Air Traffic Management

Principles, Performance, Markets

Edited by Marina Efthymiou

ROUTLEDGE

Air Traffic Management

This book addresses each of the Air Navigation Services' five broad categories of services provided to air traffic during all phases of operation: air traffic management (ATM), communication, navigation and surveillance services (CNS), meteorological services for air navigation (MET), aeronautical information services (AIS) and search and rescue (SAR).

This book is designed for working professionals in Air Transport Management, but also undergraduate and postgraduate students studying air transport management and aeronautical engineering. It will also be very helpful for the training of air traffic control officers (ATCOs). The book does not require any prior (specialist) knowledge as it is an introduction to air navigation service provider (ANSP) business. There is very little literature available that gives a detailed appreciation of the complexities, potential risks and issues associated with the provision of air navigation services. The role of this book is to fill this significant gap with a comprehensive, in-depth study of the management principles related to ANSPs. This is particularly timely given recent ATC developments in Europe, USA and New Zealand. Airlines and airports rely on the ANSPs for the management of air traffic. Hence, air navigation services (ANS) provision is considered a core element for air transportation.

Marina Efthymiou is an Associate Professor in Aviation Management at Dublin City University, Ireland. Before this, she worked for Eurocontrol. Marina holds a PhD in Sustainable Aviation Policy and Air Transport Management. In the past five years, she has published more than 30 papers in prestigious peer-reviewed academic journals. Her research interest primarily focuses on sustainable aviation, air navigation service providers, air traffic management/control, environmental, social, and governance (ESG), and airline and airport business models.

‘This textbook on air traffic management should be required reading for anyone involved in the management or regulation of this key part of the air transport ecosystem. All the key issues of supplying sufficient capacity, limiting environmental damage and the appropriate charging of users are addressed by experts in their field. For me the most important chapters are those at the end, dealing with reform and what future airspace management could deliver.’

Brian Pearce, *Former-Chief Economist at IATA*

‘This textbook provides thorough inside in the current world of global ATM. The history, the future and the complexity of air navigation service provisions are well described and offer the reader a good understanding of challenges of air traffic management.’

Marc Baumgartner, *IFATCA SESAR/EASA Coordinator*

‘This book is an ambitious attempt to draw together the evolution and current performance of the hidden backbone of aviation, one of our truly global industries. Air traffic management is an under researched area of human activity and this book does much to fill that gap.’

David McMillan, *Chair, ATM Policy Institute*

‘The publication of this textbook could not come at a better time. In 2023, the aviation community is facing unprecedented challenges, which are also rich of opportunities. Transformations are needed and on their way. I expect this book to be a thought-provoking and useful tool for both ATM professionals and students.’

Kjartan Briem, *CEO of ISAVIA ANS, Iceland*

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Marina Efthymiou

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Contributors

Dr Marek Bekier has been in the aviation sector since 1993 and holds a MSc and a PhD from the University of New South Wales (Sydney), where he lectures Air Traffic Management. He held different operational and managerial roles for the Swiss ANSP skyguide, where he was ATM Director for Zurich. Since then Marek has provided consulting services to institutional, regulatory, and commercial actors and is Senior VP with the Swedish ANSP ACR.

Dr Markus Biedermann is the Director Operational Support for the German Air Navigation Service Provider at Frankfurt/Main. He holds a PhD in Business, Finance and Entrepreneurship. His research interest lies primarily on high reliability organisations theory with a strong focus on aviation and aviation safety. He has held senior management positions at various air traffic control sites such as London Gatwick Airport and Munich Airport. He has participated in aviation regulation development and publication on national and international level.

Dr Graham Braithwaite holds a PhD in Aviation Safety Management from Loughborough University and is currently Professor of Safety & Accident Investigation and Director of Transport Systems at Cranfield University, UK. He is the Principal Investigator on the £67m Digital Aviation Research and Technology Centre (DARTeC) and independent safety advisor to two major airlines based in the UK. He has twice led successful bids for the Queen's Anniversary Prize – the highest honour for a UK University.

Dr Marina Efthymiou is an Associate Professor in Aviation Management at Dublin City University, Ireland. Before this, she worked for Eurocontrol. Marina holds a PhD in Sustainable Aviation Policy and Air Transport Management. In the past five years, she has published more than 30 papers in prestigious peer-reviewed academic journals. Her research interest primarily focuses on sustainable aviation, air navigation service providers, air traffic management/control, environmental, social, and governance (ESG), and airline and airport business models.

Dr Frank Fichert is Professor of Economics and Transport Economics at Worms University of Applied Sciences, Germany. He has published a large number of papers on the air transport sector and is co-author of the leading German textbook on air transport management. He has participated in several applied research projects, including the European SESAR H2020 projects COCTA and CADENZA. His research focuses on competition and regulation in the air transport industry and the environmental issues of aviation.

Peter Forsyth joined Monash University in 1997 and has been a Professor of Economics. His research has focused on transport economics, the economics of aviation and the economics of tourism. More recently, he has carried out research on economic policies to reduce emissions of aviation and has published *Aviation and Climate Change: Economic Perspectives on Greenhouse Gas Reduction Policies* (with F Fichert and H-M Niemeier, Routledge, 2020). In 2015, he was made a Fellow of the Air Transport Research Society.

François Huet is currently Policy and Regulatory Director for the Borealis Alliance. Since 1992 he has been working in and with several European entities: In Eurocontrol as Secretary to the Diplomatic Group for the revision of the Convention and Secretary to the Committee for route charges, in the European Commission as desk officer for the performance and charging Regulations under the SES II package, in the SESAR JU as Master Plan Programme Manager for the 2015 and 2020 update campaigns. François holds MScs in International Law and Public Administration.

Dr Radosav Jovanović is a professor at the Division of Airports and Air Traffic Safety, University of Belgrade – Faculty of Transport and Traffic Engineering (UB-FTTE). Educated at UB-FTTE (dipl. ing. and PhD, both in Air Transport and Traffic Engineering) and University of Westminster (MSc Transport Planning and Management). He is a leader of three courses at UB-FTTE. His research primarily focuses on air traffic flow and capacity management. He was the coordinator of SESAR Exploratory Research projects COCTA and CADENZA.

Peter Kearney, Chief Executive Officer of the Irish Aviation Authority, Dublin, Ireland.

Dr Wen-Chin Li is a Senior Lecturer in the Safety and Accident Investigation Centre, Cranfield University, United Kingdom. He is a Fellow and Charter Ergonomist and Human Factors Specialist of Institute of Ergonomics and Human Factors (CIEHF), and an Aviation Human Factors Specialist of European Association of Aviation Psychology (EAAP). His expertise includes accident investigation, cross-cultural research, flight deck design, and aeronautical decision-making. He has published over 100 Book, journal articles and conference proceedings related to digital tower certification, flight deck design, human factors and aviation safety.

Keith McEvoy qualified as an air traffic controller with the Irish ANSP, AirNav Ireland. He has previously held the position of Deputy Operations Manager for Dublin ATC and is currently the ANSPs Manager ATM Standards and Procedures. During his career, Keith has contributed to numerous projects, including the development of ATS procedures for the introduction of the Northern Parallel runway at Dublin airport. Keith holds a Msc in Management (Aviation Leadership) from Dublin City University.

Gary McIlroy is an ATM/ANS Inspector for the Irish Aviation Authority. He currently has 17 years aviation experience as an air traffic controller in both the civil and military environments. He holds a Msc in Management (Aviation Leadership) from Dublin City University and a Msc in Project Management from UCD Michael Smurfit Business School. His expertise is in the area of regulatory and risk based oversight of safety management systems at air navigation service providers.

Hans-Martin Niemeier is a Director of the Institute for Transport and Development at Bremen University of Applied Sciences. He is Chairman of the German Aviation Research Society and member of the Advisory Board of the European Aviation Conference. From 2014 to May 2019 he was member of the Performance Review Body of the Single European Sky. He has published on privatisation, regulation and competition of airports, the reform of slot allocation and on airline and airport alliances.

Anna Tomová is a professor at the Faculty of Operation and Economics of Transport and Communications, University of Žilina in the Slovak Republic. She is responsible for the courses of airline economics, airport economics and air navigation services economics. She participated in European projects in the field of air transportation research - SWIM-SUIT, ATARD. She took participation in an European educational project KAAT – Knowledge Alliance in Air Transport.

Foreword by EASA

With an average of 8 billion euros of route charges billed per year in Europe (Central Route Charges Office, 2019), the provision of air navigation services is a key economic component of air transport. These costs are the price to pay to guarantee safe operations in the European airspace through the establishment and provision, principally at national level, of ATM/ANS critical infrastructures and services. The final user (i.e. the passenger) is rarely aware of the complex system and organisation that lies behind this aspect of the flight and ensures its safe passage. Even aviation professionals have sometimes a limited knowledge of its functioning. I therefore welcome the initiative to publish a book dedicated so this subject, which will allow both students and professionals to understand this area of aviation better.

A cost of 8 billion euros per year represents a significant obligation to the travelling public to provide an excellent level of service. The Single European Sky legislative package adopted by the EU in 2004 and amended in 2009 introduced a series of requirements to ensure that the ATM/ANS services provided in Europe are safe, efficient, cost-effective and contribute to the reduction of the environmental footprint of aviation. As a result, the European Union Aviation Safety Agency (EASA) was entrusted in 2018 with the task of preparing the EU implementing regulations for ATM/ANS, for instance by defining the essential requirements, and to act as competent oversight authority for pan-European ANS providers or for national providers if requested to do so by Member States who opt for this oversight approach. This additional competence ensures EASA can have a holistic approach ('total-system approach') for the safety of the air transport system in Europe.

Thanks to this legislative and regulatory framework, but also thanks to the excellence of the actors of the sector, Europe has built a track record as the safest region in the world for air transport and is now a model in this field for several third countries and regions.

This track record is good, but it can always be better. As outlined by the Wise Persons Group (2019), the air navigation service domain has not yet undergone its revolution. While several other sectors, which are also sovereignty-sensitive, such as defence or space, have recently broken with taboos and made progress towards mutual and innovative engagement/

commitments by pooling and sharing capacities and investments, the ATM/ANS sector is still functioning on the same principles as 70 years ago. The exception is a few remarkable but limited developments in Europe, led by the European institutions, such as the CFMU, and then Network Manager for Air Traffic Flow Management, the EU joint research programme (SESAR), the Single European Sky in the regulatory field and the Performance Review scheme. Apart from the Maastricht centre, the core ANS services (i.e. CNS and ATS have not seen much progress towards enhanced organisational set-up at European level).

It is by no means certain that these achievements will be sufficient to meet the coming societal and political challenges, exacerbated by the successive crises we have seen in aviation in recent years. Several drivers and mega-trends call for a shift from incremental changes to fundamental transformation.

European citizens and passengers, the end-users who ultimately pay the air navigation charges, expect affordable services, resilient to disruptions and crisis, and for these to be green and sustainable, easy to use, smart, agile, borderless and well-integrated into the European multimodal transport network.

Technology is a driver for transformation and offers unprecedented opportunities to break down the barriers. Artificial intelligence, big data, machine learning, data as a service, high speed and secure connectivity facilitated by 5G and satellite applications, quantum, cloud computing are some of the game-changing technologies offering smart digital solutions to create intelligent transport systems. For instance, with three satellites jointly owned by the 27 EU Member States, EGNOS offers cross-border services and already, as of April 2022, replaces ground infrastructure at 430 airports. There is no reason why all these new technologies could not be further deployed in air transport, and in ATM/ANS in particular.

The market is also calling for modernisation to enable new modes of air mobility and their new operational needs. The current ANS organisation will have to adapt to accommodate the 'new entrants' airspace users, such as the drones, and adjust in particular for their very low operations for urban air mobility, or the higher airspace operations at hypersonic or suborbital speed.

The innovative concept of U-Space – relying on other services than ANS – which was adopted in 2021 by the European Union Regulator, is the first legislation of this kind in the world. Its implementation as of 2023 will hopefully demonstrates that there are other ways to fly safely in the European airspace and could inspire the ATM/ANS of the future. This development already shows that Europe has the capacity to be at the forefront of innovation, lead change and influence global developments.

To pursue the efforts along this path, we need the next generation of young Europeans to be fully equipped with excellent academic knowledge as well as with the capacity to think out of the box. With its 10 Chapters providing a comprehensive overview of the various components of the ATM/ANS system and of the challenges they raise, this book is the perfect tool for this. It presents an opportunity for the students of Dr Efthymiou, but also for the wider community of readers interested in aviation. I wish them as much pleasure in reading it as I had.

Patrick Ky
Director general, European Aviation Safety Agency

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Foreword by Eurocontrol

Eurocontrol is a unique, civil-military organisation covering almost all of Europe (41 Member States and two Comprehensive Agreement States). We look at the entirety of Air Traffic Management – all the way from original research through to real-time operations. Most visible is our work as the Network Manager, including flow and capacity management – making sure that ANSPs are not overloaded with traffic and that planes do not have to circle airports waiting for their turn.

We also collect route charges across much of Europe and, at Maastricht, we provide air navigation services for the upper airspace across Belgium, Luxembourg, the Netherlands and northern Germany (in the Maastricht Upper Area Control Centre – MUAC). So, overall, we have a deep understanding of how ANSPs work, particularly in the context of Europe, which has complex airspace and high levels of traffic.

What drives air navigation service providers?

Many businesses have to balance a number of different, potentially competing, drivers – and Air Traffic Management is no exception. The way these drivers are described varies but essentially they are: *safety*, *cost*, *capacity* and *sustainability*.

Safety is thought of as paramount and essential but, even here, it must be balanced against other considerations. For example, keeping every aircraft 10 nautical miles from every other aircraft at all times would be extremely safe but also completely impractical. Instead, the safety rules are developed so as to allow for more capacity and efficiency while still keeping the number of accidents down to a remarkably low level. This is despite increasing traffic; the Eurocontrol area saw over 11 million flights in 2019 with a daily peak of over 37 thousand flights. This is around four times the traffic levels in Europe when I started working in aviation, over 35 years ago.

Cost is always a consideration whether it is borne by the taxpayer (as in the United States) or the airspace user (the European approach). Airlines have examined every element of their expenditure in order to make themselves as efficient as possible. Even though they cannot directly control the level of route charges, they do put pressure on ANSPs to improve efficiency and reduce costs.

However, the cost to airlines of insufficient **capacity** can be even greater. Delays are expensive, especially within the EU (with its policy on compensating passengers for delays). As a result, ANSPs are under very strong pressure to ensure that there is sufficient capacity in the system.

Environmental concerns have always been important; reducing fuel burn has cost benefits for airspace users and reducing the noise footprint of aviation is crucial for the acceptability of airports. But now there is real public pressure to make aviation more **sustainable**. Improvements will come mostly from more use of Sustainable Aviation Fuel, more efficient aircraft and new propulsion systems (such as electric and hydrogen). However, there are also improvements to be made in ATM – enabling aircraft to fly more efficient trajectories, both horizontally and vertically, and minimising fuel burn when taxying.

Air navigation service providers as businesses

ANSPs have an unusual business model. They are safety-critical – which leads to long lead times in terms of changing systems and training new staff. Investment, again in terms of both equipment and staff, is high with the proportion of costs that are truly variable being relatively low. Coupled with a strong public sector orientation, this has led to a lack of flexibility. This can be contrasted with the airline industry, which despite being safety-critical and having high levels of investment in both equipment and staff training, has managed to achieve a much more flexible and responsive business model. There are reasons for this but the difference is striking.

Of course, airlines are not generally *required* to provide a service while ANSPs are. In fact they are typically viewed as natural monopolies, with the only real competition at present being found at some airports – which, every few years, invite bids for providing an ATC service within their area. Some people have argued that ATM is not a natural monopoly and that airlines should be able to choose their service provider. However, there is not yet any experience of such an approach and it seems unlikely that it will gain widespread acceptance.

Indeed, the attitude of governments towards ATM has long been conservative, with every country maintaining its own ANSP, even where there are clear economies of scale for merging ANSPs; this is particularly the case where the ANSPs involved are relatively small. Sovereignty is used as the reason (we can't have an organisation in another country running our airspace). However, the experience of MUAC is that sovereignty is not an insuperable problem. MUAC has been controlling the upper airspace of Belgium, Luxembourg, the Netherlands and northern Germany for a long time (it became operational in 1972) and it has also developed progressively closer working relations with the military in its members' states.

Technically, airspace can even be controlled by the ANSP of a non-contiguous state, as HungaroControl has demonstrated in the airspace of Kosovo. So the question naturally arises whether we will see ANSPs merging in the future. Despite nationalism issues, this may well happen – but gradually, with closer cooperation being the way forward. The Functional Airspace Blocks have had limited impact but we are also seeing other groupings, not necessarily geographic. COOPANS is an interesting example of ANSPs being linked by all being Thales users. Together they form a strong grouping working with their supplier to improve their performance.

So even if it is politically difficult for ANSPs to merge, we may see effective collaboration on procurement, or technical systems. After all, in this digital age, there may well be scope for an ANSP to be split up functionally, with different entities handling the various functions, such as surveillance, basic training, en-route control centres, airport towers, meteorology etc. Collaboration between ANSPs will be easier for some functions than for others.

However we get there, effective cross-border collaboration is essential as we go forward. Modern aircraft typically cross several borders in a single flight and airlines need to have the entire flight as efficient and sustainable as possible, not just individual elements within states. Efficient ATM could reduce emissions by as much as 10% – something we clearly need if aviation is to achieve Net Zero.

As monopolies, ANSPs need to be regulated, either through direct government ownership/control or by some other means. We are gaining experience of detailed, codified, regulation, notably for privatised ANSPs (such as NATS). More generally, the route charges mechanism developed by the European Commission has been applied across much of the Eurocontrol Network and this is a clear form of financial regulation, with incentives and penalties.

However, regulation needs considerable thought and planning to ensure that it is incentivising the right behaviours – and especially the balance between the drivers discussed above. A system that pushes ANSPs to reduce cost, but leaves parts of the Network with insufficient capacity to cope with traffic growth, clearly needs to be improved, especially as it can have relatively rapid deleterious effects that then take some time to address.

Regulation also needs to be resilient – to be able to cope with significant traffic variation. While the COVID19 pandemic is the most dramatic example of this, we have also seen other events changing traffic patterns, ranging from the effective closure of Belarus airspace to western airlines as a result of the events of 23 May 2021 to the invasion of Ukraine by Russia in early 2022.

Air navigation service providers at the heart of air traffic management

Even as ATM moves towards the SESAR operating concept of user-driven trajectories updated in real time, with controllers doing less active controlling, ANSPs will remain at the heart of ATM – certainly for many years to come. Understanding ANSPs, what drives them and how they operate, is therefore an essential part of understanding how modern aviation works in practice. I am very encouraged to see the wide range of topics covered by this book, which I am sure will be invaluable for anyone who wants to learn about this industry – which is so vital to ensure safe and efficient air travel.

Eamonn Brennan
Director general, Eurocontrol

Foreword by Orbis – changing the way the world sees

Orbis works to ensure everyone has sustainable access to quality eye care, no matter where they live. Orbis's mission is to eliminate the threat of avoidable blindness in low-income countries, restore sight, where possible, and build a legacy of quality eye care for a future that will ensure no one will go needlessly blind.

The concept of Orbis began in the late 1960s when Dr David Paton, a renowned US ophthalmologist, recognised the lack of eye care and ophthalmic teaching in developing nations where blindness was widespread. At the time, 90% of the world's avoidable blindness occurred in the developing world. Paton recognised the need to close this gap, but no in-country training for doctors and nurses existed, and the high costs of tuition and international travel prevented most doctors and nurses in low-income countries from travelling to receive training.

In 1973 Orbis was launched. And with that, a unique and lasting alliance was born between the aviation and medical industries. Through recognising the need for basic eye care in low-income countries, a group of aviation and medical specialists converted a DC-8 plane into the world's first fully functional teaching eye hospital, which took off on its first project to Panama in May 1982. In 2016, Orbis launched its third generation Flying Eye Hospital.

Orbis Flying Eye Hospital.

The Orbis Flying Eye Hospital is a state-of-the-art teaching facility with an operating room, classroom and recovery room. This unique plane flies a team of elite eye care specialists to developing countries, where they create a tailored and customised curriculum for partner hospitals based on existing capabilities. The plane's high profile helps raise awareness of the issues of blindness in the countries it visits. The plane always creates huge interest wherever it goes.

The need for basic eye care – and therefore Orbis – in developing countries is great, and as such, Orbis started to introduce hospital-based training programmes and fellowships to provide additional skill-building opportunities for eye care professionals.

In 1999, long-term country programmes commenced in Bangladesh, China, Ethiopia, India and Vietnam – similar programmes are also underway in parts of Latin America and the Caribbean. These permanent offices are run by local staff and develop and implement multiple multi-year projects to improve the quality and accessibility of eye care to residents, particularly in rural and impoverished urban communities. Many of these programmes focus on treating and preventing childhood blindness, cataract, trachoma and corneal disease.

Training is at the heart of Orbis. Orbis's telemedicine platform – Cybersight – allows a group of expert volunteers and staff to provide on-demand advice for complex cases and mentoring to local eye care professionals on diagnosis and treatment. This award-winning platform provides long-distance mentoring and education, online courses and lectures, symposiums and case follow-up to eye teams in 199 countries.

Dr Maurice Cox first set up Orbis in Ireland in 2005. The team in Ireland focuses on raising funds and supporting a specific project in rural Ethiopia. In countries like Ethiopia, where health care facilities are scarce and poverty rampant, blind and visually impaired people constitute some of the most neglected sections of society. Through raising awareness, building partnerships and carrying out sight-saving work in even the hardest-to-reach places, Orbis ensures that the three leading causes of preventable blindness and visual impairment – cataract, refractive error and trachoma – are being addressed.

Eye diseases like trachoma paralyse entire communities – adults unable to work, children unable to learn, and families unable to live freely. However, for every dose of antibiotics distributed, that person is no longer in pain or discomfort. They are no longer at risk of infecting their loved ones. They no longer need a family member to stay at home to care for them. It transforms lives.

Over the past two decades, Orbis has made considerable strides in fighting to end trachoma. Through the coordinated distribution of antibiotics, we have rid whole districts of this devastating disease.

Furthermore, Orbis in Ethiopia enhances the local government's capacity to manage the treatment of eye diseases through intensive training and capacity-building initiatives, health systems strengthening and community engagement.

On behalf of the board, staff, volunteers and beneficiaries of Orbis, Clare O'Dea (Chair, Orbis Ireland) would like to thank everyone involved in creating this book:

> We are always humbled by the generosity of others and it is through the support of everyone who has contributed to the publication of this book that Orbis can continue its work in the hope that one day there will be no more avoidable blindness in the world. This is a massive undertaking, but one that not only brings the gift of sight to those who are needlessly blind but is also vital to the social and economic development of the societies in which they live. Through the support of everyone who contributed to this book, and those who purchased this book, our goal could become a reality.

1 Introduction to air navigation services

Marina Efthymiou

The fundamentals of air navigation services

Airlines and airports rely on the air navigation services (ANS) for the management of air traffic. Hence, ANS provision is considered as a core element for air transportation. Air navigation services include five broad categories of services provided to air traffic during all phases of operation (area control, approach control and aerodrome control). These services are the following: air traffic management (ATM), communications, navigation and surveillance services (CNS), meteorological services for air navigation (MET), aeronautical information services (AIS) and search and rescue (SAR). These services are provided to air traffic during all phases of flight (e.g. planning, execution) and operations (approach, aerodrome and en-route).

Aeronautical information services (AIS) provide information on the availability of air navigation services and their associated procedures necessary for

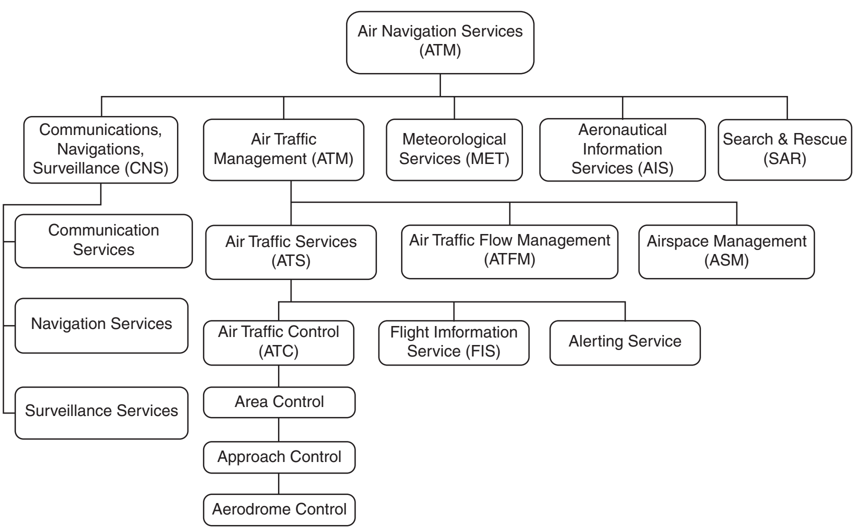

Figure 1.1 The air navigation services.

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the safety, regularity and efficiency of air navigation (i.e. AIP, AIC, NOTAM, etc.). Communications, navigation and surveillance includes communication facilities, navigation services and surveillance systems. Communication facilities have two main categories: aeronautical fixed service and aeronautical mobile service.

Under Article 1 of the ICAO Chicago Convention, States have the sovereignty over the airspace above their territory. However, States are also required to establish the provision of ANS within their airspace. The dimension of the national airspace and its organisation into flight information regions (FIR) is published in the respective aeronautical information publication (AIP).

Air traffic management (ATM) comprises three main services (Skybrary, n.d.):

- **Air traffic services (ATS)**, with the general purposes of ensuring safe and orderly traffic flow (facilitated by the air traffic control (ATC) service) as well as providing the necessary information to flight crews (flight information service, FIS) and, in case of an emergency, to the appropriate (e.g. SAR) bodies (alerting service). ATS is mostly performed by air traffic controllers. Their main functions are to prevent collisions by e.g. applying appropriate separation standards and issue timely clearances and instructions that create orderly flow of air traffic (e.g. accommodate crew requests for desired levels and flight paths, ensure continuous climb and descent operations, reduce holding times in the air and on the ground). ATS relies on tactical interventions by the controllers and direct communication with the flight crews usually during the entire flight.
- **Air traffic flow management (ATFM)**, the primary objective of which is to regulate the flow of aircraft as efficiently as possible to avoid the congestion of certain control sectors. The ways and means used are increasingly directed towards ensuring the best possible match between supply and demand by staggering the demand over time and space and by ensuring better planning of the control capacities to be deployed to meet the demand. Supply and demand can be managed by imposing various restrictions on certain traffic flows (e.g. assigning CTOTs or requiring flights matching certain criteria to use specific routes). Also, supply can be increased by appropriate sector management (e.g. increasing the number of controllers working at the same time). AFTM measures can be seen as pre-tactical, as they do not affect the current situation but rather the near future.
- **Airspace management (ASM)**, the purpose of which is to manage airspace – a scarce resource – as efficiently as possible to satisfy its many users, both civil and military. This service concerns both the way airspace is allocated to its various users (by means of routes, zones, flight levels, etc.) and the way in which it is structured to provide air traffic services.

There are three main types of air traffic control (ATC), aerodrome control (also known as tower control), approach radar control and area radar control. ATC is used to manage the safe and orderly flow of aircraft into, out of, and across the airspace. There are two categories of air traffic services, en-route services that control traffic during the cruise phase of the flight, and the Terminal Air Navigation Service (TANS) that relate to 'radar approach and departure' (approach) service and the aerodrome service (Efthymiou, 2020). The approach service typically controls the aircraft within 40–50 nautical miles from the airport. The aerodrome service relates to the visual control provided by the ATC tower. The general categories of airspace are the following:

- **Controlled airspace**. This is an airspace of defined dimensions within which air traffic control services are provided to Instrument Flight Rules (IFR) flights and to Visual Flight Rules (VFR) flights in accordance with the airspace classification. VFR aircraft operating in controlled airspace are responsible for separating themselves from all other aircraft and are permitted so long as the weather conditions are sufficient to enable pilots to 'see and avoid' other aircraft.
- **Positive controlled airspace**. Flights in this type of airspace are conducted normally under IFR. This airspace is reserved for either very high-altitude flights at or above 18,000 feet mean sea level (MSL) or around high-density airports.
- **Uncontrolled airspace**. In uncontrolled airspace, ATC separation services are not and all aircraft, whether IFR or VFR, must provide their own separation, regardless of the weather conditions.
- **Special use airspace**. This is airspace wherein activities must be confined because of their nature, or wherein limitations are imposed upon aircraft operations that are not a part of those activities, or both. Some examples of this airspace types are prohibited airspace and restricted areas.

While airspace can be simply classified as controlled and uncontrolled, ATS airspace is classified and designated in accordance with the following (ICAO, 2018):

- **Class A.** IFR flights only are permitted, all flights are provided with air traffic control service and are separated from each other.
- **Class B.** IFR and VFR flights are permitted, all flights are provided with air traffic control service and are separated from each other.
- **Class C.** IFR and VFR flights are permitted, all flights are provided with air traffic control service and IFR flights are separated from other IFR flights and from VFR flights. VFR flights are separated from IFR flights and receive traffic information in respect of other VFR flights.
- **Class D.** IFR and VFR flights are permitted, and all flights are provided with air traffic control service, IFR flights are separated from other IFR

flights and receive traffic information in respect of VFR flights, VFR flights receive traffic information in respect of all other flights.

- **Class E.** IFR and VFR flights are permitted, IFR flights are provided with air traffic control service and are separated from other IFR flights. All flights receive traffic information as far as is practical. Class E shall not be used for control zones.
- **Class F.** IFR and VFR flights are permitted, all participating IFR flights receive an air traffic advisory service, and all flights receive flight information service if requested.
- **Class G.** IFR and VFR flights are permitted and receive flight information service if requested.

The services provided and flight requirements for different classes of airspace are shown in Table 1.1.

The transition to a competitive environment for air navigation service providers

An ANSP is an organisation that provides the service of managing the aircraft in flight or on the manoeuvring area of an and which is the legitimate holder of that responsibility. An ANSP must be able to adjust service provision dynamically to the heterogeneous performance requirements of the airspace users (both civil and military; Bourgois et al., 2018).

The aircraft movements increase has created significant pressure to managing the airspace and has highlighted the inefficiencies in the provision of ANS. The European sky is one of the busiest skies in the world; yet air traffic management is organized in a fragmented way. In fact, the European airspace system covers an area of 10.8 million km^2 managed by 37 ANSPs and 62 area control centres (ACCs), 262 approach control units (APPs), and 56,300 staff. This fragmentation impacts adversely on flight safety, limits capacity, increases costs and slows down the decision-making process. Thus, better coordination for transferring the responsibility of an aircraft among ATC sectors in Europe is needed. Such an initiative to reform the architecture of ATM, known as Single European Sky (SES), was first launched by the European Commission in 1999 (Efthymiou, 2016).

The reform of the ANSPs is one of the most important issues for aviation and it is closely related to the ownership type and business model of the ANSP. Most of the ANSPs are government-owned, but there are few that are a private–public partnership (PPP), such as NATS in the UK, and private companies, such as ACR in Sweden (see Table 1.2). All the different ownership and organisational forms that exist have the potential according to ICAO (Doc 9161, 2013) to deliver excellent service under the condition of an appropriate government structure. Moreover, Air Navigation Service Providers after 2010 started forming alliances and cooperating. ANSPs may cooperate for different reason, the most important are: (a) a good cost benefit

Table 1.1 Services provided and flight requirements for different classes of airspace.

Class	*Type of flight*	*Separation Provided*	*Service Provided*	*Speed limitation**	*Radio communication requirement*	*Subject to an ATC clearance*
A	IFR only	All aircraft	Air traffic control service	Not applicable	Continuous two-way	Yes
B	IFR	All aircraft	Air traffic control service	Not applicable	Continuous two-way	Yes
	VFR	All aircraft	Air traffic control service	Not applicable	Continuous two-way	Yes
C	IFR	IFR from IFR IFR from VFR	Air traffic control service	Not applicable	Continuous two-way	Yes
	VFR	VFR from IFR	1) Air traffic control service for separation from IFR 2) VFR/VFR traffic information service (and traffic avoidance advice on request)	250 kts IAS below 10,000 ft amsl	Continuous two-way	Yes
D (1)	IFR	IFR from IFR	Air traffic control service, traffic information about VFR flights (and traffic avoidance advice on request)	250 kts IAS below 10,000 ft amsl	Continuous two-way	Yes
	VFR	Nil	IFR/VFR and VFR/VFR traffic information (and traffic avoidance advice on request)	250 kts IAS below 10,000 ft amsl	Continuous two-way	Yes
E (2)	IFR	IFR from IFR	Air traffic control service and, as far as practical traffic information about VFR flights	250 kts IAS below 10,000 ft amsl	Continuous two-way	Yes
	VFR	Nil	Traffic information as far as practical	250 kts IAS below 10,000 ft amsl	No	No
F	IFR	IFR from IFR as far as practical	Air traffic advisory service; flight information service	250 kts IAS below 10,000 ft amsl	Continuous two-way	No
	VFR	Nil	Flight information service	250 kts IAS below 10,000 ft amsl	No	No
G	IFR	Nil	Flight information service	250 kts IAS below 10,000 ft amsl	Continuous two-way	No
	VFR	Nil	Flight information service	250 kts IAS below 10,000 ft amsl	No	No

* When the height of the transition altitude is lower than 10,000 ft amsl, FL100 should be used in lieu of 10,000 ft.

Important notes: (1): In Class D airspace, both IFR and VFR traffic are required to follow ATC clearances; however, ATC are only responsible for IFR against IFR separation. (2): In Class E airspace, ATC does not provide separation between IFR and VFR traffic; IFR traffic shares responsibility for separation from uncontrolled VFR traffic with that traffic.

Source: ICAO (2018, annex 11)

Table 1.2 Organisation and corporate arrangements of selected states.

