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Task contributors	
University of Westminster; University of Palermo, University of Seville, NLR.	

Abstract

This document reports on the main activities towards the production of two journal papers and a book on complexity science in the ATM domain. The first journal paper ("Applying complexity science to air traffic management") is ready for submission. The full text is included in this document. The proposed book ("Complexity science in air traffic management") has been accepted to progress to contract by a leading publisher in aviation. We report here on the planning and development of the book's contents and on the reviewers' feedback. Next steps for taking these initiatives forward are summarised. The common objective is promoting awareness of the increasing role that complexity science is playing in the ATM research domain.

Authoring & Approval

Prepared By - *Authors of the document* *(listed by allocated work effort, then alphabetically by name per affiliation)*		
Name & Company	Position & Title	Date
XXXXXXXXXXX / University of Westminster	Consortium Member	12/12/2013
XXXXXXXXXXX / University of Palermo	Consortium Member	
XXXXXXXXXXX / University of Palermo	Consortium Member	
XXXXXXXXXXX / University of Seville	Consortium Member	
XXXXXXXXXXX / University of Seville	Consortium Member	
XXXXXXXXXXX / NLR	Consortium Member	

Reviewed By - *Reviewers internal to the project.*		
Name & Company	Position & Title	Date
XXXXXXXXXXX / Innaxis	Consortium Member	13/12/2013

Reviewed By - *Other SESAR projects, Airspace Users, staff association, military, Industrial Support, other organisations.*		
Name & Company	Position & Title	Date
-	-	-

Approved for submission to the SJU By - *Representatives of the company involved in the project.*		
Name & Company	Position & Title	Date
XXXXXXXXXXX / University of Westminster	Consortium Member	13/12/2013

Rejected By - *Representatives of the company involved in the project.*		
Name & Company	Position & Title	Date
-	-	-

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1 Introduction

1.1 Purpose of the document

This document summarises the main activities and compiles the key outputs produced under Work Order 3, for Task 33.2, which comprised the:

(a) production of a journal paper and the initial planning of a second paper;

(b) preparation towards the publication of a book on complexity science in the ATM domain.

These tasks are specified in some further detail in sections 2.1 and 3.1, respectively. However, this document does not set out to describe the step-by-step collaborative processes through which these outputs were achieved, but rather to summarise these, provide evidence of the outputs, and to define the next steps (in Section 4).

These publications are intended to take forward and further develop the content of the ComplexWorld Position Paper and dedicated wiki, thus expanding their penetration into the public domain and promoting awareness of the increasing role that complexity science is playing in the ATM research domain.

1.2 Intended readership

This document is primarily intended as an activity reporting mechanism for EUROCONTROL and the SJU, as dissemination of the journal paper(s) and book which it concerns will be achieved by separate means in Year 4 of the Network, and will be reported subsequently.

2 Journal paper submission

2.1 Papers planned

As stated in Section 1, Task 33.2 comprised the production of a journal paper and the initial planning of a second paper.

More specifically, this included the:

(i) production of a journal paper (“Paper 1”) introducing complexity science to ATM; shortlisting and then finalising the selected journal; collaborative production of the full text;

(ii) production of a complementary paper (“Paper 2”) introducing the ATM context to the complexity science community; shortlisting the potential journals and producing an abstract of the paper.

For Paper 1, two journals were shortlisted from a list of nine, discussed collaboratively in the Member’s interactive, on-line tool (Confluence), as maintained and managed by Innaxis, with task coordination by the University of Westminster. The full content of the paper was designed and developed by mutual agreement on-line.

An abstract and introduction for Paper 1 was sent to the two shortlisted journals, with positive responses from both, and neither suggesting any changes. The *Journal of Air Transport Management* was finally selected as the preferred journal, primarily because it was felt to best meet the stated objectives of extending the audience of ComplexWorld (in this case to a wider air transportation and management-oriented readership, with a strong US presence). The full draft of Paper 1 is presented in Section 2.2. It will be submitted to the *Journal of Air Transport Management* after a final review by the authors, following approval of / feedback on this Deliverable.

Initial planning details for Paper 2 are presented in Section 2.3.

Next steps for these journal papers are summarised in Section 4.1.

2.2 Paper 1: *Applying complexity science to air traffic management*

Henk A.P. Blom[a], Andrew Cook[b,*], Fabrizio Lillo[c,d], Rosario Nunzio Mantegna[d,e], Salvatore Miccichè[d], Damián Rivas[f], Rafael Vázquez[f], Massimiliano Zanin[g,h]

[a] *Air Transport Safety Institute, National Aerospace Laboratory NLR, Anthony Fokkerweg 2, 1006 BM Amsterdam, The Netherlands.*
[b] *Department of Planning and Transport, University of Westminster, 35 Marylebone Road, London, NW1 5LS, UK*
[c] *Scuola Normale Superiore, Piazza dei Cavalieri 7, Pisa, 56126, Italy*
[d] *Dipartimento di Fisica e Chimica, Università degli Studi di Palermo, Viale delle Science Ed. 18, Palermo, 90128, Italy*
[e] *Central European University, Center for Network Science and Department of Economics, Nador u. 9, 1051 Budapest, Hungary*
[f] *Department of Aerospace Engineering, Escuela Superior de Ingenieros, Camino de los Descubrimientos,Universidad de Sevilla, 41092 Sevilla, Spain*
[g] *The Innaxis Foundation & Research Institute, José Ortega y Gasset 20, 28006 Madrid, Spain*
[h] *Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal*

* Corresponding author.
E-mail address: cookaj@westminster.ac.uk (A. Cook).

Abstract

Complexity science is the multidisciplinary study of complex systems. Its marked network orientation lends itself well to transport contexts. Key features of complexity science are introduced and defined, with a specific focus on the application to air traffic management. An overview of complex network theory is presented, with examples of its corresponding metrics and multiple scales. Complexity science is starting to make important contributions to performance assessment and system design: selected, applied air traffic management case studies are explored. The important contexts of uncertainty, resilience and emergent behaviour are discussed, with future research priorities summarised.

Keywords: complexity science; performance assessment; complex network theory; emergent behaviour; resilience.

Foreword

This work is co-financed by EUROCONTROL acting on behalf of the SESAR Joint Undertaking (SJU) and the EUROPEAN Union as part of Workpackage E ComplexWorld research network in the SESAR Programme. Opinions expressed in this work reflect the authors' views only. EUROCONTROL and/or the SJU shall not be considered liable for them or for any use that may be made of the information contained herein.

1. Introduction

This paper introduces key features of complexity science with a focus on its application to air transportation in general, and air traffic management (ATM) in particular. These applications share many aspects of performance assessment and system design, not least, ultimately, through effective service delivery to the passenger. As we will explore, complexity science is the multidisciplinary study of complex systems, of which air transport networks and integrated airspace blocks are prime examples.

The foundations of complexity science can be traced back to statistical physics, non-linear dynamics and information theory (Anderson, 1972). Complex network theory plays a central role in complexity science (Newman, 2003; Boccaletti et al., 2006), since all complex systems have many interconnected, heterogeneous components. Such components interact with and adapt to each other, such that the system exhibits emergent behaviour – the hallmark of complex systems. These features cannot be understood from information at the individual agent level alone. Complex network theory and its associated metrics and tools presents an apposite approach to developing the study of air transport networks beyond what classical techniques have to offer. Indeed, the marked network orientation of complexity science lends itself well not only to ATM but also to other transport contexts. Although applied examples in transport modelling are very limited, two concise, applied air traffic management case studies are presented in Section 3.

The Single European Sky is an initiative launched by the European Commission in 2004 to reform the architecture of European ATM and to meet the performance challenges presented by one of the busiest blocks of airspace in the world, with a high airport density. This operates without many of the advantages of having a single service provider, such as the Federal Aviation Administration in the United States. SESAR (Single European Sky ATM Research) is a component of the Single European Sky initiative. It represents its technological dimension, with the objective of helping to create a paradigm shift in operations through state-of-the-art, innovative technology and research.

Much of the work presented in this paper has been supported through SESAR Workpackage E, which is dedicated to long-term and innovative research. Reflecting its innovatory outlook, this workpackage has a multidisciplinary network, numerous research projects and a number of doctoral research degrees all dedicated to the exploration of the application of complexity science in the ATM context. These activities reflect collaborative activities between industry, universities and research institutes. This workpackage is comprised of two networks and multiple projects. The fact that one of these two networks, "ComplexWorld", is dedicated to the application of complexity science to ATM speaks of the importance of this emerging approach. In an industry where innovation cycles are typically in the range of fifteen to twenty years, such exploration strikes a balance between the immediate pressures of implementing existing concepts and technologies and managing shortfalls in capacity, and the opportunities of laying novel foundations for solutions with more distant horizons.

2. Complexity science

2.1 Complex networks in ATM

The theory and application of complex networks has experienced a tremendous growth in the last decade (Albert and Barabasi, 2002). Complex network theory (CNT) has been successfully applied to different transportation contexts, including road and (underground) rail. In recent years, there has been a growing interest in the use of CNT in air traffic management: for a recent review see Zanin and Lillo (2013).

A network is composed of a set of nodes connected by a set of edges. These can be directed and/or weighted, i.e. associated with real or integer values. For example, in an airport network, each node is an airport and a link directed from a node to another can be weighted by the number of flights or passengers in a given time window. By considering sectors or navigation points as nodes, one can build other network representations of the airspace with different spatial resolution. Indeed, such is the power of CNT that one can assign almost any kind of nodal representation, including those related to delays and the associated infrastructural and passenger costs.

The interest in the study of networks stems from the observation that some generic topological properties are present in different complex systems, suggesting that some general principles govern the creation, growth, and evolution of such networks. Moreover, CNT has introduced a large set of metrics that are able to characterise the network and its organisation, thus identifying the critical nodes.

- **Degree.** The degree of a node is the number of edges connected to it, while its strength is the sum of the weights of these edges. The degree (or strength) distribution gives important information about the heterogeneity of the nodes. Several empirical analyses of airport networks (Barrat et al., 2004; Guimerà et al., 2005) have found that the distribution of the degree, k (or the strength), is described by a truncated power law: $P(k > x) = ax^{-g}e^{-ax}$, where g is typically between 1 and 2. Networks with power-law distributed degrees are termed ‘scale-free’ networks (Barabasi, 2009) and have attracted considerable attention in recent years. As a randomly distributed network increases in size, the ratio of high-degree nodes to other nodes decreases, whereas in a scale-free network this ratio remains constant as a function of network size. (We comment on the importance in a transport management context below.)

- **Betweenness.** The betweenness of a node is a centrality measure quantifying how important a node is regarding paths inside the network. Node betweenness is defined as the proportion of shortest paths, among all possible origins and destinations, that pass through a node.

