem of the effective distribution of authority remains unresolved, since two operational logics still co-exist in a way that may lead to confusion in a situation of crisis. Moreover, up to now we have only little experience with this new type of mixed governance.

Improved coordination

Therefore another path to a new order in aviation might be an improved coordination of the two systems (e.g. ATC and TCAS), as repeatedly indicated in the case study. Until now both systems are only badly interconnected, because the recommendations which are generated by TCAS are not automatically communicated to the ground. (Pilots and controllers are used to communicate via radio telephony instead, but this technology is rather trouble-prone and often insufficient in a crisis situation.) This missing link is due to the deliberations about the design of TCAS in the 1970s, where aircraft owners

[14] This is the reasons why accidents are – regarded from a methodological point of view – so worthy for application-oriented science; cf. Krohn/Weyer 1994.

were opposed to implement a more advanced, but also more costly version (cf. Deuten 2003: 233). So a cheaper, but also less efficient system came into being. Today it is possible to bridge the gap between TCAS and ATC with an automated data link, which will provide the control centre with complete information about the results of the decentralized coordination in the sky (thus establishing another variant of mode C). However, even if this data link will be installed overall in a few years, the authority conflict will remain, since both modes continue to exist side-by-side. So even if the technical problems will be resolved, the question of coordination of the two governance modes persists, especially the urgent issue, when to obey TCAS and when to listen to the ground controller.

Switch concepts

One obvious option to cope with the problem of mixed governance is to create an organization which is able to operate in different modes and, additionally, is capable to switch between different modes according to the situation (again a specimen of mode C). This concept can be found in the literature on "high-reliability organizations" (HRO, cf. LaPorte/Consolini 1991) as well as on "group interaction in high risk environments" (GIHRE, cf. Dietrich/Childress 2004). The central idea of both concepts is that organizations cannot be directed by only one mode of governance, since different situations (e.g. routine, emergency) require different responses. The message is: successful organizations, which manage complex, highly automated systems with high risks, can guarantee safety, if they develop an organizational safety culture that is based on the ability to switch between different modes – as well as an intense and systematic training of all kind of situations in order to gain and maintain this capability to switch. That way HROs can successfully cope even with unforeseen crisis.

As the TCAS case study showed, this idea may be a promising tool to analyse the governance of hybrid systems, too; future research will be necessary to explore the potential of this approach more deeply. However, it can already be assumed that the appropriate distribution of responsibility and action capability between human actors and non-human agents as well as the development of a new institutional framework of interaction will be the core of an organization's ability to manage complex, hybrid systems. In the current situation different paths to the future of aviation are open.

5 Conclusion

As the case study on TCAS showed, currently a regime change takes place in aviation, which can be interpreted as the deconstruction of the traditional order of central control, triggered by the implementation of smart technology. The invention of a hybrid system gave rise to another mode of governance (decentralized self-organization – mode B), which nowadays co-exists – badly connected – with the traditional mode A, thus raising the question of future options that may combine features of the two modes of governance (mode C). Currently experiments take place in aviation (as well as in other traffic systems such as road traffic or railway transportation), which aim at exploring the practicability of new system's architectures with different mixtures of humans and non-humans, of central control and decentralized self-organization. It is still an open question, which kind of order will succeed, but the outline of the different paths to future aviation (chapter 4.4) supports the assumption that strategies of a complete displacement of the human decision maker will probably prove to be a dead end. Even in future, aviation will remain a hybrid system of distributed agency, where good solutions for the management of crisis have to be established in order to achieve a high level of safety.

6 References

[BFU 2004] Bundesstelle für Flugunfalluntersuchung: *Presseinformation zur Veröffentlichung des Untersuchungsberichtes über den Zusammenstoß einer Boeing B757-200 mit einer Tupolew TU154M am 1. Juli 2002 bei Überlingen am Bodensee* (19. Mai 2004). <www.bfu-web.de/040519_Pressetext.pdf> (16.06.04)

Brooks, Rodney, 2002: *Flesh and Machines*, New York: Pantheon (dt.: *Menschmaschinen. Wie uns die Zukunftstechnologien neu erschaffen.* Campus: Frankfurt/M., quotes from the German issue), 2002.

Christaller, Thomas, et al., 2001: *Robotik. Perspektiven für menschliches Handeln in der zukünftigen Gesellschaft*. Berlin: Springer.

Christaller, Thomas/Josef Wehner (eds.), 2003: *Autonome Maschinen – Perspektiven einer neuen Technikgeneration*. Wiesbaden: Westdeutscher Verlag.

Denke, Christian W., 2001: *Zum Zusammenstoß von Überlingen* (Juli 2001). <www.vcockpit.de/politik.php?artikel=34> (30.08.04)

Deuten, J. Jasper, 2003: *Cosmopolitanising Technologies. A Study of Four Emerging Technological Regimes*. Twente: Twente University Press.

Dietrich, Rainer/Traci Michelle Childress, (eds.), 2004: *Group Interaction in High Risk Environments*. Aldershot: Ashgate.