ANSP	*Country*	*Organisational & corporate arrangements*
Albcontrol	Albania	Joint-stock company (state-owned)
ANS CR	Czech Republic	State-owned enterprise
ANS Finland	Finland	State-owned enterprise
ARMATS	Armenia	Joint-stock company (state-owned)
Austro Control	Austria	Limited liability company (state-owned)
Avinor	Norway	Joint-stock company (state-owned)
BULATSA	Bulgaria	State-owned enterprise
Croatia Control	Croatia	Joint-stock company (state-owned)
DCAC Cyprus	Cyprus	State body
DFS	Germany	Limited liability company (state-owned)
DHMI	Turkey	Autonomous state enterprise
DSNA	France	State body (autonomous budget)
EANS	Estonia	Joint-stock company (state-owned)
ENAIRE	Spain	State-owned enterprise
ENAV	Italy	Joint-stock company (state-owned)
HCAA	Greece	State body
HungaroControl	Hungary	State-owned enterprise
AirNav	Ireland	Joint-stock company (state-owned)
LFV	Sweden	State-owned enterprise
LGS	Latvia	Joint-stock company (state-owned)
LPS	Slovak Republic	State-owned enterprise
LVNL	Netherlands	Independent administrative body
MATS	Malta	Joint-stock company (state-owned)
M-NAV	F.Y.R.O.M.	Joint-stock company (state-owned)
MOLDATSA	Moldova	State-owned enterprise
MUAC	–	International organisation
NATS	United Kingdom	Joint-stock company (part-private)
NAV Portugal	Portugal	State-owned enterprise
NAVIAIR	Denmark	State-owned enterprise
Oro Navigacija	Lithuania	State-owned enterprise
PANSA	Poland	State body (acting as a legal entity with an autonomous budget)
ROMATSA	Romania	State-owned enterprise
Sakaeronavigatsia	Georgia	Limited liability company (state-owned)
Skeyes	Belgium	State-owned enterprise
Skyguide	Switzerland	Joint-stock company (part-private)
Slovenia Control	Slovenia	State-owned enterprise
SMATSA	Serbia Montenegro	Limited liability company
UkSATSE	Ukraine	State-owned enterprise

Source: based on Eurocontrol (2021)

business case; (b) synergies in technologies and expertise; (c) optimisation in the production and achievement of economies of scale or scope; and (d) forced by government regulation or legislation.

Regulation and market form have made ANSPs' management more complicated than ever. Compared to other areas of aviation management, only a very small number of scholars have researched the area of managing ANSPs. Nava-Gaxiola and Barrado (2016) studied the expected benefit in saving flight distance after introducing the Free Route Airspace in the Southwest FAB using traffic simulation models. Baumgartner and Finger (2014) provided a brief overview of the SES. Button and Neiva (2013) using Data Envelopment Analysis estimated the potential economic efficiency of functional airspace blocks. Pellegrini and Rodriguez (2013) made a comparison of the SES and Single European Railway Area. Button and McDougall (2006) discussed the institutional and structure changes in air navigation service-providing organisations. Comendador, Valdés and Sanz, (2012) researched the liberalisation of ATS in Spain. Efthymiou and Papatheodorou (2018, 2020) investigated the environmental area of SES and Efthymiou (2016) researched the governance of the ATM reform. Bilotkach et al. (2015) performed a cost-efficiency benchmarking of European ANSPs, whereas Grebenšek and Magister (2013) discuss the suitability of benchmarking as a measure method for ANSPs performance. Tomova (2016) discussed the commercial revenues of ANSPs. Buyle et al. (2021) discussed the ANSPs business models. Blondiau et al. (2016) developed economic models to analyse the performance of ANSPs. Nevertheless, there are not many books written about management issues of an ANSP and on the ATC reform. This edited book fills this important gap with a comprehensive, in-depth study of the issues related to ANSP business.

Aim and structure of the book

The book aims to be a unique repository of current knowledge and critical debate on the Air Navigation Service Providers business with an international focus. There are a total of 12 chapters written by a team of 14 leading researchers, scholars and industry experts based at universities, research institutes, governance authorities and ANSPs across the world. Focused on ATM and the principles, performance and markets of ANSPs, the book has the following chapters.

Chapter 2: 'The legal environment of air navigation service providers' by François Huet, Borealis Alliance

There is a wide variety of legal setups for ANSPs. However, air traffic service provision, at least for en-route services, is characterised by the designation of national monopolies, operating within national borders, which contributes to the fragmentation of the European ATM network. With the COVID pandemic following several years of traffic and delays growth, the ATM industry is now expected to carry out its digital transformation to negotiate a 'green' and future-proof return to growth, meeting public opinion expectations, and able to absorb future crises and traffic variations upwards or downwards through more agility, scalability and resilience. Such is the claimed purpose of the new Single European Sky initiative ('SES2+') and the associated roadmap towards a 'Digital European Sky'. This digital transformation may be accelerated by the arrival of 'new entrants' in the airspace, drones in particular. The SES initiative is gradually trying to decouple en-route (or area) air traffic service provision, which would remain monopolistic (and thus economically regulated), from the other, 'auxiliary', services (terminal air traffic services for aerodrome and for approach, CNS, AIS, ADS and MET), which are encouraged to be opened to market conditions. However, there is resistance from a large number of Member States who want to make sure that this evolution remains fully in their hands and is not imposed on them. The evolution of the legal environment of air navigation services provision will largely depend on the adoption of the SES2+ legislative package, expected in 2022. It is for the time being difficult to predict where the cursor will stop between the protection of services that pertain to 'the exercise of the powers of a public authority' on the one hand, and the opening to market of the other services on the other hand.

Chapter 3: 'From NextGen to SES' by Anna Tomová, University of Žilina

While many infrastructure industries in the world have undergone structural reforms, the provision of air navigation services as a part of aviation infrastructure was out of the trend for a long time. However, gradually, also the provision of air navigation services in several countries have been changed and structural reforms have been carried out. Due to structural changes, the historical model based on statutory multi-product monopolies in public ownership was changed, and third parties were allowed to participate in the provision of air navigation services and compete. Moreover, some air navigation service providers were (partially) privatised. Structural reforms could be utilised when achieving the goals of seamless single sky within the international groupings of countries for their single markets with air services.

Chapter 4: 'Air traffic control officer recruitment and training' by Gary McIlroy, Irish Aviation Authority, and Marina Efthymiou, Dublin City University

This chapter outlines the recruitment, training and licencing requirements of the Air Traffic Control sector as prescribed by ICAO Annex 1, Annex 11 and ICAO Doc 4444 PANS-ATM, ICAO Doc 9868 PANS-Training. These SARPs are then transposed by regional regulations where applicable (specifically Europe and EU 2015/340) and incorporated into state regulation. Specifically, this chapter will discuss the impact of those requirements on the people who operate within that sector (i.e. the ATCOs) from their recruitment to training and certification as licenced ATCOs operating in the live traffic environment. The chapter also researches a sample of ANSPs recruitment practices and makes some recommendations.

Chapter 5: 'Safety management in air navigation service providers' by Markus Biedermann, DFS GmbH

Air Traffic control has been introduced as the most important safety net for aviation. From the early days up until now, air traffic controllers provide airspace users around the globe with high quality service, that allows a safe, orderly, fluent and environmental flow of air traffic. Without continuous technical advancements and ongoing development on safety procedures, this complex as well as complicated system would not sustain. Therefore ANSPs grew into highly reliable organisations, which operate relatively error free over prolonged periods of time even in an environment of constant stress. This is supported by a robust framework from worldwide organisations such as ICAO but also on pan-national or national levels such as through EASA or the CAAs. The framework on the one hand and the organisation on the other hand support each other in developing and introducing constant improvements for safety of air traffic either through technological means or organisational development to maintain safety of air travel at the highest standards.

Chapter 6: 'Air navigation service provider capacity and delays' by Radosav Jovanović, University of Belgrade

The capacity of an airspace sector is influenced by several factors, including separation standards, traffic complexity, airspace design, availability of systems for communication, navigation and surveillance, human factors, weather, etc. A distinction should be made between capacity in nominal and actual, often degraded conditions. If an imbalance between capacity and demand is foreseen, actions need to be taken: first by acting on the capacity side (i.e. making the best use of available capacity), and only then, if needed, acting on the demand side.

Air traffic flow management (ATFM) measures are techniques used to manage air traffic demand according to system capacity, i.e., ensure that available airspace capacities can accommodate traffic loads safely, efficiently, and non-discriminatory. Flight delays caused by demand-capacity imbalances in ATM may have significant cost implications for the affected airspace users. For example, the costs of en-route imposed delays in the European system were estimated at about 1.9 billion euros in 2018.

Chapter 7: 'Air navigation service providers and environmental performance' by Marina EfthymiouDublin City University Business School

Environmental performance is a significant aspect of aviation. Apart from reducing the emissions of the ANSP, it is important to consider the airspace structure. The SES aims to organise the airspace uniformly, with air traffic control areas based on operational efficiency rather than national borders.

One of the main aspects of SES is performance evaluation in four areas: cost efficiency, capacity, safety, and environment. In the key performance area (KPA) of environmental, targets aiming at climate change mitigation have been set for flight efficiency and airspace structure. This chapter discusses the various measures and considers some challenges for improved environmental performance.

Chapter 8: 'Air navigation service provider charges' by Frank Fichert, Worms University of Applied Sciences

The costs of ANS provision are to a large degree covered by the airspace users, mostly via user charges (and 'earmarked' aviation-related taxes in the US). Usually, there are different charging schemes for the en-route phase and for approach and aerodrome services (also referred to as terminal services). Within the framework set by ICAO, many variants of user charges exist. For en-route services, charges are in many cases depending on flight distance and aircraft weight. Whereas weight-dependent charges (en-route as well as approach and aerodrome) might be seen as some kind of Ramsey pricing, incentives (e.g. peak-load pricing) are hardly used within actual charging schemes.

Chapter 9: 'Regulation of air traffic control services' by Hans-Martin Niemeier, University of Applied Sciences, Bremen, and Peter Forsyth, Monash University

This chapter focusses on the regulation of Air Traffic Control (ATC): how it is done, and how it can be improved. The analysis is general, but it pays specific attention to Europe, which is a region which is dominated by public but regulated suppliers. Major parts of ATC systems, especially the en-route systems, are characterised by natural monopoly. Worldwide, most ATC systems are publicly owned and operated, though there are significant exceptions, such as those of the United Kingdom and Canada. In the EU ATC systems are government owned, though many are corporatised. With ATC systems there is a short run problem of achieving productivity, and in some cases, there are also quality problems, which are manifested in delays. In the long run there are problems of achieving efficient levels of investment. In the EU there is strong evidence of productive inefficiency in many countries' systems, and pricing often involves traffic risk sharing mechanisms, which dampen incentives for efficiency. Questionable incentives for efficiency in government owned systems are an issue. Turning to the long run, in Europe there have been chronic problems of achieving adequate investment, made more complex by the difficulties in achieving interoperability between the systems of different countries. The EU system of regulation is such that incumbent operators are shielded from risks (very evident in the Covid crisis), leading to weak incentives for efficiency.

Chapter 10: 'The business framework for air navigation service providers' by Marek Bekier, University of New South Wales

In the past, ANSPs have traditionally been owned, controlled and sometimes operated by their respective governments. In recent years, along with an overall reduction of public ownership in public utilities, a trend towards separation from the government and an +increased commercialisation of the ANSP could be observed (Dempsey-Brench and Volta, 2018). Rooted in the agreements and architecture of the Chicago Convention (1944), each state organised and regulated the ANS provision under a national monopoly through dedicated ANS Providers. In recent years, a trend towards a cautious opening of the monopoly markets and a partial liberalisation of the industry is observable and is also recommended by the European Commission through adjustment proposals to its SES regulatory framework (European Commission, 2020). However, the development towards a more commercialised and competitive ANS industry requires a transition towards a more commercial management, governance and administration of the ANSP, a process commonly referred to as commercialisation. An introduction describing the origins of the vertically integrated ANSP is at the beginning of this chapter. To understand the underlying business structure of the ANS industry, the next section then introduces the cost-recovery concept and provides an overview on the key economic elements – the revenue generation and cost-structures - of an ANSP. This is followed by an overview on the various governance models of ANSP, as ownership and governance often determine the degree of commercialisation. How commercialisation impacts on the overall business models of ANSP and how a liberalisation of the ANS market is expected to change the dynamics in the industry is discussed and demonstrated through a case study from the private Terminal ANS (T-ANS) Provider ACR. This chapter, which has its focus on the European ANS market, will then conclude with a summary and an outlook on expected developments that can change the physiognomy of the ANSP business framework.

Chapter 11: 'The potential of unbundling air traffic management services in Europe' by Keith McEvoy, AirNav Ireland, and Marina Efthymiou, Dublin City University Business School

European ATM network reform has been a continual challenge for all European aviation organisations. Its fragmentation has led to cost-inefficiencies and delays, which airline groups are continually scrutinising and pushing to streamline and defragment the ATM network. Some reform initiatives, such as the SES, have been deemed, for the most part, ineffective. While the SES reform is still ongoing and modifications are taking place, a new reform theory has emerged in the guise of airspace unbundling. Although there are small pockets of unbundled terminal airspaces around Europe, the push is to unbundle en-route services. This chapter explores the current European

ATM system and outlines the different approaches to reform the ATM network. It also presents the current business models of ANSPs, an aspect that influences ANS unbundling. It discusses unbundling at a terminal and en-route level and concludes with the barriers to reform.

Chapter 12: 'Multiple remote tower operations' by Peter Kearney, Irish Aviation Authority, Wen-Chin Li, Cranfield University, and Graham Braithwaite, Cranfield University

The innovative concept of multiple remote tower operation (MRTO) is where a single air traffic controller (ATCO) provides air traffic services to two or more different airports from a geographically separated virtual Tower. Effective visual scanning by the air traffic controller is the main safety concern for human-computer interaction, as the aim of MRTO is a single controller performing air traffic management tasks originally carried out by up to four ATCOs, comprehensively supported by innovative technology. Thirty-two scenarios were recorded and analysed using an eye tracking device to investigate the above safety concern and the effectiveness of multiple remote tower operations. The results demonstrated that ATCOs' visual scan patterns showed significant task related variation while performing different tasks and interacting with various interfaces on the controller's working position (CWP). The development of Augmented Vision Video-panorama technologies has increased the monitoring capabilities of air traffic controllers. During the trials no safety occurrence was reported nor did any operational safety issue arise during the provision of air traffic services to 500 aircraft in the live exercises. ATCOs were supported by new display systems equipped with pan tilt zoom (PTZ) cameras allowing enhanced visual checking of airport surfaces and aircraft positions. Therefore, one ATCO could monitor and provide services for two airports simultaneously. The factors influencing visual attention include how the information is presented, the complexity of that information, and the characteristics of the operating environment. ATCO's attention distribution among display systems is the key human-computer interaction issue in single ATCO performing multiple monitoring tasks.

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2 The legal environment of air navigation service providers

François Huet

Introduction

> It was the best of times, it was the worst of times.[1]

It is challenging to assess whether this is the best or the worst time for drafting a contribution on the legal environment of air navigation service providers (ANSPs), particularly in Europe.

Best, because air traffic management is at a turning point in its history: In the years 2014–2019 (a return to growth period following the economic downturn of 2007–2009), most European ANSPs struggled to cope with growing traffic and delays. Now, in addition, they also have to accommodate the arrival of 'new entrants' (mainly drones of all sizes and capabilities) in all categories of airspace.[2]

In such challenging context, European institutions and all stakeholders have agreed to embark on an ambitious transformation aiming at delivering by 2035 a 'digital European Sky'.[3] This new impetus has been materialised over the recent years by the Airspace Architecture Study (March 2019),[4] the Wise Persons Group report of April 2019[5] the latest approved version of the European ATM Master Plan (Edition 2020[6]) and now the SES2+ Commission proposal, discussed since September 2020[7] between European Parliament and Council, and targeted to be approved in 2022. This impetus towards a digital transformation follows the parallel evolution of several comparable industrial sectors and aims at demonstrating that the European aviation sector and industry remains a world leader, bringing jobs to the European economy.[8] But even more importantly, in the Commission's mind it is also a way to overcome the well-identified fragmentation of the European airspace through airspace optimisation and innovative technology, enabling large-scale cross-border service provision and cooperation, where service provision is or can be disconnected from the physical location of the provider. Interestingly, it should be noted too that this digitalisation of ATM also supports the new impetus given to the 'greening' of air transport, materialised by the 'European Green Deal'[9] and the commitment that aviation must cut its CO_2 emissions by half by 2035.

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Worst, because since March 2020 aviation and ANSPs has been facing an unprecedented crisis due to the outbreak of COVID-19 pandemic, against which a return to pre-crisis traffic is planned by 2023 at the very earliest.[10] At the time of finalising this contribution to the textbook, the crisis generated by the Russian aggression in Ukraine generates another uncertainty on the short-term future of aviation. As a result, all aviation operational stakeholders, airlines, airports, air navigation service providers, remain for now in a survival mode, carrying out stringent cost-cutting measures in all possible domains, and it is hard to predict the landscape of the aviation community when traffic demand is back to pre-crisis levels.

On the other hand, to recycle the quote from a European Commission Director General, ANSPs should not 'waste a good crisis'. ANSPs rightly stated that the radical and accelerated evolution towards digitalisation and a new airspace architecture in a high traffic growth context was equivalent to asking them to 'change a wheel of the car while still driving'. In a period where traffic remains lower, and in support of the growing environmental performance expectations, now is probably the right moment to intensify efforts to carry out the structural changes needed and carry out the digital transformation.

The present situation is therefore unprecedented: Rich in threats and challenges, but also opportunities, the decisions that will be taken in the coming months/years and the strategies adopted to exit from the crisis will shape the ATM world for the long term.

The ambition of this chapter is limited to providing a snapshot of the status and situation of ANSPs, in particular European, at the time of drafting, and proposing thoughts for possible scenarios of evolution. It starts with a look back at the creation of the ANSP concept, its evolution to the well-defined operational stakeholders of aviation as we know them today, describe the evolutions generated by the successive SES packages, and offer some thoughts about today's challenges and possible future evolution scenarios.

Where did this start?

It is the Paris Convention of 13 October 1919 ('Convention relating to the regulation of aerial navigation'[11]) that created, at worldwide level, the concept of 'aerial navigation'. It also set out that each nation 'has complete and exclusive sovereignty over the air space above its territory' (Article 1) and that it should apply its rules equally to its own and foreign aircraft (Article 2). This was establishing the First Freedom of the Air, some 25 years before the Chicago Convention that created ICAO. Over the following decades, intervention in the civil aviation industry through public funding was seen as natural. Air navigation service provision was ensured and fully financed by States in the same way as all 'flag carrier' airlines were state-owned.

It is the Convention on International Civil Aviation (the Chicago Convention), [12] establishing the International Civil Aviation Organization (ICAO) that laid down the basis for today's civil aviation. Its Article 28 provided for the first time a list of air navigation facilities.[13] For years, air navigation services largely remained provided directly by State administration and ministries. However this ICAO definition facilitated the creation of entities that became the air navigation service providers (ANSPs) as we know them today, recovering their costs through air navigation charges. The movement towards better identification and separation of ANS provision from regulatory functions, sometimes functional only, sometimes structural, sometimes even through privatisation, was soon initiated. This will be detailed with a number of relevant examples below.

Before this, it is useful to get familiar with the terminology and understand the scope of terms that are commonly used in this chapter. In particular, it is essential to understand that Air Traffic Services (ATS) are a subset of air navigation services (ANS). Figure 2.1 facilitates such understanding in visual form:

It should be borne in mind too that, for the time being and in Europe at least, all National ANSPs are monopolistic ATSPs (with a few exceptions for aerodrome control services – see below), and that they also deliver all other air navigation services in a largely monopolistic manner. The opening to market of the 'auxiliary' tasks (CNS, MET, AIS), is the rare exception, not the norm. We will see below that this is one of the topics that the SES2+ proposal endeavours to address.

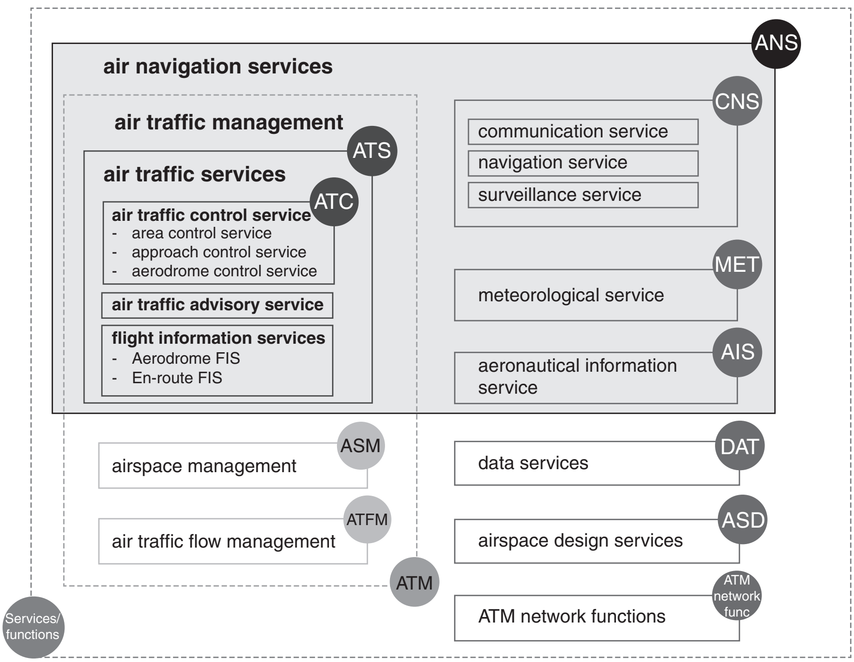

Figure 2.1 The air navigation services.
Source: EASA, the European Union Aviation Safety Agency[14]

What is an ANSP?

The Chicago Convention does not provide a definition of an ANSP, but only a description of 'air navigation facilities' in its Article 28, which also states that the provision of such facilities is a State responsibility.

The Single European Sky packages are aligned with this description, and Article 2(5) of the framework Regulation (EC) No 549/2004[15] defines air navigation service providers as 'any public or private entity providing air navigation services for general air traffic'. Clearly, even though air navigation service provision is a State responsibility, it can be carried out by private entities if the State so decides.

The Single Sky packages also add a condition to ANS provision: ANSPs have to be certified by Member States before being able to offer their services (Article 7 of the service provision Regulation (EC) No 550/2004[16]), having checked that they comply with the common requirements described in Article 6 of the same Regulation. In addition, ATSPs need to be designated on an exclusive basis (Article 8 of the service provision Regulation). Until now, MET service providers, even though not being ATSP, can also be designated on an exclusive basis by Member States (Article 9 of the service provision Regulation). This was requested by Member States to protect the monopoly of their national MET service provider. However, the Commission tries to change this in its SES2+ proposal.

Except for the designation of MET service providers, all these rules and principles are perpetuated and amplified in the SES2+ proposal. This will be developed further in Paragraph 5.4 below.

The wide diversity of ANSPs

There is here no room for an individual legal depiction of each and every air navigation service provider, even though this would certainly be of interest, allowing comparing each situation and each national laws nuances, requirements and constraints.

However, Europe, being composed of Member States with different cultures, history and legal frameworks, is a good observatory of the evolution of the provision of air navigation services and the diversity of situations and legal setups. A quick overview of the 'big five' European Air Navigation Service Providers (acknowledging that UK has left the European Union on 31 January 2020) is sufficient to describe the wide array of possibilities and situations. A further paragraph will try to give a glimpse of the variety of situations at worldwide level:

In the United Kingdom

In the United Kingdom, the National Air Traffic Control Services (NATCS)[17] were created in 1962. NATCS evolved into NATS in 1972, when responsibility for sponsoring the civil air traffic service component was transferred to the newly formed Civil Aviation Authority (CAA) and giving it legal personality. This provided one of the first examples of modern air navigation service provider, even though it remained fully state-owned. In 1992 it was recognised that as a service provider NATS should be operated at a distance from its regulator. NATS was therefore re-organised into a company in April 1996 and became a wholly owned subsidiary of the CAA. The public–private partnership for NATS was decided in June 1998 and enshrined in the Transport Act 2000. In 2001 51% of NATS was transferred to the private sector, [18] and NATS was given a twenty-year license to provide en-route air traffic services over the UK airspace with a notice period of ten years.

This evolution provided the first example of privatisation and economic regulation of an ANSP in Europe, pioneering the principles of separation of service provision from regulatory function and of economic regulation, which were to be two of the key principles underpinning the Single European Sky package in 2004. This evolution also forced in 1998 a substantial change to the Eurocontrol 'Principles for Establishing the Cost-Base for En-Route Charges and the Calculation of the Unit Rates', [19] creating an exception to the 'full cost-recovery' principle that had prevailed so far.

In the same spirit, the UK has also opened to competition the provision of air navigation services to a large number of its airports. This is why NATS is split into two main service provision companies: NATS En-Route PLC (NERL) and NATS Services Ltd (NSL), where NERL is the monopolistic and regulated provider of en-route air traffic control over the UK, while NSL is unregulated and competes for contracts to provide air traffic control at airports in the UK (and also overseas).

As a result NATS – NSL currently provides air traffic control services at the main thirteen UK airports and Gibraltar, including London-Heathrow, but to the notable exceptions of London-Gatwick, the second-busiest airport in the UK, and Edinburgh, where air traffic control services are provided by DFS, the German national air navigation service provider through its subsidiary Air Navigation Solutions Ltd. This transfer took place in since 2014 for Gatwick and 2018 for Edinburgh, for 10-year licenses.

On the other hand, NATS, through NSL, has established an alliance with Spanish partner Ferrovial in 2011, forming FerroNATS, which provides air traffic control services at nine airports across Spain. FerroNATS was awarded the contract to provide these services through a competitive tender process run by the Spanish aviation authority between November 2012 and January 2014, and this contract has been renewed in 2020.[20] NATS also won the competition for the provision of ATC tower and approach services to Hong Kong International Airport.

With this structure and legal setup, the United Kingdom implements its policy of legally and structurally separating, on the one side the en-route air navigation services, provided by a monopolistic, designated entity, in line with the Chicago Convention and, on the other side, air navigation services at and around airports, which are largely open to competition. In this setup, NATS-NSL has lost the ANS provision for a number of UK airports, including two major ones, but has gained others abroad.

In France

In France, the 'Direction des Services de la Navigation Aérienne – DSNA' (Directorate for Air Navigation Services) has always been integral part of the French Directorate General for Civil Aviation. In 1985 it was for a while granted its own budget, separated from the DGCA (The 'Budget annexe de la navigation aérienne' – BANA), but this experience stopped in 1992 with its merger in a single budget for the entire DGCA, [21] combining again in a single vehicle the budget for ANS provision and for regulatory and oversight missions. At the time of finalising this chapter, the DGCA is located under the 'Ministère de la transition écologique' (Ministry of Ecological Transition).

The DSNA is and remains integral part of the French DGCA. Within it, it is functionally separated from the regulatory functions, which are located in another Directorate of the DGCA. DSNA is the only air navigation services provider in France for en-route, approach / terminal and tower control.

In Germany

In Germany, the air navigation services were provided since 1953 by the Federal Institute of Air Navigation Services (BFS – Bundesanstalt für Flugsicherung), a government authority. It evolved in 1993 into the German DFS (Deutsche Flugsicherung), a limited company organised under private law but 100% owned by the German State. This was a difficult process at the end of which corporatisation was allowed, but not privatisation. This was because the German Constitution was stipulating that air traffic control in Germany must be administered by the German government. The corporatisation therefore required amending the German Constitution and the German Aviation Act (LuftVG).[22] Since 1994, DFS is responsible for handling both civil and military air traffic (in peacetime), which is quite unusual and unique in Europe.

DFS is responsible for en-route air traffic control services and tower services at the fifteen international airports in Germany (It was sixteen until the closure on 8 November 2020 of the Berlin Tegel airport).

Air navigation service provision in domestic airports is decentralised, and open for competition by the Länder, but the result of the competition process still requires the formal designation of the air navigation service provider by the Ministry for Transport. As a result of this process, DFS currently provides air traffic services at nine regional airports through its subsidiary DFS Aviation Services GmbH.[23] For the other airports, Germany has designated and licensed a number of other air traffic service providers: Austro Control GmbH, Rhein-Neckar Flugplatz GmbH, and Airbus Operations GmbH.[24]

It should be noted in addition that specific airspace blocks of the German upper airspace are served by the Maastricht Upper Area Control Centre (MUAC) of Eurocontrol, enabled by the signature in 1986 of the Maastricht Agreement by the four participating states (Belgium, Germany, Luxembourg and the Netherlands) and Eurocontrol.[25]

In Spain

In Spain, civil air traffic and airport management was exercised by the Autonomous National Airport Authority (OAAN) within the Air Ministry through various setups, until 1977 and the creation of the Ministry for Transport and Communications, which integrated the Subsecretariat for Civil Aviation (replaced in 1982 by the General Directorate for Civil Aviation) into the national civil service. In 1991 the public entity Aena (Aeropuertos Españoles y Navegación Aérea – Spanish Airports and Air Navigation) was created, becoming the first truly identified Spanish air navigation service provider with competences for the management of the Spanish airports, air navigation facilities and air traffic control. This entity had its own legal status and '*full public and private management capacity*', [26] meaning that it was governed by public law in its public functions, and by private law in all matters relating to its assets and hiring decisions.

2011 saw the separation between Aena Aeropuertos S.A. and Aena (Public corporate entity – EPE). The main goal was to modernise the airport system through liberalisation of aerodrome control. All the duties and obligations previously exercised by the public corporate entity Aena in relation to the management and operation of airport services were entrusted to Aena Aeropuertos S.A., while Aena remained in charge of en-route and approach/terminal air traffic control.

In 2014 Aena Aeropuertos S.A. changed its name into Aena S.A., and then Aena SME S.A., and the public corporate entity Aena changed its name to ENAIRE, continuing with the same nature and juridical regime and holding exclusive competences in relation to the provision of en-route and approach / terminal air traffic services. In addition ENAIRE also operates 21 control towers.

ENAIRE public corporate entity is attached to the Ministry for Public Works. It holds 51% of the shares of Aena SME S.A, which has been listed on the Madrid Stock Exchange since February 2015.

Aena SME S.A. operates 46 airports in Spain, including the two largest: Madrid-Barajas and Barcelona El Prat. It also participates in the management of London Luton, with a 51% stake. In America, it has won tenders for the operation of 22 airports in Brazil, Mexico, Jamaica and Colombia, making it the world's number one airport operator in terms of passenger traffic.[27]

Finally, FerroNATS Air Traffic Services S.A., [28] the joint venture between Ferrovial Services and NATS NSL (referred to in Paragraph 4.1 above on UK) should be mentioned again as the leading private air navigation service provider in Spain, present in nine airports.

This example shows that Spain, like UK, has achieved separation between en-route / terminal / approach air navigation services provision and the provision of airport air navigation services and management. While en-route and terminal air navigation services remain monopolistic even though the provider may be partially privatised, airport services (tower control and/or airport management) are now liberalised and open to competition, even though the entities may remain majority-owned by the monopolistic and 'legacy' air navigation service provider.

In Italy

In Italy, the provision of ANS was a military responsibility exercised by the Ispettorato delle Telecomunicazioni e Assistenza al Volo (ITAV – for Inspectorate of Telecommunications and Flight Assistance) until the creation in 1981[29] of the AAAVTAG (Azienda Autonoma di Assistenza al Volo per il Traffico Aereo Generale), a State company. The Italian ANSP as we know it today, ENAV (for 'Ente Nazionale di Assistenza al Volo') was created in 1996. It became a public limited company in 2001 in the context of liberalisation and privatisation of the air transport market. The objective was 'to achieve efficiency and operational targets, and improve quality and reliability of services, ensuring a high level of safety and quality, as per international standards'.[30] ENAV was listed on the Italian stock exchange market in July 2016 and privatised to the level of 46,7%, 53.3% remaining held by the Ministry of Finance. ENAV is therefore legally and structurally separated from its regulator while being supervised by the Italian Ministry of Transport.

… And beyond

As can be seen from the above basic descriptions, Europe contains a wide array of possibilities and situations, from an integration of the ANSP into the Directorate General of Civil Aviation and a simple functional separation (DSNA–France), to a partial privatisation (NATS-UK, ENAV-Italy), with in between the possibility of corporatisation, the company remaining 100% state-owned (DFS-Germany, ENAIRE-Spain).

To give a broader, picture, CANSO[31] has produced Table 2.1, which is far from being exhaustive but shows the wide variety of ANSP setups. It gives examples from around the globe and classifies the ANSPs into five categories, as follows:

- A A government department or authority that is subject to government accounting and treasury rules and staff are employed under civil service pay and conditions.
- B A government entity empowered to manage and use the revenues it generates through charges for the services it provides.

C A corporatised entity with special status, not governed by normal commercial law, but by a specific founding law or statute (and wholly owned by the government).
D A company established as a public-private partnership to provide the services on behalf of the government, and part-owned by the government.
E A private sector company owned and/or operated by private interests to provide the service on behalf of the government.

While most European ANSPs belong to the categories B or C (UK-NATS and ENAV Italy being 'D' but not present in this table), it is interesting to note the existence of fully private ANSPs (e.g. NAV Canada) or, at the other end of the spectrum, ANSPs that are a government department or authority subject to government accounting (Category 'A', such as FAA – USA, and, in Europe, ANA – Luxembourg).

The Single European Sky: From separation between service provision and regulatory functions to opening to market conditions

The first SES package (2004): Separating service provision from regulatory functions

It is the saturation of airspace and worsening flight delays at the end of the nineties that triggered the first Single European Sky package. The 1999 Commission's Communication on 'the creation of Single European Sky' (COM/99/0614/final)[32] highlighted the inadequacies of the traditional working methods, based on intergovernmental cooperation, to resolve the sector's problems and advocated structural reform. Notably, it stated that

> a first essential step is to establish a clear separation between service provision and regulatory functions. This would allow indeed service providers to concentrate on their managerial tasks and avoid they use regulatory powers to impose their views to their customers. This also would strengthen relations between providers and their customers, facilitating trade-offs between quality of services and costs.

The first SES package was adopted in March 2004 as a set of four basic Regulations.[33] Article 4 of the framework Regulation (EC) No 549/2004 materialised the creation of national supervisory authorities and its Paragraph 2 imposed the principle of separation between service provision and regulatory / oversight functions: 'The national supervisory authorities shall be independent of air navigation service providers.' While such separation had been already carried out in a number of States (Such as, as we have seen, UK, Germany, Spain and Italy), this was a new and often disturbing obligation for a number of other EU Member States and this is why, after intense discussion

Table 2.1 CANSO's classification of ANSP setups.

Region	*Member*	*Legal status*
Africa	ATNS	B
	KCAA	B
	EANA	B
	FAA-ATO	A
Americas	NAV CANADA	E
	AEROTHAI	D
	AAI	B
Asia Pacific	Airways NZ	C
	CAAS	B
	JANS	A
	PNGASL	B
	ANA	A
	ANS Finland	C
	ANS CR	C
	DHMI	B
	DSNA	B
	EANS	C
	HungaroControl	C
	Isavia	C
Europe	LGS	C
	M-NAV	B
	NAV Portugal	C
	Oro navigacija	C
	PANSA	B
	SMATSA	Other
Middle East	SANS	C

Source: CANSO, 2020

between co-legislators (Council and European Parliament), the obligation of separation was finally limited to being 'at the functional level at least', meaning that ANSPs could remain within their respective DGCA or CAA provided that they were identifiable in terms of human and financial resources with a separate and transparent accounting.

Importantly, the first SES package established 'common requirements for the safe and efficient provision of air navigation services',[34] which ANSPs needed to comply with in order to be certified and thus allowed to provide air navigation services.

It also created at EU level a performance benchmarking system 'drawing upon the expertise of Eurocontrol' (Article 11 of the Framework Regulation).