- **Clustering coefficient.** The clustering coefficient of a node is the fraction of pairs of its neighbours that are directly connected. Empirical studies (Guimerà et al., 2005; Bagler, 2008) show that airport networks have relatively high average clustering coefficients across nodes. This, together with small average shortest path lengths, indicates that airport networks have the ‘small-world’ property (Watts and Strogatz, 1998). Indeed, many real world networks demonstrate this property: that is, they exhibit a low average shortest path, characteristic of random networks, while maintaining the high clustering coefficient found in regular networks.

There exists a strong correlation between the degree of a node, and the quantity of flights and passengers managed through it (Barrat et al., 2004; Guimerà et al., 2005; Wu et al., 2006). The more connections a node has, the more passengers are likely to use that node to reach their destination, and thus the frequencies of such connections strongly increase.

The analysis of the structure of flight networks in air transport, especially when focused on individual airlines, is motivated by the aim of defining the most efficient structures for flights for a given airline – both in terms of yields (and thus profit) and of passengers' mobility. For this reason, a large number of studies have focused on the long-term dynamics of airport networks, with the aim of investigating the transition from point-to-point to hub-and-spoke structures observed first in Europe and the US, and more recently in emerging economies. For example, in the European air network between 1990 and 1998, it has been observed (Burghouwt and Hakfoort, 2001) that medium-sized airports have attracted most of the intra-European traffic, creating specialised internal hubs, while intercontinental traffic has also been concentrated, but on different hubs, usually large airports.

The structure of the air transport network strongly affects the capability of a passenger to reach their destination from a given origin in the shortest possible time and with fewest changes. However, purely topological metrics can be poor indicators for assessing passengers' needs. In fact, a short path (in terms of number of flights) can be (relatively) useless for a passenger if the constituent flights are very infrequent or if their scheduling renders the connections unworkable. One can therefore adapt many complex network metrics to describe both direct and indirect connectivities for passengers (Malighetti et al., 2008). We pursue this theme in Section 3.2.

CNT is also important in assessing the resilience of the air transport network, i.e. its ability to adjust its functioning prior to, during, and following internal and external disturbance. It has been shown that the network topology is critical to model failure cascades. Scale-free networks are extremely resilient to random failures. However, this comes at a high price, because they are also extremely vulnerable to targeted attacks (Albert et al., 2000) and other forms of localised failure. This suggests that a suitable characterisation of air traffic topologies and the identification of the most central nodes, according to CNT, can give valuable insights into modelling the resilience of the network and identifying critical elements of the system.

Finally, the topologies of air transport networks play an important role, not only for the mobility of people, but also for the dynamics of entities that depend on human mobility. An important example is the spread of an epidemic, for which air passenger transport constitutes one of the most important vectors for long-range spreading. For example, Colizza et al. (2006) used real data on passenger mobility to build a large-scale agent-based model to predict epidemic spreading worldwide.

We have focused here mainly on the airport network. However, navigation-point networks and sector networks are receiving increasing research interest because of their importance in modelling air traffic control (Cai et al., 2012; Gurtner et al., 2013). In contrast with airport networks, these are geographically constrained and therefore (almost) planar. Centrality analyses, for example, can be used to identify potential bottlenecks of the air traffic. Moreover, as we will show in Section 3.1, the use of community detection in navigation-point and sector networks has been recently suggested (Gurtner et al., 2013) as a means to improve the design of airspaces by using a bottom-up, traffic-driven approach.

2.2 The context of uncertainty

The application of complex network theory in air transport must also take account of a fundamental property of such operations: uncertainty. Understanding how uncertainty affects the ATM system is key to properly modelling and controlling it, and ultimately improving its performance. There are different sources of uncertainty that affect ATM, which can be classified into the types shown below (see also Heidt and Gluchshenko, 2012).

- **Data uncertainty**. This type of uncertainty exists when there are known data but with some level of uncertainty, and/or when there are imperfect models.

- **Data unavailability**. In contrast to the previous source of uncertainty, this affects predictions made without precise knowledge of the system: knowledge which could be obtained by sharing the necessary information, but whereby this is prevented by managerial and/or technological barriers.

- **Operational uncertainty**. Decisions taken by humans (e.g. managers, pilots and air traffic controllers) have a significant influence on operations but are difficult to predict.

- **Equipment uncertainty**. This type of uncertainty refers to problems with equipment, such as aircraft or vehicle breakdown, or other system failure modes.

- **Weather uncertainty**. Meteorological conditions comprise a wide group of sources of uncertainty (Matthews et al., 2009). In particular, adverse weather can introduce high levels of localised or widespread uncertainty and poses problems with clear links to resilience (which we discuss in Section 2.3).

The analysis of uncertainty in ATM must take into account the time horizon under consideration and the different scales of the system, because, depending on these, the various uncertainty sources affect the system in different ways. According to the time horizon, one can find two types of problem: (1) estimation of the present state, e.g. over a short-term time horizon, identifying primary actions for maintaining safety; and, (2) prediction of the future state, i.e. with regard to actions over medium- and long-term time horizons, identifying efficient planning for flights in the context of weather forecasts and predicted traffic, etc. Three scales of the system can also be clearly differentiated:

- **Microscale** – a single flight. At this smallest scale one must analyse all the uncertainty sources that affect the flight, at its different stages. These stages are: (a) strategic, covering the timeframe from months before the flight up to two hours before the off-block time, including the filing of flight plans but not the flow-management slot allocation process; (b) pre-departure, which includes flow-management slot allocation (commencing two hours before the flight and continuing up to the off-block time); (c) gate-to-gate, including the ground phases (such as taxi-in and taxi-out) and the airborne phase (where one must consider the dynamics of the aircraft and the changing environment through which it moves: see for instance Vazquez and Rivas, 2013); and, (d) post-arrival, which commences once the aircraft is on-blocks. Uncertainty affects both the spatial and temporal dimensions; while the spatial uncertainty affects mainly safety issues (loss of separation) and efficiency, the temporal uncertainty manifests itself primarily as delay (flight delay being an important phenomenon that affects all scales, see Cook et al. (2009) and Section 3.2).

- **Mesoscale** – air traffic. This is an intermediate scale that allows one to focus on a given area that contains many individual aircraft that interact following a given set of rules. Examples include terminal manoeuvring areas or sectors. The analysis of flow management problems can be also framed within this scale (Clarke et al., 2009). Mesoscopic models exploit probabilistic methods to account for details of the microscopic scale without completely losing the macroscopic and strategic view of the system. This scale still considers individual aircraft, but describes their activities and interactions based on aggregate relationships. At this scale, safety has to be enforced whilst, at the same time, capacity needs to be maximised and deviations from user-preferred trajectories minimised. To accomplish this effectively, it is necessary to develop algorithms that include uncertainty models in their formulation (Tomlin et al., 1998).

- **Macroscale** – the air transport network. Air transport can be considered at the level of regional, national, or supra-national networks, or even at the level of the global ATM system. This scale integrates the state of multiple ATM elements and allows one to focus on the network properties, giving a high-level view of the system. It is important to study how uncertainty in flights and air traffic (the microscopic and mesoscopic scales) propagates to affect the macroscale. At this scale, it is best to abstract and integrate the various complex and heterogeneous ATM elements in a way that allows one to assess uncertainty and other properties of interest without needing to include fine detail.

CNT is a particularly useful framework for analysing the macroscale (Boccaletti et al., 2006), although it may also be used on mesoscale applications. We discuss these scales in the context of emergent behaviour in Section 2.4. According to the scales of the system, the time horizon under analysis, and the types of uncertainty, different research challenges can be identified in terms of using CNT to offer insights into progressing performance assessment and management.

2.3 Defining and modelling resilience

Air transportation constitutes a complex socio-technical system that is constantly influenced by internal and external disturbances of various forms. These disturbances may interact with each other, potentially creating a cascade of adverse events that may span over the different scales outlined in the previous section. Such disturbances could affect a single aircraft or crew, or impact a whole network.

Thanks to decades of evolutionary development of the air transportation system, many disturbances may not cause significant disruptions for passengers. However, in some cases the disruption is significant (e.g. due to convective weather), and in some exceptional events the disruption is of great impact. There are two categories of rare exceptional events: (i) (catastrophic) accidents involving one or two aircraft; and, (ii) events that push the dynamics of the air transportation system far away from its point of operation and therefore dramatically affect the performance of the system. Examples of the former category are: fatal runway incursions (e.g. Linate, 2001); fatal mid-air collisions (e.g. Überlingen, 2002); loss of control of an aircraft flying through a hazardous weather system (e.g. Air France crash in Atlantic Ocean, 2009). The latter category poses particular challenges for tactical management, examples including: terrorist actions causing the closing down of air travel in large areas (e.g. the events of '9/11' in New York, in 2001); a disease causing passengers to change their travel behaviour (e.g. the SARS outbreak in Asia, in 2003); or, volcanic plumes impacting air travel over much of northern Europe (Eyjafjallajökull ash cloud, April-May 2010).

In view of the complexity of the socio-technical air transportation system, there is also an obvious need to study resilience from a complexity science perspective. The term 'resilience' was first introduced in a physical context by Hoffman (1948) in the field of mechanics as the "ability of a metal to absorb energy when elastically deformed and then to release it upon unloading". Some decades later, Holling (1973) extended this resilience concept to ecological systems as the "persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables". Since then, various other extensions of the resilience concept have been introduced in other domains, such as social science, economic science, organisation science and safety science.

Triggered by the resilience engineering paradigm (Hollnagel et al., 2006), a qualitative study of resilience started some five years ago in ATM (EUROCONTROL, 2009). Here, EUROCONTROL (ibid.) has provided a rather complete overview of the various modelling approaches available, such as those comprised of, or based, on: empirical modelling; agent-based modelling; system dynamics; economic theory; network topology; network flow; Petri nets; control system theory; hierarchical holographic modelling; high level architecture; and, Bayesian networks. A good illustration of the associated impacts for future ATM is provided by Woltjer et al. (2013).

In Ouyang (2014), these modelling approaches have been systematically assessed against various resilience improvement objectives for critical infrastructure systems. In addition, ComplexWorld (2012) has identified some complementary stochastic modelling and analysis techniques that are able to capture the various forms of uncertainty in ATM, i.e.: stochastic hybrid systems (Blom and Lygeros, 2006; Cassandras and Lygeros, 2007); viability analysis (Martin et al., 2011); and, reachability analysis (Bujorianu, 2012).

Based on a review of the complementary resilience developments in these various domains, Francis and Bekera (2014) identified the following three key capacities of resilience: absorptive capacity, recoverability, and adaptive capacity. These key capacities have been integrated into a unifying resilience framework for complex socio-technical systems (ibid.). Since the air transportation domain covers so many resilience sub-domains, this integrated resilience framework is expected to be of great value for air transportation and the management of its performance from both a strategic and tactical perspective.