Epstein, Joshua M./Robert Axtell, 1996: *Growing Artificial Societies. Social Science from the Bottom Up*. Washington D.C.: Brookings Inst. Press.

Esser, Hartmut, 1991: *Alltagshandeln und Verstehen. Zum Verhältnis von erklärender und verstehender Soziologie am Beispiel von Alfred Schütz und 'Rational Choice*'. Tübingen: Mohr.

Esser, Hartmut, 1993: *Soziologie. Allgemeine Grundlagen*. Frankfurt/M.: Campus.

Fiorino, Frances, 2006: Midair over Amazon. TCAS, altitude deviation among key factors in Brazil's worst air disaster. In: *Aviation Week & Space Technology*, Oct. 9, 2006: 44-46.

Friese, Ulrich/Christoph Hein, 2004: Rüstungshersteller setzen auf den Verkaufserfolg von Drohnen. In: *Frankfurter Allgemeine Zeitung* 24.07.2002: 12.

Gras, Alain, et al., 1994: *Faced with Automation. The Pilot, the Controller and the Engineer*. Paris: Publications de la Sorbonne.

Greshoff, Rainer/Uwe Schimank, 2003: *Die integrative Sozialtheorie von Hartmut Esser* (unpubl. paper).

Hubig, Christoph, 2003: Selbständige Nutzer oder verselbstständigte Medien - Die neue Qualität der Vernetzung. In: Friedemann Mattern (ed.), *Total vernetzt. Szenarien einer informatisierten Welt.* Heidelberg: Springer, 211-229.

Hughes, David, 2005: Without Radar - Precisely. ADS-B promises improved accuracy and lower-cost surveillance. In: *Aviation Week & Space Technology,* Jan. 31, 2005: 42-43.

Hughes, David/Michael Mecham, 2004: 'Free-Flight' Experiments. In: *Aviation Week & Space Technology*, June 7, 2004: 48-50.

Krohn, Wolfgang/Johannes Weyer, 1994: Society as a laboratory: the social risks of experimental research. In: *Science and Public Policy* 21: 173-183.

Kron, Thomas (ed.), 2002: *Luhmann modelliert. Sozionische Ansätze zur Simulation von Kommunikationssystemen*. Opladen: Leske + Budrich.

Krücken, Georg/Johannes Weyer, 1999: Risikoforschung. In: Stephan Bröchler et al. (eds.), *Handbuch Technikfolgenabschätzung* (3 vol.). Berlin: edition sigma, 227-235.

Langheinrich, Marc, 2003: *Vom Machbaren zum Wünschenswerten: Einsatzmöglichkeiten des UbiComp, paper presented at the workshop* "*Mobil in intelligenten 'Welten' - Szenarien – Visionen - Trends*", Universität Stuttgart, 11.-12.12.2003.

LaPorte, Todd R./Paula M. Consolini, 1991: Working in Practice But Not in Theory: Theoretical Challenges of "High-Reliability Organizations". In: *Journal of Public Administration Research and Theory 1:* 19-47.

Latour, Bruno, 1996: On actor-network theory. A few clarifications. In: *Soziale Welt 47*: 369-381.

Latour, Bruno, 1998: Über technische Vermittlung. Philosophie, Soziologie, Genealogie. In: Werner Rammert (ed.), *Technik und Sozialtheorie*. Campus: Frankfurt/M., 29-81.

Locquenghien, Kerstin von, 2006: On the Potential Social Impact of RFID-Containing Every-day Objects. In: *STI-Studies 2*: 57-78.

Macy, Michael W., 1998: Social Order in Artificial Worlds. In: *Journal of Artificial Societies and Social Simulation 1*, No 1. <www.soc.surrey.ac.uk/JASSS>

Malsch, Thomas, 1997: Die Provokation der "Artificial Societies". Warum die Soziologie sich mit den Sozialmetaphern der Verteilten Künstlichen Intelligenz beschäftigen sollte. In: *Zeitschrift für Soziologie 26*: 3-21.

Mattern, Friedemann (ed.), 2003: *Total vernetzt. Szenarien einer informatisierten Welt* (7. Berliner Kolloquium der Gottlieb Daimler- und Karl Benz-Stiftung). Heidelberg: Springer.

Mensen, Heinrich, 2004: *Moderne Flugsicherung. Organisation, Verfahren, Technik*. Berlin: Springer (3rd edition).

Nordwall, Bruce D., 2002: TCAS more 'foolproof' than generally recognized. In: *Aviation Week & Space Technology*, July 15, 2002: 36.

Perrow, Charles, 1984: *Normal Accidents. Living with High-Risk Technologies*. New York: Basic Books.

Rammert, Werner, 2003: Technik in Aktion. Verteiltes Handeln in soziotechnischen Konstellationen. In: Thomas Christaller/ Josef Wehner, *Autonome Maschinen – Perspektiven einer neuen Technikgeneration.* Wiesbaden: Westdeutscher Verlag, 289-315.