These steps may appear modest in today's context, but they contained the foundations needed for the development of the second package. First, they materialised the idea that air navigation service provision was indeed a service, even if monopolistic, to be kept at arms' length from the national regulators. As a result, all European ANSPs were now identifiable, with a separate cost-base, and they were accountable to their regulator. Secondly, while time was not yet ripe for a binding performance target-setting, the collection and analysis of a huge amount of data by Eurocontrol's Performance Review Unit (already created in 1998 and with an unrivalled reputation in the field of performance data collection and analysis) allowed baselining and contextualising the actual level of performance, studying what was the 'performance pool' that may be gained, in the Key Performance Areas of safety, capacity, environment and cost-efficiency. Six years later, in 2010, this would allow the SES II package to establish the performance scheme with the setting of binding targets as we still know it in 2022.

In a nutshell, this first phase of the SES (2004–2010) allowed European ANSPs to:

- Acquire their specific and visible identity;
- Be submitted to common requirements to be certified, thus setting a European standard and level playing field of quality of service, which paved the way to mutual recognition of certificates and cross-border service provision;
- See their performance benchmarked against their peers.

The second SES package (2010): Installing performance target-setting and the first steps towards economic regulation

The first package contained a clause of assessment of the results achieved after three years of implementation. (Article 12 of the Framework Regulation (EC) No 549/2004). The exercise[35] revealed both the improvements achieved through the first package and the need to set up a second package to create a 'true' Single European Sky (according to the foreword from Commissioner Barrot in the High-Level Group report), in particular consolidating the performance and governance of the system.

The second SES package was adopted in October 2009 through Regulation (EC) No 1070/2009, amending the four basic Regulations of the first package. This brought a number of substantial changes, crucial for the ANSPs. The first performance scheme, adopted as Regulation (EU) No 691/2010 of 29 July 2010, the amendment of the service provision Regulation and the amendment of the charging Regulation by Regulation (EU) No 1191/2010 on 16 December 2010 together achieved the quantum leap of putting an end to the paradigm of automatic full cost recovery that had prevailed in Europe since 1981 (and the Eurocontrol multilateral route charges system) and make the charging scheme evolve into a tool for achieving cost-efficiency performance.

A European performance scheme with binding performance targets and associated bonuses/ penalties

Building on the historical data gathered and analysed since 1998 by Eurocontrol's Performance Review Unit, the benchmarking carried out since 2004, and the adoption of the first Performance Regulation, a first performance reference period of three years was launched in 2012 with associated performance targets in the Key Performance Areas of safety, capacity, environment and cost-efficiency. For the first time States and their ANSPs had to reach performance targets and there were financial consequences to achieving or not the cost-efficiency target, and possibly financial penalties or rewards in case the capacity target would not be met.

Charging scheme: the end of the principle of 'automatic full cost-recovery'

The several crises faced in the 2000s (11 September 2001 attacks, second Gulf War in 2003, SARS in 2002–2004, Economic crisis of 2008) had demonstrated concretely the perverse effects of the automatic full-cost recovery of air navigation charges: In periods of traffic decrease, this system generated an automatic increase of charges, thus aggravating the difficulties already faced by airlines and leading to a further decrease of demand. Conversely, additional revenue obtained through good management and cost-containment had to be returned to airspace users: the system did not offer any incentive to ANSPs to encourage good management, cost-containment and productivity increase.[36]

The charging scheme adopted in 2010 put an end to this situation by introducing the concept of 'determined costs' (as opposed to the previous 'full costs'), where costs bases are fixed in advance of the reference period and accepted as part of the performance plans.

From there, cost variations are only allowed in application of a limited number of parameters, listed in the Regulation (Article11a.(8)(c)). To enforce this a 'risk-sharing' mechanism is enforced, by which, as a result of a compromise, additional or loss in revenue due to differences in the ANSP cost-base or differences between traffic forecast and actual traffic were also shared between airspace users and ANSPs. In addition some costs are kept outside of this risk sharing as they are not under the control of the ANSPs, such as the regulators costs, the MET costs, or the costs of international agreements.

This scheme, perpetuated in Regulation (EU) No 2019/317,[37] has introduced a new paradigm where ANSPs are truly incentivised to improve their management as they can retain at least part of their productivity increase and bear the consequences of at least part of their failure to contain costs. Similarly, the financial consequences of unexpected variations in traffic are now shared between airspace users and ANSPs. This is planned to continue with the Commission's SES2+ proposal.

The separation of en-route from terminal cost-bases with the associated obligation to set terminal unit rates

Until the second SES package there was no obligation for a State – and therefore an ANSP, to set up a terminal air navigation services cost-base and unit rate. As a result of this, those States which calculated terminal ANS costs and recovered them through the imposition of a terminal charge did so in a completely uncoordinated way, resulting in the coexistence in Europe of a patchwork of schemes and formulas, without any centralisation of information and therefore no possibility to compare and benchmark. There was also a risk of double counting of the same costs (as the same cost may appear both in the en-route and the terminal cost-bases) without any real tool to oversee and control. The charging Regulation put an end to this situation and established a transparent level playing field between all European air navigation service providers through the requirement to calculate costs according to the same rules and apply charges using the same formula.

While since then both the performance and charging Regulations have been amended, (Regulation (EU) No 390/2013 for the performance scheme, (EU) No 391/2013 for the charging scheme, and then Regulation (EU) No 2019/317[38] merging the performance and charging Regulations), these major changes remain relevant to date.

In a nutshell, this second phase of the SES had the following consequences for ANSPs:

- The implementation of a performance scheme in the key performance areas of safety, environment, capacity and cost-efficiency, including the imposition of binding performance targets, with financial incentives associated to reaching or not the capacity and cost-efficiency targets;
- The end of the 'automatic full cost-recovery' and its replacement by the concept of 'determined costs' fixed in advance for the duration of the performance reference period; and
- An obligation to differentiate and bring transparency between en-route and terminal services, costs and unit rates.

The mixed record of the Functional Airspace Blocks (FABs) and the rise of ANSP Alliances and partnerships

The first SES package had defined the concept of Functional Airspace Blocks in the airspace Regulation, and the second one had broadened it to service provision. This was meant to support the defragmentation of airspace through collaboration between neighbouring ANSPs.[39] The combination of this concept with the notion of charging zone, which could be cross-border, aimed at encouraging States to agree on en-route charging zones that would be cross-border and if possible covering the FAB airspace, with a single unit rate (see e.g. Recital 9 of the first charging Regulation (EC) No 1794/2006). However this had to be abandoned due to the identification of a number of potential perverse effects and thus a legitimate resistance from States, ANSPs and even airspace users.

It can be argued that the concept of Functional Airspace Blocks has been a disappointment. While it was meant to contribute to the defragmentation of airspace, it in fact created yet another layer of fragmentation, where FABs became an additional intermediate between States/ANSPs and the Commission.

As the Commission had forced States to create FABs, with the associated heavy procedures at governmental level, and even launched infringement procedures against those States that were late in setting up their FAB, it took years for it to acknowledge that FABs were probably not the right answer to the fragmentation problem. Now, FABs are absent from the current SES2+ proposal, while States may continue them on a voluntary basis. Several States have indeed claimed that FABs have given them the virtuous habit of collaborating with neighbours, to implement cooperative decision-making on a systematic basis, and therefore announced their intention to continue this cooperation model.

In the meantime the ANSPs did not wait for the 'mixed record' of the FAB experience to develop innovative and interesting ways to cooperate and improve their performance – and also their visibility and influence at European level. Beyond CANSO, the Civil Air Navigation Services Organisation created in 1996 as a trade organisation to express the 'global voice of ATM worldwide' and who represents the interests of ANSPs that provide about 85% of worldwide air traffic, a number of regional alliances or partnerships have also been created in Europe, either around an adjacent airspace or around the same supplier of ATM systems:

- **Around the same supplier of ATM systems**. The COOPANS and iTEC alliances gather ANSPs that have decided to join forces, mainly to enable common procurement for their ATM systems and thus better cost-efficiency, economies of scale, interoperability, and strengthen their voice in their dialogue with their system manufacturer:
  - **COOPANS**[40] is a **partnership** established in 2006. It is currently composed of the ANSPs of Austria, Croatia, Denmark, Ireland, Portugal and Sweden, and the supplier of their system, Thales. Its vision is to 'operate the ATM system of choice worldwide'.
  - **iTEC** (Interoperability Through European Collaboration)[41] was signed in 2007 and now includes the seven ANSPs of Spain, Germany, UK, the Netherlands, Poland, Lithuania, Norway and the supplier of their systems, INDRA system. Their goal is to 'Work together to generate service alignment and cost efficiencies', notably through a 'common ATS system with interchangeable ATS components supported by open standards'.

- **Around a geographical area**. Alliances have also been created by ANSPs that cover adjacent airspaces with common characteristics and needs:
  - The **Borealis Alliance**[42] gathers since 2012 nine northern European ANSPs (from Denmark, Estonia, Finland, Iceland, Ireland, Latvia, Norway, Sweden and UK), representing 39% of the European traffic, who have the ambition of being 'The leading ANSP Alliance that enables its members to drive better performance for stakeholders through business collaboration'. The Borealis Alliance has been pioneering the implementation of a seamless Free Route Airspace (FRA).[43]
  - **Gate One**, a ANSP initiative established in 2013 in central and Eastern Europe, was initially composed of the ANSPs of Austria, Bulgaria, the Czech Republic, Croatia, Poland, Lithuania, Hungary, Romania, Slovakia and Slovenia. The accession in 2014 of the ANSPs of Bosnia-Herzegovina, Macedonia, and Serbia and Montenegro, brought the membership to thirteen ANSPs. The purpose of the coordination platform is to 'promote the efficiency of European ATM through enhanced cooperation among the participating service providers, as well as to ensure a more powerful and coordinated advocacy of the region in the European decision-making processes'.[44]

- In addition, the **A6 Alliance**[45] was founded in 2011 by the six ANSP members of the SESAR Joint Undertaking (i.e. DFS (Germany), DSNA (France), ENAIRE (Spain), ENAV (Italy), NATS (UK) and **NORACON** – a consortium including Austro Control (Austria), AVINOR (Norway), EANS (Estonia), Finavia (now Fintraffic ANS) (Finland), IAA (Ireland), LFV (Sweden) and Naviair (Denmark)). This Alliance sees itself as a coalition of ANSPs 'who are committed to helping modernise the European ATM system'. It also 'provides leadership at a European level in critical technical and strategic area'. In 2015 PANSA (Poland) became member of the Alliance, together with the COOPANS Alliance for the work associated with the SESAR Deployment Manager (SDM) and SESAR 2020, and the **B4 Consortium**[46] for the work associated with SESAR 2020. Skyguide (Switzerland) became a full member of the Alliance in 2020.[47] This Alliance is therefore focused on the modernisation of European ATM through deployment of technology and processes arising from the SESAR Joint undertaking R&D programme.

As can be seen from the above, many ANSPs are members of several different alliances or partnership, depending on their purpose. UK NATS for example is simultaneously Member of CANSO, the A6, the Borealis Alliance, and iTEC.

De facto bypassing the concept of FABs, these ANSP alliances gain importance as the aviation industry is starting taking initiatives on its structural transformation through, its digitalisation enabling a more performing, scalable and resilient European ATM network, and the 'greening' of its operations, as required by the SES2+ proposal (see below).

On the other hand the multiplication of these alliances risks diluting the voice of ANSPs at European level. At present, the European Commission has decided that its official discussion and consultation interface with ANSPs is CANSO. However this does not prevent other Alliances from having informal and lobbying access to Council representatives, European Parliament Members, or to the Commission.

The SES2+ proposal: digitalisation, opening to market condition, a stronger role for designated air traffic service providers

In 2013, a first SES2+ proposal had been an attempt from the Commission to reinvigorate the SES2 package to try and tackle more efficiently the capacity shortage and the need for more performance, in particular on environment. However the political willingness was lacking among Member States and the initiative was stalled, officially because of a disagreement between UK and Spain over the Gibraltar airport.

2020 was a turning point for this SES initiative: After several years of sustained traffic growth with associated growing delays, the adoption in December 2019 of the 'European Green Deal', and the unprecedented, unforeseen traffic collapse caused by the COVID-19 pandemic, showed the need for a strengthening of European action. For the sake of simplicity and in an attempt to save procedural time, the Commission decided to adapt its former SES2+ proposal rather than start a completely new initiative.

The updated SES2+ proposal, published as a draft Commission proposal on 19 September 2020,[48] is therefore an adaptation of the former proposal to the new context, with an explicit focus on:

1 The need to set up and implement a resilient and scalable European ATM network that will be fit to absorb efficiently expected or unexpected variation of traffic, upwards or downwards. This is to be achieved through the implementation of the 'Digital European Sky', and

2 The reduction of aviation emissions.[49]

The SES 2 + package also pays attention to the need for a smooth integration of unmanned air traffic in the airspace. The SES 2 + package is supported and enabled by the ambition to establish by 2035 the 'Digital European Sky'.

The Commission proposal, as it is known at the time of drafting this contribution, has potentially a lot of consequences on the ANSP structures and business models:

- En-route Air Traffic Services Providers (ATSPs) would still be designated by States on an exclusive basis. This complies with the ICAO principle of sovereignty and responsibility of States over their airspace. However this designation would be limited in time (10 years in the Commission proposal). Furthermore the designation must not limit the possibility of cross-border / remote service provision, which is encouraged (and supported by the evolution towards the 'Digital European Sky').
- The performance plans would be developed by the designated ATSPs, not anymore the States. This is a major evolution as compared to the SES2 situation. With such evolution the performance scheme would somehow become an industry-led topic, with the ATSPs getting a prominent role.
- There would be separate performance plans for en-route and for terminal services. En-route plans would be assessed by the PRB while terminal plans would be kept at national level and assessed and approved by the relevant NSA, whose independence and resources would be strengthened.
- The Commission wants to encourage and facilitate the procurement under market conditions of Terminal ATS, both for Approach and Aerodrome. If they would be procured, the Performance and Charging schemes would not apply to them, which is a strong incentive.
- The Commission also wants to encourage the procurement under market conditions of all air navigation services that are not air traffic services (i.e. CNS, AIS, MET, and ADS, for ATM Data Service Provision, a service that is currently provided by ATSPs but has been identified for potential opening to market in the SES2+ proposal and the Airspace Architecture Study). To effectively enable this, air traffic services would be 'organisationally separated' from the other air navigation services. Furthermore, ANSPs that continue delivering such services would have to keep separate accounts for each air navigation service, as they would do if they were carried out by separate undertakings.

With these new features, the Commission obviously aims at encouraging a trend by which, progressively, only core en-route ATS provision would be submitted to the performance scheme, all other air navigation services being procured under market conditions.

A 'professionalisation' of the performance scheme would be achieved with permanent structure and resources for the Performance Review Body, who would deal directly with the designated ATSPs, which would therefore be given a prominent role. With its proposal, the Commission appears to want to somehow take some distance from the performance scheme it has been managing for the last ten years. Having secured the adoption of Union-Wide performance targets through comitology (advisory procedure), the Commission would then leave it to the PRB (located in – but independent from – the EASA) to assess and approve the en-route performance plans (through formal approval by the EASA 'acting as PRB'), and the NSA at national level for the terminal performance plans. There would be no SSC involvement anymore in this approval process.

Several States claim that, according to the subsidiarity principle and the need to take into account local context and requirements, which are better known at local level, the en-route performance plans would be best approved at national level. But, to be more acceptable to the Commission, this would go together with a strengthening of the independence and resources of the NSAs, which several of the same States are reluctant to accept.

The evolution proposed by the Commission, if successful, would place the performance scheme at arms' length from States and politics to hand it over to the industry (ANSPs) and independent regulators (at European level: PRB under the administrative umbrella of EASA, and at national level: the NSAs). While this would be coherent with the evolution of similar sectors (e.g. energy), this evolution faces a strong opposition from several Member States.

At the moment of finalisation of this chapter (March 2022), the 'trialogue' between European Parliament, the Council and the Commission is difficult and progress is very slow. In a nutshell, the European Parliament is supportive of the Commission proposal (and sometimes goes even beyond) while the Council expresses major disagreements against what is perceived as a weakening of national sovereignty and defence requirements, a forced evolution towards market conditions and an excessive interference into the management of the national and designated ANSPs. It is at present impossible to predict if and when the SES2+ legislation will be adopted, what compromise will be reached, and where the cursor will be placed between the very diverging views of the European Parliament and the Council. The outcome of this process will be of major interest for the academia and will undoubtedly trigger additional research.

The challenges ahead

Public service or competition?

The SES regime as we know it today is slightly ambiguous. On the one hand, it appears to shield service provision from competition-related market forces (see e.g. Recitals (1) and (2) of Service provision Regulation (EC) no. 550/2004 referring to 'public-interest requirements', and Recital (5) stressing that the provision of air traffic services 'is connected with the exercise of the powers of a public authority, which are not of an economic nature justifying the application of the Treaty rules of competition').

On the other hand, it more and more refers to the promotion of market conditions and competition for service provision (see e.g. Recital 13 of the service provision Regulation where the provision of CNS 'should be organised under market conditions'). This is not in contradiction with the Chicago Convention / ICAO regime, provided that the 'mantras' of Articles 1 and 28 (on the sovereignty of States over their airspace and the States' ultimate responsibility to organise air navigation services over their territory) are respected.

This duality is clear in the Commission proposal on SES2+ where the Commission's almost explicit intention is to focus on en-route air traffic service provision where air traffic service providers remain designated by States on an exclusive basis. They are considered as exercising 'the powers of a public authority'. Because of this monopoly situation they are to be economically regulated (Through the performance scheme).

On the other hand all other air navigation services (terminal and airport air traffic service provision, CNS, AIS, ADS and MET) would be encouraged to be provided under market conditions, and thus unregulated.

The question on whether such services delivered under market conditions could be declared of 'economic nature' and thus submitted to the European competition should deserve close attention, as indicated in Annex F Paragraph F.3.6 of the SESAR JU Airspace Architecture Study. This paragraph addresses the topic of ATM Data service provision, but may be valid for any ANS provided under market conditions[50]: It suggests a possible evolution where an economic activity, even provided by a publicly-owned entity, may be subject to EU competition law, including antitrust and State aid law. The qualification of ANSPs as undertakings subject to EU competition law would hence be assessed in relation to the nature of their activity, rather than their form or structure.

The final report commissioned by the EC on the 'Legal, economic and regulatory aspects of ATM data services provision and capacity on demand as part of the future European Airspace Architecture' of December 2020[51] contains in its Annex III a list and summary of relevant law cases without offering clear conclusions on the topic, which therefore remains open and should be subject to specific study.

Integrating the 'new entrants' in the network

In the current crisis context, ANSPs also have to prepare for the arrival of 'new entrants' (mainly drones of all sizes and capabilities, but also urban mobility vehicles, suborbital flights or even high-altitude pseudo satellites – HAPS) in all categories of airspace. The business of these new users is growing fast, and already well installed in several States.

The SESAR JU 'European drones Outlook Study: Unlocking the value for Europe' of November 2016[52] had already highlighted the expected exponential growth of this new business with an estimated value of more than 10 billion euros per year by 2035. This trend has been confirmed recently by a study on 'the Future of the Drone Economy / A comprehensive analysis of the economic potential, market opportunities, and strategic considerations in the drone economy',[53] estimating that, by 2030, at worldwide level, the drone economy will have grown from today's 15 billion to 90 billion US dollars.

To support this growing business and enable a smooth and safe, first, separation, and then integration of these new air vehicles into the airspace, controlled or uncontrolled, the European Commission has adopted on 22 April 2021a Regulation (EU) 2021/664 'on a regulatory framework for the U-space'.[54]

The new entrants enter in the game with considerable financial power and much shorter investment cycles than the 'traditional' aviation and ANSPs. Unmanned aviation is also, by nature, already digital. The prospect of integrating manned and unmanned aviation within the same airspace, which is the ambition at horizon 2035, already forces ANSPs to review their ways of working (as stressed in the 2020 Edition of the European ATM Master Plan), and pushes for the acceleration and delivery of the 'Digital European Sky'. This re-thinking of business models is also encouraged in the SES2+ proposal, as has been described above.

While the provision of air traffic services is a monopolistic, public service activity (except tower services), the provision of U-space services is intended to be open to competition.

The coming years will probably see a tension, hopefully productive, between the business models and practices of the new entrants, based on agility and adaptability to market demands, and the 'legacy' air navigation service provision with long investment cycles and focused on safety, capacity delivery, and now environment requirements.

The need to ensure a smooth, safe and efficient integration of manned and unmanned traffic in the same airspace is likely to trigger an acceleration towards the digitalisation of air navigation service provision.
It is remarkable to see that a number of members of the drone industry have become founding members of the newly created SESAR 3 joint undertaking, which succeeded on 14 December 2021 to the previous SESAR Joint Undertaking.[55]

Digitalising air transport, enabling large-scale remote service provision

Before the arrival of new entrants in the airspace, the digitalisation of air navigation service provision had already been identified as a must to, first, accommodate the traffic growth up until 2019, and then, enable a modular, scalable and resilient European network that will be able to safely and efficiently absorb expected or unexpected traffic evolutions, upwards or downwards. Digitalisation indeed aims at enabling large-scale cross-border and remote service provision, allowing the provision of 'capacity on demand' as identified and recommended in the Airspace Architecture Study.

Digitalisation is also expected to support better flight trajectories, thus supporting the improvement of the environmental performance of aviation.

Today's paradox is that, as all ANSPs face huge financial difficulties due to the drop in traffic and corresponding loss in revenue, they should also accelerate investment in innovative technology that will allow building this targeted 'environment-friendly', scalable and resilient network. Public funding support will therefore be needed to enable this, and the topic is currently high on the Agenda of the Commission and policy-makers, around the creation of the SESAR 3 partnership and of the SESAR Deployment partnership that succeeds to the SESAR Deployment Manager.

Recital (2) of the Commission Proposal for a Council Regulation 'establishing the Joint Undertakings under Horizon Europe' (COM/2021/87 final)[56] synthesises well the issue by stressing the importance of the 'strategic objectives such as accelerating the transitions towards sustainable development goals and a green and digital Europe' and the 'recovery from the unprecedented COVID-related crisis'.

> The digitalisation of aviation and therefore of air navigation service provision is both a must to address today's and tomorrow's challenges, but also a difficulty in the current difficult financial situation.

Conclusion: What may the future of ANSPs look like?

This chapter expresses the view that the European aviation industry, and in particular ANSPs, are maybe at the most important crossroad of their history since the Chicago Convention. The need for the digital transformation of air transport was perceived and announced in Europe already in 2017 to face the growing traffic demand and integrate the 'new entrants' in the European airspace. It has become now even more necessary to better absorb in the future the shocks of traffic variations, upwards or downwards, and support a 'green recovery' of air transport.

In such context, what could be the evolution of ANSPs? Several scenarios seem to be possible. One could derive from the dire financial situation of all aviation stakeholders: As a result of the COVID crisis, airspace users struggle to pay their air navigation charges. On their side, ANSPs have to face an unprecedented loss in revenue due to the drop in traffic. Unlike airlines, which can cancel flights when there are no passengers, ANSPs have the obligation to keep their airspace open and to offer air navigation services even if there are only very few flights. ANSPs are indeed managers of a critical national infrastructure that needs to be maintained and kept open. On the other hand, airspace users are more and more reluctant to pay for facilities they do not use or services they do not receive. In such situation, States may have to, or choose to, finance part of the costs incurred for providing air navigation services (for example the costs of regulators, all or part of the cost of ground infrastructure, in particular the one that is used or will be used in the future only or mainly by general aviation or military, such as VORs, DMEs or SSR Mode A/C radars). This would be likely to support the financial health of the sector and facilitate its expected return to growth. However, this would mean a step back to the pre-1981 situation, date at which the Eurocontrol Member States decided the 100% recovery of their ANS costs.[57] Furthermore, this step back, if not strictly limited in time, e.g., to recover from today's crisis, would not give a positive political signal as it may have the negative effect of bringing air navigation service provision and investments firmly back within national borders, which could weaken or slow down the needed digital transformation of the industry, the interoperability of infrastructure, and jeopardise the goal of enabling cross-border cooperation and large-scale remote service provision. Furthermore, one can ask the question of whether States would be ready to subsidise an industry that is under the spotlight of the public opinion as a substantial source of pollution and negative environmental impact (think of 'flygskam', also known as 'flight shame').

Another scenario would be, on the contrary, to open largely the provision of air navigation services to competition with the expectation to trigger cost-efficiency gains, economies of scale (e.g. through ground infrastructure optimisation) and cross-border service provision. This contains however an inherent risk of weakening of State sovereignty and defence requirements, which are becoming even more crucial as the Ukrainian crisis intensifies. It may also gradually promote an attitude of maximisation of profit instead of overall network performance, environmental performance, and quality of service to citizens. Furthermore, because of the small number of competitors in the ATM manufacturing industry, this may enable the creation of oligopolies or even new monopolies, which is of course not the intention and may not be cost-efficient for airspace users in the longer term.

Trying to address this, the SES2+ proposal aims at combining both scenarios in focusing its economic regulation on en-route services, to be provided by monopolistic, designated service providers, and encouraging the decoupling of service provision from infrastructure and the opening to market conditions of all 'auxiliary' services (CNS, AIS, ADS, MET) and the airport air navigation services.

Discussions are intense between European co-legislators and the Commission, stakeholders and State representatives, and the future of ANSPs will depend on the outcome of these discussions and the consensus that is targeted to be found before the end of 2022.

Discussion questions

1 There is a fundamental tension between the traditional statement that air navigation service provision is a public service and the growing tendency to encourage decoupling of a large number of services to open them to competition. Is there a choice to make, or can we reconcile and combine these two visions for the benefit of citizens and passengers?
2 The 'new entrants' in the airspace (drones, urban mobility, HAPS …) will first have to be segregated from traditional, manned, traffic, before achieving in the longer term the seamless integration of both traffics in a single airspace. Whose vision will be prominent in the long term? Will the drone industry, with its digital nature, very short investments cycles and fast reactivity to market opportunities, influence the evolution of manned aviation, or will the traditional ANSPs impose their culture of 'safety first' and provision of services to travelling passengers as the overriding objectives?
3 Is it reasonable to expect a return to the ex-ante situation and behaviours once the COVID-19 crisis will be overcome? Is it conceivable that the current crisis triggers a return to State-funding of at least part of air navigation service provision, which would in a way mean a return to the pre-eighties situation? May it on the contrary trigger a larger transfer of service provision to competition and market conditions?
4 Knowing the evolution of jurisprudence, is it expectable that the air navigation services that are open to market conditions will eventually be submitted to European EU competition law, including antitrust and State aid law?

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Notes

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3 From NextGen to SES

Structural reform in the air navigation service provider industry

Anna Tomová

Introduction

Any structural reform is a fundamental supply-side change of industries. After the Second World War, the provision of air navigation services (ANS) within countries was captured by statutory geographical monopolies of air navigation service providers (ANSPs). ANSPs in countries had different organisation formats. They were often established within civil aviation authorities or governmental departments (ICAO, 2013). For instance, in Germany, the Federal Administration of Air Navigation Services (BFS) was founded as a government authority in 1953 (DFS, 2020). The forerunner of NATS in the UK, the National Air Traffic Control Services (NATCS), was established in 1962. Then after the formation of the Civil Aviation Authority in 1972, NATCS became a part of it and shortened its name to NATS (NATS, 2020). However, despite diverse national peculiarities, the provision of ANS within countries was the same from the perspective of industrial structure. In principle, a single ANS provider in a country delivered the bundle of ANS services to airspace users. However, some ANS did not have to be produced in-house by the monopolist itself (for instance, MET). Thus, the ANS industries in countries could not be entered by (potential) competitors which would deliver ANS (or some of them) within the respective airspaces.

Moreover, the monopolistic multi-product ANSPs were publicly owned. Accordingly, there were no private or public/private providers in the ANS industries within countries. In this traditional structural model, governments exploited full political control over the provision of ANS within the frame of their airspaces. The management of the ANS provision was mainly operationally driven.

As the Chicago Convention (1944) neither forbids the entrance of third parties inside or outside the countries in airspaces nor insists on the public ownership of legacy ANSPs, some countries initiated more fundamental (i.e. structural reforms) which changed the supply side in the provision of ANS in terms of ownership and/or the number of providing ANS entities. Nevertheless, in the structurally reformed ANS industries, states (governments) are responsible for the safe and cost-effective delivery of ANS within their

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airspaces as the Chicago Convention sets. This chapter is focused on the options for structural reforms in the ANS industries. After explaining the motivations behind the structural reforms, two levers of structural reforms are discussed, delivering illustrative examples of possible options. After that, supranational dimensions in restructuring the ANS industries are explicated to understand the specifics of the Single European Sky (SES) as an ambitious structural reform of the European Union (EU). At the end of this section, the costs and benefits of structural reforms are discussed, and some issues of the structural architecture of world airspace(s) in the future are presented.

Motivations behind structural reforms

Over time, the historical model of monopolistic multi-product ANSPs broke out in falling cost-efficiency and certain performance problems, including delays. The absence of business-like management of traditional ANSPs led to certain innovations of the traditional model, such as commercialisation and/or corporatisation (McDougall & Roberts, 2009), but not in all countries.[1] Acquiring more decision-making autonomy due to commercialisation and/or corporatisation, the innovated ANSPs were thus focused more on the requirements of airspace users in terms of performance and economic effectiveness. The political control of governments over the commercialised and/or corporatised ANSPs was weakened. Despite the changes, the innovated ANSPs remained geographical multi-product monopolists in public ownership in principle.

Consequently, the structure of ANS industries in the countries that innovated their ANSPs and those that did not innovate their ANSPs was still the same. From a structural point of view, these legacy ANSPs (or incumbencies) were the only ANS providers within their countries' airspaces, being in public ownership. Economies of scale, economies of scope, and safety issues were the most common arguments defending the traditional structure of the ANS industries in countries.

Motivations behind the structural reforms of the ANS industries in countries are complex and related to specific contexts. They may be found both at the supply and demand sides of ANS industries.

In the traditional model, characterised by the ANS industry's monopolistic structure and providers' public ownership, the incentives to be cost-effective were missing due to the absence of market mechanism forces (competition). Similarly, the public ownership of statutory geographical monopolists did not create sufficient pressure on permanent technological and managerial modernisation as it is characteristic for industries in which private ownership is prevailing or at least present.

At the supply side of the ANS industries, governments as the ANSPs' owners may cope with the problems of the ANSPs funding. This may be a very urgent matter, especially in terms of investment needs, due to the nature of the ANS industry as capital intensive production (Robyn & Neels, 2008).

Regarding advanced ANS technologies, the need to invest in these technologies spurred the structural reforms of the ANS industries in countries. Some of these technologies themselves even act as technological enablers of such structural reforms (Arblaster, 2018). Technological reforms aimed at modernisation are carried out in many airspaces, but only in several countries these technological modernisations are implemented together with structural reforms. Structural reforms may be differently perceived by governments in different phases of the economic cycle and may be subject to different ideologies of governmental economic (and infrastructure) policies. The activation of structural reforms at the supply side of the ANS industry may also be triggered by events resulting from the nature of the industry as labour-intensive production.[2] On the supply side, among the factors encouraging structural reforms in the ANS industries that must be mentioned is the provision of ANS itself as an attractive production alternative for private capital and private capital entities.[3]

On the demand side of the ANS industry, airlines as airspace users demand the delivery of ANS in a cost-effective manner and of high quality. The matters of cost-efficiency in the delivery of ANS are among the priorities of competing airlines in their cost-cutting strategies when many domestic markets with air services are liberalised, and many international markets with air services are being gradually liberalised. Similarly, delays in airspaces impact the quality of air services perceived by the flying public, which consequently also deteriorate the competitiveness of airlines. Just the monopolistic structure of the ANS industries was considered by airlines as a source of economic inefficiencies and failures in performance. Such attitude strongly contrasted with arguments based on economies of scale and economies of scope behind the traditional architecture of ANS industries in countries after the Second World War. Adopting international optics, airlines in their cost-cutting strategies may decide among the supply of airspaces (and ANS supplied in these airspaces) if substitute trajectories exist for overflights, particularly in politically fragmented world regions. This further pushes on the changes of traditional ANSPs (incumbencies) in terms of their capability to compete by prices and quality internationally to exploit economies of density within their airspaces.

Therefore, the option to restructure the provision of ANS in countries more fundamentally may be decided as a track to achieve the competition targets of airspaces by creating incentives stemming from the introduction of competition and/or private ownership.

The growing commercial potential of ANS business in foreign countries (Tomová, 2016) may also act as an external driver to reform the structure of the whole ANS industry in a country more fundamentally, not relying only on the effects of corporatisation and/or commercialisation of an incumbent provider in the country. It should be recalled that structural reforms themselves are among the factors which generate more business opportunities for manifold ANS providers, not only traditional (legacy, incumbent) ones.

Except for the country-specific motives behind structural reforms mentioned above, certain specific ones relate to international integration groupings such as the EU. In 1987, markets with air services in the EU were completely liberalised, resulting in a single market with air services covering the EU (plus Island and Norway). However, the provision of ANS within the EU remained fragmented, still copying the political borders of member states. As traditional ANSPs in the EU's member countries had been built for the needs of national markets with air services, the historical industrial structure(s) of the ANS provision within the EU did not satisfy the needs of the single market with air services on such issues as capacity, safety, environment, and cost-efficiency. Therefore, the SES initiative was launched in 2004 to achieve the de-fragmentation of European airspace. The SES is inherently a challenging supranationally driven structural reform of the ANS industries aimed at integrating currently fragmented European airspace. Prospectively and in the long-term, structural reforms cannot be excluded in further world regions in connection with advancing integration processes among countries in the future.[4]

There may also be further situational (contextual) factors that influence the ANS provision's structural design in countries. Notwithstanding the motives to re-structure the traditional ANS industries, any structural reform in the ANS provision in a country and/or within an international integration grouping is not a simple infrastructure change.

Options for structural reforms in the ANS industry

Key structural options and examples

Structural reforms in infrastructure industries are based on two key levers: the introduction of competition and/ or privatisation of legacies. Both reform levers may be combined. The introduction of competition into the ANS industry within a country may be implemented through liberalisation (i.e. the allowed access of third parties to the industry). In principle, the liberalisation

Table 3.1 The 2020 reform status of the ANS industries in chosen countries in terms of two reform levers.

	Ownership status of incumbency			
Third party providers' access	*Governmental publicly run entity*	*Corporatised entity in public ownership*	*Public–private corporation*	*Private corporation*
Not allowed	Poland	Slovak Republic	Italy	
Liberalised	US	Germany	UK	

Source: chapter author

of the ANS industry may be activated regardless of whether a legacy is or is not corporatised or privatised as Table 3.1 demonstrates.