In the literature, corresponding metrics have also been proposed to quantify resilience. Gunderson et al. (2002) introduced two such key metrics: (1) *ecological* resilience is the "amount of disturbance that a system can absorb before it changes"; (2) *engineering* resilience is the "time of return to a global equilibrium following a disturbance". In the study by Francis and Bekera (2014), a third quantitative metric has been termed as a 'resilience factor', which aims to take account of all three key capacities. There is, we suggest, a need for the systematic application, validation and integration of complementary approaches, in addition to assuring data access (European legislative change is currently helping Europe to catch up with the more open culture in the US) and the systematic collection and empirical modelling of these data. Although high-level architecture modelling is the most generic approach, it faces many challenges in realising a mature and practical application for complex socio-technical systems. With regard to uncertainty, as discussed in the previous section, viability and reachability analysis of stochastic hybrid systems are particularly adept at allowing researchers to model and analyse the various forms of uncertainty in air transportation. Overall, agent-based and network flow based approaches have the widest and proven applicability to complex socio-technical systems.

2.4 Emergent behaviour

Another key feature of complex systems is emergent behaviour. It often cannot be (fully) determined by knowledge of its individual components. (A physical analogue is the highly complex structures of water, not predictable a priori from knowledge of the properties of hydrogen and oxygen atoms.) Emergent behaviour that is not well understood often leads to poor performance. Only after such emergent behaviour is better understood, may it be exploited by researchers and managers to deliver better performance.

Air transportation is indeed challenged to accommodate much higher future traffic demand, whilst maintaining performance across a number of key performance areas (KPAs), and with respect to safety and delay metrics. Awareness is growing (e.g. Holmes, 2004) that this cannot be accomplished by focusing on the individual elements of the socio-technical air transportation system. Instead, it is essential to study and understand the interaction between the many individual elements, i.e. their joint emergent behaviours (ComplexWorld, 2012; EUROCONTROL, 2010; Shah et al., 2005). Furthermore, with the introduction of advanced ATM concepts, as yet unknown emergent risk may appear (EUROCONTROL, 2010). Whilst new paradigms (such as self-separation) could give rise to new vulnerabilities, they could also remove existing ones (Woods et al., 2010). In the literature, a number of types of emergent behaviours are discussed. In order to bring some order to these emergent behaviour types, the classification proposed by Fromm (2005) is useful:

- **Type I emergence** is totally predictable due to the controlled and planned interaction of the individual components. In air transportation this applies, for example, to the multitude of technical systems either on-board an aircraft or on the ground, including their reliability.

- **Type II emergence** is characterised by top-down feedback from the components (agents) imposing constraints on the local interactions. Without conducting simulations, it is not predictable (Bedau, 1997). Type II behaviour is observed, for example, when cognitive processes of pilots and controllers are involved. For example, in a sequence of airborne aircraft with limitations on their possible speed adjustments, each flight crew adjusts its behaviour and role in the group according to the context, e.g. following an ATC instruction or a traffic collision avoidance system warning.

- **Type III emergence** is characterised by *multiple* positive and negative feedback loops appearing in complex systems with many agents. Completely new roles can appear while old ones disappear. The behaviour is not deterministic and can be chaotic – hence it poses significantly more challenges for simulation.

- **Type IV emergence** is not predictable, even in principle, because it describes the appearance of a completely new system in a multi-level or multi-scale system. This is often referred to as 'strong' emergence, although there is no universally agreed definition. Combinatorial factors render futile any attempt at explaining emergent macroscopic phenomena in terms of microscopic phenomena. A mesoscopic level often protects the macroscopic level from the microscopic one (i.e. the microscopic layer is irrelevant to behaviour at the macroscopic level). Life is a strongly emergent property of genes, the genetic code and nucleic/amino acids; culture is a strongly emergent property of language and writing systems. In the air transportation domain, one can think of the safety culture, inter alia, as the product of routine aspects of everyday practice and rules, and of management and organisational structures (Ek et al., 2007; Gordon et al., 2007). However, even agent-based modelling and simulation do not reveal an understanding of the causal relationships (Sharpanskykh and Stroeve, 2011).

Type III exceptional, safety-critical behaviour may be observed where the propagation of hazards through the socio-technical air transportation system creates a condition under which the application of established procedures by crew or ATC unintentionally causes the situation to deteriorate. This may, for example, occur when situational awareness differences arise amongst different agents in the system, and these differences are not recognised by the critical agents (De Santis et al., 2013).

Type III emergent behaviour is also associated with other particularly interesting properties with regard to the management of air traffic: phase transitions and percolation. A phase transition refers to many locally interacting elements causing a collective phase change (returning to the example of water, a physical analogue is the melting of ice, i.e. a transition from the solid to liquid phase). Typically, there exists a critical point that marks the passage from one phase to another (e.g. Helbing, 2001). Particularly remarkable is that the well-known phase transition behaviour of road traffic on a highway seems to be absent in air traffic.

Percolation refers to probabilistic, network-wide emergent behaviour, between sites or sub-systems, across links in the network. In air transportation, there are several networks where percolation may happen. For example, the spatio-temporal propagation of congestion over airspace sectors (Ben Amor et al., 2006; Conway, 2005) or how the queuing of passengers evolves within the total air transportation system. We take up the conclusions to be drawn for air traffic management with regard to emergent behaviour in Section 4.

3 ATM case studies

An important characteristic of a complex network is its organisation into communities (Fortunato, 2010). Communities are generically defined as sets of nodes that are more connected among themselves than with the rest of the network. Communities are, therefore, important to the understanding of airspace structure and operation. The two case studies summarised in this section are both examples of SESAR Workpackage E projects and both draw on community analyses. In the first case study, we present the results of a recent investigation performed within the ELSA project (Gurtner et al., 2013), whereby network community detection algorithms were used to monitor current use of the airspace and to improve it by informing the design thereof. In the second case study, we show how the POEM project (Cook et al., 2013) has demonstrated the need for dedicated passenger metrics in performance assessment and how community functionality and vulnerability may be radically changed under flight prioritisation rules.

3.1 From network behaviour to better airspace design

The application of complex network theory to air traffic is not new (Zanin and Lillo, 2013), although such studies have mainly focused on the topological characterisation of the airport network (Bagler, 2008; Colizza et al., 2006; Guida and Funaro, 2007; Guimerà et al., 2005; Li and Cai, 2004; Lillo et al., 2011; Popovic et al., 2012; Quartieri et al., 2004; Wang et al., 2011; Xu and Harriss, 2008). In Gurtner et al. (2013), community detection algorithms were applied to different types of air traffic network. We will illustrate this case study by considering a network of airports, which is probably the most studied type of air traffic network. This network was constructed using the DDR (Demand Data Repository) dataset maintained by EUROCONTROL.

Airspaces are complex systems already partitioned, mainly for reasons related to air traffic control. In fact, at the lowest level, airspaces are partitioned into several sectors. In European airspace, each National Airspace (NA) comprises between one and five area control centres (ACCs). The two-dimensional boundaries of an NA are often very close to the country's national borders. At a more aggregate level still, we have functional airspace blocks (FABs), comprising several NAs. Reorganising NA blocks into FABs is one of the cornerstones of the Single European Sky first legislative package, and was further enhanced in the SES second package. Nevertheless, only a few of the planned nine FABs are currently operational.

We suggest that community detection in air traffic networks is important for two reasons. Firstly, it improves the characterisation of networks, powerfully complementing other complexity metrics (such as degree distribution, betweenness centrality, small world effects, etc.). Secondly, we believe that community detection could be helpful to guide, in an unsupervised way, the design of new airspaces in order to achieve better management of the air traffic based on its actual conditions. In fact, network community detection may provide information on the appropriateness of the airspace design, based on the sole knowledge of the actual air traffic data. Therefore, methods devised for identifying communities in networks could be used to help design the structure of airspace, starting from the observed behaviour of the system.

An example of a partition is presented in Figure 1, where we show the different communities of the European airport network for 06 May 2010. Each circle is an airport, its radius proportional to its strength. Each community is represented by a different colour. The links between nodes have been omitted for legibility. This partition is obtained by using an algorithm (Blondel et al., 2008) that maximizes the modularity. Modularity is a network metric that measures the excess of the number of links within a community with respect to a null hypothesis of the random presence of links.

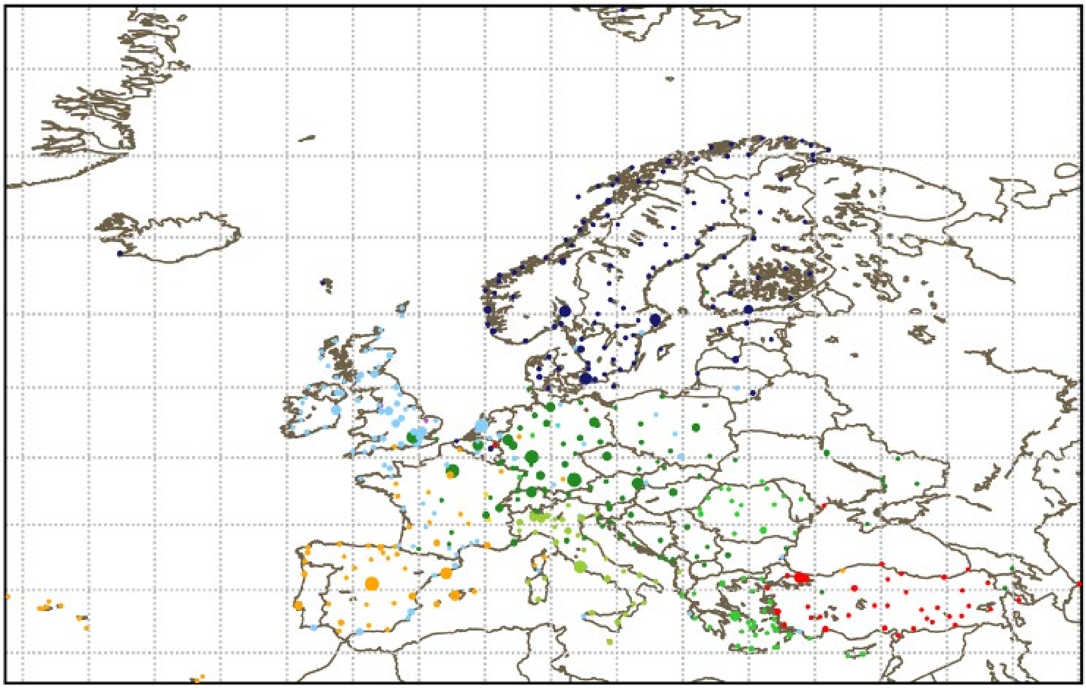

Fig. 1. European network of airports on 06 May 2010.

As illustrated, the typical size of a community is supra-national, roughly the same as an FAB. The communities are mainly geographical with the majority of nodes close to each other in a single community. Moreover, the borders of the communities seem to be more or less consistent with national borders. Nevertheless, some nodes are far away from their communities.