Rammert, Werner/Ingo Schulz-Schaeffer, 2002: Technik und Handeln. Wenn soziales Handeln sich auf menschliches Verhalten und technische Abläufe verteilt. In: Werner Rammert/Ingo Schulz-Schaeffer (eds.): *Können Maschinen handeln? Soziologische Beiträge zum Verhältnis von Mensch und Technik*. Frankfurt/M.: Campus, 11-64.

Resnick, Mitchel, 1995: *Turtles, Termites, and Traffic Jams. Explorations in Massively Parallel Microworlds (Complex Adaptive Systems)*. Cambridge/Mass.: MIT Press.

Richter, Klaus/Jan-Michael Rost, 2004: *Komplexe Systeme*. Frankfurt/M.: Fischer.

Rochlin, Gene, 1998: *Trapped in the net. The unanticipated consequences of computerization*. Princeton: Princeton UP.

Rochlin, Gene I., 1991: Iran Air Flight 655 and the USS Vincennes: Complex, Large-scale Military Systems and the Failure of Control. In: Todd LaPorte (ed.), 1991: *Social Responses to Large Technical Systems. Control or Anticipation*. Dordrecht: Kluwer, 99-125.

Schimank, Uwe, 1992: Erwartungssicherheit und Zielverfolgung. Sozialität zwischen Prisoner's Dilemma und Battle of the Sexes. In: *Soziale Welt 43*: 182-200.

Schimank, Uwe, 2005: *Die Entscheidungsgesellschaft. Komplexität und Rationalität der Moderne.* Wiesbaden: VS-Verlag.

Skiera, Bernd, 2000: Preispolitik und Electronic Commerce - Preisdifferenzierung im Internet. In: Christoph Warmser (ed.), *Electronic Commerce – Grundlagen und Perspektiven*, München: Vahlen, 117-130.

Spehr, Michael, 2006: Die Ratlosigkeit des Menschen im Dickicht des Digitalen. In: *Frankfurter Allgemeine Zeitung* 12.09. 2006: T1.

TA-Swiss (ed.), 2003a: *Auf dem Weg zur intelligenten Mobilität. Kurzfassung des TA-Arbeitsdokumentes "Das vernetzte Fahrzeug"* (TA 43A/2003). Bern. <www.ta-swiss.ch/www-remain/ reports_archive/publications/2003/ KF_Verkehrstelematik_d.pdf> (06.10.03).

TA-Swiss (ed.), 2003b: *Unser Alltag im Netz der schlauen Gegenstände. Kurzfassung der TA-Swiss-Studie "Das Vorsorgeprinzip in der Informationsgesellschaft"* (TA 46A/2003). Bern. <www.ta-swiss.ch/www-remain/ reports_archive/publications/2003/TA_46A_2003_deutsch.pdf> (06.10.03).

Timpe, Klaus-Peter, et al., (eds.), 2002: *Mensch-Maschine-Systemtechnik. Konzepte, Modellierung, Gestaltung, Evaluation*. Düsseldorf: Symposion.

Vanberg, Viktor, 1975: *Die zwei Soziologien. Individualismus und Kollektivismus in der Sozialtheorie*. Tübingen: J.C.B. Mohr.

[VC 1997] Vereinigung Cockpit: *TCAS - Traffic Alert and Collision Avoidance System.* <www.vcockpit.de/presseaktuell.php? artikel=67> (20.07.04)

[Venik] (Venik's Aviation) 2002: *Mid-Air Collision over Germany* (July 13, 2002). <www.aeronautics.ru/news/news002/news053.htm> (16.06.04)

Weiser, Mark, 1991: The Computer for the 21st Century. In: *Scientific American*, Sept. 1991: 66-75.

Weyer, Johannes, 1993: *Akteurstrategien und strukturelle Eigendynamiken. Raumfahrt in Westdeutschland 1945-1965*. Göttingen: Otto Schwartz.

Weyer, Johannes, 1997: Die Risiken der Automationsarbeit. Mensch-Maschine-Interaktion und Störfallmanagement in hochautomatisierten Verkehrsflugzeugen. In: *Zeitschrift für Soziologie* 26: 239-257.

Weyer, Johannes, 2006a: *Die Zukunft des Autos - das Auto der Zukunft. Wird der Computer den Menschen ersetzen?* (Universität Dortmund, Soziologische Arbeitspapiere Nr. 16). <www.techniksoziologie-dortmund.de/ veroeffentlichung/files/ap14.pdf>

Weyer, Johannes, 2006b: Die Kooperation menschlicher Akteure und nicht-menschlicher Agenten. Ansatzpunkte einer Soziologie hybrider Systeme. In: Günter Getzinger/Wilhelm Berger (eds.), *Intervention und verteiltes Handeln* (in print).

Wille, Walter, 2004: Die neuen Fahrer heißen Bit und Byte. Deutschlands erste vollautomatische U-Bahn. In: *Frankfurter Allgemeine Zeitung* 19.10.2004: T 1-2.