As Table 3.1 indicates, some countries have not reformed their ANS industries in terms of structural changes, such as the Slovak Republic. While in some countries, only the (partial) privatisation of legacies was realised, not utilising liberalised access such as Italy, there are countries which enabled access to the ANS industry, keeping the public ownership of their legacies such as Germany. Connecting both reform levers (as in the UK) is still rare, and the full privatisation of legacies did not take place up to now in the world.[5]

More massive privatisations of legacies in Europe were carried out only in the UK and Italy. Although being only partial privatisations (49% of NATS' shares held by the government together with a golden share giving the government the right to outvote other shareholders; 53.3% of ENAV's shares held by the government), they transformed the ownership of ANS industries in their countries fundamentally in comparison with still prevailing public ownership of traditional ANSPs in Europe. It must be noted that the ownership profile of the ANS industries is not impacted only by the privatisation of legacies themselves but also by the third-party providers' access if third parties are private entities. Thus, both structural reform's tracks (legacy's privatisation and access of third parties) may change the ANS industries' ownership structure.

The liberalised access of third parties to ANS industries was de-facto implemented in the US, the UK, Germany, Spain, Sweden, Norway, UAE. In Switzerland, a change in civil aviation law was made in 2019 to allow regional airports in Switzerland to be served by foreign ANSPs instead of Skyguide.[6] In this regard, Arblaster and Zhang (2020) point out there are countries such as Australia and New Zealand where it is legally possible for third party providers to enter the ANS industries. Still, this legal option has not been used.

While third party providers of ANS in the US are private companies, similarly as SAERCO, Aviation Capacity Resource or GAL ANS LLC, Austro Control is an incumbent ANSP in public ownership of the Republic of

Table 3.2 Illustrative examples of third-party ANS providers in chosen countries.

US	*UK*	*Germany*	*Spain*	*Norway*	*Sweden*	*UAE*
Midwest Air Traffic Control RVA Serco	Air Navigation Solutions Ltd	Austro Control	FerroNATS SAERCO	SAERCO	Aviation Capacity Resources	GAL ANS LLC[a] Serco Middle East

Note: [a]GAL ANS LLC (2020) has in its product portfolio Air Traffic Control Tower Services, Air Traffic Contrvol Approach Services, Communication, Navigation and Surveillance (Engineering) Services, Aeronautical Information Services, ANS Training Services, ANS Management and Consulting Services.
Source: chapter author

Austria that conducts ANS business as a third-party provider in Germany (at several regional airports). Air Navigation Solutions Ltd is a 100% daughter company of German publicly owned DFS. FerroNATS is a joint venture between Ferrovial Servicios SA[7] and NATS. This demonstrates that there are miscellaneous third-party ANS providers in terms of ownership, organisation format, country's affiliation, and links to existing incumbencies. In several countries, such as in Germany or the UK,[8] innovations in the organisation format of incumbencies were realised to separate the management of regulated ANS business and commercial one (business resulting from liberalised ANS regimes at home and abroad including). Due to liberalisation, airports (or dedicated airport's companies) are among potential new entrants in the delivery of terminal ANS (TANS).[9]

The process of entering the liberalised ANS industries usually forms competition for the market. Competition for the market is a specific case of competition that has been used so far when restructuring many infrastructure industries in the world. Through a competitive tender, the respective market is contracted upon an awardee that obtains the exclusive (time-limited) right to supply the whole *respective* market. The respective market in this regard is represented by the portion of ANS designed for competition. As for the portfolio of ANS suitable for competition, the liberalisation of TANS has predominantly taken place. There may be different designs of liberalisation in terms of ANS, which may be selected to be procured through competition for the market, mainly: aerodrome control service, approach control service, aerodrome flight information service. ATM Policy Institute (2016) emphasises there are also further core ANS and non-core ANS in the portfolio of ANS, the supply of which may be subject to competition for the market. When liberalising the ANS industry through the regime of allowed access of third parties, further options are available regarding incumbencies. An incumbency may continue the traditional organisation form of multiproduct ANS provider, or it may be split to several institutional product successors. While the former option allows third-party access without impacting the institutional integrity of incumbencies, the latter one combines third-party access with product unbundling of incumbencies into institutional successors, which is a more radical reform solution from a structural point of view. The creation of dedicated daughter companies 'under the roof' of incumbencies, competing with liberalised ANS may be a step towards the full institutional separation of incumbencies based on product splitting.

Structural reforms in the provision of ANS within an international integration grouping

The need to reform the ANS industries within an international integration grouping of countries (such as the EU) calls for a specific approach, policy, and alternative structural options to overcome the fragmentation of ANS industries within the integration grouping. In principle, such an integration reform is more complex and challenging than structural reforms implemented individually by countries. When in 2004 the SES began as the ANS reform for the EU, the ANS industries in the EU member countries were represented mainly by incumbencies in public ownership. However, the UK had carried out both privatisation of NATS in 2001 and the liberalisation of TANS in 1985. Moreover, the incumbent ANSPs in the EU member countries were undergoing the processes of corporatisation[10] and/or commercialisation differently, some of them still resistant to any such innovations. Geographically (horizontally) fragmented structure of the ANS industry in Europe according to political borders manifested in the surplus of operating units and staff compared to the single ANS system of the US with similar airspace size and traffic numbers (Eurocontrol & FAA, 2009). In addition, the EU member countries applied their still national ANS policies within their airspaces, also in such cardinal economic issues as ANS charging (despite some harmonisation achieved in the field of ANS charging systems, mainly in the field of en-route services). Due to ongoing competition with en-route services among the EU member countries for overflights, longer flights than optimal, delays, extra fuel burns and CO_2 emissions had been recorded as other detrimental impacts of such fragmented structure. In such a fragmented ANS system, cross-subsidising between en-route and terminal services occurred. In the field of investment policies, the EU's incumbencies could prefer technological solutions acting against the requirements of common interoperability within the European airspace.

The initiative to defragment the European airspace into the Single European Sky was mainly motivated by integration motives. After achieving integration goals in many economic sectors and industries, the need to create a single (and more efficient) sky for a single market with air services in the EU[11] began to be a societal demand of integration progress. Theoretically, there are several reform options to integrate fragmented airspaces copying the political borders of states. An option to integrate horizontally separated ANSPs within the EU into a single successor – the pan-European ANSP, would not be feasible for many reasons, particularly political, economic, and legal ones. As the Chicago Convention (1944) is agreed on the principle of the sovereignty of states above their airspaces, a horizontal merging of the EU's incumbencies into the pan-European entity would clash not only against the sovereignty and responsibility articles of the Chicago Convention but also on the issues of pan-European accordance among the EU member countries concerning ownership and profit allocations among the member states, rationalisation of operating units, and employee's reduction, all being very sensible economic and social problems. The disputable question would also be whether monopolies in the EU's member countries should be replaced by a single multi-country monopoly with bundled ANS. In principle, such a reform solution would mean reversion to the traditional monopolistic model in delivering ANS services, however, established on a pan-European scale. Moreover, various organisation formats of the EU's ANSPs, certain peculiarities in the delivery of ANS, such as traditional self-supply of air traffic control services at airports in some countries, and structural third-party access reforms realised in certain countries by then were exposed as further obstacles to reform the ANS industry through complex horizontal integration.

From SES I to SES II

The SES reform was initiated by issuing four basic regulations in 2004 (the first legislative package of the SES known as SES I). The regulations were in line with the obligations of member states stemming from their membership in Eurocontrol[12] and the rights and obligations as set in the Chicago Convention. The Framework Regulation (EC, 2004a) laid down a harmonised regulatory framework for creating SES, requesting member states to establish national supervision authorities (NSAs), which ought to be independent of air navigation service providers, at least functionally. Within the newly created regulatory framework, the European Commission (EC) as a supranational body was determined as a driving force of the SES reform, acquiring regulatory competencies over the provision of ANS in the EU (plus Norway and Iceland). The Airspace Regulation (EC, 2004b) was aimed at creating a single European Upper Information Region (EUIR), within which the airspace would be reorganised into functional airspace blocks (FABs). At that time, FABs were intended to play a key role in the process of European airspace de-fragmentation (Efthymiou & Papathedorou, 2018). The Service Provision Regulation (EC, 2004c) set common requirements for the provision of ANS by ANSPs (technical and operating compliance and suitability, quality of services, reporting systems, security etc.). The providers of ANS had to be certified by member states. The competencies of national supervisory authorities in this regard were established and the principle of mutual recognition of ANSPs' certificates among member countries was adopted. The Interoperability Regulation (EC, 2004d) aimed to achieve interoperability between technical systems, components, and procedures and introduce new operating concepts and technologies. In 2007, SESAR (Single European Sky ATM Research) Joint Undertaking was founded to develop and deploy new ATM technologies in an integrated way. The SES I package focused on safety and capacity issues (ICAO, 2008).

The second legislative package of the SES, known as SES II, was adopted in 2009. Addressing firstly four, later five pillars – legislative (including performance-based regulatory framework), technological (SESAR), safety, human, and airports optimisation – the SES II legislation was focused on operating improvements in the functioning of the European ATM system (cutting costs, reducing delays, and further enhancing safety). As a part of the SES II package, Eurocontrol was appointed as Network Manager in 2011.[13]

Due to the SES II legislation, the European-wide regulatory scheme over the performance of the EU's ANS system started to function. This regulatory scheme, known as the common performance scheme, contains four key performance areas (KPAs): capacity, safety,[14] environment and cost-efficiency. Through the so-called performance plans (PPs), the EC began to execute its regulatory powers over the European ANS system. The EC decided common (pan-European) planning represented by performance plans to be the key regulatory tool to push forward the process of European airspace integration. Performance plans for the respective planning periods (the reference periods (RPs)) are elaborated by member states (or optionally by FABs) and by Eurocontrol as Network Manager before the respective RP starts. Through the performance plans assessed by the Performance Review Body (PRB), [15] which the EC authorises, all regulated incumbencies must contribute to accomplishing Union-wide key performance targets. Implementing a common performance scheme over European incumbencies is a pan-European regulatory intervention to their decision-making (including pricing of the terminal and en-route services, investment levels, etc.)

Addressing structural issues in this context, it is necessary to remark that starting from RP1, air navigation services provided under market conditions in the SES countries could be exempted from the regulatory framework of the common performance scheme. In RP3, such services are not subject to

Table 3.3 Overview of the SES Common Performance Scheme regulations according to three reference periods.

Reference period	*Years*	*Regulations*
RP1	*2012–2014*	Commission Regulation (EU) No 691/2010 of 29 July 2010 laying down a performance scheme for air navigation services and network functions and amending Regulation (EC) No 2096/2005 laying down common requirements for the provision of air navigation services.[a]
RP2	2015–2019	Commission Implementing Regulation (EU) No 390/2013 of 3 May 2013 laying down a performance scheme for air navigation services and network functions.[b]
RP3	2020–2024	Commission Implementing Regulation (EU) 2019/317 of 11 February 2019 laying down *a performance and charging scheme* in the single European sky and repealing Implementing Regulations (EU) No 390/2013 and (EU) No 391/2013.

Notes: [a]Linked to the Commission Regulation (EU) No 1191/2010 of 16 December 2010 amending Regulation (EC) No 1794/2006 laying down a common charging scheme for air navigation services. [b]Linked to the Commission Implementing Regulation (EU) No 391/2013 of 3 May 2013 laying down a common charging scheme for air navigation services.
Source: chapter author, with data from EC (2010, 2013a, 2019)

European-wide common performance scheme (Box 3.1). In this connection, it must be emphasised that the liberalisation legislation in several member countries of the EU was adopted just after 2012. However, there could be further motivations to liberalise the provision of ANS in the countries, as mentioned at the start of this chapter. Nevertheless, the liberalisation of mainly TANS in several member countries of the EU contributed to structural changes in the European ANS industry. Due to structural reforms, there are new ANS providers and more diverse ownership in the European ANS industry.

Box 3.1 Services under market conditions in common performance scheme regulations according to reference periods

RP1 – Article 1 – Subject matter and scope.

4. Where a Member State considers that some or all of its terminal air navigation services are submitted to market conditions, it shall assess in accordance with the procedures laid down in Article 1(6) of Regulation (EC) No 1794/2006, and with the support of the national supervisory authority, no later than 12 months before the start of each reference period, whether the conditions laid down in Annex I of that Regulation are met. Where the Member State finds that these conditions are met, regardless of the number of commercial air transport movements served, it may decide not to set determined costs under that Regulation nor apply binding targets to the cost efficiency of those services.

(Commission Regulation (EU) No 691/2010 of 29 July 2010)

RP2 – Article 23 – Exemptions.

Where, in accordance with the procedures laid down in Article 3 of Implementing Regulation (EU) No 391/2013, it has been established that some or all terminal air navigation services and/or CNS, MET and AIS services of a Member State are subject to market conditions, and the Member State has decided under that Regulation not to calculate determined costs for these services, not to calculate and set terminal charges, and not to apply financial incentives to these services, cost-efficiency targets do not apply to these services.

(Commission Implementing Regulation (EU) No 390/2013)

RP3 – Article 35 – Terminal air navigation services and CNS, MET and AIS services and ATM data services subject to market conditions.

1. Subject to the provisions of this Article, Member States may decide, either before or during a reference period, that the provision

> of some or all of the terminal air navigation services, CNS, MET, AIS services or air traffic management ('ATM') data services provided in their charging zones established in accordance with Article 21 is subject to market conditions.
>
> 2. Where a Member State or Member States decide to apply paragraph 1, for the upcoming reference period or, as the case may be, for the remaining duration of the reference period and in respect of the services concerned they shall not: (a) apply cost-efficiency targets, including the setting of determined costs, for the key performance indicators referred to in point 4.1 of Section 2 of Annex I; (b) apply traffic risk sharing and cost sharing mechanisms in accordance with Articles 27 and 28; (c) set financial incentives in the key performance areas of capacity and environment in accordance with Article 11; (d) calculate terminal charges in accordance with Article 31(2); (e) set terminal unit rates in accordance with Article 29; (f) be subject to the consultation requirements specified in Article 24(3). Points (d) to (f) apply only to terminal air navigation services.
>
> (Commission Implementing Regulation (EU) 2019/317)

The current structural model of the ANS industry within the EU (plus Norway and Iceland) as of 2021 was based on the transnational centralisation of certain operating functions in the delivery of ANS within Eurocontrol, while regulating incumbencies and Eurocontrol as Network Manager by the European Commission through the mechanism of common performance scheme (utilising performance plans as the main regulatory tool). Simultaneously, the liberalisation of some ANS services in the EU member states was supported transnationally through the respective liberalisation articles of the SES II common performance scheme's regulations. The combination of transnationally driven common performance scheme and transnationally supported liberalisation of some ANS was the essence of such a reform approach. However, the decision to liberalise or not to liberalise the provision of (some) ANS was and still is in the competencies of the EU's member states in line with the sovereignty article of the Chicago Convention.

SES 2+ proposed reforms

In the middle of RP1, the Proposal for a Regulation of the European Parliament and the Council on implementing the Single European Sky known as the SES2+ initiative was presented (EC, 2013b). The proposal envisaged splitting the EU member states' incumbencies into separate product successors alongside the edge between core ANS and support ones. According to the proposal, Member States should take all necessary measures to ensure that the provision of air traffic services (ATS) would be (institutionally) separated from the provision of support services (CNS, AIS, MET) and such product splitting of incumbencies into separated undertakings ought to be finalised at the latest by January 2020. The newly established support services providers would compete within the EU on equitable, non-discriminatory, and transparent conditions. In contrast, the entities procuring support ANS would freely choose competing provider(s), considering overall service quality, cost-efficiency and safety.

Moreover, the proposal assumed the privatisation of the providers of support services as *member states* or *the EU's nationals* should own more than 50% of the providers. By the clause of effective control over the ownership of support services providers, the control of member states of the EU nationals would be ensured, enabling the foreign equity investment out of the EU in the delivery of support ANS. As for the Network Manager, the delivery of some support services for the European ATM network could be realised in two manners – in the form of centralised provision by the Network Manager itself or exclusive provision by a selected provider(s). The proposed SES2+ structural reform built upon the product separation (splitting) of incumbencies into separate institutional successors, (assumed) privatisation of support services providers and strengthened centralised functions of the Network Manager was not realised due to the resistance, which was stemming from the wide range of stakeholders, including member states. If realised, such reform based on product unbundling of legacies and incentivised liberalisation would significantly change the ANS industry structure in the EU. The Network Manager would provide centralised network functions and services within the ANS industry in the EU, (potentially privatised) support services providers would compete with the services on a pan-European basis, and national legacies (after cutting-off support services) would be dedicated only to ATS. Moreover, some legacies would face market competition (mainly with TANS) if the respective markets were liberalised in some member states. The SES 2+ package also proposed the full institutional separation of national supervising authorities (NSAs) from ANSPs.[16] The issues of economic regulation, new dimensions of economies of scale and scope connected with this multinational structural reform of the European ANS industry based mainly on the institutional separation of incumbencies according to delineated services (product splitting) were discussed by Tomová (2015).

Table 3.4 Overview of the SES2+ recast 2020 chapters.

Chapter I	General provisions
Chapter II	National supervisory authorities
Chapter III	Service provision
Chapter IV	Network Management
Chapter V	Airspace, interoperability, and technological innovations
Chapter VI	Final provisions

Source: EC (2020)

In September 2020, the EC revived the SES2+ initiative, using the recast technique and published the amended proposal for a regulation on the implementation of the SES (EC, 2020).

From a structural point of view, the SES2+ recast supposes the changes impacting NM, NSAs as subjects co-regulating the system, and incumbencies in the SES countries. In principle, the SES2+ recast 2020 pursues the same goals as the original SES2+ proposal, however, using different realisation paths while exploiting previous experience with European airspace de-fragmentation. The SES2+ recast 2020 intends to introduce more market mechanisms into the provision of (some) ANS to support the cross-border provision of ANS among member states and rebalance some regulatory functions over the SES.

The SES2+ recast classifies ANS as air traffic services (distinguishing between en-route and terminal air traffic services), CNS, AIS, ADS[17] and MET. In the proposal, the provider of ANS is defined as a public or private entity providing one or more ANS for general air traffic. From this definition of ANSP, a more radical structural solution is expected within the economic architecture of European airspace if the proposed changes are carried out. According to the proposal, the providers of ANS will also be required to hold economic certificates (in addition to the certificates required according to the Regulation (EU) No 2018/1139). The economic certificates are intended to serve as the confirmation of sufficient financial robustness and appropriate liability and insurance cover of ANS providers. ANS providers that will be holders of the economic certificates and safety certificates shall be entitled to provide ANS within the EU for airspace users under non-discriminatory conditions.

According to the proposed SES2+ recast 2020, member states would be obliged to take all necessary measures to separate the provision of CNS, AIS, ADS, MET, and terminal ATS from the provision of en-route ATS *in terms of organisation and separation of accounts*.[18] ATS providers will decide whether to procure CNS, AIS, ADS or MET services under market conditions or not. Moreover, airports themselves or airport operators will be allowed to decide on the procurement of terminal ATS if it will be beneficial for them in terms of cost-efficiency for airspace users. If terminal ATS and/or support ANS will be procured on the principles of the market mechanism, the supranational regulation (common performance scheme) will not be applied in such cases. In line with the SES2+ recast 2020 proposal, NSAs will issue economic certificates. They should have additional regulatory competencies in implementing the SES performance and charging scheme. To achieve the objectives and functions, full (also financial) independence of NSAs out of the service providers will be required. Reflecting the experience gained during RP1 and RP2, the SES2 + recast 2020 strictly defines and balances more regulatory functions between supranational and national levels.

As for the Network Manager functions, the SES2+ recast 2020 defines network functions and sets out their objectives, requiring the publishing of financial accounts and undergoing an independent audit of the Network Manager. The proposal assumes separate accountabilities for service provision and regulation where the Network Manager will also have some regulatory powers.

The recast of the original SES 2+ initiative supposes introducing more market mechanisms in the delivery of some ANS services while regulating the rest of the sector supranationally through the mechanism of performance plans. Private ownership of ANS providers (mainly CNS, AIS, ADS, [19] MET and terminal ATS providers) could be expected due to the competition in the form of time-limited tenders in which financially robust and technologically progressive firms may have an advantage. Thus, new entrants in the provision of ANS could emerge, some of them cooperating with the product dedicated successors of the original incumbencies and/or technological companies delivering advanced technologies to the ANS industry. Conceptually taken, the new proposed SES 2+ recast 2020 sticks to main reform lines of the original SES2+ reform (restructuring incumbencies and market mechanism introducing), distinguishing between the regulated and liberalised provision of ANS. The organisation separation of terminal ATS provision connected with the separation of accounts is a new reform element included in the SES2+ 2020 compared to the original SES2+. If realised, the SES2+ recast reform would bring a new pattern of fragmentation in the EU's ANS industry – more according to the sort of provided ANS and less according to the political borders of member states. Also, the restructuring of ownership within the ANS industry in the EU could be expected as a potential long-term output of such reform, bringing new investors (owners) into the industry.

In comparison with the original SES 2+ reform, regulatory issues are proposed more elaborately in the SES2+ recast reform together with some new regulatory tools such as economic certificates of ANS providers governed by NSAs. The SES2+ recast 2020 abandons functional airspace blocks as key structures in integrating the European airspace. Although some benefits of cooperation among ANSPs were delivered by FABs so far, more significant results in the de-fragmentation of European airspace were not achieved, mainly in terms of expected structural changes.

Technological versus structural reforms

Technological reforms of the ANS industries are commonly known through their acronyms, such as SESAR in the EU, NexGen in the US, CARATS in Japan, SIRIUS in Brazil, OneSky in Australia, FIANS in India (GAO, 2015). In the EU, the SESAR reform is closely attached to the gradual implementation of fundamental structural changes; however, there are countries in which the technological progress of the ANS industry is not planned to be linked with any structural reform. In the US, the corporatisation of the air traffic control system out of the FAA was intended, which would be a prerequisite for potential future structural changes in the US ANS industry and ownership.[20] The technological reforms are from a strategic point of view guided by the Global Air Navigation Plan (Doc. 9750) in line with the Global Air Traffic Management Operational Concept (Doc. 9882) of ICAO.

While the need to reform the ANS industries structurally may be (among others) motivated by the necessity to fund advanced technologies, ANS technologies themselves act as technological enablers of structural reforms. For instance, remote (virtual) towers are currently being implemented to deliver air traffic services for flight operations at some European airports (Efthymiou, 2020). As location-independent solutions, they are among technological solutions which spur structural reforms in the ANS industries in Europe. Promoting the provision of airport air traffic control services on a cross-border basis, the remote tower concept is thus very important in the geographical de-fragmentation of European airspace aiming at a single sky goal. Remote tower concept in the delivery of airport air traffic services may also be an attractive cost-efficient option for individual countries compared to location-dependent models in the delivery of such services. The requirement on cost-efficiency over the regulated part of the ANS system may strengthen the trend. The implementation of the concept may be realised as a part of third-party access liberalisation or without it.

The proposal for the future architecture of the European airspace (SESAR Joint Undertaking, 2019) set that by 2035 the next generation of SESAR technologies should be implemented continuously in three phases, thus changing the current architecture to a new one which is labelled as the Single European Airspace System (SEAS).[21] Among the new technologies, the new ATM data service provision model[22] is projected as a part of the SEAS, which shows how regulatory and structural issues designed in the SES2+ 2020 proposal interact with the technological essence of Single European Sky reform. Among reform dimensions of the SES, a green one acquires more political attention in the present to convert the SES to Green Single European Sky (EASA & Eurocontrol, 2021).

Discussion

Structural reforms applied in the ANS industries belong to the most challenging infrastructure reforms. In principle, there are nationally or supranationally driven structural reforms. However, both nationally driven structural reform and supranationally driven reform may be activated together, which is just the case of the SES reform. Supranationally driven structural reforms of ANS industries within international integration groupings aimed at single sky goal cope with a wider range of problems compared to only nationally driven structural reforms. The currently realised Single European Sky reform is a unique historical experience in this regard. Motyka and Njoya (2020) evaluated the SES reform development. Gradually realised, the SES is a robust systemic change that underwent multiply twists, internal evolution, and corrections. The contribution to the process of de-fragmentation of European airspace by the SES reform is still questionable as the European ATM system is still lagging behind the US ATM system in operating efficiency and economic effectiveness (Eurocontrol & FAA, 2019). This pushes the further progress of the SES reform towards a more radical change as expressed in the SES2+ 2020 structural and regulatory vision. In general, there is still a lack of research methodologies that would assess the benefits delivered by reform changes and the costs of such reforms. Among the costs, the costs of economic regulation in a newly re-structured ANS industry appear the most relevant in this regard, but also the cost of adaptation to a new system on all levels of impacted stakeholders, and transaction costs occurred in the new system as well. On the benefit side of the problem, the competitiveness of newly re-structured ANS industries in global airspace should be considered together with the impacts on emerging global commercial business with air navigation services (Tomová, 2017). In this connection, economic research ought to reflect the research of different categories of air navigation services in the light of new structural models more carefully, investigating mainly economies of scale, economies of scope, and safety issues.

If realised, the SES2+ recast 2020 proposed reform will bring another fragmentation pattern within the EU's ANS industry. Subsequently, economies of scale, economies of scope and/or further factors may actuate consolidation processes in the ANS industry on a cross-border basis. Such consolidation, resulting in a less fragmented ANS system should also lead to a more efficient delivery of ANS to airspace users, and just this will be among the most discussed questions of the SES 2+ 2020 proposed reform (together with safety and security issues). Similarly, who and what would be the consolidated providers of ANS in the European ANS system in the EU ought to be carefully supervised and regulated. Just the issues of supervision and economic regulation of the European ANS system in terms of quality in connections with undergoing structural changes on more than national pattern will be among the decisive factors for the success of the SES structural reform.

Due to the changes and in comparison with the historical structure of ANS industries in countries, the future worldwide supply of ANS services to airspace users will be driven by structural and/or technological reforms implemented in countries or international groupings of countries. This will be changing the traditional provision of air navigation services towards the business-like provision. Such business will tend to transcend the geographical borders of countries and the participation of private capital in this business will inevitably impact the further structural architecture of ANS industries worldwide.

Conclusions

Structural and technological changes in the ANS industries together with expanding global commercial business with air navigation services may transform global airspace as an economic space in the long-term to a new structure with more market players, also new kinds of market players in terms of ownership, product portfolio, the way of starting a business, principal place of business, forms of cooperation etc. Being changed significantly due to realised structural reforms, the sustainability and effectiveness of the reformed ANS industries will highly depend on the country's and/or integration grouping of countries' regulatory framework over the respective ANS systems. The pressure of this new global economic architecture of airspace due to realised structural reforms on the current Chicago Convention's global regulatory framework as of 1944 cannot be excluded in the distant future.

Discussion questions

1 What indicators and/or data could be useful to monitor the process of ANS liberalisation in countries and/or integration groupings?
2 What are the goals of international integration groupings (ASEAN and others) in airspace integration? Which reform levers are prepared to be applied if structural reforms are intended? Which pillars of integration could be preferred – multinational or supranational ones?
3 Which postulates of economic theory may be used when discussing pro/cons arguments in the context of structural reform in ANS industries?
4 If – hypothetically – there would be no airspace sovereignty article in the Chicago Convention, how would this impact the global ANS industry? Are there any alternatives driven by modern ANS technologies? What could be the role of integration groupings of countries in this regard?
5 How do safety and security issues relate to the realisation of structural reforms in the light of the One Sky concept of ICAO?

Notes

1 According to Eurocontrol (2020) ACE Benchmarking Report, which covered 38 European ANSPs in 2018, 4 ANSPs were limited liability companies, 16 state enterprises and 12 joint stock companies. As an example of traditional ANSP, Japan Air Navigation Service which is a branch of Japan Civil Aviation Bureau may be mentioned.
2 In 1981, air traffic controllers in the US went on nationwide strike. In 1982, the Contract Tower Program was established, and the operation of certain towers was contracted out to private providers (FAA, 2021). The strikes of European air traffic controllers and their impacts on European aviation are analyzed in Study on Options to Improve ATM Service Continuity in the Event on Strikes (Ricardo Energy & Environment, 2017).
3 IATA (2013) estimated that ANSPs between 2004 and 2011 years had earned on average return on invested capital 9%. The reasoning of the fact lied in regulated cost-recovery funding principle irrespective of the ANSPs' funding (eventually charging) model.
4 Lee (2018, p. 11) notes: 'the creation of Seamless ASEAN Sky by way of the integrated management of airspace will be beneficial to ASEAN aviation'; he also emphasises: 'As aviation traffic will continue to increase in ASEAN, ASEAN must enhance the efficiency and capacity of air traffic management. A common

air navigation organization like Eurocontrol, is not the only option for developing Seamless ASEAN Sky.'

5 More than 70% of German incumbency DFS was planned to be privatised, due to the veto of German president the intended privatisation was not realised.

6 'Foreign providers looking to enter the Swiss market include Austria's Austro Control, Germany's DFS Aviation Services, and Sweden's Aviation Capacity Resources. Norway's Avinor Air Navigation company is also rumoured to be in the running' (SWI, 2019).

7 Ferrovial Servicios SA is a transportation infrastructure management company in Spain.

8 DFS Aviation Solution GmbH is a daughter company of DFS; NATS (Services) Limited (NSL) is a part of NATS Holding.

9 In 2012, Birmingham airport moved to self-supply by Birmingham Airport Air Traffic Ltd wholly owned by Birmingham Airport (UK CAA, 2018).

10 In Europe, DFS was corporatised as the first one in 1993.

11 Completed in 1997.

12 As a part of European ANS system, Eurocontrol has several operating and support functions. Founded at the beginning of sixties in the last century, Eurocontrol represents an intergovernmental component in the European ANS system.

13 Eurocontrol performs several functions of pan-European scale, also the function of Network Manager; through its operating unit Network Manager Operations Centre (NMOC) it runs three major operational services: air traffic flow and capacity management, flight planning services, airspace data management; NMOC evolved from the Central Flow Management Unit, which began tactical operation in 1995 (Eurocontrol, 2019).

14 In KPA safety, EASA (European Union Aviation Safety Agency) plays a role in the mechanism of common performance scheme.

15 In reference period 1, Eurocontrol had performed the functions of Performance Review Body for European Commission, then the functions were transferred to an independent body composed of the group of experts.

16 So far, in some countries only functional separation was carried out, separating NSAs from ANSPs in functional regard (i.e. in terms of organisation, decision-making and hierarchy in the EU). According to ACE ATM Benchmarking Report of Eurocontrol (2021), DCAC in Cyprus, HCCA in Greece are examples of such functional separation.

17 Air traffic data services (ADS) are services consisting in the collection, aggregation, and integration of operational data from providers of surveillance service, from providers of MET and AIS and network functions and from other relevant entities, or the provision of processed data for ATC and ATM purposes.

18 Several incumbent European ANSPs such as German DFS has already undergone such restructuring as it was investigated by Materna et al. (2020).

19 A proposal for the future architecture of the European aispace (SESAR Joint Undertaking, 2019) states that ADS providers (ADSPs) could operate in miscellaneous forms, joint ventures of existing ANSPs or as a certified external entity.

20 'Privatizing the air traffic control system is a risky and unnecessary step at this pivotal point in modernization of the US aviation system. True progress is being made in development and implementation of critical technology and systems through the initiatives and projects associated with the Next Generation Air Transportation System (NextGen). Breaking apart the system at this point would reset the clock on progress and threaten this country's status in the aviation community' (PASS, 2017).

21 The analogy in the US is the National Airspace System.

22 The certification of the first ADSP is expected by 2025.

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4 Air traffic control officer recruitment and training

Gary McIlroy and Marina Efthymiou

Introduction: the global standards for ATCO licencing

Aviation is regarded as the safest form of travel with every corner of the globe accessible by an aircraft. It has taken decades of commitment and desire for continuous improvement to bring the aviation industry to where it is today, allowing the management of millions of flights per year in a safe manner. Thousands of air traffic controller officers (ATCOs) are employed worldwide, all of whom have a common objective: providing safe air traffic control services.

Due to the nature of the aviation system and how that system must be robust when coping with the volume and complexity of aviation traffic worldwide, all concerned states must consistently apply the regulatory requirements. Doing so enhances standardisation and reduces the scope for differences and associated margins of error within the entire system.

ICAO aims to provide SARPs through 19 Annexes that govern the aviation industry's various elements across all 193 member states. The regulations providing the foundation for the recruitment, training and certification of air traffic controllers is contained within ICAO Annex 1 – Personnel Licencing.

Section 4.1.1 and 4.1.2 outline the requirements for those who are not flight crew in the areas of 'age, knowledge, experience and where appropriate, medical fitness and skill, as are specified for that licence or rating' (ICAO, 2020a, p. 97) This applies to air traffic controllers and identifies that the State determines the demonstration of knowledge and skill. These standards provide the specific areas for which a contracting state must operate under and address when training and certifying an ATCO.

Section 4.3 addresses the management of student air traffic controllers but keeps the process to be followed open for contracting states to determine. It states: 'Contracting States shall take the appropriate measures to ensure that student air traffic controllers do not constitute a hazard to air navigation' (ICAO, 2020a, p. 102). It also ensures that student air traffic controllers cannot receive instruction in the operational environment unless they hold a Class 3 medical assessment. This is the key piece of regulation that transfers the responsibility for accepting student ATCOs into the aviation system and setting the minimum standard for their acceptance to each State.

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The basic requirements for licencing and the awarding of ratings cover the areas of:

- **Minimum age**. ICAO requires the minimum age of an applicant for an air traffic controller licence to be 21 years of age. EASA, however, filed a difference to that requirement by prescribing a minimum age of 18 years for a student air traffic controller licence. This allows for the interim time period to cover the training as a student and maximises an ATCOs career by certifying them as operational as soon as legally possible.
- **Knowledge**. Consisting of knowledge of air law, air traffic control equipment, general knowledge, human performance, meteorology, navigation and operational experience.
- **Experience**. Based on receiving a minimum amount of instruction from an on-job-training instructor (OJTI) in the live operational environment and satisfactorily passing all assessments.
- **Medical fitness**. A Class 3 medical assessment is required for an air traffic control licence.
- **English language proficiency**. As English is the recognised global language for aviation, all ATCOs must have a defined minimum command of the English language to conduct their duties safely. This enhances the standardisation process worldwide by ensuring the main language for communication with pilots and ATCOs is English.

The main requirements for air traffic controller ratings are in the areas of:

- Knowledge of various topics that are either generic or specific to a particular rating.
- Appropriate skill level demonstrated to ensure a safe, orderly, and expeditious service can be provided.
- Experience gained from having successfully completed a minimum number of hours or approaches depending on the rating and as specified in the Unit Training Plan developed upon the requirements.

Chapter 6.5 of Annex 1 outlines the requirements for the issuance of a Class 3 medical assessment to ATCOs and encompasses the following areas:

- Physical and mental requirements;
- Visual requirements; and
- Hearing requirements.

Appendix 1 to Annex 1 outlines the requirements for proficiency in languages used for radiotelephony communication as outlined in section 1.2.9. The requirements apply to all aviation staff and are not specific to ATCOs only. Each state will determine when to use the local language for coordination purposes with other air traffic control units, but English will remain in use for interactions with flight crew. For ATCOs, the requirement is contained within Annex 11 – Air Traffic Services section 2.31 (ICAO, 2018, p. 51) whereby it states:

> 2.31.1 An air traffic services provider shall ensure that air traffic controllers speak and understand the language(s) used for radiotelephony communications as specified in Annex 1.
>
> 2.31.2 Except when communications between air traffic control units are conducted in a mutually agreed language, the English language shall be used for such communications. Appendix 1 describes the holistic descriptors which determine what qualifies as a proficient English language speaker.