When considering the whole AIRAC (Aeronautical Information Regulation and Control) period from 06 May to 02 June, 2010, the average number of communities is 9.4 ± 1.2. The average value of the minimum number of communities which include 90% of the nodes in the network is 7.2 ± 0.4. The number of FABs and NAs considered is 12 and 42, respectively[1]. The average number of FABs and NAs that include 90% of the nodes in the network is 9.1 and 21, respectively. Clearly, the number of detected communities is closer to the number of FABs.

A further quantitative comparison between unsupervised and existing partitions of the airspace can be obtained by computing the mutual information (Danon et al., 2005). The mutual information is a measure of the mutual dependence of two variables, based on the computation of their commonalities. The results are summarised in Table 1 (values of unity from modularity versus modularity, etc., and the duplicating value of 0.42 ± 0.02 (top-right cell) are not shown).

Table 1.
Comparisons of the partitions using the mutual information.

Mutual information	**Modularity**	**National Airspace**
Modularity	-	-
National Airspace	0.42 ± 0.02	-
FABs	0.53 ± 0.02	0.70 ± 0.01

According to mutual information, the existing partition given by FABs seems well represented by a partition of the airport network obtained by using the modularity method. However, the match is not perfect. There could be two reasons for this. Firstly, geographical borders of communities are different from the FABs' tiling. Secondly, communities are actually non-geographical and some nodes of a given community are in the middle of another one, as shown in Figure 1. Nevertheless, overall these results support the introduction of FABs, although their actual boundaries could be sometimes different from those obtainable by applying an unsupervised modularity-based community detection algorithm to the airport network. Looking further ahead to concepts such as free routes and dynamic airspace structures, these type of community detection methods may make particularly valuable contributions to both strategic and tactical design.

3.2 Evaluating new flight prioritisation strategies

The average delays of flights and passengers are not the same and they are even observed to move in opposite directions under certain types of flight prioritisation (Bratu and Barnhart, 2004; Calderón-Meza et al., 2008; Cook et al., 2013; Manley and Sherry, 2008; Sherry et al., 2008; Wang, 2007). The air transport industry is lacking passenger-centric metrics; its reporting is flight-centric.

There is growing political emphasis in Europe on service delivery to the passenger, and passenger mobility (European Commission, 2011a, 2011b, 2013). However, how are we to measure the effectiveness of passenger-driven performance initiatives in air transport if we do not have the corresponding set of passenger-oriented metrics and understand the associated trade-offs in the context of delay propagation? How can we better characterise and differentiate the performance of the network from a flight and passenger perspective, under new types of flight and passenger prioritisation scenarios? We set out to answer these questions by building the first explicit passenger connectivity simulation of the European air transport network, with full airline delay cost estimations. The two principal datasets used to prepare the input data for the model were IATA's PaxIS passenger itineraries and EUROCONTROL's PRISME traffic data. A baseline traffic day in September 2010 was selected as a busy day in a busy month – without evidence of exceptional delays, strikes or adverse

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[1] Since we are considering the whole ECAC airspace (which is only partly covered by FABs), we included in our partition the nine FABs planned by EUROCONTROL plus three pseudo-FABs defined by the authors and based on geographic proximity.

weather. The busiest 199 European Civil Aviation Conference (ECAC) airports in 2010 were modelled, having identified that these airports accounted for 97% of passengers and 93% of movements in that year. Routes between the main airports of the (2010) EU 27 states and airports outside the EU 27 were used as a proxy for determining the major flows between the ECAC area and the rest of the world. This process led to the selection of 50 non-ECAC airports for inclusion of their passenger data.

The key results observed through (new and established) classical metrics were as follows. Firstly, flight prioritisation rules operating during arrival management based simply on the numbers either of inbound passengers or on those with connecting onward flights, were ineffective in improving overall performance. Secondly, a policy-driven scenario was considered, representing a special case not driven by current airline rules or ATM objectives but designed to benefit the passenger. This scenario, with rules rebooking disrupted passengers at airports based on minimising their delay at their final destination, produced very weak effects when current airline interlining hierarchies were preserved. When these restrictions were relaxed, marked improvements in passenger arrival delay were observed, although at the expense of an increase in total delay costs per flight (due to passenger rebooking costs). Thirdly, a prioritisation process assigning departure times based on cost minimisation markedly improved a number of passenger delay metrics and airline costs, the latter determined by reductions in passenger hard costs to the airline (falling on average by €40 per flight). The importance of using passenger-centric metrics in fully assessing system performance was repeatedly observed, since such changes were not expressed through any of the currently-used flight metrics at the common thresholds set (Cook et al., 2013).

Granger causality (Granger, 1969) is held to be one of the only tests able to detect the presence of causal (as opposed to associative) relationships between time series. It is an extremely powerful tool for assessing information exchange between different elements of a system, and understanding whether the dynamics of one of them is led by the other(s). A network reconstruction was computed for the flight and passenger layers for the baseline (no prioritisation scenario) and cost-minimisation scenario simulations, i.e. four reconstructions in total. The two baseline networks are shown in figures 2 and 3. The colour of each node represents its eigenvector centrality, from green (low centrality) to red (most central nodes). The size represents the out-degree, i.e. the number of airports that a given airport Granger ‘forces’ in terms of delay. The eigenvector centrality is a metric defined such that this centrality of a node is proportional to the centralities of those to which it is connected.

Comparing eigenvector centrality rankings through Spearman rank correlation coefficients showed that all four network layers were remarkably different from each other (r_s: 0.01 – 0.07). These rankings demonstrated that different airports have different roles with regard to the type of delay propagated (i.e. flight or passenger delay) and, furthermore, that these were further changed by the cost-minimisation prioritisation rules. Indeed, a trade-off was introduced under these rules: the propagation of delay was contained within smaller airport communities, but these communities were more susceptible to such propagation. The absence of major hubs in the top five ranking lists for in-degree, out-degree and eigenvector centralities was notable. Indeed, the largest airports present in these rankings were Athens, Barcelona and Istanbul Atatürk.

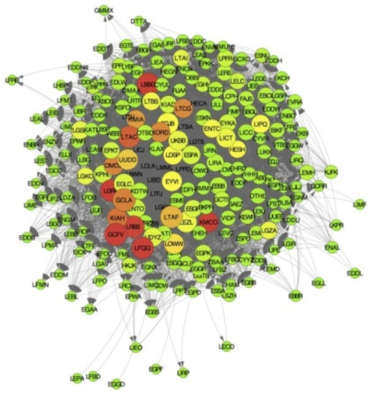

Fig. 2. Flight delay causality network for baseline simulation.

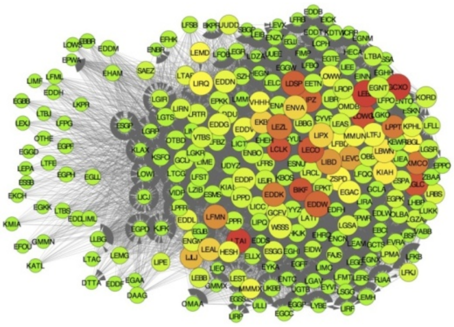

Fig. 3. Passenger delay causality network for baseline simulation.

This modelling has also identified that smaller airports were significantly implicated in the propagation of delay through the network at a level that has hitherto not been commonly recognised. This is probably due to reduced delay recovery potential at such airports and whether a given airport has sufficient connectivity and capacity to reaccommodate disrupted passengers. It was apparent that applying CNT techniques and exploring community properties such as vulnerability, afforded performance insights rather more readily than using classical techniques alone. We believe that a complementary approach using both complexity and classical approaches offers managers and designers, both on the supply and demand side, the most powerful insights into the impacts of potential new operational rules on performance.

4 Conclusions and outlook

In this paper we sought to identify the key features of complex systems and to illustrate the current and future capacity of complexity science techniques to make valuable contributions to the management of air transport. Complex network theory has a range of metrics and methods well adapted to developing the study of air transport networks beyond that which classical techniques have to offer. Its applicability to performance assessment is readily apparent, not least due to the flexibility with which we may define the constituent nodes.

It seems that emergent behaviour research in ATM, and many other fields, would be most productively focused on Type III emergence. This implies the following main research lines. Firstly, increasing our understanding of phase transitions in air traffic management. Why do these not arise in conventional air traffic situations, and which types of change in air transportation in the future could lead to, or further avoid, phase transitions from impacting air traffic? (One possible explanation for the lack of some types of phase transition is that in the current air transportation system traffic demand within each sector is regulated through flow control such that certain critical points are often not reached, but there is still only a relatively poor understanding of how phase transitions from nominal behaviour to propagated network delays occur). Secondly, a better understanding of various percolation phenomena in air transportation is required, again including the context of future operational paradigms, and of exceptional emergent behaviours and the corresponding implications for safety. Thirdly, we need to develop better macroscale models that capture the characteristics of emergent behaviours, e.g. in terms of the associated power laws. Such models would allow the communication of learning from Type III emergent behaviour with other experts in air transportation, not least (tactical) network managers and (strategic) system designers.

Automatically detecting patterns that may compromise the safe operation of the ATM system has to overcome several challenges. One of these is the nature of ATM data, *i.e.* the fact that they emerge from the interaction of a plethora of elements. Due to this, classical techniques like multiple linear regression are not suitable. The high number of elements composing the system also results in the generation of large datasets that cannot easily be aggregated and suitably codified. This process requires automated mechanisms that can filter and organise high volumes of heterogeneous, incomplete or unreliable information in an intelligent manner. Not all such challenges have yet been met, with many benefits to the air transport community yet to be realised, although early research has yielded highly promising results constructing predictive models able to successfully forecast unsafe events. Such tools may have a particular role to play in future, more automated environments.

Any attempt to build a truly holistic performance assessment framework must also take account of uncertainty, another inherent property of real-world complex systems. We are here obliged to consider the multiple temporal and spatial scales associated with such systems, in addition to the various types of uncertainty and the degree to which some of them may be mitigated. Much research has focused on the macroscale, thus rather following the level at which performance targets are set, but there remain particular opportunities to improve our understanding and modelling at the mesoscale. We have also demonstrated the need to differentiate between the passenger and flight layers of such analyses and to ensure that the metrics used are appropriately sensitive to the changes we are trying to measure. Whilst much of this work has focused on operational network models, with corresponding attention on airport functionality, these methods are equally adept at assessing the performance impacts of new policies and at the airline (sub-)network level.

The importance of CNT in assessing network resilience, e.g. through characterisation of air traffic topologies and the identification of vulnerabilities, will become even more useful as further performance demands (e.g. from high-level target-setting) and traffic demands are placed on the system. Based on the resilience developments for complex socio-technical systems in other domains, we may identify four key directions for addressing resilience in air transportation. The first is the elaboration of the unifying resilience framework of Francis and Bekera (2014) for the air transportation domain – one of the challenges here is to incorporate the various stakeholders in a unifying framework, with clear links to the SESAR objectives of collaborative decision making (CDM). The second is the further investigation and incorporation of dedicated resilience metrics in air transportation, as discussed in Gluschenko and Foerster (2013). The third direction is the improvement of access to, inter alia, appropriate resilience data, coupled with the systematic collection and empirical modelling of these data.