As set by ICAO in Annex 1, these requirements are binding for the 193 member states. This ensures a minimum standard across the world of aviation English and allows for a mutual understanding of instructions, clearances, and interactions between ATCOs and flight crew. In general, native English speakers are exempt from this requirement; however, for EU states, since the publication of EU 2015/340, the requirement was introduced for native English speakers to also conduct an assessment with a maximum period before reassessment being reduced from no requirement to a maximum of nine years.

Air traffic controllers and pilots must meet a minimum standard of operational English to exercise the privileges of their licences. Air traffic controllers should also have a command of the language used in the country where the service is provided. By agreement, the local language may be primarily used when coordinating with colleagues at other units within the same state. There are six levels of proficiency, where the minimum level required to keep a licence valid is level four which indicates an operational level of English. Level four air traffic controllers must be evaluated every three years. Level five, also known as 'Extended Level', must be evaluated every six years. Finally, Level six is classified as 'Expert' level. While ICAO Annex 1 (2020) states, 'Formal evaluation is not required for applicants who demonstrate expert language proficiency, e.g. native and very proficient non-native speakers with a dialect or accent intelligible to the international aeronautical community', for European air traffic controllers, EU 2015/340 states, '(3) for expert level (level six): (i) nine years from the date of assessment, for the English language'.

Both documents are quite specific in the requirements to be met to be classified under any level. While level 4 is the stated minimum requirement for operational use, some air navigation service providers (ANSPs) may specify a higher level due to the complexities of their operation considering the volume of traffic, the airlines' geographical spread subject to air traffic control and the quality of English from those pilots where English is not their native language.

While ICAO Annex 1 and Annex 11 are the overarching standards for the licencing and procedures for ATCOs, PANS – ATM Doc 4444 is then utilised for providing in more detail the procedures to be used for licenced ATCOs to provide a service in the operational environment. It forms the basis for the theory during training and for live operations by ATCOs when providing a service worldwide. It comprises the various elements of Annex 2 – Rules of the Air and Annex 11 – Air Traffic Services.

Much of Doc 4444 for European states has been transposed into EU Law via EU 923/2012 SERA (Standard European Rules of the Air) and EU 2017/373 Air Traffic Management/Air Navigation Services Common Requirements. Doc 4444 (2016) specifies in section 2.5.1 that safety reviews must be conducted on ATS units at regular intervals, and one of the areas of focus is on licencing and training issues. This is conducted to ensure the following (ICAO, 2016, p. 44):

a) Controllers are adequately trained and properly licensed with valid ratings;
b) Controller competency is maintained by adequate and appropriate refresher training, including the handling of aircraft emergencies and operations under conditions with failed and degraded facilities and systems;
c) Controllers, where the ATC unit/control sector is staffed by teams, are provided relevant and adequate training in order to ensure efficient teamwork;
d) The implementation of new or amended procedures, and new or updated communications, surveillance and other safety significant systems and equipment is preceded by appropriate training and instruction;
e) Controller competency in the English language is satisfactory in relation to providing ATS to international air traffic; and
f) Standard phraseology is used.

As prescribed by Doc 4444, this mechanism allows for the continued monitoring and improvement of the ATC element of the overall aviation management system.

For the European States, ICAO Annex 1 has been largely transposed into European Law via regulation EU 2015/340. Most of the principles of Annex 1 are included with additional content inserted by EASA to outline AMC and GM for each of the regulations. While the regulation itself is classed as hard law, the AMC and GM are classed as soft law, meaning it is a recommendation rather than a requirement.

The terminology described is common to most ICAO states, but some states do have some differences. For example, in the United States and under the FAA, the various ratings and endorsements differ greatly. The FAA basics course is like ab-initio training as generic training delivered to all students. Initial Tower Cab is like the training delivered to become an aerodrome controller (ground movements control and air movements control). Finally, the terminal basics radar is like an approach radar training course. This training is broken down into three levels which increases in complexity and assist in determining the type of terminal area the student will be capable of working in, from complex to non-complex.

ICAO Doc 9868 PANS training was initially introduced to provide the competencies-based approach to training for pilots. In 2015 this was further expanded when the development of competency-based frameworks and assessment practices for ATCOs occurred. This document complements the ICAO SARPs and contains the actual procedures to follow when training organisations to train industry-specific personnel. As specified in chapter 2.1.1 in the document:

> The goal of competency-based training and assessment is to provide a competent workforce for the provision of a safe and efficient air transportation system. To focus training and assessment on how an aviation professional is expected to perform on the job competently, a description of this performance in the particular operational and environmental context is needed. The adapted competency model, with its associated performance criteria, provides a means of assessing whether trainees achieve the desired performance.
>
> (ICAO, 2020b, p. 33)

As summarised in Figure 4.1, the recommended format is to first outline the training specification for the required role (i.e. exactly what the service provider is looking for within a specific role). This process takes the various inputs of the training request, task list, operational documents, technical documents, regulatory documents, and organisational documents as terms of reference and identifies the requirements associated with each.

That specification is then adapted along with the ICAO competency framework into a competency model for that role by selecting the necessary competencies and observable behaviours required and to what level the individual should perform those skills through the implementation of performance criteria.

Once that competency model has been established, then two plans are created. A training plan details the structure of the course, the syllabus, the milestones, the modules, training events and their delivery sequence and the

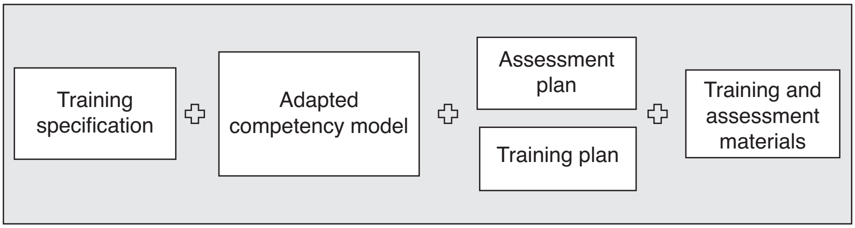

Figure 4.1 Competency-based training and assessment components.
Source: ICAO (2020b).

course schedule. The training plan forms the main reference guide for training delivery to ensure the correct information is delivered in the correct sequence. The training plan is an assessment plan that outlines the standards expected and the parameters for each assessment, such as the grade required, the tools to be used and the time allowable.

The assessment plan should also include various mechanisms such as appeals procedures or the processes to be followed in an unsuccessful assessment. This is critical as it ensures a robust process and does not leave it open to differences in interpretation and appeal. These materials are then submitted to the competent authority or regulator of the state for review and approval. The competent authority reviews the content and compliance with the ICAO standards before approving or rejecting the submission.

Once approved, the training and assessment materials must be created for delivery to the individuals. This process takes the adapted competency model, assessment, and training plan and develops training materials, examinations, and assessments.

This results in the course schedule, training event materials such as notes, case studies, exercise briefings, presentations, video clips, training airspace and exercises, examinations, practical assessments, and other assessments. Instructors assist in its creation as it proves to be a useful mechanism for restorative procedures before delivering the content to the students.

There are several benefits and challenges to the competency-based training and assessment system. The benefit allows for increased potential from the candidate as it divides the qualities between theory-based knowledge and skill-based knowledge. Both types are very different as a student may excel at academia and can absorb large volumes of information but may struggle to put that knowledge to use by displaying the skills required to perform the role. Likewise, the system allows for a student who may not have the same capacity for absorbing information but understands how the role works and can display the skills appropriately. Using the competency-based training and assessment system allows a wider range of students to perform adequately across both areas. It further guarantees for the ANSP that the minimum quality required for the role is being achieved.

By conducting the course as intended, competent trainees should be the output. Once training is complete, for continuous improvement and quality management purposes, the ANSP needs to evaluate the course and the training. This involves the analysis of the course results, trainee feedback, instructor and assessor feedback and any audit reports that may have been generated. These will determine improvement areas and generate a comprehensive course report for the training organisation and ANSP. In some circumstances, the ANSP may be acting as a customer of the training organisation.

The competency-based training and assessment system carries its challenges, particularly with the constant evolution of roles within the aviation industry resulting from increased automation and new technologies, leading to different operating methods. This results in the competencies being adjusted and the requirements to be met being altered. However, through constant review and updating of the various training plans, the system can address many challenges. ICAO Doc 9868 Attachment A to Chapter 2 outlines some challenges to competency-based training, mainly based on ensuring the right competencies have been identified and the proper delivery of KSAs to perform effectively.

For ATCOs to meet the defined performance criteria under the competency-based framework, they need to display the appropriate levels of knowledge, skills and attitudes as defined in ICAO PANS-Training Attachment B to Chapter 2 section 2.2, section 3.1 and section 4 respectively and outlined below. Knowledge is defined as 'an outcome of the learning process, whether learning occurs in formal or informal settings' (ICAO, 2020b, p. 41). A skill is defined as 'an ability to perform an activity or action. It is often divided into three types: motor, cognitive and metacognitive skills' (ICAO, 2020b, p. 41). Finally, attitude is defined as 'a persistent internal mental state or disposition that influences an individual's choice of personal action toward some object, person or event and that can be learned' (ICAO, 2020b, p. 41). Only when an acceptable level of all three of these qualities is displayed can a student ATCO be assessed and certified as competent to perform the role in the operational environment without supervision.

PANS – Training Doc 9868 also outlines the processes for the training of OJTIs. These are qualified air traffic controllers who, following a predefined number of years of gaining experience within the role, can then receive training to become OJTIs. This is a nuanced area as they provide instruction within the classroom environment to student ATCOs and utilise their own ATCO licence to provide instruction to student ATCOs in the live operational traffic. This allows the students to display their knowledge, skills, and attitudes in the live environment and allows for the most accurate assessments of the student's capabilities when performing the role. Pans – Training Doc 9868 Part IV Chapter 3 provides the framework for OJTIs to be trained using the competency-based framework. Those competencies include:

- Situational awareness;
- Safety and efficiency management;
- Mentoring;
- Teaching, instructing and coaching;
- Communication;
- Assessment;
- Collaboration;
- Self-assessment; and
- Ethics and integrity.

Successful completion of the OJTI training and assessment programme entitles the ATCO licence holder to an additional endorsement on that licence which permits them to provide OJT in the live operational environment.

These standards and procedures provide the framework that permits the various states affiliated with ICAO to develop and deliver air traffic control training within their State, thus contributing to the safety and integrity of the overall aviation management system. The next section analyses in further depth the various ratings and endorsements a student ATCO can achieve and their pathway from recruitment until receiving the new ATCO licence.

An ATCO licence contains several elements. The main elements are ratings and endorsements. Ratings are the specific type of air traffic control to be provided. Air traffic controller ratings consist of the following:

- Aerodrome Control Visual (ADV).
- Aerodrome Control Instrument (ADI).
- Approach Control Procedural (APP).
- Approach Control Surveillance (APS).
- Area Control Procedural (ACP).
- Area Control Surveillance (ACS).

The word surveillance indicates the use of a surveillance radar system, and the word instrument indicates that the aerodrome controller can use a surveillance monitor to assist with their duties.

The following rating endorsements then supplement the ratings mentioned above:

- Air Control (AIR).
- Ground Movement Control (GMC).
- Tower Control (TWR).
- Ground Movement Surveillance (GMS).
- Aerodrome Radar Control (RAD).
- Precision Approach Radar (PAR).
- Surveillance Radar Approach (SRA).
- Terminal Control (TCL).
- Oceanic Control (OCN).

Multiples of these endorsements can supplement any one of the ratings specified above. Finally, a unit endorsement is required to be included on the licence. This outlines where the air traffic controller can provide the service and will include for radar controllers multiple sectors or for an aerodrome controller, the specific aerodrome the service will be provided. These ratings and endorsements determine the training a student receives and depend on where the student is destined to operate within the ANSPs organisational structure.

The ATCO categories

Wickens et al. stated:

> The typical controller is able to address the sometimes-conflicting pressures for safety and efficiency in two ways: (1) by adhering to a

> well-developed and extensive set of FAA procedures that have evolved over the years and (2) by being able to augment them with skilled problem solving on the infrequent occasions when following procedures fail to specify the appropriate actions.
>
> (Wickens et al., 1997, p. 23)

It indicates that an air traffic controller must have the aptitude to process an abundance of information about the environment they are controlling and compare that information against published procedures to make informed decisions about the next course of action. But in the absence of a procedure for a particular circumstance, the air traffic controller relies upon their knowledge, skills, and attitude to make their personal decision towards a safe course of action to resolve an issue.

An air traffic controller can operate in any one of several capacities which cover the various phases of a typical flight. A Tower controller comprising a ground movements controller and an air movements controller are the first and last ATCOs a typical flight will be speaking to. There could be multiples of these operations at an airport at any one time depending on the airport's configuration, such as single runway operations or parallel runway operations. The ground movements controller is responsible for the safe movement of the aircraft pre-flight, from the moment it is ready to push back from the gate through to taxiing safely around the taxiways at the airport to the holding point of the runway in use. They also manage vehicles that have been authorised to operate around the taxiways and runways and ensure no risk of collision between aircraft and vehicles. The aircraft is handed over to the air movements controller at the holding point for the runway in use. The air movements controller manages the runway in use and ensures that arrivals and departures to that runway occur safely while also maximising the use of the runway depending on demand and how busy the airport is. The air movements controller is also responsible for the airspace around the vicinity of the aerodrome. This allows the ATCO to control other aircraft flying in close proximity to the airport, known as general air traffic (GAT). Suppose the airport is configured for parallel runway operations.

In that case, there may be a second air movements controller working close to their colleague, whereby one runway is used for arrivals in some circumstances, and the other runway is used for departures. Again, these configurations can vary depending on traffic demand. Suppose an aircraft executes a missed approach or 'go around'. In that case, communication and separation from any essential traffic become the priority for these controllers to ensure the manoeuvre is safe and does not interfere with any other traffic in the vicinity of the aerodrome. Once the departing aircraft has reached a certain point on its climb out, it will transfer over to the first radar controller, commonly known as the departure controller for busier airports. They ensure the aircraft clears the busy aerodrome environment before transferring it onto the area radar controller, who controls the aircraft up to its cruising altitude.

Depending on the airspace layout, the aircraft may still climb to its cruising altitude before it leaves the airspace sector concerned.

The aircraft will then be transferred to the area controllers counterpart in the next sector that will continue to provide the service in their sector of responsibility. With the assistance of their colleagues in different sectors and countries, the aircraft safely navigates towards its destination, where it will then begin its descent for its arrival. The area radar controller will then transfer the aircraft for the arriving sector to the approach controller, who sequences the aircraft with the other arrivals. Once the aircraft is established on its instrument approach for the arriving aerodrome, it will be transferred to the air movements controller, who will clear the aircraft to land when the runway is clear. When the aircraft vacates the runway, it will be transferred to the ground movements controller, who will provide route instructions to the parking stand. Each commercial flight worldwide will undergo the same or a similar process and engage with multiple air traffic controllers, either as tower controllers or radar controllers.

A successful candidate receives basic air traffic controller training or ab-initio training at a high level. This is training common to all air traffic controllers, irrespective of which area they eventually end up providing a service in. It covers eleven modules with an exam for each with a pass mark of 75% required to complete the training. Once this training is completed, they will commence rating training, generally for either aerodrome control or radar control. One of the ratings is supplemented by at least one endorsement. This training will contain a mixture of theoretical and simulation training, with multiple exams and checks. From here, the controller will be awarded a student air traffic controller licence. This allows the student to exercise their knowledge in the live environment under the supervision of an OJTI.

ATCO Training

ATCOs receive a combination of formal classroom instruction and on the job training. But a candidate must possess certain qualities to be successful in the various phases of training. These qualities are identified at the screening stage through interviews and aptitude testing with current emphasis on a 'train for success' philosophy, designed to reduce training programme attrition as identified by Wickens et al. (1997).

For training delivery, it is not up to the ANSP to decide what should and should not be included. ICAO Annex 1 – Personnel Licencing provides an overview of what subjects must be delivered when training air traffic controllers for each rating and endorsement. These are also reflected for European ANSPs but in more detail in EU Regulation 2015/340 'Rules for Air Traffic Controller Licencing and Certification'. It also specifies the requirements for instructors, assessors, training organisations, competence schemes and medical certificate requirements. While it is based on ICAO Annex 1, EU 2015/340 has developed these regulations significantly. For the delivery of Initial Training, for example, EU 2015/340 AMC1 ATCO.D.010(a)(1) outlines the various subject objectives and training objectives for each subject which includes:

1 Introduction to the Course.
2 Aviation Law.
3 Air Traffic Management.
4 Meteorology.
5 Navigation.
6 Aircraft.
7 Human Factors.
8 Equipment and Systems.
9 Professional Environment.
10 Abnormal Situations.
11 Aerodromes.

Subjects 1–9 are generic across all ratings, while subjects 10 and 11 are specific to Unit Training.

Much of the content of air traffic controller training is contained across the 19 ICAO Annexes or, more specifically, in EU Regulations, where training objectives and AMCs are included. This ensures a minimum level of knowledge is possessed by air traffic controllers worldwide. That knowledge is consistent whether a pilot receives instructions from an air traffic controller in the United States, Europe or New Zealand. In support of the ICAO Annexes are ICAO Docs which provide further details to the standard contained in the Annex. For example, Doc 4444 contains the procedures relative to air traffic management and is the global bible for air traffic controllers worldwide. In Europe, the European Commission, through EASA, has outlined the procedures through regulation and categorised them differently. For example, ICAO Annex 11 – Rules of the Air is captured under EU 923/2012 SERA (Standardised European Rules of the Air). Much of the content is the same, and EASA does attempt to comply as much as possible with the ICAO standards. The European regulations are more comprehensive in their provision of soft law AMCs and GM, which complement the regulations. This ensures a harmonised approach by all member states towards adopting the regulations.

Selected examples of ANSP recruitment and training practices

We compared the practices for recruitment and training of 8 ANSPs worldwide. More specifically, we looked at Federal Aviation Administration (FAA), Nav Canada, Irish Aviation Authority (later renamed to AirNav Ireland), PANSA (Poland), ATNS (South Africa), GCAA (UAE), Aerothai (Thailand)

and Airways New Zealand. We focused on the minimum and maximum age, medical requirements, security checks required, education requirements, citizenship, English language proficiency, aptitude testing, training costs, and duration. From the sampling of ANSPs regarding the recruitment policies, the analysis produced some interesting observations. Table 4.1 below provides a high-level overview of the main areas considered in the training and recruitment of ATCOs by various ANSPs.

Minimum and maximum age requirements

The ICAO minimum age requirement is 21 years for the issue of an ATCO licence. This requirement does not prohibit an ANSP from hiring at a younger age to provide training leading to the 21st birthday and the application of an ATCO licence. This is the approach that most ANSPs have followed. EASA specifies a minimum age of 18 years, focusing more on education and aptitude testing for a better recruitment policy. However, the two European states sampled at IAA and PANSA have opted for a minimum age of 19 years, considering their estimated 24-month training programme. GCAA has followed the European model in applying the minimum age profile. This allows for two years of training and maximises the ATCOs' availability to be ready for operations as close to the 21st birthday as possible. The FAA, Nav Canada and ATNS have specified 18 years as minimum age while surprisingly Airways New Zealand specified 20.5 years.

Interestingly the FAA, ATNS and GCAA specified an upper age limit of 30, 33 and 35 years respectively for recruiting new ATCOs. An increase to 36 years of age is possible for the FAA to concern a rated controller with 52 weeks of experience. When queried with the IAA about a maximum age limit, they stated that it is impossible to introduce a maximum age within the EU as it breaches equality legislation for equal opportunities. PANSA also confirmed this. For Aerothai, as training leads to awarding a third level degree, the minimum age of 21 is applied. However, the training is delivered before that age, as upon graduation, all candidates will naturally exceed the minimum age requirement. Aerothai also has a maximum age requirement of 27 years.

Medical requirement

A class 3 medical assessment is required by ICAO and is largely included within the recruitment campaigns for each of the ANSPs. However, some differences in terminology are used. The FAA filed a difference to ICAO regulations within their AIP section Gen 1.7, requiring an 'FAA Second Class medical'. Airways New Zealand specified 'to pass a medical test'. Still, as it is an ICAO requirement for a Class 3 medical assessment and no differences were filed, it can be assumed that this is the standard of medical examination used.

Table 4.1 Comparative analysis matrix of sample ANSPs.

	FAA	*Nav Canada*	*IAA*	*PANSA*	*ATNS*	*GCAA*	*Aerothai*	*Airways New Zealand*
Minimum age	18	18	19	19	18	19	21	20.5
Maximum age	30	Nil	Nil	Nil	33	25	27	Not Stated
Medical	FAA second Class medical	Class 3	Class 3	Class 3	Class 3	Class 3	Class 3	Class 3
Security check	Yes	Yes	Yes	Yes	Yes	Yes	Not stated	Yes
Education	Third level	Secondary level	Secondary level	Secondary level	Secondary level	Secondary level	Third level	Secondary level
Citizenship	Yes	Yes + permanent resident	No	No	Yes	Yes + foreign direct entries	Yes	Yes + permanent resident
Training costs	Not stated	Yes	Yes	Yes	Yes	Yes	Yes	Not Stated
Aptitude tests	Online + written	Online + group + interview	Online + group + interview	Online + interview	Written + interview	Not stated	Yes	Online + group + interview
Allowance	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Not stated
Accommodation	Yes	Not stated	No	Yes	Yes	Yes	Yes	Not stated
ELP	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Not stated
Duration	60 months	10–27 months	24 months	20–22 months	30 months	36–60 months	48 months	12 months

Security check

While ICAO and EASA do not specify the requirements for candidates to undertake a security check, this is required under national law and is captured under each ANSPs security and human resources policy. Since the various high-profile security attacks on aviation and counter-terrorism efforts, background checks (including cyber security checks) are performed on all candidates. Except for Aerothai, all sampled providers specify the requirements to clear a security check successfully. Nav Canada includes drug screening (including cannabis) as part of the check.

PANSA specifies that candidates enjoy full public/civil rights. Still, security checks may be performed randomly by requiring the candidate to deliver an actual document confirming that they are not figuring in their National Criminal Register. Also, during the licencing process, the candidate must sign a form that declares that they have not been sentenced for a deliberate offence, have the capacity for legal acts, and were never convicted of motoring offences.

ATNS specify that the security check process is to verify qualification, identity, and criminal record. For recruitment with the GCAA, the security check is to verify completion of the military service training. This is a different scenario versus recruiting direct entry controllers from abroad.

Education requirements

ICAO and EASA do not specify specific education requirements, with each State determining their requirements to perform the role. It coincides with the different approaches to training and assessment, with the more common form now being the Competency-Based Framework per Pans Training Doc 9868.

The FAA has one of the most interesting education requirements. The FAA (2020) specifies, 'Have three years of progressively responsible work experience, or a Bachelor's degree, or a combination of post-secondary education and work experience that totals three years.' There is a third level education pathway through the FAA accreditation programme to allow a candidate to be considered for a training programme. Education requirements are an interesting area for analysis as they are set by the State and differ greatly from one State to another. A third level qualification is required in countries like the United States and Thailand. It is catered for specifically in aviation colleges with a bachelor of science degree related to Air Traffic Management. This shows an incredibly long pathway towards an ANSP gaining new operational staff.

The most common form of recruitment into the FAA is directly from the military pool of ATCOs, which guarantees the experience and takes advantage of the military training system to ensure an acceptable level of competence. The Air Traffic Collegiate Initiative (AT-CTI) programme, implemented in 1989, supplements the FAA's hiring pool. The AT-CTI programme objectives are the following (Ruiz & Ruiz, 2003):

- Test the concept that non-federal, post-secondary educational institutions can develop, deliver, and implement air traffic control recruiting, selection, and training programmes.
- Attract females and minorities to careers in air traffic control.
- Develop a more educated work force in the FAA.
- Use collegiate aviation as one of the primary means of meeting the future needs of the FAA for air traffic control specialists (ATCS).

The AT-CTI programme is conducted across 14 educational facilities across the United States. The FAA does not fund it, so students must pay for their education. As Ruiz (2007) suggests, the FAA's endorsement of the AT-CTI programme increases the programme's credibility, legitimacy, and popularity among potential applicants. Nevertheless, there is still no guarantee that the knowledge and skills of a student graduating through the AT-CTI programme will transfer over effectively to the FAA training academy and the operational air traffic environment. It also takes four years before FAA has an investment return from this endorsed programme and then a steady flow of students annually after that. The length of the process could result in a decline in the number of potential candidates interested in following this pathway.

Another point of consideration is that those who receive a college education will also be more suitable for continuing through the organisational structure into management positions with basic qualifications already achieved rather than relying on continual professional development when operational.

Nav Canada and PANSA, on the other hand, requires a high school diploma or equivalent. Similarly, IAA's focus is on secondary level education requirements, allowing the candidate to prove their eligibility through aptitude testing and the competency-based training framework. The IAA specified a leaving certificate with five passes (including maths) with grade C in two higher-level papers. This ensures that the candidate not only passed secondary level education but achieved a certain standard in doing so.

ATNS also focuses on secondary level education requiring a grade 12 with mathematics and English. GCAA requires a high school certificate with a minimum average of 70%. This minimum percentage is consistent with an acceptable level whereby the pass grade for any ATCO assessments is at 75%, thus ensuring an acceptable level of competence before recruitment. Airways New Zealand has several entry paths. They require a National Certificate in Educational Achievement (NCEA) Level 3 or a personal or commercial pilot licence to be accepted. They specify that NCEA Level 3 is required for tertiary training with subjects including mathematics and English.

Aerothai specifies their education requirements through the CATC used to train aviation personnel, including ATCOs. Aerothai requires candidates to have completed high school or equivalent while majoring in science and mathematics. As all elements of aviation training are associated with a third level qualification, the delivery and assessment methods are subject to additional academic rigour and aviation regulatory oversight.

Citizenship

While ICAO and EASA do not have any citizenship requirements, many nations do. Primarily this is because ATCOs can be classed as civil servants. Many countries will only accept citizens as civil servants, narrowing the pool of eligible ATCOs. This has a negative effect on mobility and interoperability between states which can limit the number of options available when trying to address a shortfall in the number of ATCOs from time to time.

The FAA, ATNS and Aerothai specify the requirement to be a citizen while Nav Canada and Airways New Zealand require citizenship and accept permanent residents. The same applies to GCAA when recruiting citizens, but they also accept direct entry ATCOs from abroad, which are accepted subject to other assessments discussed further below.

For IAA and PANSA, there is no citizenship requirement as the eligibility falls within EU 2015/340, which facilitates interoperability and mobility across all EU states under the Single European Sky concept. However, particularly for Poland and other EU states where English is not the native language, it is also a requirement for the ATCO to be fluent in the native language of that State.

English language proficiency

ICAO Annex 1 and EU 2015/340 outline the English language proficiency requirements that all states must follow. These requirements can be interpreted in several ways by ANSPs. For example, The FAA (2020) requires that candidates speak English clearly enough to understand communications equipment. Nav Canada (2020) requires candidates to meet language requirements (a high level of proficiency in English and French for the Montreal Flight Information Region (including the National Capital Region) and just English for all other regions**.** The IAA, as a native English-speaking country, requires the language level in accordance with EU 2015/340.

PANSA conducts their aptitude testing in English and interviews in both English and Polish. The initial acceptance of a candidate's level of English is by the recruiting board and the competent authority conducts the first English language proficiency exam before a student licence is issued. On the other hand, ATNS amalgamate the level of English required into the academic qualifications needed to gain entry for training. Once a grade 12 with maths and English is achieved, that is acceptable for further training. GCAA specifies that UAE Nationals must have the ability to understand and fluently communicate in English. At Aerothai, the English language teaching is conducted at the training college and forms part of the overall third level degree in air traffic management. The candidates are assessed at the interview stage for a certain level of English and then, on completion of training, will conduct the ELP as required.

Aptitude testing

ICAO and EASA do not specify the standard for aptitude testing, and this is a concept that is very much ANSP specific. A company wishes to hire the right people for the job and thus will tailor their screening forms accordingly. Various digital programmes are designed for aptitude testing of potential ATCOs with other ANSPs also using variations of the same concept.

The FAA conducts two forms of assessment. The first is a biographical assessment, which is used to identify candidates who have the highest probability of reaching final controller certification. They also conduct an Air Traffic Control Specialist Skills Assessment (ATSA), a battery of tests that measure abilities and characteristics shown to be predictive of success as an air traffic control specialist (ATCS). Depending on the pathway the candidate is being recruited for, it will be either the biographical assessment on its own or both biographical assessment and ATSA if destined for more pressurised environments.

Nav Canada conducts an online assessment for cognitive testing as the initial screening mechanism. This is followed up with an in-person test that may test communication, memory, working speed, spatial visualisation, thinking and reasoning, attention, information processing, and simple math. Finally, an in-person assessment is undertaken at a Nav Canada facility whereby an interview, group and individual exercises or simulations occur.

The IAA breaks their aptitude testing into four parts. Part one is the FEAST (First European Air Traffic Controller Selection Test) which Eurocontrol designed to help identify the most suitable candidates. It covers the areas of cognitive ability, knowledge, English language comprehension, multitasking, and a personality questionnaire. All these areas satisfy the ICAO standard of addressing knowledge, skills and attitude. Part two is the DART (Dynamic ATC Radar Test) test which simulates a Radar environment for which candidates must guide aircraft to various positions. Part three covers work strengths profiling conducted through a group interview and exercise. This part assesses the teamwork element of the screening process. Finally, part four is a competency-based interview.

PANSA also conducts FEAST and DART testing as part of their screening process. This is combined with a complex interview that focuses on multitasking, English language comprehension, memorising capabilities, spatial and situational awareness. ATNS require candidates to undertake written ability assessments. An interview then follows this. GCAA also specifies that aptitude testing is undertaken, but it does not specify what mechanisms are in place for the f aptitude testing. Aerothai also does not specify their aptitude testing process, but it is believed to be associated with the third level degree and acceptance to that form of training.

Airways New Zealand specifies that candidates must pass aptitude tests, interviews and group exercises but does not specify the mechanism for conducting those assessments. Aerothai likewise indicated that aptitude testing does occur but did not provide any further information on the testing method.

Training costs and student allowance

It is a business decision for each ANSP to manage the costs of providing training to student ATCOs. The costs associated with the provision of training can vary, but this is often offset against contractual financial commitments for the ATCO to remain with the ANSP for at least a specified period for the ANSP to recoup the cost of investment.

In the case of the FAA, Nav Canada and Airways New Zealand, this financial aspect is not specified as part of the recruitment campaign for ATCOs. For the IAA, PANSA and GCAA, the training costs are covered by the ANSP. For ATNS, the first year is covered by a bursary awarded by the company. On completion of that first year, a review is conducted to ascertain students' performance before commencing year two. If successful, they will be retained as employees for year two and paid. Finally, for Aerothai, although training is linked with a third level degree, the cost is paid by Aerothai.

It is an ANSP decision as to whether to award an allowance to students. The level of financial assistance awarded to students will influence the candidates' pool. The FAA pays their students an allowance of $18,343 while at the FAA Academy in Oklahoma. Nav Canada also pays an allowance, but the exact figure is not listed as it depends on the training pathway for the student and the ratings they are training for. The IAA pays an allowance to students until they commence OJT, which will move them onto the first point of the ATCO pay scale as employees. PANSA also pays their students as they become PANSA employees from the beginning. ATNS, Aerothai and GCAA pay their students a monthly allowance.

In terms of accommodation, the FAA provides accommodation to students in the Oklahoma area with several approved housing providers. It is a cost to the student with pre-defined daily rates at $62.40 for long-term letting (16 class days or more) and $104 for short term letting (15 class days or less). The training facility will pay the costs associated with student ATCOs only. ATNS and GCAA both provide accommodation for students, whereas the IAA does not arrange accommodation for students. PANSA does provide accommodation for students living outside of Warsaw, where the training headquarters is located. Aerothai provides accommodation depending on where the student placement takes place. If the placement takes place at one of the regional centres, accommodation is provided, but accommodation will not be provided if the placement is at Aerothai headquarters.

Training duration

There are varying degrees of length in training for ATCOs. This depends primarily on the business needs of the ANSP. For the FAA, because of the educational requirement before joining the academy, it is approximately five years of training broken down into three years for a college degree and two years of academy training. This seems overly restrictive on mitigating against a turnover of air traffic controllers, which has been an issue in the past.

Nav Canada is more expeditious in the delivery of its training programmes. Tower ratings will take between 10 to 18 months of training. For Radar training, the time period is increased to between 20 and 27 months. The IAA has indicated that it is 24 months of training, irrespective of the rating to be achieved. PANSA training is up to 33 months, but the students will often be operational between 20 and 22 months. ATNS training is 30 months in length, with the contractual obligations are broken down into the 12-month bursary followed by an 18-month fixed contract to finish the unit training.

For the GCAA, recruiting and training internally shows quite a variance in the time required to train an ATCO. Depending on the air traffic facility, from classroom student to licenced air traffic control officer can take three to five years. As Aerothai associates their training with a third level degree, it takes four years to train ATCOs. Airways New Zealand has the quickest turnaround in ATCO training, outlining that a 12-month period is required to provide a diploma in air traffic control (Level 7). This comprises six months of theory and six months of on-the-job training.

Labour market mobility considerations

While ATCOs do not experience retention issues like those of pilots (Efthymiou et al., 2021), there can be a significant shortage of experienced ATCOs. Across the world, there have been continued reports of shortages in air traffic controllers. People management by the respective service provider may have added to those difficulties through negative reactions to industry shocks such as 9/11, the financial crisis of 2008 and COVID-19, whereby the initial reaction is to adjust the level of service to meet the immediate demand. As a reaction to these shocks, ANSPs tend to cancel air traffic controller training and encourage retirements, therefore, choking the supply of controllers for operational use.

Unfortunately, it takes a long time to train an air traffic controller. As discussed in the previous section, some countries take quite a bit longer than others because of a national requirement for an air traffic controller to possess a third level qualification first. The quickest time period for training an air traffic controller for operations is a minimum of two years. This means that ANSPs will struggle with the consequences of staffing decisions as an initial reaction to an industry shock. It is difficult to manage as the aviation industry has a history of rebounding from shocks quickly (Corbet et al., 2019;

Akyildirim et al., 2020; Warnock-Smith et al., 2021), faster than the training of any ATCO. When that environment is created, the demand and urgency for air traffic controllers increase, so ANSPs look at ways to recruit air traffic controllers through other means. In the United States, after the air traffic controller strike against President Reagan in 1981, the focus turned towards hiring current and ex-military air traffic controllers and endorsing a collegiate training initiative for educating potential air traffic controllers as part of a university degree programme to help address the shortage. These processes are still in existence today.

In the UAE, an Assessment of Previous Competence (APC) is conducted on experienced air traffic controllers from other nations before direct entry recruitment to determine their level of suitability for operations in the busy traffic environment before deciding on whether to employ the controller or not. It is a cost-effective tool that helps the ANSP determine that the candidate has the right knowledge, skills and attitude for the role in the high-intensity work environment. While APCs are commonplace for airlines recruiting flight crew, it is a concept that some states have adopted for the recruitment of licenced ATCOs to determine that the level of competence is suitable for the demands of that State. APCs are not regulated by ICAO for ATCOs. Still, they are viewed by the states that use them and have received Competent Authority approval for their use as an effective screening mechanism.

For the UAE, the process spans three days. The candidate is provided with the relevant procedures and materials to pre-brief on before arrival to reduce briefing time on site. A written exam is conducted with the candidate based on the procedures and relevant ATC knowledge required before the simulation assessments. The exam was introduced as candidates were arriving without understanding the procedures to be employed in the simulator resulting in a high failure rate. The candidate would then get a test run on the simulator to understand the landmarks and aerodrome layout. The airspace is Class D which means there is a higher rate of VFR arrivals to be factored into the arrivals sequence with the IFR arrivals. The candidate is then assessed on two simulator exercises ranging from 75 to 90 minutes, depending on the rating for which the candidate is being assessed. This was originally just one assessment, but the failure rate was high. So, a second opportunity was introduced as a business decision to ensure better value for money as the ANSP paid for the candidate to attend the APC. The assessors are from the training department and have vast experience in training and operational practices. They would assess versus a prescriptive checklist to determine the controller's suitability. The outcomes are not always a foregone conclusion as an ATCO with significant experience from a high-intensity work environment in a different country may not adapt to the high work rate in the UAE. This could be because of a range of reasons, including cultural reasons where the candidate may not adapt to the fast-paced, high-intensity environment. The process is viewed as a good business practice as it results in a higher success rate not only at the unit training level but operationally too.

In Europe, EU Regulation 2015/340 does not legislate for Assessment of Previous Competence as a tool for recruiting qualified air traffic controllers. However, some ANSPs use it with specific approval from their competent authority. The regulation only permits the assessment based on interruption of training or non-exercise of the rating within the same unit. However, it appears that some ANSPs conduct Assessment of Previous Competence with their Competent Authority Approval being given. This will often occur when, like the UAE, air traffic controllers are recruited externally from the ANSP or when recruiting training instructors for the ANSPs training school. This ensures that the ANSP can be confident in the quality of the candidate before employment commences. Within Europe, it may not be a straightforward process and appears to differ with each ANSP. This makes it difficult to ensure a minimum standard is applied when conducting an APC. This impacts the mobility of ATCOs from outside of the EU attempting to gain employment from within the EU. It is a barrier that is not too dissimilar to the various citizenship requirements.

The only solution to this mobility barrier within the EU is for the ATCO to retrain to be brought into the European system. This is a common practice and applies when an ATCO transfers from military to civilian operations. While the content of the training will be identical to the basic training and rating training, the experience of the candidates is taken into consideration. Therefore, a compressed time frame is set for the delivery of the training. While it is a frustrating process for the candidates to satisfy the legal requirements, it is necessary to ensure a successful transfer of the knowledge, skills, and attitude onto a European licence.

EASA (2021) issued the updated European Plan for Aviation Safety (EPAS) which covers from 2022 to 2026. Contained within the plan in volume II section 5.3.6 are some subtasks aimed at maintaining EU 2015/340 resulting from feedback from EU states indicating the need for enhancing and simplifying the ATCO licencing system. Subtask 1 is aimed at, 'introducing a controlled mechanism of crediting of training, experience or other qualifications of military ATCOs for the purpose of obtaining ATCO licences under Regulation (EU) 2015/340.' Subtask 3 is aimed at, 'introducing a mechanism for the recognition of third-country ATCO licences under Regulation (EU) 2015/340'. This could well be the steps required to address the mobility issues outlined above and potentially formalising in regulation a mechanism such as an APC for ATCO assessment with a new ANSP. It is an interesting development in light of BREXIT and the classification of the United Kingdom as a third-country.

While understandable from one perspective, the citizenship requirements to allow candidates to fall within the civil service system are overly restrictive on ANSPs from recruiting direct entry controllers from outside the state and affect the mobility and interoperability of ATCOs within the aviation system. For example, some ANPS (e.g. Nav Canada and Airways New Zealand) accept permanent residency.

Conclusion

Air traffic control officers are valuable to the ANSPs business and therefore their recruitment and training is important. The recruitment of air traffic control officers is the responsibility of each State as outlined by section 4.3 of ICAO Annex 1 by stating: 'Contracting States shall take the appropriate measures to ensure that student air traffic controllers do not constitute a hazard to air navigation' (ICAO, 2020a, p. 102). This is the key piece of regulation that transfers the responsibility for accepting student ATCOs into the aviation system and setting the minimum standard for their acceptance to each ANSP.

For EU states, the incorporation of ICAO Annex 1 requirements into EU 2015/340 has provided some standardisation. The mechanism of supplying additional information through AMCs and GM has been invaluable for ANSPs to provide training to a verified standard and ensure that they comply with the remainder of the EU and contribute to the SES concept. ANSPs and competent authorities are subject to oversight also from EASA through regulation EU 2017/373 to ensure that each State follows the provisions of the various regulations, including EU 2015/340.

Nevertheless, there are variances in recruiting student ATCOs, but they do not differ greatly. The result of the recruitment analysis highlights some states' inefficiency concerning the provision of new ATCOs in good time to manage against staff turnover. The data analysis has allowed the author to determine the preferable elements of the recruitment and training process that should be applied uniformly across all ICAO states. This will ensure that no deficiencies in the recruitment and screening processes occur, leading to any deficiencies within the aviation management system.

Discussion questions

1 What are the main areas for ATCO licencing requirements as outlined by ICAO?
2 What are the main ATCO categories?
3 What are the competencies for the OJTIs?
4 How do recruitment and training differ across various ANSPs around the world?
5 What factors act as a barrier for ATCO's mobility, and how?

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5 Safety management in air navigation service providers

Markus Biedermann

Introduction

ATC has been introduced as a safety net for aviation. During the First World War (1914–1918), planes were used for the first time in history on a large scale. However, primarily for combat, to spot enemy positions and movements and not transport goods or passengers.

Right after the war, in 1919, the International Convention for Air Navigation (also known as Paris Convention; United Nations, 1919) laid down the basic rules for air navigation, such as the sovereignty of airspace for each country and the rules for overflying or flying to and from a country, enabling civil aviation.

The speed and flexibility in aircraft movement made them interesting for civil use, and in 1921 James Herbert Knight made the first transcontinental mail delivery in the United States. The way pilots were navigating back then was just as the birds fly. They had a lookout on significant spots on the ground and followed them. Traffic levels soon increased – yet still very low compared to nowadays levels – and the need for support to the pilots flying became obvious. The idea of air traffic control was born and with it, the main purpose of it: providing safety to the pilots flying their aircraft.

The first air traffic controllers were located in the UK at airfields and informed pilots of other aircraft or vehicles in the area, using flags, flashing lights or radio communications (introduced around 1930) (Air Traffic Control, 2020). But with the introduction of civil aviation, the risk of flying soon also became apparent. In 1922, at Croydon airport (south of London), the first minor collision happened between an aircraft and a vehicle. Before that incident (i.e. in 1920), an aircraft crash landed near Burte Gardens, which is just outside of Croydon airfield (Croydon Airport Society, 2020). This accident led to the introduction of the first aerodrome control procedures and the requirement for ATC clearances.

ATC was and is part of aviation safety and always has a major role from the very first steps. ATC uses surveillance equipment, worldwide connected systems with data on aircraft flying or about to depart but also most communication technology, which ranges from radiotelephony to datalink, allowing

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to transfer information between aircraft and the controller almost in real-time (Lootens & Efthymiou, 2021).

Ever since the first steps in civil aviation, a rapid development took place and with it a rapid development of safety. ATC, introduced to support safe flying, was always on its leading edge.

If we go back to the example of the first known major accident in aviation, the 1922 Picardie mid-air collision, the nature of safety in ATC becomes quite apparent. A French aircraft carrying passengers and a British aircraft carrying mail hit each other mid-flight over the French village of Picardie. Both aircraft crashed, burst into flames and no survivors could be recovered. The flight took place in bad weather conditions and with early days aviation equipment. It is unknown whether the two aircraft could see each other before the collision (Croydon Airport Society, 2020). As a result of this accident, representatives of the airline industry came together at Croydon airport (where the British aircraft involved departed). They defined the 'right of way' rule in aviation to improve safety, still in force today. In areas where ATC coverage is unavailable, such as central African countries, each aircraft always stays slightly right of the airway. In case of an unexpected opposite aircraft, they would safely pass by each other.

Would ATC have been available at that time, it could have provided the pilots with directions to pass each other safely even during bad weather or at least enough information about the other aircraft so that the pilots could decide on a track that would lead them safely.

As one can see, the focus of safety in ATC is slightly different from other industries or even from other organisations within the aviation industry. An air traffic controller has little direct control over an aircraft. But even more, ATC will not be harmed in an accident, even one that supposedly would have been caused by it, such as the Ueberlingen Accident on 1 July 2002. In this mid-air collision, a Russian passenger aircraft (TU-154M) and a Cargo aircraft (B757-200) hit each other during a night flight with clear skies. No survivors could be recovered from the crash site.

The ATC staff involved was forced to watch the accident happen. A large-scale investigation took place, and as a result, several suspended prison sentences against members of the involved ANSP were issued. This accident changed the landscape of aviation safety in many ways. Technology, such as the Traffic Alert and Collision Avoidance System (TCAS), was made mandatory to be adhered to at all times, which was not standard by that time. ATC once again developed its approach to safety further.

Then and even today, there is no technology available to fly a plane from the ground as an ATCO. Remotely piloted aircraft systems are known, but they play very little role in civil aviation. So, whatever ATC is doing, they will always have to rely on the aircraft or vehicle they control to comply with their instructions. A pilot, on the contrary, has direct control over the aircraft they are flying. This, and contradicting recommendations by TCAS were the main reasons for Ueberlingen. In short, ATCO's plan to prevent the accident from happening would have worked.

On the other hand, the instructions given to the flight crews by TCAS would have achieved the same. The catastrophic factor was that the systems and the ATCO's plan did not match. While one crew followed the ATCO's instruction, the other crew adhered to their system.

Within the aviation industry, a debate started back then. Why would a pilot not follow the instruction of an ATCO? There is a simple, yet a not widely known answer to that: while the rules of the air state that any aircraft has to follow the instructions of ATC (ICAO, 2016a), they also state that the pilot in command has ultimate authority over the safe flight of an aircraft. According to this law, a pilot does not need to adhere to ATC instruction. So, one aspect of safety in ATC is mutual trust. Trust on ATC, their capabilities and technology to manage all aspects of air traffic. If everybody follows ATC instructions, it will reach its destination safely, orderly, and expeditious way. In this very case, one crew decided to trust ATC and the other one to trust the system. A fatal mistake.

Therefore, the nature of safety in ATC is less of a direct nature. ATC has little direct influence over the aircraft they provide safety for. However, ATC can have a wider picture of the situation in the air as their technology, such as radar, allows them to look way further than any pilot. ATC can identify potential conflicting flight paths, optimal routes and ways around adverse weather and it will work towards an optimum provision of service to anyone under their control.

In case of an incident, or even worse, an accident, ATC provides their service for the search and rescue services. The effects from such incidents range from disruption in the regular traffic flow up to temporary closures of airspace (i.e. volcanic ash clouds) and/or airports (aircraft in distress on the ground, blocking a runway) depending on the nature of the event.

No matter the event, ATC continues to provide any information relevant for the safety of any flight. ATC developed several methods to manage these events very effectively, which all originate in the theory of high-reliability organisations (HROs). This theory, which will be explained in more detail later, allows organisations such as ATC to operate relatively error-free over prolonged periods, which is highly important for a 24/7 industry such as aviation.

This chapter will focus on the safety aspects of ATC. It will provide an overview of the special nature of ATC safety, followed by the current regulation around safety management. It will show how today's ANSPs operate to maintain their levels of safety and conclude with a selection of safety nets that help air traffic controllers worldwide provide their high-quality service to any aviator within their area of responsibility.

Safety management rules and standards

A global industry such as air traffic requires global standards and operating practices to maintain its level of safety across the globe regardless of which country an airline originates. Common aviation safety standards drive rules and standards in air traffic control. While in general, operational, and technical safety is the main area, where regulation on safety play a role, in particular in air traffic control, the focus tends to be more on the operational side. While technical standards on redundancy and failure tolerance are important in air traffic control. Because a system failure in ATC less likely results in a critical situation for an aircraft, the focus on operational rules and standards seems legit as the more important focus of safety regulation.

The Paris Convention in 1919 paved the way towards the foundation of the International Civil Aviation Authority (ICAO) in article 34. This institute sets the international standards for civil aviation, including air navigation services (ANS). From there, regulation on ANS developed and alongside with it, the regulation of safety in ANS.

Today, common approaches on safety standards are no longer solely driven by ICAO and other authorities. For example, within Europe, the European Aviation Safety Agency (EASA) or national transport safety boards (NTSB), which in Germany, for example, sits with the Bundesstelle für Flugunfalluntersuchung (BFU).

The foundation of EASA on 15 July 2002 was just two weeks after the Ueberlingen accident. This accident resulted in the mid-air collision of two aircraft (one of which was a cargo aircraft and the other with passengers), resulting in a total loss of the aircraft and people on board. The investigation concluded that a major failure within the ATC system contributed to the accident. The European Commission reacted in the foundation of an agency on a European Union level, focusing on safety. Since then, EASA has focused on harmonising aviation safety standards across and within the European Union.

Initially, the power of EASA did not include air traffic management (ATM) or air navigation service providers (ANSP). These were included in 2009 by the European Commission. Today, the EASA issues binding regulation for all European member states on a European level. To guarantee the national implementation of European standards within ATM, separate ATM specific national supervisory authorities (NSAs) were introduced in 2009 across Europe. All member states implemented NSAs, which are tasked to supervise the regulatory framework on behalf of the member state.

There are three different types of rules and standards: (i) regulation, (ii) legislation and (iii) recommendation. All three shape the way of safety management in aviation, particularly ATC. All are monitored by the responsible NSA and overseen by the EASA. The three different standards will be introduced now.

Safety regulation, legislation and recommendation

Regulations in safety are a set of rules and standards issued by competent authorities such as the ICAO or the EASA, which members must apply locally or where members have to base a local ruleset. Regulations exist on a supranational level, national level, and local levels based on the specifics of the area

(Murphy & Efthymiou, 2017). The most relevant regulation for air traffic control is ICAO Document 4444 (ICAO, 2016b), which sets the standard for air traffic management across all ICAO member states. This document outlines the various requirements as to which structures must be implemented for ATM and specifics on how the governance is to be set up.

In this document, Chapter 2 describes safety management and prescribes the requirements on ATS safety management:

> States shall ensure that the level of air traffic services (ATS) and communications, navigation and surveillance, as well as the ATS procedures applicable to the airspace or aerodrome concerned, are appropriate and adequate for maintaining an acceptable level of safety in the provision of ATS.
>
> (ICAO, 2016b, p. 31)

ICAO published 19 Annex to the Convention on International Civil Aviation to further specify the various requirements. An Annex sets specified requirements on relevant subjects such as Personnel Licensing (Annex 1), Rules of the Air (Annex 2) or Airworthiness of Aircraft (Annex 8). While any of them focusses on standards to maintain an optimum level of safety, Annex 19 sets the standard on Safety Management (ICAO, 2016a).

Furthermore, ICAO Document 9859, Safety Management Manual (ICAO, 2017), provides further guidance on safety management standards and practices alongside Annex 19. Other regulations on safety are from the EASA, which has the safety oversight within and on behalf of the European Union, or from Eurocontrol in their Safety Regulatory Requirements (ESARR), which are a set of regulations required to be adopted by the Eurocontrol member states. Currently, 6 ESARR are available, covering the following topics:

- ESARR 1: Safety Oversight in ATM.
- ESARR 2: Advisory Material.
- ESARR 3: Use of Safety Management System by ATM Service Providers.
- ESARR 4: Risk Assessment and Mitigation in ATM.
- ESARR 5: ATM Services Personnel.
- ESARR 6: Software in ATM Systems.

While ICAO regulation has a global focus, the EASA and Eurocontrol regulations normally take the ICAO publications and create a joint perspective within their member states to be implemented by the local regulatory bodies, the national supervisory agencies (NSA). In most cases, the implementing rules published by EASA are almost identical to the corresponding ICAO publications. The ESARR are not directly derived from ICAO regulations but aim to harmonise safety approaches and regulation across all member states to create a common ground for safety.

Legislation on safety is laid down in a countries code of law. To date, there is no specific legislation on aviation known to the author, but there is workplace safety legislation just as the UK's Health and Safety Executive (HSE) legislation. Although not specific to air traffic control, it has to be adhered to and can get into conflict with the requirements for service provision. One example of this is workplace safety requirements in Germany, which would mandate a specific setup of screens. As the law was based upon normal office spaces, it does not consider the setup of an air traffic controller working position. However, only military working positions are exempted (Bundesministerium für Arbeit und Soziales, 2015). In addition, the regulation set out by EASA is lifted into European law by legal acts. There is no difference between a regulation and legislation on air traffic management or air traffic control within European ATM.

Within the regulatory framework for ATM, there is a set of recommendations issued by competent authorities such as EASA. They are published annually and include the latest intelligence on safety alongside recommendations for consideration (EASA, 2020). Although they are not mandatory, the EASA safety recommendations have become a standard for the EASA to announce potentially upcoming changes in regulation over the years. Most of the recommendations are related to aircraft operations (e.g. B737 MAX) (EASA, 2020, p. 33).

But there are also recommendations, published by other agencies such as Eurocontrol or Civil Air Navigation Services Organization (CANSO), with the CANSO Standard of Excellence in Safety Management Systems (CANSO, 2018) or the CANSO Standard: Common Safety Method on Risk Evaluation and Assessment for ANSPs (CANSO, 2014). Although there is no requirement to implement the recommendations, local procedures of individual ANSPs reflect many of the recommendations to maintain a high standard of safety and proactively engage in safety measures.

Redundancy versus Resilience

The regulation prescribes procedures or specific rules and requires local ANSPs to engage in organisational and technical strategies to maintain, promote and increase safety.

The two most important air traffic control safety strategies are redundancy and resilience. One will often come across these terms in the documentation and description of the concepts. Both terms originate in systems design and are IT concepts. However, it can be applied to many things and even organisations, introduced in the following chapter.

Sometimes the terms are used synonymously, which might be confusing as they are not the same. At the same time, there are arguments ongoing on whether one can exist without the other. A system can be redundant but not resilient or the other way round. As it is key to understand the concepts of air traffic control safety, these two terms will be introduced in more detail.

If one part of a system is doubled by another part, which can continue the task, something is redundant. An example would be network wiring. If two network cables connect the same two access points and the required bandwidth is less than the two cables together provide, any of the two cables may be pulled or cut at any time without the loss of service. Another term for redundancy would be backup. If a system or organisation holds backup structures that can actively take over, it is redundant if the primary system fails. On an organisational level, redundancy is achieved by deputies or standby workers that can take over.

In ATC, one aspect of redundancy is the four-eye principle. This concept will put two similarly qualified staff members in charge of the same area. They will, together as a team, provide ATC service. Should one overhear an important message or make a mistake, the other has a high chance of realising the potential error and step in or correcting it before it can result in a problem.

Contrary to redundancy, resilience is the capability of a system or organisation to contain, converge, recover or self-heal in case of disruption back to normal operations. It does not mean that no loss in performance might occur, but that the system will not collapse in case of an error.

In the example of our network, the cables themselves would be redundant as there are two components in the systems that can replace each other. The system would also be resilient as it can recover from the loss of one cable without additional action. Another form of resilience is laid down in processes. When, for example, staff members are trained to understand how to operate a system and how the system operates, they might be able to deal with an unexpected error because they can analyse the potential problem and create a workaround without coming to a sudden halt.

It becomes apparent that one key aspect in resilient organisations is the human itself. In particular, in complex environments, where it becomes impossible to oversee all aspects of a system, the ability to react and adapt to unforeseen situations is a key for success. Resilient Organisations can adapt to these situations and recover. The human brain can think of new ways to solve a problem, even with unknown factors. Within ATC, a lot of effort is put into training members of staff and their managers to identify abnormal situations and find an alternate way to complete the task (Eurocontrol, 2009).

Highly reliable organisations

To fully understand safety in ATC, it is important to understand the nature of ATC and what kind of organisations they are. We have already learned that, unlike airlines or airports, ATC has been introduced to primarily maintain safety in air travel. Therefore, these organisations incorporate some very specific concepts and organisational structures that go beyond the concepts of redundancy and resilience but also complement them.

Air traffic control is a highly reliable organisation. This term is used for organisations operating under high pressure and close to the point of failure without collapsing or a very low risk of it happening.

According to Roberts and Bea (2001), any organisation qualifying as an HRO shares three key principles. Those principles all together are not found in other organisations and therefore qualify to be an indicator when searching for HRO:

- HROs aggressively seek to know what they do not know: any HRO has a process and people in place to conduct training, assessment of training outcomes and re-training of staff to improve and maintain the competence of any member of staff. A special focus is taken on special occurrence handling, for example, how to deal with unexpected events. As part of it, incidents and near misses are continuously recorded and analysed to find potential errors in the system.
- HROs balance efficiency with reliability: Although HROs in today's world are subject to economic pressure, the trade-off between reliability (which is at the same time safety) and efficiency is very carefully assessed. The focus is on quick wins for safety and going for profit in the long-term planning.
- HROs communicate the big picture to everyone: The last key factor for HROs is internal communication, which allows everybody to report and access the results of reports at any time. At the same time, it is communicated on how to behave during normal and abnormal situations. As an example, the hierarchy in HROs is different in normal operations than in emergencies. In the latter, everybody is encouraged and allowed to intervene at any time if the safety of operations might be affected (Roberts & Bea, 2001).

The five dimensions of HRO theory

A group of scientists, the Berkeley Group, revealed five characteristics in these organisations, which are responsible for the high reliability of operations, namely (Roberts & Bea, 2001):

1. Preoccupation with failure;
2. Reluctance to simplification;
3. Sensitivity to operations;
4. Commitment to resilience; and
5. Deference to expertise.

These characteristics are also referred to as the five dimensions of high reliability (Roberts & Bea, 2009).

Preoccupation with failure

An HRO is careful in investigating failures. The assumption is that any mistake or failure is a potential crack in the system rather than an individual failure. And it is in line with the approach to be mindful of any incidents.

On 25 March 2016, Germanwings 9525 was purposively descended into terrain, and all 150 people on board were killed. This event was a shock to modern society. A person with significant psychological disorders flew an aircraft and subsequently caused a catastrophe when committing suicide (Bureau d'Enuqetes et d'Analyses, 2016). The investigation report of the event shows early warning signs that highlighted the potential issue early on. The pilot in question was pausing his training for 10 months due to medical reasons. During this period, his certificate of medical fitness for pilots (Class 1 Medical) has not been renewed due to depression and medication to treat it. This was refused some months later another time, and only with restrictions. The medical was re-instated a year later. The restrictions were an annual check for medical fitness and a statement that the medical would be suspended immediately if the depression would come back (Barreveld, 2016). The pilot in question had several short periods of sickness-related absence in the time before he committed suicide.

These events happened over a longer period and could have potentially been known. The HRO should have dealt with the early warning signs in a strong response but were not interpreted accordingly. The restriction in the medical to be re-assessed results in economic pressure. A pilot is normally insured by a loss-of-license cover, which supports the pilot in case of a permanent loss of his medical fitness certificate. In this instance, the restriction in the medical disqualifies from such insurance as the risk of losing the medical is too high. Pilots normally have to contribute a large amount of money to their training. The pilot in question was still in depths by about €40,000 (Bureau d'Enuqetes et d'Analyses, 2016). And he was at high risk of losing the license due to his medical record – many different factors, which together build up the full picture of the event's root cause.

According to HRO principles, early warning signs must be treated as a potentially significant event and a likely systemic failure. The response to the weak signals in the Germanwings crash was also weak (= restriction to an annual medical check as an only response) but should have been strong (i.e. no medical, withdrawal from duties).

Hopkins (2007) describes the preoccupation with failures as a constant search for possible lapses in the system with the view they might be a precursor for larger unwanted events. He further stresses that in HRO this is primarily achieved through reporting systems for incidents and investigation of even minor events against this principle. Young (2011) supports this approach in his investigation on failure in banks and bank systems. In particular, missing or ignoring weak early warning signs is a cause for failure. Reason (1997), with his Swiss cheese model of accident causation and Rasmussen (1997) in his analysis of human error, follow the same approach and highlight the importance of understanding the impact of accumulating weak signals and their correlation to larger incidents or accidents.

Reluctance to simplification

> Knowing that the world they face is complex, unstable, unknowable, and unpredictable, HROs position themselves to see as much as possible.
> (Weick & Sutcliffe, 2007, p. 26)

In accepting the importance to understand the wider implication of weak signals, the interpretation of such in HROs starts with the view that there is always a bit more to the story as one might see in the first place. It also means that events, which have already been analysed and understood, are treated seriously if they happen again. An HRO would question whether the past event was fully understood or if the new event appears similar but is more important. According to HRO theorists, it is important to treat every event as the first instance and be reluctant to put it to bed quickly (Sutcliffe, 2010; Weick, 1987; Youngberg, 2004).

The ground team recognised a burst of debris from the left stabiliser wing of the Challenger Shuttle only about 80 seconds from lift off as a normal event without bigger implications as it had happened before and did not cause any problems (McDonald & Hansen, 2009). This time, it was the starting point of a catastrophe.

Reducing the complexity of a problem to increase manageability is a common method of addressing complicated and complex phenomena. Various approaches exist, such as dimension reduction, including filtering and statistical methods (Spears, 1999) or pattern detection, which reduces unstructured data down to identifiable patterns (Holzinger, Popova, Peischl & Ziefle, 2012; Valdeza et al., 2015). They all share the principle of reducing complexity by excluding various (supposedly) irrelevant factors for the problem-solving task. Within HRO, such an approach increases the risk of missing small incidents or ignoring early warning signs.

Sensitivity to operations

The third element of HROs is dealing with the management of the organisation. With this principle, Weick and Sutcliffe (2007) highlight the importance for any organisation member to understand how the system operates even beyond their area of responsibility. The front-line operators have a clear picture of other organisational elements and how they interact. Identifying an anomaly is largely increased, and the risk of missing an important small event becomes low.

HRO strives to provide important information to the whole organisation rather than keep it within silos (Hopkins, 1999). The background is that a *big picture* is barely achievable if the individual elements are withheld from the organisation as a whole. Young (2011) identified the silo-based approach, which is common in banks, as a key element to the failure of such systems. He acknowledges the HRO approach and strives to overcome the silo-thinking in their organisations.

Hoppes et al. (2014) describe the sensitivity to operations and the resulting reduction or removal of silo-based risk management as key success criteria for managing uncertainty in enterprise risk management processes. The particular benefit identified in this work is the potential to find risk families, which exist across different departments of an organisation, which can be mitigated more effectively if all information is shared across the organisation.

The US Navy Seals operate in a way so that every member of a team knows the full extent of the mission and the roles, responsibilities, and limits of the team members. Vogus and Sutcliffe (2017) investigated a Navy Seals team and how they operate to compare their creating mindfulness against the HRO principles. Regarding sensitivity to operations, they were able to provide evidence about how important it is to share information among all team members. Only front-line operators (soldiers in the field or workers on site) have first-hand knowledge. This information needs to be placed in the organisation. It creates a better understanding of the overall situation allowing every member of the system to increase resilience.

This has been supported by Hopkins (2007) when he investigates high reliable organisations. Front-line operators are important to be sensitive to the operations, but the same accounts for the managers who usually don't have any first-hand knowledge but need to trust and rely on the information they are provided with. When a front-line operator speaks up, he needs to be confident that it does not fall back on him regardless of what he might have to share. Weick and Sutcliffe relate to this:

> people who refuse to speak up out of fear enact a system that knows less than it needs to know to remain effective. People in HROs know that you can't develop a big picture of operations if the symptoms of those operations are withheld.
>
> (Weick & Sutcliffe, 2007, p. 29)

Research in safety management, particularly aviation safety, refers to this as the Just Culture. It is a principle that James Reason first mentioned in his work on Human Errors (Reason, 2000) and subsequently was adopted by Eurocontrol as a guiding principle for safety management and Safety culture (Eurocontrol, 2020).

Just Culture in aviation is defined as 'a safety culture as including: just reporting, learning, informed and flexible cultures' (Eurocontrol, 2020, p. 11). Dekker (2009) refers to finding a balance between accountability and safety. It highlights the importance of learning from mistakes rather than blaming an individual who might have made one. A good example is aircraft carrier operations at the USS Enterprise, investigated by HRO researchers Roberts and Rousseau. In the investigated case, a stray bolt left on the airfield is used as a prime example of sensitivity to the operations. Such a small metal object by itself does not harm an aircraft carrier. But it could cause a significant problem if ingested by a jet engine. During take-off, it might lead to man engine stall, loss of thrust, and a hull loss.

To mitigate for that, not only each member of the team can put a halt to the deck operations if such an object is found, but also so-called foreign-object damage (FOD) walk-downs are carried out several times a day to mitigate that risk (Weick & Sutcliffe, 2007).

When the Concorde accident in 2000 happened, the root cause was a metal object on the runway, which caused significant and unrecoverable damage to the airframe (Ministere de l'Equipement des Transports, 2003). A FOD walk down would have prevented this accident from happening. The object would have been found and removed from the runway before it could cause an accident. These walk-downs are an important safety (and therefore risk management) process and a mandatory procedure several times a day.

Commitment to resilience

The fourth principle of an HRO is, at the same time, a larger area of research on its own. Resilience is the ability to recover from failure or operate after major incidents or under continuous organisational stress. We have already learned in Chapter 4 about resilience versus redundancy. But these principles specifically highlights the aspect of resilience on an organisational level within HRO or within air traffic control.

Weick and Sutcliffe define resilience as a 'combination of keeping errors small and of improvising workarounds that allow the system to keep functioning' (Weick & Sutcliffe, 2007, p. 14). Steen and Aven (2011) refer to resilience as the ability of a system to accept variability in performance while reducing the negative variances to avoid unwanted outcomes.

A key point within HRO, which is acknowledging the finding of NAT and DIT, comes down to accepting the error as part of the organisation. Also, an HRO is not error-free. The difference between normal organisations and HRO is that error will not disable the organisation as a whole regardless of the magnitude. In particular, during a crisis or shortly before a major incident, a system is stressed to its limits and ultimately beyond.

An example of a resilient system is the power grid. Irrespectively of where a failure in the system occurs, the key is to keep the breakdown isolated and prevent knock-on effects to the rest of the grid, for example, due to overload scenarios. The system needs to react to instantaneous events, affecting performance (Lundberg & Johansson, 2015). A more common example is Christmas when the electricity consumption peaks. Although this is a known event, situations like these may occur unforeseen and put stress onto the whole system.

Air traffic control is another example. The variability in directing flights are primarily prevailing weather conditions and variability of aircraft performance depending, which is again dependent on the weather conditions. The system air traffic control is set up to compensate for this variability and keep the system stable even during high demand and workload over continued periods (Lundberg & Johansson, 2015). HRO plans for that as they are aware of their systemic limits and allow for processes and procedures, which provide enough variability to maintain stability even under stress.

When Germanwings pilot Lubitz descended the aircraft into the ground, there would have been time to enter the cockpit and address the situation. The cockpit entry system, focused on protecting the pilots from intruders from the cabin, prevented this. All possible ways to get into the cockpit did not take into account someone being inside, unwilling to let the door open, or it has been considered. Still, nobody imagined that someone maliciously would prevent the door from opening (Barreveld, 2016). At this point, a resilient system aircraft crew could have had an alternative way to recover from this situation. This shows that any system or part of it can have a failure. A resilient system will maintain stability and recovery, and HROs are aware of this fact and focus on building their structure and culture to guarantee this (Le Coze & Dupre, 2006).

Deference to expertise

The fifth and final element that make up HROs is their deference to expertise. Any organisational structure follows a certain hierarchy. A typical pyramidical setup ranges from front-line workers via lower and middle managers up to a board of directors or similar body to make the decisions. Considering the sensitivity to operations in HROs and the importance of sharing knowledge, it becomes apparent that the decision-making needs to be able to be placed with the element in the organisation who can make the right decision as and if required. The respect to the expertise and knowledge of a front-line worker by higher management will increase an organisation's resilience (Weick, 1987; Weick & Roberts, 1993; Youngberg, 2004). A good example lies in the US Navy SEAL operations. Each SEAL team member needs to fully understand all the missions and the strengths and weaknesses of each team member. They need to rely on each other, and during a mission, the contribution of every member of the team, regardless of where in the hierarchy the member is placed, is to be considered of equal value (Vogus & Sutcliffe, 2017).

Some organisations have the deference to expertise built into their organisational processes, for example, in air traffic control, where the ultimate decision-making to maintain air traffic safety is placed with the front-line air traffic controller. The German air traffic control provider has set out that only someone holding an air traffic control license can perform air traffic control, which includes giving instructions to aircraft in the area of responsibility (DFS GmbH, 2018). In doing so, the German air navigation service provider (ANSP) prohibits direct influence by a manager without required expertise onto the operations but at the same time respects the expertise of the air traffic control officer (ATCO), which in the context of HRO theory is seen as a front-line worker. Perrow (1994) describes it as 'at air traffic control centres, supervisors and controllers may switch responsibilities when necessary and informal teams are often formed to trade advice and manage dangerous operations' (Perrow, 1994, p. 214).

Safety nets and concepts

Within air traffic control, there are various safety nets and concepts in use across the globe. Primarily driven by ICAO regulation and recommendations and promoted by agencies such as the EASA. This chapter will introduce some examples that show how air traffic management applies specific measures within ATC to maintain an optimum level of safety alongside some examples. While there are various approaches to maintain safety in ATC, threat and error management (TEM) is specifically developed for the ATC environment, published by ICAO (2005). The TEM framework is based on a threat assessment process, which aims to identify threats leading to errors with the potential to adversely effecting safety in ATC.

The concept focuses on the air traffic controller as the ultimate part of the system, who can detect an error and respond to it before it results in an incident. Therefore, the ATCO needs to be supported by either technical (=system-based) or organisational (and/or team) countermeasures. A few measures used within ATC will be introduced to provide an overview of what safety nets or concepts are in place.

Technical

In technical category are systems or functions of systems that support the controller in its work. They provide information on the safety status of the current traffic and highlight any potential risks in advance. They are sometimes also referred to as controller assistant tools (CATO).