The fourth direction is the modelling and analysis of future air transportation design from a resilience perspective, using the most suitable approaches identified in Section 2.3 and illustrated in the case studies of Section 3. The practical alignments with ATM paradigms are apparent, from FAB implementation and high-level network design down to modelling the tactical practicalities of flight prioritisation rules, thus linking with SESAR's central concept of the User Driven Prioritisation Process (SESAR, 2012, 2013).

A key remaining challenge is the appropriate treatment of the multi-dimensional nature of performance in air transportation and the trade-offs between its KPAs. Such complex interdependencies and non-linearities are often overlooked. In on-going work, using CNT with interacting elements and feedback loops, we are investigating such trade-offs for various stakeholder investment mechanisms (such as new technologies to increase capacities) in the context of uncertainty. We foresee that complexity science is set to make significant contributions to the management challenges of improving our understanding and optimising the design of future ATM, from both the strategic and tactical perspectives.

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2.3 Paper 2: *Air traffic management – a new opportunity for complex systems science*

Two journals were shortlisted from a list of ten, discussed collaboratively in Confluence:

- *Complexity*
- *Advances in Complex Systems*

Both journals are open, interdisciplinary and indexed by Thomson Reuters. Both accept review papers. The current abstract proposed for Paper 2 is:

Air transportation is an indispensable component of the modern transport infrastructure and air traffic management (ATM) is vital for its functioning. The increasing demand for air transportation, coupled with more challenging performance targets, is set to dramatically change the way air traffic is managed, as testified by the programs SESAR in Europe and NextGen in the US. Despite its importance, complex system science has only marginally considered ATM as a possible field of application of its methods and tools. The purpose of this review is to present a description of the functioning of ATM, highlighting, with selected examples, some of the research questions that could be investigated by using complex system science. We present a schematic description of ATM in its current and future scenarios and we review some of the literature on the existing applications of complex system science to ATM. Finally, we present a range of research questions that we believe will foster further research integration between ATM and complex system science.

This may be refined in 2014 subject to the final planning regarding this paper, and its inclusion in the next Work Order. The next steps for both of these journal papers are summarised in Section 4.1.

3 Book publication process

3.1 Background and preparatory work

Complexity science in air traffic management

As stated in Section 1, Task 33.2, comprised the preparation towards the publication of a book on complexity science in the ATM domain.

The content and authorship of the book was designed and developed by mutual agreement on-line, in Confluence, with some supporting bilateral discussions. EUROCONTROL, Innaxis and DLR researchers were also included in these exchanges to afford them the opportunity of bringing their expertise to the book in 2014, since they were not explicitly included (funded) in Task 33.2.

Chapter summaries were sent to two shortlisted publishers (selected from a list of five), with whom meetings were coordinated by the University of Westminster. In addition to the Member's research, a set of key questions was put to each publisher and a decision was taken on the best publisher with which to proceed. With positive feedback from both publishers and closely comparable *modi operandi*, the final selection was a difficult choice. Ashgate publishing was finally nominated as the preferred publisher, partly due to its strong *specific* range of books in aviation and the fact that it has already produced several complementary books on complexity in other domains.

The final proposal submitted to Ashgate is shown in Section 3.2, including the Consortium-agreed details regarding the title, aims and rationale, chapter details, editorship and contributors (with supporting biographies) and market definition.

Instead of receiving royalties on the book, the Consortium has agreed with Ashgate to transfer these into free copies of the book to give primarily to students.

Feedback from three reviewers is given in Section 3.3, with the outcome summarised in Section 3.4. Open issues are presented in Section 4.2.

3.2 Book proposal submitted to selected publisher

ASHGATE PUBLISHING LIMITED
Wey Court East, Union Road, Farnham, Surrey GU9 7PT, UK
Telephone: +44 (0)1252 331551 Fax: +44 (0)1252 736736 Web: www.ashgate.com

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Please complete the following details as fully as you can and return to the address above. We do appreciate that some information may be provisional.

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Email:	XXXXXXXXXXX	**Fax:** (By arrangement)

* Provisional coordinating contact for the 'Consortium'. The 'Consortium' collectively comprises the contributors and editors. Please see also under copyright ownership.

Working title of book: Complexity science in air traffic management

Subtitle (if any): N/A

Estimated length in number of words: 65k

Approximate number of:

Figures*:	40 (greyscale only)
Maps:	Nil
Maths:	40

Other (please specify): Nil

Number of black and white photographs: Nil

*Please note that a charge of approx. £8 per photo / unusually complex figure may be made to cover the extra costs of screening, reduction and insertion into the text

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Estimated delivery date of final typescript: Q4/2014 or Q1/2015

The proposal that you submit to Ashgate will be the basis on which the commissioning editor, external reviewer or the series editors/advisory board will judge your book's suitability for publication within the Ashgate Aviation & Human Factors list. The proposal should therefore be between 6 and 15 pages long, and be supported by a recent CV and, if possible, a sample chapter. The key areas below should be covered in the proposal:

- **Statement of Aims & Rationale** – including details of the work's key themes and objectives and why you think this book will prove to be a valuable publication. If you are proposing a volume for a specific series, the proposed book's suitability for publication within the chosen series should also be explained briefly.

ATM comprises a highly complex socio-technical system, that works worldwide, every minute through the year. In the past, ambitious ATM performance improvement programmes have been undertaken. Such programmes have mostly delivered local technological solutions, although the corresponding ATM performance improvements have lagged far behind expectation. In hindsight, this disappointing progress can be explained from a complexity science perspective: ATM simply is too complex to address through classical approaches such as system engineering and human factors. In order to change this, complexity science has to be embraced as ATM's 'best friend'. The applicability of complexity science paradigms to the analysis and modelling of future operations is driven by the need to accommodate long-term air traffic growth within an already-saturated air traffic management infrastructure. The validity of this view is slowly starting to gain ground; hence it is the right time for a book exploring complexity science in the context of air traffic management.

SESAR is the air traffic management technological and research pillar of the Single European Sky. Its research is coordinated through various workpackages, of which Workpackage E focuses on long-term and innovative research. This multi-million Euro workpackage is comprised of two networks and multiple projects. The fact that one of these two networks, *ComplexWorld*, is dedicated to the application of complexity science to ATM speaks clearly of the importance of this emerging, multi-disciplinary approach. The number of major research projects dedicated to complexity science in ATM has now reached double figures. The *ComplexWorld* Network is comprised of partners across Europe: the Innaxis Research Institute (Coordinator), the University of Seville (scientific lead), the University of Westminster and the University of Palermo, in addition to both the German and Dutch national aerospace enterprises – DLR (Deutsches Zentrum für Luft- und Raumfahrt) and NLR (Nationaal Lucht- en Ruimtevaartlaboratorium). All of these partners are represented on the Scientific Board of the *ComplexWorld* Network and are contributing to the book (the Consortium), drawing not only on their experience of activities within SESAR but also more widely in complementary research fields. The editors of the book are from the University of Westminster and the University of Seville. Throughout the activities coordinated by the *ComplexWorld* Network, not least through the popular conferences and workshops cited below, the team became convinced of the appeal of a book drawing on such activities, and the team's breadth of corresponding research experience, to present the role of complexity science in ATM.

The proposed work is an academic book targeted particularly, but not exclusively, at transport researchers. In addition, we would like to stress the complementary appeal to practitioners, supported through the frequent references to be made to practical examples and operational themes (such as performance, airline strategy, passenger mobility, delay propagation and free-flight safety). The book should also have significant appeal beyond the transport domain, due to its intrinsic value as an exposition of applied complexity science and applied research, drawing on examples of simulations and modelling throughout, with corresponding insights into the design of new concepts and policies, and the understanding of complex phenomena that are invisible to classical techniques.

- **Project Synopsis & Chapter Details** – including an extended contents list with an abstract of each chapter, which should include details of the geographic range of content, any case studies, and illustrations (where relevant).

Chapter 1. Introduction

1.1 What is complexity science?
1.2 An initial look at the state of the art
1.3 Complexity science and ATM
1.4 Objectives and key themes of this book

We here present an overview of the book, explaining the context of complexity science and the rationale for the content of the chapters as an integrated whole. A high-level commentary is provided on the state of the art, relating to the research areas presented, identifying the major accomplishments in the field to date and the potential value for air traffic management. In particular, we identify areas of common interest and synergies with other SESAR activities, with special attention to the research in Workpackage E (this is primarily to set a context for the book – it is not presented as an extension of Workpackage E, but as a stand-alone work of value in its own right). The introduction will also comment on the provenance of the book and the collaborative effort that brought it into being.

Chapter 2. Complex network theory

2.1 Representing the world with networks
2.2 Characterising networks
2.3 Classes of complex networks
2.4 Applications outside air transport
2.5 Conclusions

This chapter presents an overview of the mathematical field known as complex network theory, its origin, and its relevance for the study of complex systems. It is aimed at the reader not familiar with the theory, in order to support the concepts presented in the following chapters. Complex network theory was developed from graph theory (beginning with Leonhard Euler in 1735) and deals with the study of complex systems by representing their constituent elements by nodes, with pairs of them connected with links whereby specific relationships are observed. This technique allows the creation of elegant representations of such relationships, avoiding any unnecessary details about the nature of the elements themselves. In other words, by means of a network it is possible to represent in an abstract form the underlying structure of a system, independently of the nature of the system itself. In the last decade, this methodology has been applied to many different complex systems, from biology (e.g. interactions between proteins and genes), to epidemiology (e.g. the diffusion of disease) and to technological systems (e.g. the internet). The main concepts associated with complex networks are presented. This starts with the description of different *topological* metrics, *i.e.* measures that quantify structural properties of the network, with their organisation into micro-, meso- and macro-scale metrics. The chapter also presents a review of the main families of theoretical and real networks: random graphs, small-world and scale-free networks.

Chapter 3. Complex networks in ATM

Air transport is a key infrastructural component of modern societies. In this chapter, we discuss various networks that can be defined for air transport. The most-investigated type is the network of airports. We consider the topological and metric properties of these networks, showing how airport network metrics relate to operational concepts such as passenger mobility and airline strategy. Moreover, we discuss the topology of these networks and their dynamics for time scales ranging from years to intra-day intervals, considering also the resilience of air transport networks to extreme events. Other important, yet less-investigated, networks are those of sectors and navigation points. These are two specific instances of air traffic networks and are particularly relevant for air traffic management. The topological and metric analysis of the structure of these networks, often very close to planar graphs, gives important information on the most central regions of the airspace, i.e. regions that are more critical for the functioning of the air transport system. These regions are also those that could be more sensitive to safety events and capacity-driven rerouting activities. Finally, we show how to use network community detection methods to monitor use of the airspace and to identify (with a bottom-up approach starting from traffic data) sensible partitions of the airspace. Specifically, we compare the performance of different community detection algorithms, by using a null model that takes into account the spatial distance between nodes, and we discuss their ability to find communities that could be used to define new control units of the airspace.