Short term conflict detection

Modern ATC equipment is often fitted with short term conflict detection. This tool constantly calculates any aircraft's flight path (trajectory) on the screen and predicts the position. It then compares all trajectories and should potentially get too close together. The system will notify the controller in charge. The main challenges of such a tool are to predict the unpredictable. One is the influence of weather, particularly during climb or descent operations, the wind changes significantly and with it the speed of an aircraft. While initially these systems were only able to take into account the horizontal flight path of aircraft, more modern versions also take into account vertical flight paths.

Approach path monitoring

This system alerts the air traffic controller if an aircraft would be at risk of a controlled flight into terrain (CFIT). In particular, the final approach phase of a flight puts a lot of workload on the flight deck and minor errors might result in an approach being too low, touching down before the runway. The Eurocontrol Safety Net Guide mentions the effectiveness of such a system (Eurocontrol, 2017) and for the development of such a system, specific criteria have been laid out (Ben, 2017). Today, such a system is mandatory for major airports if certain arrival procedures need to be applied, requiring a higher accuracy and quicker reaction to deviations from the intended flight path.

Organisational

Organisational concepts are specific measures that rely on processes and people and support safety culture and promotion. Various structures are available within ATC, but the two most important ones shall be introduced in more detail in this section.

Critical incident stress management

Critical incident stress management (CISM) has not been developed within ATC or the aviation industry. It is a concept to deal with highly traumatic events and has been used for combat veterans and civil first responders such as firefighters, disaster rescuers, ambulances or police forces. The process includes several methods to address the situation of an individual or a group after a highly traumatic event. It is often defined as a process to address a traumatic event that initiates a crisis response of a person and potentially can overwhelm the usual coping mechanisms of individuals. It is typically accompanied by stress's cognitive, emotional, physical and behavioural manifestations.

Within ATC, CISM has been known for many years but did not play a major role in dealing with traumatic events of ATCOs before 2001. In the Uberlingen accident (BFU, 2004), CISM was a key factor in supporting ATCOs, which had to overcome the traumatic event of that night. CISM peers have been quickly deployed to support the ATCOs and other ATC staff directly involved in the accident.

It is within the field of CISM known as 'dealing with the survivors' guilt' (Vogt & Leonhardt, 2006):

> An aircraft crash causes even greater emotional shock for people who work within the aviation industry. They feel the same shock, horror and grief as everyone else. However, they also feel responsibility and guilt because they design, manufacture, maintain, operate, communicate with,

> and control the aircraft that crisscross the sky. The media, politicians, the public, and sometimes even the airline's corporate leadership, are quick to blame the airline's employees and hold them accountable. This often occurs before the actual facts are known.
>
> (Vogt & Leonhardt, 2006, p. 14)

CISM allows individuals to talk to trained colleagues (CISM-Peers) about an event in confidence. The colleagues are no psychologists and do not identify themselves as such. But due to their profession (ATCO), they know what that colleague is talking about, they can listen and help get the situation 'off the chest'. The traumatic event can be addressed through an exchange within this safe environment called defusing. Since the Uberlingen accident, the CISM concept has been introduced across Europe as a standard in all ANSPs and with the concept originally deployed during the Uberlingen accident.

Just culture

The concept of just culture is a form of organisational behaviour and culture, which is common in the aviation industry but lies in the DNA of an ANSP. Just culture is promoted by Eurocontrol and EASA (Dekker, 2009; Vanderhaegen, 2015; Weick, 1987) and is also a key concept within HROs. Just culture is defined as follows:

> Operators, irrespective of whether they are front-line operators or not, cannot be punished for actions, omissions or decisions which are commensurate with their experience and training. However, gross negligence, wilful violations and destructive acts cannot be tolerated.
>
> (Eurocontrol, 2006)

In other words, if something goes wrong and you do everything to prevent it from happening, you will not get punished. This is a strong statement and protects members of staff. It also supports open communication as an individual is more willing to omit a mistake if they are aware that it will not be punished (E, 2004). On the flip side, the principle of just culture brings conflict of interest with some legal principles. Within law, it is required to hold the individual or organisation responsible for the unlawful action. Just culture might conflict with that as it could protect an individual from breaking the law. However, even the definition of just culture does not state that there cannot be any action against the individual, but it includes 'gross negligence', which is subject to debate as long as the principles exist (Dekker, 2009; Pellegrino, 2019).

To date, the just culture principle has been respected, but there has been a critical moment in 2019 when a Swiss ATCO has been convicted for gross negligence. Across Europe, this decision has been recognised as a paradigm change in the ATC world, undermining the concepts of just culture and potentially leading to a decline in safety culture.

Skyguide filed an appeal against the court's decision, and in November 2019, the highest court in Switzerland decided to acquit the defendant. With its decision, the Swiss court, as the first court in Europe, set precedence for the legal approach on just culture, supporting the concept and principles and putting trust and faith in the safety culture of ATC.

Team resource management

A third concept and safety net in ATC is team resource management (TRM). It is a concept, also outlined in the TEM by ICAO, which intends to bring ATCOs, Pilots and sometimes airport staff together in a training environment to exercise abnormal situations and improve team structures.

TRM allows the participants better to understand the implications on human performance during adverse scenarios and take it into account when applying countermeasures. It supports the exchange of experience and bridges the gap between the participants in air traffic due to the sole communication via radio. In a normal work environment, ATCOs, pilots and airport staff do not meet face to face. TRM allows direct interaction in a controlled environment, leading to improved teamwork.

Conclusion

In this chapter, safety in air traffic management has been discussed. At first, the specific nature of safety and safety culture within ATM was introduced, and it highlighted that ATC is developed to maintain safety. The special nature of ATC as normally not being directly involved in incidents or accidents shows the special nature of safety within ATC and the subtle difference in safety requirements. Furthermore, this chapter introduced the framework of regulation and legislation on safety within the ATM world and provided an insight on the ICAO, EASA and Eurocontrol regulation, legislation and recommendations. High-reliability organisation theory is key to maintaining safety across the ATM world. The concepts of reliability, resilience and some key organisational methods such as CISM and just culture have been discussed.

Discussion questions

1 What is the main purpose for which air traffic control has been introduced and why?
2 Which (legal) framework accounts for the majority of ANSP safety?
3 Which role does the EASA play?
4 What organisational/technical developments increase the level of safety for air traffic?

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6 Air navigation service provider capacity and delays

Radosav Jovanović

Introduction

This chapter sheds some light on airspace capacity and delays and on-air traffic flow and capacity management principles and practices, which are topics of substantial and growing importance for airlines and passengers and highly influential upon air traffic management performance as a whole.

The chapter begins with a brief overview of global and European traffic development in the last 15 years, including annual figures and an indication of typical seasonal and hourly traffic variations. The airspace capacity matter is then addressed, encompassing key notions – a distinction between declared (nominal) and operational capacity, metrics used, as well as an insight into approaches and methods for determining en-route sector capacities. It continues with discussing general principles for managing capacity and traffic (demand-capacity balancing), including illustrative examples from the European context. The flight delays – consequences of the mismatch between the traffic demand and available airspace capacities are then examined, differentiated across various delay causes and including the estimates of the costs of en-route air traffic flow management delays.

Traffic development

According to International Civil Aviation Organization (ICAO), the total number of passengers carried worldwide on scheduled flights increased by a factor of 2.3 over the last 15 years: from just below 2 billion passengers in 2004 to 4.5 billion in 2019, implying an impressive average annual growth rate of 5.6% over this period. The growth was even more pronounced in passenger-kilometres (pkm), averaging 6.1% per annum over this period, suggesting that average trip length was also increasing. Notably slower, yet solid growth had been achieved in scheduled freight transport (freight tonnes carried), with a 3.3% average annual growth rate between 2004 and 2019 (ICAO, 2014; ICAO, 2020).

The increase in passenger numbers was coupled with strong growth in average load factors: from 73% in 2004 to a record-high 82% in 2018 and 2019.

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Overall weight load factor (i.e. including scheduled passenger and freight transport) also substantially increased, from 61% in 2004 to 68% in 2019 (ibid.).[1]

The World Bank's database offers an insight into historical numbers of 'registered carrier departures worldwide', as supplied by ICAO. According to this database, in 2019, there were 37.5 million registered aircraft departures globally, compared to 23.8 million departures in 2004, suggesting that the number of flights worldwide was increasing at 3.1% per annum on average over this period (Figure 6.1).

In Europe (ECAC[2] area), traffic growth[3] averaged only 1.5% per annum between 2004 and 2019. After healthy growth of traffic in Europe between 2004 and 2007, there was a strong traffic downturn in 2009 (–6.7% vs 2008), owing to the global economic crisis, which was followed by another traffic decline in 2012–2013, resulting in a fact that only in 2016 flight numbers reached the pre-crisis (2008) levels, Figure 6.1. Subsequently, following a few more years of solid growth (2016–2018), ECAC traffic equalled just short of 11.1 million flights in 2019, equivalent to the average daily traffic of 30,371 flights.

Looking at European (ECAC) 2019 monthly traffic data, overall strong seasonality is easily observable. Traffic in peak month was 48% higher than in the lowest-traffic month and about 18% higher than average monthly traffic (Figure 6.2).

Seasonality can be far more pronounced if one looks at traffic volumes of individual air navigation service providers (ANSPs), in particular for what concerns the so-called south-east axis, including airspaces of Greece, Albania, North Macedonia, Bulgaria, Serbia/Montenegro, Croatia, Hungary,

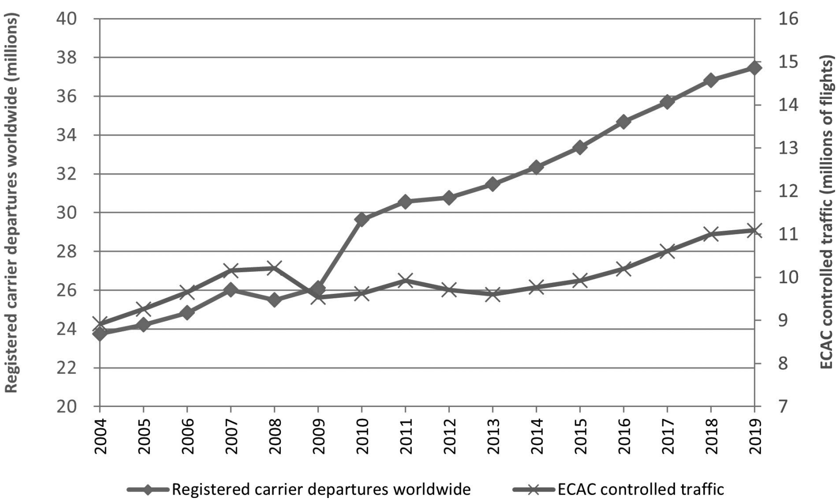


Figure 6.1 Air traffic development in Europe and worldwide, 2004–2019.
Sources: Eurocontrol STATFOR, World Bank

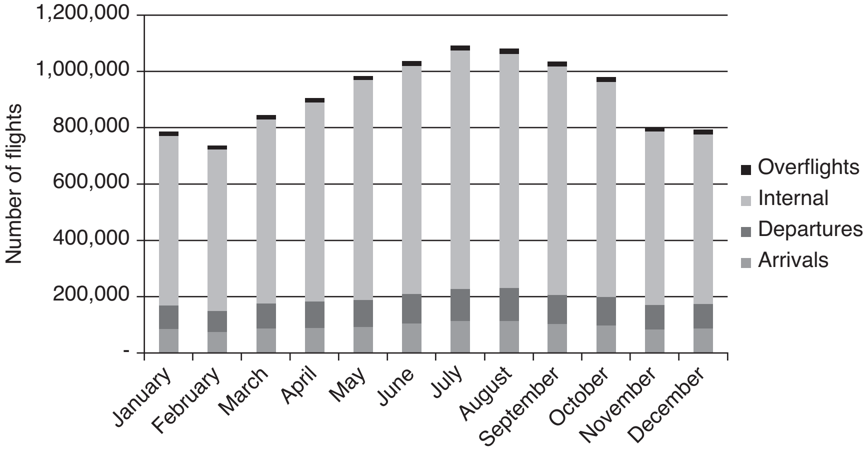


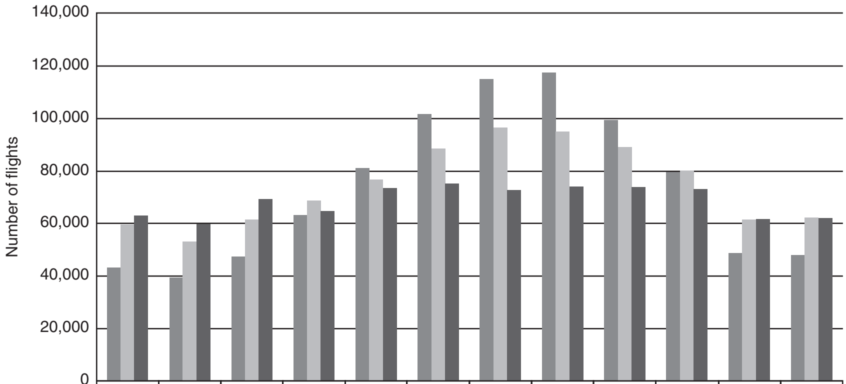
Figure 6.2 ECAC monthly traffic data, 2019.
Source: Eurocontrol STATFOR

Romania, etc. At the same time, far lower-than-average seasonal variation can be found in Northern Europe (e.g. Sweden and Denmark) and Lisbon Flight Information Region (FIR). In Western and Central European ANSPs, there is typically a moderate seasonal variation.

Figure 6.3 tellingly demonstrates how very similar annual traffic levels (884,000 flights in Greece, 892,000 flights in Hungary, 823,000 in Sweden) can be very differently spread over a year in different national airspaces. For example, traffic in the peak month in Greece was three times higher than the lowest month traffic and 1.6 times higher than average monthly traffic in 2019. Far less pronounced but still substantial seasonality can be seen in Hungarian airspace (peak-to-lowest month traffic ratio: 1.82; peak-to-average month traffic ratio: 1.3). A remarkably different monthly pattern is obvious in Sweden, with basically flat traffic levels across the year (peak-to-lowest month traffic ratio: 1.24; peak-to-average month traffic ratio: 1.08).

Because airspace capacity figures by definition refer to shorter time units (typically one hour, as shall be detailed), it is also of interest to reflect upon the hourly distribution of traffic in a given volume of airspace. Figure 6.4 shows an example of hourly traffic distribution in the airspace of SMATSA[4] on a busy summer day in 2018, suggesting a very high variability of controlled traffic volume throughout the day.

Finally, we quickly reflect upon the traffic structure in Europe. In 2019, scheduled traffic[5] catered for nearly 85% of total overall traffic in Europe (ECAC), i.e. about 9.3 million flights (out of 11.1 million total), Figure 6.5. This share of scheduled traffic has been slightly rising over the 2004–2019 period, with however notably increased relative importance of low-cost



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Greece	43,392	39,473	47,641	63,339	81,232	100,536	115,044	117,370	99,375	79,687	48,832	48,169
Hungary	59,488	53,135	61,600	68,761	76,797	87,552	96,687	95,009	89,002	80,113	61,531	62,289
Sweden	63,191	59,814	69,313	64,847	73,676	74,360	72,803	74,290	74,024	73,167	61,766	62,157

Figure 6.3 2019 monthly traffic data for Greece, Hungary and Sweden.
Source: compiled from Eurocontrol STATFOR

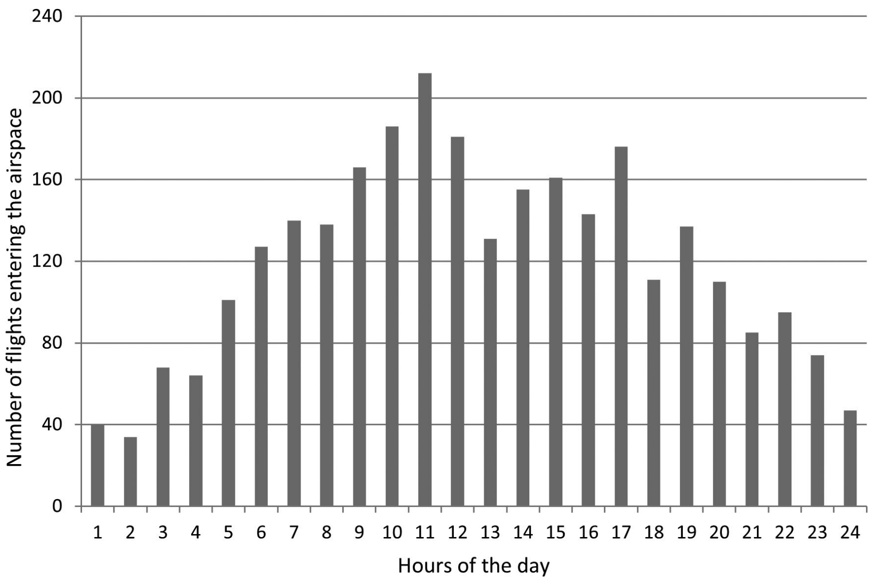


Figure 6.4 Hourly traffic distribution in SMATSA, busy summer day, 2018.
Source: SMATSA

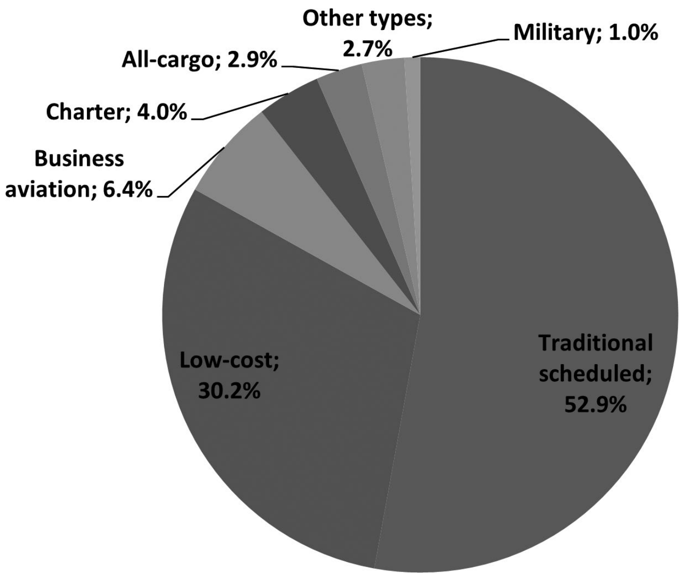


Figure 6.5 Structure of ECAC traffic per carrier's business model, 2019.
Source: Eurocontrol STATFOR

carriers (LCC) compared to traditional scheduled traffic: LCCs' flights represented only 10.6% of total traffic in Europe in 2004, and have reached the 30% share lately. This growth came largely at the expense of decreasing share of scheduled traffic of legacy carriers (from nearly two-thirds of the total in 2004 to 52.9% in 2019) and some decline of charter traffic share over time. The remaining approximately 15% of traffic demand is non-scheduled and is by definition not as predictable for ANSPs concerning its spatio-temporal distribution (i.e. typically reveals itself at much shorter notice, in particular, business aviation and military[6] traffic).

Airspace capacity

Definition and metrics

Operationally, the air traffic flows are controlled by national air traffic control agencies (*Air Navigation Service Providers* – ANSPs), typically responsible for their national airspaces. In Europe, these partial national responsibilities are coordinated and governed by Eurocontrol, a pan-European, civil-military organisation dedicated to supporting European aviation. This organisation was established in 1960; as of 2021, it has 41 member states.

The two notions that are of prime interest when (en-route) airspace capacity is considered are sector and Area Control Centre (ACC). Each has its declared capacity plan, which is normally published to users (Baumgartner, 2007). The European (ECAC) airspace, for example, is fragmented into more than 60 area control centres (ACCs), which are operational units of ANSPs that control both upper and lower airspace and have various sizes and shapes. Those ACCs are further split into more than 730 'sectors' in total (Eurocontrol, 2020c). 'Sector' stands for the smallest element of airspace under specific control, i.e. it is a primary operational component of the airspace structure, and as such can be considered an elementary capacity reference of the air traffic management (ATM) system (Eurocontrol, 2013).

The capacity of a given air traffic management resource (e.g. airspace sector, but also holds for airports) generally refers to its *maximum safe throughput capability* (Flynn, 2014). Capacity is normally expressed as the maximum number of aircraft that can be accepted and handled over a given time period at an ATM resource. The normally measured time period is one hour (ICAO, 2018). The need for capacity measurement and management in air traffic management/air traffic control (ATC) is self-explanatory: it is an essential prerequisite for managing and controlling air traffic demand safely and efficiently.

The capacity for an airspace sector is defined either as an **entry count** (sometimes called 'traffic count'), i.e. the maximum number of aircraft entering an airspace sector in a given time period) or a maximum **occupancy count** (maximum number of aircraft simultaneously present in a sector) over a specific time period (e.g. 15 minutes;[7] Figure 6.6; ICAO, 2018).

Different capacity notions

An important distinction should be made between airspace capacity available under normal (nominal) conditions and that which is made available under – often degraded – actual operational conditions. As shall be detailed, the latter is of particular importance for air traffic flow management (ATFM) solutions, which are based on the expected dynamic operational capacity.

In this respect, CANSO[8] distinguishes between nominal and real-time dynamic capacity. *Nominal (baseline) capacity* is determined assuming ideal conditions, whereas *real-time dynamic capacity* reflects the weather, staffing, equipment failures, and other temporary constraints (CANSO, 2019). The *nominal capacity* for flights that can transit a defined area is determined by several factors including (ibid.):

- Type of surveillance used by ANSP;
- Type of communication used;
- Equipage of aircraft;
- Airspace design; and
- Type of operation.

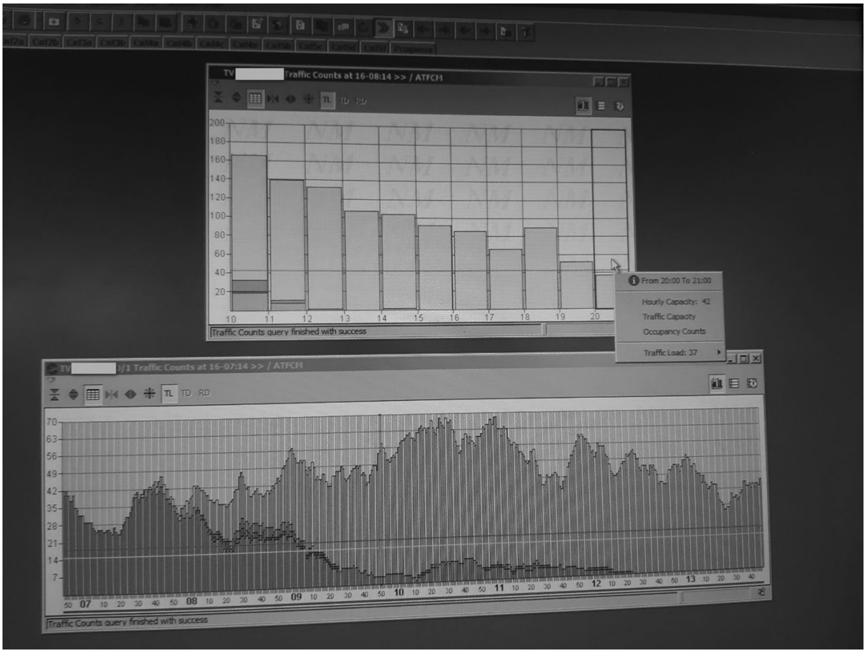


Figure 6.6 Traffic count (above) and occupancy count (below) – an example.
Source: photo courtesy of Fedja Netjasov

Working from the baseline of nominal airspace capacity, the *airspace dynamic capacity* is dynamically adjusted, taking into account various factors such as impacts from (ibid.):

- Convective weather;
- Turbulence;
- Equipment outages;
- Special/flexible use airspace (military activities); and
- Staffing.

ICAO similarly recognises the distinction between the *declared* and *operational* capacity. *Declared capacity* for an airspace sector is defined as the maximum number of flights that can be safely managed, as assessed and declared by the appropriate Air Traffic Services (ATS) authority (ICAO, 2018). On the other hand, *operational capacity* is the expected capacity associated with the tactical[9] situation in the airspace sector. Dynamic factors, including meteorological conditions, Communication/Navigation/Surveillance (CNS) status, fleet mix, military activities, staffing in an ACC may result in an operational capacity inferior to the declared capacity (ibid.).

Table 6.1 Capacity nomenclature across different organisations and authors.

Organisation or author	*Conditions*	
	Normal (nominal)	*Degraded (actual)*
ICAO	Declared capacity	Operational capacity
CANSO	Nominal (baseline) capacity	Real-time dynamic capacity
Skyguide	Standard capacity	Declared capacity
Welch et al., 2007	Design capacity	Dynamic capacity

Skyguide (Swiss ANSP), on the other hand, uses similar terms as ICAO, yet in a notably different fashion. More specifically, *standard capacity* refers to the capacity of a given sector in normal operational conditions. In contrast, *declared capacity* refers to sector capacity actually (made) available (i.e. under current/actual operational conditions). In the Skyguide terminology, declared capacity is lower than standard capacity if operational conditions are degraded, owing to any factors already mentioned above (Herda, 2020).

In summary, while the concepts of nominal and actual sector capacity are very much self-explanatory, the terminology used by different relevant organisations and researchers is not entirely harmonised (unified), as summarised in Table 6.1.

Approaches and methods to determine ATC sector capacity

Several factors influence sector capacity, including separation standards, traffic complexity, airspace design, CNS/ATM system availability, ATM factors, human factors, weather, etc. (ICAO, 2018). In general terms, air traffic *complexity* is a concept introduced to measure the difficulty and effort required to safely and efficiently manage air traffic (Prandini, 2010). Slightly less vaguely, air traffic complexity can be defined as 'the level of either perceived or actual spatial and time-related interactions between aircraft operating in a given airspace during a given period' (Pejović et al., 2020). However, there is no consensus concerning a specific/detailed definition and the corresponding measurement of complexity[10].

When it comes to methods of assessing and establishing the capacity of an ATC sector, ICAO (2018) identifies two principal schools of thought:

1. **Mathematical occupancy and complexity models**; and
2. **Controller workload assessment models**. The term *workload* generally refers to the mental and physical work done by the controller to control traffic (Majumdar & Polak, 2001).

Whichever method is employed, it is essential that the capacity calculated using these models be subsequently validated by other means, e.g., real-time observations or real-time simulations (ICAO, 2018).

The first class – mathematical occupancy and complexity models for sector capacity assessment – take account of factors such as (ibid.):

(a) Traffic profile: cruise, climb, descent;
(b) Traffic mix: light, medium, heavy aircraft;
(c) Speed mix;
(d) Number and types of typical ATC interventions;
(e) Sector flight times; and
(f) Default workload per flight.

The model developed by Janić and Tošić (1991) may be considered one of the earliest examples of such an approach, largely employing a 'geometric point of view'. The authors developed a simple model to compute the expected capacity of an ATC en-route sector, given its geometry (including the number of sector entry points and the configuration of air routes), traffic characteristics for a specified period of time (temporal and spatial distribution of demand, aircraft mix, etc.) and ATC separation rules, taking no explicit account of human factor, i.e. of air traffic controller (ATCO) workload on calculated sector capacity. Expected sector capacity was calculated under saturation conditions (i.e. presence of continuous/constant demand for service at each entry point). The model was intended to analyse the 'possible partitioning of an air route network into sectors together with an analysis of ATCO workload in different sector schemes' (Janić and Tošić, 1991).

More recently, CANSO suggests that nominal sector capacity can be calculated based on years' worth of operational data analysis. To do so, the type of traffic operation should be divided into various categories, including (CANSO, 2019):

- 'Cruise operation with low separation assurance duties (parallel traffic with altitude separation).
- Cruise operation with high separation assurance duties (crossing traffic).
- Transitioning traffic with low and high separation assurance duties (arrival and departure traffic).
- Delay inducing traffic (airborne holding).'

Once the share of each type of operation is established for each sector, and the average workload for each type of operation is assigned, the capacity for each sector can be calculated. Presently predominant school of thought on sector capacity assessment heavily relies on the *human factor*, meaning that sector capacity is often directly deducted from the assessed associated ATCO workload. Such an approach is motivated by recognising that the controller workload is a key driver of airspace capacity in high traffic density areas (Majumdar et al., 2005). This is because the controller workload is highly correlated with the *air traffic complexity*, which is in turn linked mainly to: *occupancy*, i.e. number of flights present in a sector (sometimes referred to as *aircraft density*), number of *climbing /descending flights* (related to potential vertical interactions), sector *entry/exit coordination* actions, etc. (Herda, 2020).

In such a context, the second class – controller workload assessment models for sector capacity assessment – break down the controller workload into a set of definable and measurable tasks for which average execution times are defined. These tasks typically include coordination, handling flight data, radiofrequency, communications and conflict management (ICAO, 2018). Since the amount of mental reasoning a controller uses cannot be explicitly measured, the workload is represented by a proxy, e.g., summing the average execution times of individual tasks that a controller undertakes (Flynn et al., 2005). Then an acceptable workload threshold (% of the time during an hour) is usually established, and capacity is assessed to be at the point where this threshold is reached, see Figure 6.7. The models from this class require intensive participation by the control staff in establishing task execution workload metrics (Flynn et al., 2005; ICAO, 2018).

For example, in the course of Eurocontrol's *Complexity and Capacity* (COCA) project the *Macroscopic Workload Model* was developed, using the following simplified formula for workload calculation (Flynn et al., 2005):

$$WL = t_{AC} \cdot O_{AC} + t_{Cnf} \cdot O_{Cnf} + t_{Cl} \cdot O_{Cl}$$

where: WL is workload; O_{AC}, O_{Cnf}, O_{Cl}, are the occurrences of routine, conflict and climb/descent tasks during the time period considered (one hour), respectively; t_{AC}, t_{Cnf}, t_{Cl} are the duration times of routine, conflict and climb/descent tasks, in seconds, respectively.

In the same study the resulting workload threshold values were interpreted as shown in Table 6.2.

To estimate en-route capacity, ANSPs have traditionally employed 'fast-time' (or 'model-based') simulation (FTS) techniques – i.e. computer modelling of controller workloads[11] (Majumdar et al., 2005). The outputs of the simulations are then typically post-processed to formulate a relationship between the number of aircraft entering the sector and the workload associated with controlling traffic in the sector over a given period of time (ibid.), similarly as presented in Figure 6.7.

More recently, there have been attempts to derive an aggregate functional relationship between a range of air traffic and sector factors[12] and controller workload. As opposed to the aforementioned *simulation models*, Welch et al. (2007), for example, developed a general *analytical macroscopic workload model* to quantify the impact on ATCO workload of the following factors:

- Traffic density;
- Sector geometry;
- Flow direction; and
- Air-to-air conflict rates.

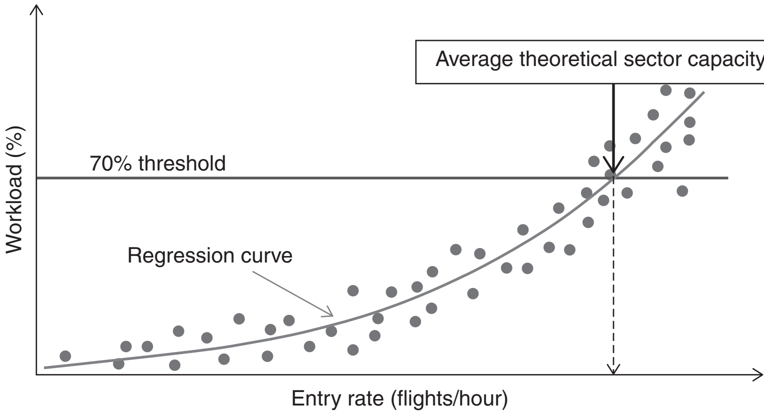


Figure 6.7 Relationship between controller workload and theoretical sector capacity.
Source: adapted from Herda (2020)

Table 6.2 An example of used workload thresholds in a task-based workload model.

Workload threshold	*Interpretation*	*Recorded working time during 1 hour*
≥ 70%	Overload	≥ 42 minutes
54% – 69%	Heavy load	32–41 minutes
30% – 53%	Medium load	18–31 minutes
18% – 29%	Light load	11–17 minutes
0% – 17%	Very light load	0–10 minutes

Source: Flynn et al. (2005)

This work also came in response to arguably inadequate subjective thresholds[13] used for representing design capacity, as used by traffic flow managers in the United States (US). In subsequent work, postulating that controller workload is the main determinant of sector capacity, Welch (2015) proposed/developed a workload-based capacity model for en-route ATC sectors. Unlike the uni-dimensional model previously used by the US Federal Aviation Administration ('Monitor Alert' model, based solely on 'handoff workload'), this new model explicitly considered three controller workload types (Welch, 2015):

- 'Handoff (transit) workload', related to mean sector transit time (average time required for aircraft to fly through the sector);
- 'Conflict workload', which occurs when the controller team perceives a potential loss of separation; and
- 'Recurring workload' results from periodic activities such as surveillance monitoring, vectoring, metering, and spacing.

Managing capacity and traffic – principles and European examples

Demand-capacity balancing – acting on the capacity side

As already mentioned, the European en-route airspace is fragmented into more than 60 area control centres (ACCs), with the airspace of each ACC being further divided into sectors. Each sector represents a volume of airspace managed by one or more air traffic controllers (ATCOs).

In total, the European airspace is divided into hundreds of so-called *elementary* sectors, which can be assembled into larger units – sectors.[14] Any specific combination of sectors covering the entire airspace volume for an ACC is called a *sector configuration* (see Figure 6.8).

Based on anticipated traffic in their airspace for a considered day of operations, knowing capacities of individual sectors, ACCs plan how many ATCOs need to be at their positions to safely and efficiently manage traffic, that is, how many sectors should be opened during the day. As a principle, everything else being equal: the more sectors are open, the more traffic an ACC can handle for a longer period. However, this principle holds in a limited domain, i.e. there is a practical ('structural') limit to increasing the number of sectors. In addition, it should be noted that there is a diminishing marginal throughput gain of opening additional sectors, i.e. increase in ACC throughput capability is slower than an increase in the number of open sectors (Wangnick, 2020).

In line with the above, the capacity of an ACC can be defined as 'the theoretical maximum number of flights that may enter an ACC per hour, over a period of time (e.g. 3 hours), without causing excessive workload in any of the sectors' (Eurocontrol, 2013). Nevertheless, this capacity indicator is used primarily for capacity planning and monitoring purposes and has no operational value (ibid.).