Chapter 4. Uncertainty

In this chapter, the problem of how uncertainty affects the performance of the ATM system is addressed. Different sources of uncertainty that affect the system are described; the following types are identified: data uncertainty, operational uncertainty, unavailable data, equipment uncertainty, and weather uncertainty. These sources affect the system in different ways and pose different research problems. Given the complexity of the whole ATM system, the analysis is divided into various problems, according to the system's scales. There are three clearly differentiated scales depending on the level of detail and aggregation: a single flight (microscale), a given volume of air traffic (mesoscale), and an air transport network (macroscale). Hence, the three following problems are considered: flight uncertainty, traffic uncertainty and network uncertainty. (i) Flight uncertainty encompasses all the uncertainties present at the different stages of the flight: strategic, pre-departure, gate-to-gate, and post-arrival. Whereas the spatial uncertainty affects mainly safety issues (such as loss of separation), the temporal uncertainty manifests itself as delays (which affects other scales). (ii) Traffic uncertainty appears at the TMA or sector level. Microscopic uncertain objects (flights) interact with management procedures and separation rules of macroscopic objects (nodes of the network), and uncertain atmospheric conditions. This generates a dynamic, rapidly changing environment. (iii) To analyse uncertainty at the scale of the air transport network (be it at a regional, national, trans-national or at a global level), it is best to abstract and aggregate the various complex and heterogeneous ATM elements without including too much detail (which would be impractical or even impossible if dealing with the whole ATM system). The proper framework for this analysis is complex network theory.

Chapter 5. Resilience

5.1 Introduction
5.2 Resilience - the state of the art
5.3 Moving forward - concepts of resilience in air transport
5.4 The 'resilience engineering' concept
5.5 The 'engineering resilience' concept
5.6 Conclusions

Historically, one concept of resilience prevailed in the ATM context. It was formulated by Hollnagel in 2006: "Resilience is the intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions." This concept has been called 'resilience engineering' and is a paradigm for safety management. Resilience engineering investigates human and organisational aspects with regard to the design of safety-critical, socio-technical systems. It focuses on helping people to cope with complexity, when exposed to pressure. This safety-related definition of resilience was adopted by EUROCONTROL in 2009. However, a second concept of resilience in ATM is now established, which is aligned with performance. The performance-related concept defines resilience within some time horizon (with the implicit assumption that the system performs safely). This form of defining resilience originates in earlier work on material testing and is called 'engineering resilience'. This chapter will explore both the safety management and performance-related perspectives of resilience, defining the terms, exploring how they may be measured, and their relationships with robustness and disturbance. To date, the main principle of a modelling approach to investigate resilience in ATM has been to choose a particular case and then generalise. To what extent is this approach, grounded in safety management, applicable in the performance-related context? For example, how does it depend on the definitions and types of disturbance modelled? To what extent can the ATM system be modelled holistically, taking into account the context of complexity?

Chapter 6. Data science

6.1 Shortcomings of the classical approach
6.2 Tackling cause and effect in the complexity context
6.3 Networks and layers from an ATM performance perspective
6.4 Causality
6.5 Extracting meaningful information
6.6 Conclusions

This chapter explores the holistic concept of data science, embracing complex data analysis and performance metrics. Classical, deterministic models are not well suited to the exploration of complex systems. Holistic, network treatments are required, rather than bottom-up, disaggregate approaches and extrapolations of averages over multiple scales. Relationships between different phenomena, including cause-effect relationships, are often overlooked in a purely theoretical analysis. Indeed, emergence in complex systems produces behaviours at the macroscale that cannot be predicted by means of the analysis of each single element at the microscale. Just as classical models are not well suited to the exploration of complex systems, we should not limit ourselves to the use of classical metrics in our endeavours to better understand ATM. Most of the metrics currently in use in air transport performance assessment may be described as classical metrics: average delay is a typical example. Key strengths of network theory include the researcher's freedom to define the nodes of the network. In the context of air transport, nodes will often be airports, although they could be more abstract, such as accumulations of airline delay costs. Considering the system as a complex network we may significantly advance the state of the art by embracing a new set of analytical methods and corresponding metrics. This chapter deals with techniques for extracting meaningful information from a complex system, and specifically from air traffic management data, defining various terminologies and exploring different approaches available to the researcher, from the pre-processing and cleaning of the data to the visualisation and interpretation of the results. A key objective is understanding the propagation of delay – perhaps one of the most practical contributions that complexity science may bring to ATM.

Chapter 7. Emergent behaviour

7.1 Introduction
7.2 Emergent behaviour types in ATM
7.3 Airborne self-separation concepts
7.4 Applicable complexity science techniques
7.5 Agent-based model of airborne self-separation
7.6 Rare event Monte Carlo simulation results
7.7 Conclusions

This chapter discusses how agent-based modelling and simulation is an indispensable tool regarding the early learning about potential positive and negative effects of emergent behaviour in future designs of air traffic concepts of operations. Commercial aviation is feasible thanks to a complex socio-technical system, which involves interactions between human operators, technical systems, and procedures at airlines, airports, air traffic service providers, and authorities. In view of the expected growth in commercial aviation, significant changes in this socio-technical system are in development both in the USA and Europe. Such changes may lead to changed and novel, rare emergent behaviour. In this chapter, we first illustrate that this complex socio-technical system generates various types of emergent behavior, ranging from simple emergence, through weak emergence, up to strong emergence. The chapter then demonstrates, through a case study, that agent-based modelling and simulation allows the identification of change and novel, rare emergent behaviour in this complex socio-technical system. The case study considered is an agent-based modelling and Monte Carlo simulation of two different airborne self-separation concepts of operation. The simulation results show previously unknown emergent behaviour between the aircraft involved. The results show that very high en-route traffic demand can safely be accommodated by an adequate airborne self-separation concept of operation, which resolves a long-standing dispute between two schools of research, holding opposite beliefs regarding the safety of free flight under high air traffic demand.

Chapter 8. Conclusions and a look ahead

8.1 A résumé of themes and progress
8.2 Key research opportunities ahead
8.3 A roadmap for complexity and ATM
8.4 Future impacts and closing thoughts

We here draw together the major themes of the book into some common conclusions, identifying the most promising research avenues and the major research challenges ahead for the application of complexity science in the context of air traffic management, with particular attention to their impact and potential benefits for the ATM communities – both academia and industry alike. We present an indicative roadmap on how these research challenges should be accomplished, providing guidance on how to leverage various aspects of complexity science research more broadly in air transport.

- **A Short Biographical Paragraph** – on all the authors/contributors involved in the book, including a concise CV and details of qualifications and relevant experience relating to writing the proposed book.

Editors

Andrew Cook is a Principal Research Fellow at the University of Westminster, where he manages the Department's ATM research. He has been a research fellow of the University for 20 years. In addition to air transport industry and EU framework research coordination, Andrew has led eight projects for EUROCONTROL and is currently engaged in several projects in SESAR's Workpackage E (long-term and innovative research). Responsibilities include serving on the programme committee for the annual SESAR innovation conferences and on the Editorial Board of the Journal of Aerospace Operations. Andrew has published widely in ATM, across a number of domains, and frequently reviews journal submissions for Elsevier. He was editor of the first book on European ATM, published by Ashgate. Andrew holds a BA (Hons) Natural Sciences, with supplementary Distinction, and a DPhil Physiological Sciences, both from the University of Oxford.

Damián Rivas received his first degree in Aeronautical Engineering from the Polytechnic University of Madrid and has a PhD from Case Western Reserve University (Cleveland, Ohio). He is currently: Professor in the Department of Aerospace Engineering of the University of Seville, teaching flight mechanics and air navigation; Director of the Group of Aerospace Engineering of the University of Seville; scientific coordinator of the SESAR WP-E ComplexWorld Network; and, a member of the programme committee of the annual SESAR Innovation Days conferences. His main research interests are aircraft trajectory optimisation, aircraft conflict detection and resolution, and uncertainty propagation in air traffic management.

Chapter 1. Introduction

Marc Bourgois. For the last ten years, Marc Bourgois has been managing innovative research activities for air traffic management at the EUROCONTROL Experimental Centre, Paris. He has a long career in computer science research, starting in factory automation at Siemens Corporate Research in Brugge, followed by contributions in high-level distributed programming languages at the European Computer-Industry Research Centre in Munich and systems architecture at EUROCONTROL Headquarters, Brussels. Marc holds master of science degrees in engineering and in artificial intelligence from the Katholieke Universiteit, Leuven.

Chapter 2. Complex network theory

Massimiliano Zanin is a researcher at Innaxis. He graduated in Aeronautical Management at the Universidad Autónoma de Madrid, and with more than 75 published peer-reviewed contributions in international conferences and journals, he has considerable experience in complex systems research, both theoretical and applied, and in collaborating with scientists from all over the world. His main topics of interest are complex networks and data science – and their application to several real-world problems, in addition to modelling and understanding the ATM system and mining complex data sets.

Andrew Cook – please see above.

Chapter 3. Complex networks in ATM

Fabrizio Lillo received a PhD in Physics at the University of Palermo where he is assistant Professor in Physics. He is also currently Professor of Mathematical Finance at the Scuola Normale di Pisa. He is an External Faculty member of the Santa Fe Institute (USA), after being a member of the Resident Faculty for three years. He was post-doc and researcher at the National Institute of the Physics of Matter. He was awarded the Young Scientist Award for Socio- and Econophysics of the German Physical Society in 2007. He is author of more than 60 refereed scientific papers, a member of the editorial board of the journals JSTAT, Fluctuation and Noise Letters, and responsible for the SESAR Workpackage E project ELSA (Empirically grounded agent based models for the future ATM scenario; Pisa unit).

Salvatore Miccichè is an Assistant Professor of Applied Physics at the Department of Physics and Chemistry of Palermo University. After obtaining his PhD in General Relativity from Loughborough University, he held a post-doc position in Palermo working in the field of econophysics. He is interested in the analysis of financial, economic, social, socio-technical and biological systems with the tools and methodologies of statistical physics and network theory. He has participated in a number of Italian European framework projects, including the MIUR strategic project ("High frequency dynamics in Financial markets"), DYSONET ("Human behaviour through Dynamics of Complex Social Networks"), and GIACS ("General Integration of the Application of Complexity in Science"). Recently, he was involved in the SESAR Workpackage E project ELSA (Palermo unit coordinator).

Rosario N. Mantegna is one of the pioneers in the field of econophysics. He started work in this field in 1990, publishing the first paper on econophysics in 1991 and co-authoring the first econophysics paper in Nature. He also edited the first Proceedings published in this field. In 1999, he established the Observatory of Complex Systems, a research group of Palermo University, when he also proposed the use of data mining tools to obtain similarity-based networks. Since this first proposal, the use and applications of similarity-based networks has grown steadily in the statistical physics community and in related fields. In 2000, Mantegna co-authored one of the leading monographs in the field of econophysics. He is currently Professor at the Center for Network Science of the Central European University of Budapest and at the Department of Physics and Chemistry of Palermo University.

Chapter 4. Uncertainty

Rafael Vazquez received PhD and MS degrees in Aerospace Engineering from the University of California, San Diego, and degrees in Electrical Engineering and Mathematics from the University of Seville. He is currently an Associate Professor in the Aerospace Engineering Department in the University of Seville. His research interests include control theory, distributed parameter systems, uncertain systems and optimisation, with applications to flow control, air traffic management, UAVs, and orbital mechanics. He is co-author of the book *Control of Turbulent and Magnetohydrodynamic Channel Flows* (Birkhauser, 2007).

Damián Rivas – please see above.

Chapter 5. Resilience

Henk Blom is Full Professor at Delft University of Technology (chair ATM Safety) and Principal Scientist at NLR. He received his BSc and MSc degrees from Twente University, and his PhD from Delft University of Technology in 1990. Dr Blom has over thirty years' experience in exploiting the theory of stochastic modelling and analysis for safety risk analysis and multi-sensor data fusion in air traffic management. He is author of over a hundred refereed articles in scientific journals, books and conference proceedings, and of the volume *Stochastic Hybrid Systems, Theory and Safety Critical Systems* (Springer, 2006).

He has coordinated several European collaborative research projects such as ARIBA, HYBRIDGE and iFly. Dr Blom is a Fellow of the IEEE.

Olga Gluchshenko is a researcher at DLR, Braunschweig. In 2009, she joined DLR's Institute of Flight Guidance in Braunschweig and works on the development of novel algorithms and concepts for various ATM applications. Formerly, she was a researcher at the Fraunhofer Institute for Industrial Mathematics (Kaiserslautern), where she worked on optimisation tasks in logistics projects. Dr Gluchshenko holds a Diploma degree in Mathematics from Karaganda State University (Kazakhstan) and MS and PhD degrees in Optimisation and Statistics from the Technical University of Kaiserslautern.

Peter Förster is a researcher at the Institute of Flight Guidance at DLR, Braunschweig. His fields of study are discrete event simulation in the context of ATM and trajectory calculation. He joined DLR in 2006 after finishing his Diploma in Aerospace Engineering at the Technical University of Berlin. Peter is currently pursuing a PhD in Aerospace Engineering.

Chapter 6. Data science

Andrew Cook and **Massimiliano Zanin** – please see above.

Chapter 7. Emergent behaviour

Henk Blom – please see above.

Chapter 8. Conclusions and a look ahead

David Pérez. Since its foundation in 2006, David Pérez has been a Director at Innaxis. He is in charge of defining the research lines of Innaxis and leading the research activities of the team. He received an MS in Aerospace Engineering from the Polytechnic University of Madrid and has more than 20 years of experience in different air transport areas, covering airline and airport operations, aircraft manufacturing and aerospace supply industry. David is interested in the applicability of innovative and breakthrough technologies such as complexity science techniques and data science in air transport operations.

- **Likely Competition** – listing where possible the publisher, price and publication year of directly competing and closely related book and their strengths and weaknesses. How does your book differ from these?

We have **not identified any directly competing titles**. However, we have identified two areas of complementarity, the first of which is the most significant.

(i) Complementarity with existing books in the ATM context

We have identified three key books with a certain complementarity to the proposed book:

- Computational models, software engineering and advanced technologies in air transportation
  Eds: Li Weigang, A. De Barros, I. Romani de Oliveira (Hershey, 2010);

- European Air Traffic Management – Principles, Practice and Research
  Ed: A. Cook (Ashgate, 2008);

- Human factors impact in air traffic management
  Eds: B. Kirwan, M. Rodgers, D. Schaefer (Ashgate, 2005).

The first book focuses on technological developments and the second introduces key features of European ATM. Neither deals with complexity science. The proposed book could act as a complement to both of these, extending the modelling of the first and building on some of the performance characteristics addressed in the second. The third book presents human factors in ATM from the top human factors researchers in ATM, with a focus on challenges for air traffic controllers and pilots, whereas the overall *socio-technical system* view would be addressed in the proposed book: instead of localised operational challenges, our proposed book examines the network from the complexity science perspective – thus looking at the system from almost the opposite perspective.

(ii) Complementarity with existing books in the non-transport context

Ashgate has already published several books addressing complexity science. Three are in the context of urban planning (ISBN 978-0-7546-7918-9, ISBN 978-1-4094-0347-0 and ISBN 978-1-4094-0265-7), one addresses complex socio-technical systems (ISBN 978-0-7546-7026-1) – we discuss ATM in our proposed book as an example of such a system – and a further book (ISBN 978-0-7546-0972-8) is a more generalist discussion on complexity science. Readers of the latter two might well be interested in the more applied work that we are proposing.

- **Your Definition of the Market** – including details of the level of readership and the disciplinary and geographic range of the potential audience. Please give information on any relevant undergraduate/postgraduate courses, or other college or non-college courses, where you think the work will be appropriate for use. Please also give details about research institutes, conferences, or associations which link closely to the subject of the work (and which may also prove to be invaluable sources for direct mail of promotional material). If the book is likely to appeal to a non-academic audience, eg professionals in a particular field, please give details.

The geographical range of the potential readership would certainly not be limited to Europe, although the examples and case study references would be heavily focused on this region. We can offer some sense of the potential market size based on the Consortium's coordination of the *ComplexWorld* website www.complexworld.eu and associated activities. The website attracted around 4 700 visits in the first three quarters of 2013, with around 13 000 page hits. We also post to the following groups in LinkedIn, promoting *ComplexWorld* news: SESAR WP-E ComplexWorld Network; Air Traffic Complexity; Air Traffic Management, ATC Global Networks, Complexity Science, Data Science Central, Aviation & Aerospace Professionals. Some of these groups have tens of thousands of members. The new ComplexWorld wiki (http://complexworld.eu/wiki/ - an interactive environment dealing with many of the topics proposed for the book chapters) has so far received 1 500 visits with good growth demonstrated. We also have 2 300 contacts in our database, acquired through events, workshops, or sign-ups through the website.

The market appeal, geographical scope and interdisciplinary facets of the application of complexity science to ATM are all reflected in part through the number of successful events organised this year by *ComplexWorld*, with the objective of promoting this application. This applies both within the air transport community and beyond. These events aimed to create a suitable platform to enable the sharing of knowledge across innovative fields of expertise, allowing researchers from diverse institutions to share and debate their most recent results, thus stimulating interest in the field and disseminating the Consortium's (network's) research activities to achieve a wider audience. Each year, the Consortium also organises full-day tutorial sessions on selected, associated topics for the Network's PhD students. These activities all complement the *ComplexWorld* wiki activity.

In summary, the events of 2013 include: a workshop on uncertainty in ATM (with the *International Conference on Application and Theory of Automation in Command and Control Systems '13;* Naples, May 2013); papers and tutorials sessions at ATOS 2013 (with the conference series on *Interdisciplinary Science for*

Innovative Air Traffic Management; also with: ENAC, ASDA, TU Delft; Toulouse, July 2103); a workshop on resilience and robustness in ATM (also with the ISIATM, ENAC, ASDA, TU Delft; Toulouse, July 2103); a satellite event at the *European Conference on Complex Systems '13*, dedicated to complexity science and transport systems (Barcelona, September 2013); a workshop, also coordinated with ECCS '13 on *The air transport network - an integrated view* (Barcelona, September 2013); a workshop on data science in aviation (Madrid, October 2013); and, a forthcoming workshop on complex metrics in ATM (at the SESAR innovation days conference, Stockholm, November 2013). Even as a relatively new network, our dedicated complexity events attracted delegates from across Europe, including industry and academia. It will be noted how the themes addressed are very closely aligned, by design, with the chapters of the book.

The strength of the field in general can be demonstrated by both the number of journals now specifically dedicated to complexity science (e.g: *Advances in Complex Systems*, *Complexity*, *International Journal of Complex Systems in Science* and *Journal of Complexity*) and non-dedicated journals also carrying articles on complexity (e.g: *Contemporary Physics*, *The European Physical Journal B*, *Physica A: Statistical Mechanics and its Applications*, *Physical Review E*, *Physical Review X* and *Reviews of Modern Physics*). In addition, the *Journal of Aerospace Operations* has carried some articles relating to the application of complexity science in ATM and the Consortium will be submitting a journal article to the *Journal of Air Transport Management* in November 2013 which will be closely allied to various themes of the book, thus further raising awareness of this topic to a broader (management) audience in air transport.

The proposed book would be of interest to scholars of complexity science (e.g. statistical physics, network theory, computational economics and sociology, etc.), who could find in the book the material needed to understand where and how their methods and tools could be applied to the growing research field of air traffic management. From this point of view, there is a potential market for the book comprised of scientists not currently expert in the ATM domain. As in any interdisciplinary field, books may be considered as extended reviews that are able to constitute a bridge between different communities and have the potential to accelerate dramatically the convergence between such fields.

In complex system science there is a growing interest in the modelling and analysis of traffic. However, so far, attention has been focused more on non-air-transport traffic (e.g. urban transport (and planning) and pedestrian flows). Potentially, therefore, the field of complex system science applied to air traffic management should experience a dramatic growth, due also to the availability of high-resolution data and to European projects (not least in SESAR Workpackage E, on which the book will draw significantly) focused on the application of complexity science to air traffic management (as mentioned above on the rationale for the book).

Already, in these early stages of development, two university courses are aligned with the book:

- In the Aerospace Engineering programme at the University of Seville, there are two subjects in which part of the syllabus corresponds to contents of the book, covering topics such as uncertainty, delay propagation, airport congestion, complex networks and complex metrics; these subjects are Air Traffic Management (undergraduate level) and Advanced Air Traffic Management (graduate level, to be taught for the first time in 2014);
- At Delft University of Technology, Aerospace Engineering MSc students with a focus on Air Transport Operations have to follow the obligatory MSc course on Agent-Based Safety Risk Analysis. Based on the positive reception of this course by the students, a complementary elective course – Agent-based Modelling and Simulation in Aviation – is now in preparation. Having a book on complexity science in ATM would definitively support these courses.

Based on this experience, we may expect that the book could be used to complement the syllabus of courses in ATM and air transport at other universities, by including such advanced topics, especially at the postgraduate level. Other universities in the Consortium would naturally promote the book to its students. The on-going initiative of dedicated workshops and (satellite) conference events will also be a sustainable environment for promotion of the book. We note in closing this section that the Consortium currently plans to request from the publisher complementary copies of the proposed book in lieu of royalties, which would be used to seed the market (e.g. amongst students) and promote interest.

- **Thesis Revision** – if your proposed book is a revised version of your PhD thesis, has the thesis been posted onto any institutional repository? If yes, is the institutional repository publicly accessible or accessible only to members of the institution? Please give details.

  N/A

- **Any Special Features** – eg glossaries, sections on further reading, CDs, unusual/complex diagrams.

  N/A

Reviewers

Although we have our own network of academic and practitioner contacts across the disciplines from which we can select appropriate reviewers to comment on proposal, it would also be helpful if you could list two or more academics in your field who you would expect to provide useful feedback on your work. If you could provide both email and postal addresses that would be a great help.

Details of four potential reviewers provided under separate cover, accompanying this form.

Please submit your proposal directly to the Publisher (XXXXXXXXXXX, XXXXXXXXXXX@ashgatepublishing.com), and please feel free to contact him if you require any further information or would like to discuss ideas or simply to offer comments on Ashgate's publishing programme in general.

References

We have collected below a selection of references from the contributors to chapters 2 through 7, inclusive. We have also presented numerous papers at each of the *ComplexWorld* events mentioned above. As commented, the team contributing to the book will also be submitting a journal article to the *Journal of Air Transport Management* in November 2013 which will be closely allied to various themes of the book, thus further raising awareness of this topic to a broader (management) audience in air transport.

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3.3 Reviewers' feedback *via* selected publisher

The anonymous reviews are reported *verbatim* below. Reviews 2 and 3 were received very close to the deadline for the production of this Deliverable. These two reviews included two specific comments on particular chapters (one from each reviewer), for which there has not been time to coordinate a full response from the contributors concerned. These specific comments have therefore been omitted from the text below. A response will be subsequently coordinated with the publisher.

The overall positive feedback from the reviewers is reflected in the outcome presented in Section 3.4.

3.3.1 Review 1

A. Readership

1. Do you feel there is a sizeable potential audience for this proposed book?

There is an audience for the proposed book but I am not sure that it will go beyond those with an interest in the field of Complexity Science. I am sure that some ATM engineers will have an interest but in my view this will not be a large market. Similarly, some courses may recommend the work but it would only be supplementary reading for anything beyond modules in Complexity Science. For example, I teach both ATM concepts and safety-critical systems design and the proposal would be too specialised in either area to make it a core text.

2. Can you identify the main readership groups, so far as not clearly stated?

See comments above. The readership is not clearly stated, and that is a problem that should be addressed. I think the proposal is rather optimistic – both in terms of readership and the existing track record for complexity science in ATM. I think many researchers will be interested, hence libraries will acquire copies but I am more sceptical about practitioners and have noted my caveats about courses above.

3. Are there courses for which the material is appropriate?

As mentioned, post graduate courses in complexity science – possibly some undergraduate courses in Engineering. Beyond that it is difficult to say.

4. What do you think would be the primary appeal of this book?

The primary appeal of the proposed book is to provide a glimpse of potential applications for Complexity Science in an engineering domain. However, I believe that it would be important to strike a more balanced note. While some of the criticisms of the conservatism of ATM engineering are very valid, it is unclear in my mind that complexity science will offer all of the benefits claimed in this proposal. I am familiar with the SESAR project that forms the basis of the consortium and have been impressed by their work but I think if the claims were more modest, more people might be persuaded to read the book, especially if it addressed the challenges of introducing the techniques into conventional engineering and management practices.

B. The Proposal

1. Is the material structured in a logical and helpful way? In what way, if any, could the structure be improved?

The material is well structured but I would raise a number of further caveats about the need to include contributions from a more operational perspective if the readership is to be enlarged beyond the academic research audience (see below).

2. Are there obvious omissions, superfluous portions or serious errors within the content? Does the range and weighting of different topics seem appropriate?

The consortium is largely academic – there is a lack of input from the operational elements of ATM, airports or airlines. As a result I worry that the book will lose this audience – especially given that some of the claims in the outline lack detailed validation by these end users, at least in my view.

For instance, "The applicability of complexity science paradigms to the analysis and modelling of future operations is driven by the need to accommodate long-term air traffic growth within an already-saturated air traffic management infrastructure. The validity of this view is slowly starting to gain ground; hence it is the right time for a book exploring complexity science in the context of air traffic management". This validity is based on the SESAR work but this is a research project and a long way from operational validation.

3. From what you've seen, does the style seem fluent and appropriate for the readers?

Yes – however, there is often a problem with the mathematical nature of work in this area. Clearly, the proposal is pitched at a more abstract level so it is hard to know whether the final draft will be accessible to a broad range of readers.

4. Does the author write with the required authority and/or qualification?

Yes – but as noted above there is a lack of input from end users, in particular ANSPs, airlines and airports.

C. Conclusion

1. Do you recommend publication as it stands, or with major/minor alterations?

Yes, I would recommend publication. It will provide an important reference for the network and for the application of complexity science in ATM. ***The caveats I have mentioned are all relatively minor*** *and focussed on expanding the market/readership for the work.*

Any additional comments:

N/A

3.3.2 Review 2

A. Readership
1. Do you feel there is a sizeable potential audience for this proposed book?

Yes.

2. Can you identify the main readership groups, so far as not clearly stated?

The readership is not clearly stated, and that is a problem that should be addressed.

3. Are there courses for which the material is appropriate?

Courses on complex networks and air transport are appropriate.

4. What do you think would be the primary appeal of this book?

Embedding air transport management in the topic of complex networks

B. The Proposal

1. Is the material structured in a logical and helpful way? In what way, if any, could the structure be improved?

Yes. I like the structure of the book. The topic of complex science and complex networks is not new. However, the organization of the book, embedding air transport management in the topic of complex networks, is useful for researchers, since it provides a homogenous platform, from where ATM issues depart. […]

2. Are there obvious omissions, superfluous portions or serious errors within the content? Does the range and weighting of different topics seem appropriate?

Comments: *A) Chapter 1 (Introduction) should also show research questions, to which each chapter should reply; B) Chapter 8 (conclusion) should summarize the replies to the initial research questions, by proposing new paths and research directions. […] Section 5.3 should show a link with ATM. Thus the title should be something like: "The resilience concept applied to ATM" (I would cancel the engineering resilience concept in the title, since it is more interesting the ecological resilience concept).*

3. From what you've seen, does the style seem fluent and appropriate for the readers?

Yes

4. Does the author write with the required authority and/or qualification?

Certainly.

C. Conclusion

1. Do you recommend publication as it stands, or with major/minor alterations?

See the requested revisions at Point 2, concerning Chapter 1, 5 and 8. The remaining chapters seem, in principle, OK.

3.3.3 Review 3

A. Readership
1. Do you feel there is a sizeable potential audience for this proposed book?

There could be if they add a chapter on Future Applications of Complexity Science

2. Can you identify the main readership groups, so far as not clearly stated?

See comments above. The readership is not clearly stated, and that is a problem that should be addressed.

The ATM community and the ICT industry.

3. Are there courses for which the material is appropriate?

-

4. What do you think would be the primary appeal of this book?

Introduction of Complexity Science into ATM.

B. The Proposal

1. Is the material structured in a logical and helpful way? In what way, if any, could the structure be improved?

Yes the material is well structured, however an additional chapter about the Future Applications of Complexity Science will be beneficial for the book and increase the readership.

2. Are there obvious omissions, superfluous portions or serious errors within the content? Does the range and weighting of different topics seem appropriate?

To add in the section Statements of Aims & Rationale after the first paragraph to expand about the Europe's future ATM challenges, like increased flights, increased congestion issues, reduced airspace capacity, etc….

All the references to WP-E to be exchanged with references to SESAR Exploratory Research program.

3. From what you've seen, does the style seem fluent and appropriate for the readers?

Yes.

4. Does the author write with the required authority and/or qualification?

Yes, most of the Authors have the necessary research experience to write about the proposed topic because they are involved in several projects under SESAR Exploratory Research program. […]

C. Conclusion

1. Do you recommend publication as it stands, or with major/minor alterations?

I recommend the publication of the book with minor alterations in Chapter 1 like adapting the structure and adding a section on the expected conclusions.

Chapter 1 Introduction

- *What is complexity science?*
- *Objectives and key themes of this book*
- *Complexity science and ATM*
- *An initial look at the state of the art*
- *Conclusions*

Chapter 2 Complex network theory

2.4. Applications outside air transport – to be taken out and integrated in a future chapter Future Applications

Chapter 6 Data science
Include an introduction to Data science and a short description

Any additional comments:

The book covers the important aspects of Complexity science in the context of ATM, however I hope in Chapter 8 to see recommendations for long-term future research topics in the context of the future ATM evolution.

The book has to contain a clear justification ”Why complexity science is relevant to ATM today and tomorrow?” Is Complexity Science relevant to ATM in the context of the European ATM Master Plan, Step 3?- if so what is the is relevance?

The Authors of the book have sufficient knowledge and experience both in ATM and Complexity Science in order to write a good book.

3.4 Review process and book publication outcome

We are most grateful to Ashgate and the reviewers for the valuable feedback. This feedback has clearly identified some useful points for discussion with the publisher. Some of these are potentially helpful enhancements, others are mutually incompatible, and we need to be careful not to lose the focus of the book by trying to broaden the readership too widely and thus diluting the core academic market (on which point both publishers approached agreed). All of the points raised will be discussed with the publisher, and considered carefully. According to the reviewers, there is also an opportunity to further define the market – a further topic for discussion.

Based on the overall positive feedback, and dialogues between the University of Westminster and the publisher, we are pleased to declare that Ashgate has approved the proposal and wishes to proceed with the book in 2014.

4 Next steps

4.1 Next steps with regard to journal papers

- Paper 1 ("Applying complexity science to air traffic management") will be submitted to the *Journal of Air Transport Management* after approval of / feedback on this Deliverable, allowing for a final review by the authors. This submission should take place in January 2014.
- The progressing of Paper 2 (provisionally titled "Air traffic management: a new opportunity for complex system science") will be decided in the context of the Year 4 Work Order and its priorities.

4.2 Next steps with regard to book publication

Between the ComplexWorld Members and EUROCONTROL, the next steps are to discuss the:

- delivery timeframe;
- appropriate work effort for Year 4, for the contributions to chapters and for the editorial roles of the universities of Westminster and Seville;
- role of, and potential funding for, any external contributors;
- appropriate budget for Year 4 for external copyediting - this will reduce the amount of post-submission editing carried out by the publisher (which otherwise increases the sale price of the book and delays publication whilst we assess the edits).

Note. The copyright issue has been resolved with EUROCONTROL and the SJU. The Consortium will own the copyright (the Consortium collectively comprises the contributors and editors).

Between the Consortium and the publisher (Ashgate), the next steps, to be coordinated by the University of Westminster, are to discuss the:

- reviewers' feedback, to mutual satisfaction;
- delivery timeframe;
- progression to formal contract.

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