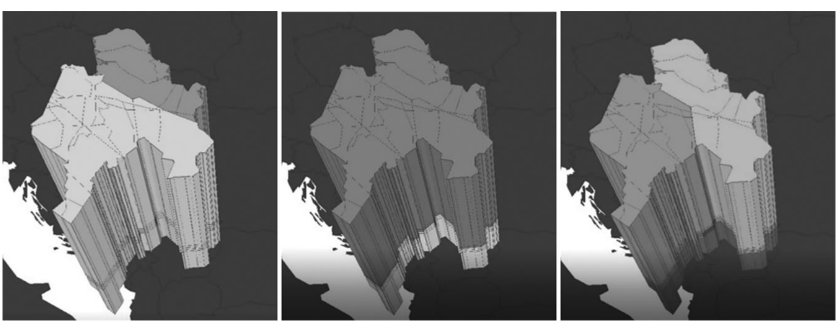


Figure 6.8 SMATSA: three different sector configurations.
Source: Eurocontrol NEST

The capacity (or, precisely speaking, the *throughput capability*) provided by an ACC for a given day of operation effectively depends on (Herda, 2020):

(a) Whether the sectors in that ACC have sufficient capacity to accommodate the traffic, i.e. is there a sector configuration that theoretically allows handling the expected traffic?
(b) Suppose the answer to A is 'yes'. In that case, the question that follows is if that sector configuration can be open provided that there is a sufficient number of controllers available to facilitate/deliver it?

The answer 'no' to either A or B implies an imbalance between capacity and demand. If so, certain actions need to be taken, ideally first by acting on the capacity side, i.e. making the best use of available capacity, and only then, if needed, acting on the demand side, i.e. modifying the spatio-temporal profile of demand to safely and efficiently fit it into available capacities. These efforts traditionally fall under the *air traffic flow and capacity management* (ATFCM) heading/service and are more recently also labelled *demand capacity balancing* (DCB). The capacity- and demand-management measures are naturally heavily interrelated. The demand-side measures (i.e. air traffic flow management – ATFM) will be discussed in the next section, while here, we will briefly reflect upon the capacity management process.

As a digression, it should be noted that capacity management is also related to the third branch of the ATM service[15] – *air space management* (ASM). Recognising that airspace is a valuable resource, ASM involves planning, sector definition, use and management of airspace to satisfy the needs of airspace users in the most efficient and equitable manner (Eurocontrol, 2021). This, however, typically occurs more than a year before the day of operations.

Capacity planning in an ACC for a specific day of operations starts 6–12 months in advance[16] (Tobaruela et al., 2013; see Figure 6.9).

Acting on the capacity side of the capacity-demand inequality in the course of ATFCM involves optimising the utilisation of (potentially) available capacity to align it as much as possible with the demand profile. This may involve measures such as (Eurocontrol, 2021):

- Sector management – adjusting sector configuration (for a given number of sectors), adapting a number of sectors (e.g. opening additional sectors compared to the plan), collapsing/splitting the sectors, etc.;
- Balancing arrival/departure capacity; and
- Central body (e.g. Network Manager[17]in Europe) negotiating extra capacity with ACCs involved, by means of (upwardly) adjusting declared capacities (e.g. occupancy counts), etc.

The ATFCM execution process in Europe (ECAC region) is carried out in four phases (Eurocontrol, 2021; ICAO, 2018; Figure 6.9):

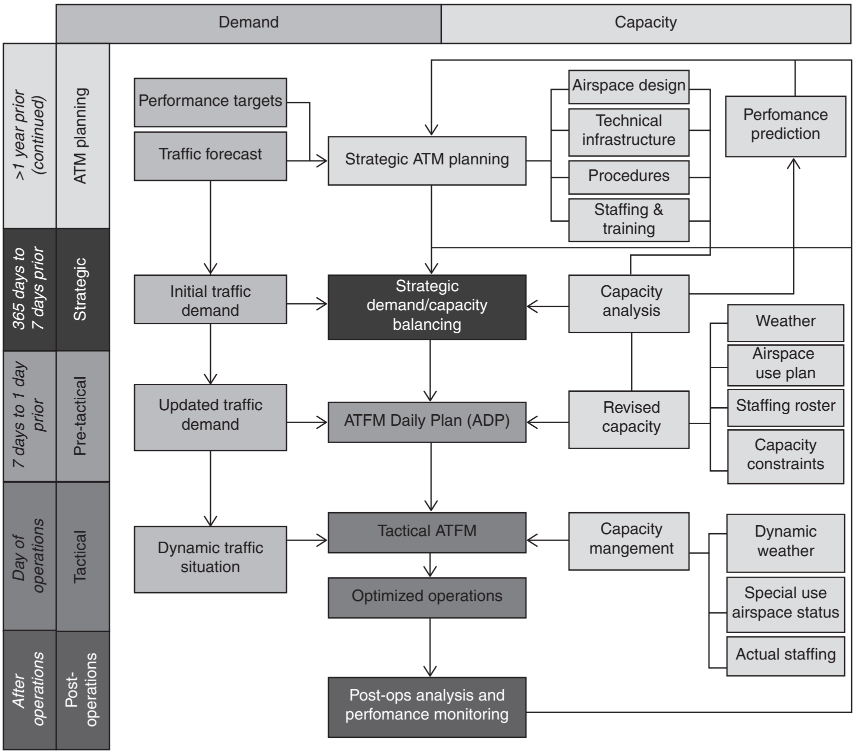


Figure 6.9 ATM planning and ATFCM phases.
Source: adapted from ICAO (2018), courtesy of ICAO

1 *Strategic phase* occurs seven days or more (up to a year) before the day of operation when long-term capacity-demand matching is planned, i.e. early indications of potential demand/capacity imbalances. A great deal of this work is accomplished two months or more in advance (ICAO, 2018). The output of this phase is the *strategic plan*, which is called the Network Operations Plan (NOP) in a European context.

2 *Pre-tactical phase* takes place in the last week before the day of operation. During this time, the strategic plan is adapted to update demand, employing a collaborative decision-making (CDM) process between the stakeholders. More specifically, in Europe, this phase examines the demand for the day of the operation, compares it with the predicted available capacity on that day, and makes any necessary adjustments to the plan (NOP) developed during the Strategic phase. The main objective of the pre-tactical phase is to optimise capacity through an effective organisation of resources (e.g., sector configuration management, use of alternate flight procedures). The output of this phase is the ATFCM Daily Plan

(ADP), which describes the necessary capacity resources and if needed, the measures to manage the traffic (Eurocontrol, 2021; ICAO, 2018).

3 *Tactical phase* takes place on the day of operations, with necessary updates made to the ADP, as actual traffic and capacity become known. This phase ensures that the measures taken during the strategic and pre-tactical phases solve the demand/capacity imbalances. The need to adjust the original plan may result from disturbances such as staffing problems at ACCs, significant weather phenomena, equipment failures, crises and special events, etc. and taking advantage of any opportunities that may arise (ibid.).
4 *Post-operations analysis* is the final phase in ATFCM, which effectively closes the loop and feeds back to the strategic ATM planning. During this phase, analyses are carried out to measure, investigate and report on the effects (outcomes) of relevant operational processes and activities. This phase thus compares the anticipated outcome with the actual measured outcome, typically in terms of delay and route extension. Post-operations analysis is of substantial importance for developing best practices and consequently improving operational processes and activities (Eurocontrol, 2021; ICAO, 2018).

Demand-capacity balancing: acting on the demand side – ATFM measures

During the pre-tactical and tactical phases of ATFCM, should the forecasted demand exceed the capacity of an airspace sector (or an airport), an ATFM measure may need to be implemented to balance demand and capacity. ATFM measures are thus techniques used to manage ('regulate') air traffic demand according to system capacity[18] (ICAO, 2018), i.e. to ensure that available airspace capacities can accommodate traffic loads in a safe, efficient and non-discriminatory manner. We here remind of the principle that ATFM measures should only be implemented when other solutions to optimise the capacity of a resource have been exhausted (CANSO, 2019).

In the following list, we briefly reflect upon the commonly used ATFM measures, summarised in Table 6.3.

- **Ground delay programme** (GDP) is a pre-tactical or tactical ATFM measure used to manage demand in a volume of airspace or at an airport by holding aircraft (part of excessive demand) on the ground. In the course of GDP flights are assigned departure times ('ATC slots') which correspond to entry times at the constrained airspace sector or arrival time at the constrained airport (ICAO, 2018; CANSO, 2019). GDPs principally aim to reduce airborne holding and tactical ATC actions (radar vectoring, speed control, etc.) – which would otherwise expectedly arise – by delivering a flow manageable for the conditions to the point of constraint. Transferring the delay from the airborne phase to the ground

Table 6.3 Summary of traditional ATFM measures.

ATFM measure	*Constraint*			*Control mechanism*	*Timeframe*
	Airport arrivals	*Airport departures*	*Airspace*		
Ground delay programme	X	X	X	Calculated take-off time (CTOT)	Pre-tactical and tactical
Re-route			X	Flight path change (in horizontal or vertical plane) to avoid constraint	Pre-tactical and tactical
Miles in trail / Minutes in trail	X		X	Time- or distance-based separation on a single stream of traffic	Tactical
Minimum departure intervals	X		X	Time-based separation from departures from the same airport	Tactical
Fix balancing	X		X	Flight path change to avoid constraint	Tactical
Level capping			X	Flight path change (in vertical plane) to avoid constraint	Tactical
Ground stop	X			Prevent departures from specific airports to address existing tactical load on an arrival airport	Tactical

Source: adapted from ICAO (2018)

phase of a flight increases both safety and efficiency (CANSO, 2019). A variant of GDP applied in Europe will be reflected later in the text.

- **Miles in trail** (MIT) and **minutes in trail** (MINIT). MINIT and MIT are tactical ATFM measures implemented when there is a requirement to increase the spacing between aircraft to manage the flows of aircraft into a sector or airport that is anticipated to have a demand/capacity imbalance. They are expressed as the number of minutes or miles between each successive aircraft at airspace or airport boundary point (ibid.).
- **Minimum departure intervals** (MDIs). 'MDIs are tactical ATFM measures and are applied by setting a rate of departure flow of, as an example, 3 minutes between successive departures from a single airport. MDIs are typically applied for short periods when a departure sector becomes excessively busy, when sector capacity is suddenly reduced (due to equipment failure, meteorological conditions, etc.), or to support

demand smoothing at an arrival airport exhibiting a short-term demand/capacity imbalance' (ICAO, 2018).

- **Re-routings**: route-based ATFM measures (horizontal or vertical) aim to remove (offload) a number of flights scheduled to arrive at a constrained ATM resource so that traffic load does not exceed its available capacity. Re-routings are typically organised in scenarios and can be mandatory or advisory (CANSO, 2019).
- **Level capping scenarios** are carried out by means of vertical (flight level) restrictions limiting climbs or descents to avoid congested areas (ibid.).
- **Fix balancing**. This tactical ATFM measure, usually applied during flight, aims to distribute demand and avoid delays. With this measure, the aircraft is assigned a different arrival or departure fix than the one indicated in the flight plan (ICAO, 2018).
- **Ground stop** (GSt) is a tactical ATFM measure taken in reaction to an unpredicted adverse situation at the arrival airport, e.g. runway closure due to aircraft accidents/incidents or significant meteorological event, or to preclude an airspace sector or ACC from reaching near-saturation levels or airport gridlock. GSt means that some selected aircraft remain on the ground. It is also sometimes known as a 'zero rate ATFM measure' (ibid.).

As ATFM systems and experience keep developing, variations and new types of ATFM measures have started emerging. Those are primarily short-term measures, which effectively bridge the gap between ATC and ATFM.[19] They usually consist of ATC actions that have an ATFM purpose or use aircraft capabilities to ensure a requested time of arrival at the constrained ATM resource (ibid.).

Short-term ATFM measures (STAM). Such measures are typically variations of traditional measures described above, aiming at smoothing sector workloads by reducing traffic peaks through the short-term application of MDI and flight level capping. STAMs are normally selected and implemented tactically by air traffic controllers rather than regional[20] ATFM units. They are usually of very limited duration and are applied to individual flights or small numbers of flights using a constrained ATFM resource (ibid.).

Calculated time over (CTO) and *required time of arrival (RTA).* Most modern aircraft and aircraft operators' flight planning systems can fully integrate the required time at the constrained resource directly into their flight management system and trajectory plan. This means that such a flight can manage its speed to meet the ATFM constraint with a high degree of accuracy. In this way, the compliance responsibility for ATFM measures is delegated more to the airspace user, while the ATS unit has an oversight role (ibid.).

Cherry picking. As opposed to ATFM measures traditionally applied to a traffic flow, e.g., to all flights planned to use an ATM resource, with cherry picking techniques a small number of flights are assigned delays or re-routing to meet capacity constraints without regulating the entire traffic flow. Such targeted measures have been demonstrated to reduce overall delay (ibid.). In Europe, for example, the so-called *Mandatory Cherry Pick* regulation is used as a measure to solve short peaks (e.g. 1 h or 1.5 h) of a limited number of flights in congested areas. It consists of selecting flights that generate complexity and applying ATFCM measures only to those flights (Eurocontrol, 2021).

Since some further detail of ATFM delays in a European context is forthcoming in the next section, the coming paragraphs will first shed some more light on the principles and mechanics of the slot-based ATFM regulations in Europe as a long-established practical representative of ground delay programmes.

Slot-based ATFM measures in Europe

It has already been mentioned that each ACC and sector in Europe have their declared capacity plans. Those are published to users and the Network Manager Operations Centre (NMOC). The NMOC provides ATFCM service to airspace users throughout the ECAC states. To do so, the NMOC receives filed flight plans (airspace users' desired 4D flight profiles) as well as the declared sector and ACC capacities from the European ANSPs. The window for filing a flight plan to the NM's flight plan processing system is between 3 and 120 hours in advance of that flight's estimated off-block time (EOBT) (Eurocontrol, 2020a).

NMOC can calculate the ('unconstrained') traffic demand in every airspace sector within its area of responsibility based on received flight plans. Having obtained the capacity information, it then compares planned traffic demand (based on filed flight plans with requested 4D flight profiles) and declared departure airport, arrival airport and en-route sector capacities. When filed traffic demand is forecast to exceed the available capacity of an ATM network element (typically ATC sector or an airport), *an ATFM 'regulation'* is imposed[21] to prevent an overload, i.e. to keep the traffic load within acceptable limits.

In the course of an ATFM regulation, flights subject to regulation are assigned new take-off times – 'calculated take-off times' (CTOTs) through so-called *ATFM take-off slots* (time windows). This is done in an automated centralised process using the *computer assisted slot allocation* (CASA) algorithm. Each flight whose CTOT is worse (i.e. later) than its original take-off time gets delayed. The system of ATFM slot allocation in Europe employs the 'first planned – first served' principle in the following manner: the system extracts all the flights entering the specified (regulated) airspace and sequences them in the order they would have arrived at the airspace in the absence of any restriction. On this basis, the Take-Off Time for the flight is calculated. Calculated Take-Off Time (CTOT) information is transmitted to the aircraft operator concerned and to the control tower at the airport of departure (Eurocontrol, 2021).

ATFM regulations may therefore give rise to the so-called *ATFM delay,* which is calculated as the duration between the last take-off time as requested by the aircraft operator in the flight plan (ETOT) and the calculated take-off time (CTOT) allocated by the Network Manager in the course of the ATFM regulation (European Observatory on Airport Capacity and Quality, 2015). The CTOT issued to a flight as part of the ATFM regulation become the ATC slot. Affected ('regulated') flights will need to ensure that they take off within the specified compliance window, typically –5 minutes and +10 minutes of the ATC slot assigned (CANSO, 2019).

Delays

Delay definitions

Delay can most generally be defined as the time lapse which occurs when a planned event does not happen at the planned time (European Observatory on Airport Capacity and Quality, 2015). In air transport, obvious reference times are contained in the published airlines' flight schedules, so one can then distinguish between, e.g. *departure delay* (difference between actual and scheduled departure time) and *arrival delay* (difference between actual and scheduled arrival time).

However, when it comes to air navigation services provision and its contribution to air transport delays, more specific and detailed notions/definitions of delay are typically used. Here one frequently comes across the following notions (Eurocontrol PRC, 2002):

- *Air Traffic Flow Management (ATFM) delay*: delay at departure caused by ATFM regulations (either en-route or airport). ATFM delay is calculated concerning filed flight plans and is based on the difference between calculated take-off time (CTOT)[22] and the last estimated take-off time (ETOT).[23]
- *En-route ATFM delay* then stands for the ATFM delay caused by en-route regulations (i.e. the reference location, in this case, is airspace or special point).
- *Airport ATFM delay* analogously stands for the ATFM delay caused by airport regulations (i.e. the reference location, in this case, being aerodrome or aerodrome zone).

These notions and distinctions deserve some further elaboration, which will relate primarily to the European context, where numerous stakeholders are involved. Except for more than 100 airlines and hundreds of airports, there are also about 40 ANSPs and the Network Manager (NM), which manages the entire European ATM Network. While carriers (and to a large extent airports) are chiefly interested in 'all-causes delay', ANSPs and the NM focus on measuring only a part of all-causes delay – the aforementioned ATFM delay.

Causes of flight delays in Europe are systematically recorded and analysed by the Eurocontrol Central Office for Delay Analysis (CODA), which aims to provide consistent and comprehensive information on the air traffic delay situation in Europe. The data is provided by aircraft- and airport operators and includes information on delay causes, using delay codes established by the International Air Transport Association (IATA). CODA publishes monthly reports for airlines and quarterly, seasonal and annual public digests on delays to air transport in Europe, using its classification based on IATA delay codes. Table 6.4 shows the relationship between IATA standard delay codes and the CODA reporting format. It can be seen that CODA categorisation distinguishes between six large groups of primary delay causes only (airline, airport, en-route, weather, 'governmental', and miscellaneous), each comprised of akin delay causes as defined in IATA classification. CODA 'reactionary' group comprises IATA delay codes 91–96.

An ATFM regulation, described in the previous section, imposes *ATFM delay* for each flight for which the Calculated Take-Off Time (CTOT) allocated by the NM is later than the last take-off time requested by the aircraft operator in the flight plan (ETOT) (European Observatory on Airport Capacity and Quality, 2015). Each ATFM regulation is explicitly attributed to a specific reason for its activation[24]. Regulation reasons include ATC Capacity,

Table 6.4 Departure delay causes – classification by IATA and Eurocontrol CODA.

CODA cause	*Description*	*IATA Code*
	Primary delays	
Airline	Passenger and Baggage	11–19
	Cargo and Mail	21–29
	Aircraft and Ramp Handling	31–39
	Technical and Aircraft Equipment	41–49
	Damage to Aircraft and EDP/Automated Equipment Failure	51–58
	Flight Operations and Crewing	61–69
	Other Airline Related Causes	Others
Airport	ATFM due to Restriction at Destination Airport	83
	Airport Facilities	87
	Restriction at Airport of Destination	88
	Restriction at Airport of Departure	89
En-route	ATFM due to ATC En-route Demand / Capacity	81
	ATFM due to ATC Staff / Equipment En-route	82
Governmental	Security and Immigration	85–86
Miscellaneous	Miscellaneous	98–99
Weather	Weather (other than ATFM)	71–79
	ATFM due to Weather at Destination	84
	Reactionary delays	
Reactionary	Late Arrival of Aircraft, Crew, Passengers or Load	91–96

Source: Eurocontrol (2020b)

ATC staffing, weather, industrial action, etc. See standardised pre-defined classification in Table 5. The regulation reason is used to ensure that accurate and consistent information is provided to users and at the same time contributes to correct statistical analysis. The delay cause assignment of an ATFM delay relates to the relevant ATFM regulation reason and location (ibid.).

Table 6.5 A classification of ATFM regulation reasons as applied in Europe.

Regulation reason	*Guidelines for application*
ATC Capacity	En-route: Demand exceeds, or complexity reduces declared or expected ATC capacity Airport: Demand exceeds declared or expected ATC capacity.
ATC Industrial Action	Reduction in any capacity due to industrial action by ATC staff.
ATC Routeings	Network solutions/scenarios used to balance demand and capacity
ATC Staffing	Unplanned staff shortage reducing expected capacity.
ATC Equipment	Reduction of expected or declared capacity due to the non-availability or degradation of equipment used to provide an ATC service.
Accident / Incident	Reduction of expected ATC capacity due to an aircraft accident/incident.
Aerodrome Capacity	Reduction in declared or expected capacity due to the degradation or non-availability of infrastructure at an airport, e.g. work in progress, shortage of aircraft stands etc. Or when demand exceeds expected aerodrome capacity.
Aerodrome Services	Reduced capacity due to the degradation or non-availability of support equipment at an airport, e.g., fire service, de-icing / snow removal equipment, or other ground handling equipment.
Industrial Action NON ATC	A reduction in expected/planned capacity due to industrial action by non-ATC personnel.
Airspace Management	Reduction in declared or expected capacity following airspace/route availability changes due to small scale military activity.
Special Event	Reduction in planned, declared or expected capacity or when demand exceeds the above capacities due to a major sporting, governmental or social event. It may also be used for ATM system upgrades and transitions. Large multinational military exercises may also use this reason. This category should only be used with prior approval during the planning process.
Weather	Reduction in expected capacity due to any weather phenomena. This includes where weather impacts airport infrastructure capacity but where aerodrome services are operating as planned/expected.
Environmental Issues	Reduction in any capacity or when demand exceeds any capacity due to agreed local noise, runway usage or similar procedures. This category should only be used with prior agreement in the planning process.
Other	This should only be used in exceptional circumstances when no other category is sufficient. An explanatory ATFM Notification Message remark must be given to allow post ops analysis.

Source: Eurocontrol (2021)

Examples of the difference between the ATFM delay and delay all-causes calculation method are illustrated through two examples below (European Observatory on Airport Capacity and Quality, 2015).

Setting: Flight ABC123 from airport XXX to airport YYY has an STD (Scheduled Time of Departure as communicated to the passengers) at 10.00h. This is aligned with the strategic (departure) airport slot[25] obtained for 10.00h.

Situation 1: The airline does not anticipate a departure delay and has filed the ICAO flight plan with an EOBT (Estimated Off-Block Time) at 10.00h. The Network Manager (NM) will calculate an Estimated Take-Off Time (ETOT) at 10.15h based on the EOBT taking into account 15-minutes taxi-out time. The capacity in one of the en-route sectors that this flight is planning to cross is reduced due to a technical problem at that Area Control Centre (ACC). Therefore, an ATFM regulation is issued, which results in an ATFM en-route delay of 60 minutes to avoid over-deliveries (i.e. traffic exceeding declared capacity) in that sector. The 10.15h ETOT of flight ABC123 will become a CTOT at 11.15h, resulting in an ATFM delay of 60 minutes.

At 10.00h (i.e. at the scheduled time of departure), not all passengers have boarded the aircraft due to a problem at immigration. All aircraft doors were finally closed at 10.15h, but the aircraft was still delayed due to the ATFM Regulation. At 10.58h, the aircraft departed from the gate after the start-up was given.

The total ATFM delay as calculated by the NM remained unchanged at 60 minutes (= CTOT – ETOT).

The delay all-causes reported by the airline is driven by the ATFM delay but has another delay absorbed within the ATFM delay. The airline will report an actual departure delay of 58 minutes (= AOBT – STD) split between 43 minutes en-route ATFM delay (IATA delay code 81) and 15 minutes due to issues at immigration (IATA delay code 86).

Situation 2: The airline anticipates a departure delay of 90 minutes due to the late arrival of the aircraft from a previous flight. The airline has consequently filed the ICAO flight plan with an EOBT (Estimated Off-Block Time) at 11.30h, with the STD remaining unchanged at 10.00h. The NM will calculate an Estimated Take-Off Time (ETOT) at 11.45h based on the EOBT taking 15-minutes taxi-out time into account. The capacity in one of the en-route sectors is reduced due to a technical problem at that ACC. An ATFM regulation is therefore issued, which results in an ATFM en-route delay of 10 minutes to avoid over-deliveries in that sector. The 11.45h ETOT of flight ABC123 will become a CTOT at 11.55h, resulting in an ATFM delay of 10 minutes. At 11.30h (at the EOBT) all passengers have boarded the aircraft and all doors are closed. At 11.40 the aircraft departed the gate after start-up was given.

In this case, for NM the total ATFM delay of flight ABC123 was 10 minutes (= CTOT – ETOT). For the airline, the departure delay all-causes was

1h40 (= AOBT – STD) split between 90-minutes reactionary delay (IATA delay code 93) and 10 minutes due to en-route ATFM delay (IATA delay code 81).[26]

Magnitude, causes and distribution of all-causes and en-route ATFM delays in Europe

All-causes delays

To get a flavour of the broader delay situation in Europe, here is a closer look at Eurocontrol Central Office for Delay Analysis (CODA) figures. In 2019 average all-causes departure delay per flight was 13.1 minutes (down from 14.7 minutes in 2018), of which 7.4 minutes was the so-called 'primary' delay, and the remaining part was categorised as 'reactionary' delay[27]. Looking then at average causes of primary delays, nearly a half – about 3.4 minutes – was attributed to 'airlines', with ATFM en-route contributing about 1.5 minutes, whereas ATFM airport delays were slightly below 1 minute, on average, and weather contributed additional 0.5 minutes, on average (Eurocontrol, 2020b).

It should be noted that, over the past five years, persistently more than 40% of all flights were delayed ≥5 minutes at departure in Europe. Average departure delay for such (i.e. delayed) flights ranged between 26 and 30 minutes per flight in this period (ibid.). Importantly, in particular for what concerns the associated/resulting cost of delay (as shall be detailed), 4.3% of flights experienced (all-causes) departure delay longer than 60 minutes in 2019 (vs 5.2% in 2018). These longer delays are unsurprisingly particularly pronounced during summer months, due to airline-related causes, insufficient capacities (be it en-route or at airports) to accommodate peak traffic demand, and often due to adverse weather and industrial actions (ibid.).

It should be stressed that airlines and passengers are naturally more concerned with delays on arrival than on departure. Yet, the two are very much collinear and follow very similar trends (e.g. in 2019 average all-causes arrival delay was 12.2 minutes per flight, compared to 13.8 minutes in 2018) (ibid.).

En-route ATFM delays

Figure 6.10 shows the evolution of average daily ECAC traffic and average en-route ATFM delay per flight between 2004 and 2019. Apart from a clear outlier in 2010, there was most of the time a fairly evident trend indicating, on a network level, a close-to-linear relationship between traffic volume and en-route ATFM delays: in particular between 2004 and 2009, and then 2012–2017. However, as traffic kept growing, uncoupled by an adequate capacity profile, this relationship became strikingly non-linear. More specifically, while traffic increased by 3.8% in 2018 compared to 2017, en-route ATFM delays doubled! In 2019 slight improvement in delay levels was

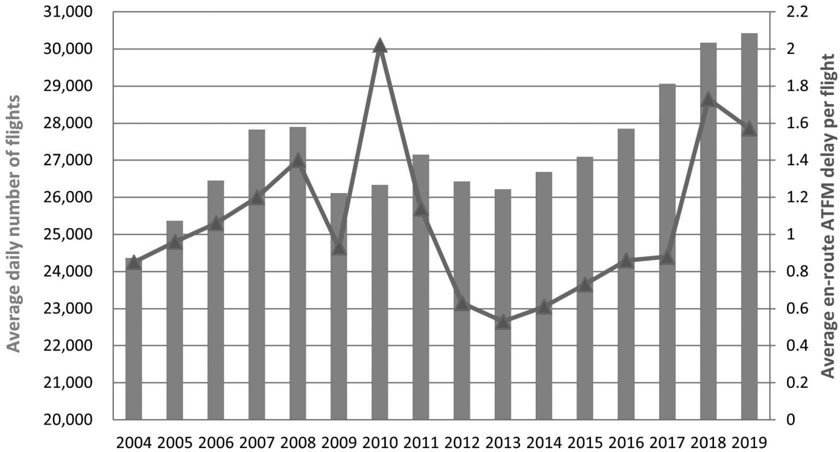


Figure 6.10 ECAC average daily traffic and average en-route ATFM delay, 2004–2019.
Source: compiled by the author from Eurocontrol (2020c) and Eurocontrol Performance Review Reports 2004–2009

witnessed, despite increased traffic, due to coordinated measures taken to better utilise available capacities in the network (Eurocontrol PRC, 2020). It should be underlined that spatial distribution of delays in Europe is typically far from uniform: in 2018, for instance, more than half of all en-route ATFM delay minutes were generated by only four European ACCs: Karlsruhe UAC, Marseille ACC, Maastricht UAC and Reims (Eurocontrol PRC, 2019).

As for number of flights affected, in 2019, approximately one flight in six was subject to en-route ATFM regulations in Europe, while 10% of all flights (i.e. more than 1.1 million flights during the year) were *delayed* by such regulations. The average en-route ATFM delay was 1.57 minutes *per flight*, Figure 6.10, while the average en-route ATFM delay *per delayed flight* was 15.8 minutes.

Concerning the temporal distribution of en-route ATFM delays in 2019, it should be emphasised that about 4% of all flights were delayed for more than 15 minutes. However, those 4% of flights accumulated 70% of all en-route ATFM delays. Further, 1% of all flights (i.e. about 110,000 flights in total) were delayed 30–60 minutes, with finally 0.2% (about 20,000 flights) delayed more than 60 minutes in 2019 (Eurocontrol PRC, 2020).

Finally, according to the *regulation reasons* as originally attributed by ANSPs which implemented the regulations, in 2019, about 44% of en-route ATFM delay minutes were caused by ‘ATC Capacity’, followed by ‘ATC Staffing’ (24%), weather-attributed delays (21%), and ATC disruptions/industrial actions (7%).[28] The critical period is naturally the summer, owing to high traffic levels, inadequate ATC staffing and adverse weather (ibid.).

Table 6.6 Full tactical cost ('at-gate / Base') of delay for several aircraft types, in euros.

Aircraft type	*Maximum take-off mass (t)*	*Delay (minutes)*						
		5	*15*	*30*	*60*	*90*	*120*	*180*
ATR 72	22.1	40	240	820	3,600	9,690	18,430	25,380
Boeing 737–800	72.6	90	540	1,940	8,860	24,270	45,570	61,740
Airbus 321	86.4	100	580	2,160	10,010	27,580	51,990	70,060
Airbus 330-200	230.0	180	990	3,550	16,480	44,620	95,330	136,120
Boeing 747-400	392.5	240	1,370	5,000	23,430	63,710	136,330	194,330

Source: extracted from University of Westminster (2015), table 26

Cost of delays

Flight delays, including those caused by en-route ATFM regulations, may have significant cost implications for the affected airspace users. Airlines' costs associated with delays include increased operating expenses for the crew, fuel, maintenance, handling, accommodation and rescheduling of affected passengers. Delays experienced by airlines comprise airline schedule buffers (i.e. delay accounted for in advance, sometimes referred to as 'strategic delay') and unforeseen delays (i.e. incurred on the day of operations and not accounted for in advance, sometimes labelled 'tactical'; Federal Aviation Administration, 2020; University of Westminster, 2015).

For example, the costs of en-route imposed delays in the European system were estimated at about 1.9 billion EUR in 2018 (Eurocontrol PRC, 2019). To come up with estimates like this one, the conversion of delay minutes into delay costs has long been performed in an overly simplistic manner by (uniformly) using an average value for cost per minute of delay and multiplying it by total delay minutes. However, such an approach may fail to capture the well-known non-linear relationship between the delay duration and delay costs of any given flight. More specifically, it has been shown that, for a considered flight, the cost per minute of tactical delay is considerably higher for longer delays than for relatively short ones. For example, the estimated *full* cost[29] of a tactical at-gate 15-minute delay is about six times higher than the corresponding cost of a 5-minute delay, while the cost of a 30-minute delay is nearly four times higher than the cost of a 15-minute delay. The estimated costs to the carrier further quadruple if the delay doubles from 30 to 60 minutes, etc., Table 6.6.

Conclusions: A look further ahead

Flight delays are an undesired and costly phenomenon resulting from demand-capacity imbalances in the ATM system. Despite the present (2020–2021) traffic downturn caused by the COVID-19 pandemic, which strongly reduced the delays, the problem is expected to re-appear as soon as traffic reaches the close-to-pre-pandemic levels.

Notwithstanding its importance, there is still no sufficiently harmonised approach to airspace capacity definition and measurement neither in ANSP practice nor in academic circles, which calls for further attention to this challenging matter. Nevertheless, regardless of the actual method used to establish and/or measure en-route sector capacities, there are indications, especially in the European context, that it is *more flexible use of available airspace capacities* which has the potential to bring about considerable performance improvement in terms of the overall magnitude and distribution of delays (SESAR Joint Undertaking, 2019). In addition, a more intense, network-minded combination of capacity and demand management measures may yield further performance benefits. More specifically, recent research findings suggest that such measures could tangibly decrease total cost imposed on users – comprising the cost of capacity provision, the cost of delays, and the cost of spatial deviations from user-desired trajectories – without deterioration of other performance indicators (Ivanov et al., 2019).

Discussion questions

1 Explain the difference between the declared and operational capacity of an airspace sector.
2 What are the two principal schools of thought concerning methods for airspace capacity assessment? Which one do you find more reasonable?
3 Briefly elaborate on the four phases which typically constitute the Air Traffic Flow and Capacity Management (ATFCM) process.
4 Explain the key characteristics of the mechanism of slot-based ATFM regulations in Europe.

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Notes

1 Concerning non-scheduled traffic volumes (i.e. non-scheduled traffic of both scheduled and non-scheduled operators), ICAO only provides estimates of international revenue passenger-kilometres. Non-scheduled traffic nevertheless represents a fairly small fraction of total international traffic, which, in addition, has been steadily decreasing over the period analysed: representing more than 11% of total international revenue-passenger-kilometres in 2004, but less than 4% in 2019 (ICAO, 2014; ICAO, 2020).

2 The European Civil Aviation Conference (ECAC) is an intergovernmental organisation, established by ICAO and the Council of Europe. As of February 2021, ECAC totals 44 members, including all 41 Eurocontrol member states, plus Iceland, San Marino and Azerbaijan.
3 It should be stressed that this relates to number of flights controlled by ECAC member states, and not to number of departures as such.
4 ANSP of Serbia and Montenegro.
5 Comprising scheduled flights of traditional carriers, low-cost carriers and a portion of all-cargo flights.
6 Comprising flights where ICAO type of flight 'M' was specified in the flight plan (under Item 8), see e.g. www.skybrary.aero/index.php/Flight_Plan_Completion.
7 In some cases, instantaneous or short-duration occupancy counts (e.g., per one minute) can be used to complement entry counts and allow higher values for such entry counts. Such *occupancy count* capacities require accurate and frequent live ATC message and surveillance data updates to the Air Traffic Flow Management (ATFM) system. (ICAO, 2018).
8 Civil Air Navigation Services Organization – a representative body of companies that provide air traffic (control) services.
9 In ATFCM planning terminology, adjective 'tactical' commonly refers to the day of operations.
10 For interested readers, Pejović et al. (2020) offer a comprehensive and up-to-date review on this matter.
11 Such capacity estimates from FTS alone are not sufficient, as they lack the human elements, most importantly controller judgement and thinking. As a consequence, FTSs are often supplemented by so-called *'real-time' simulations (RTS)*, that involve building an operational environment, complete with the technologies to be tested, as well as pseudo-pilots (i.e. pilots situated in a room next to the control room, and communicating with controllers) (Majumdar et al., 2005).
12 As opposed to initial efforts which were taking only the volume of traffic (e.g. number of flights) as explanatory variable (Majumdar et al., 2005).
13 More specifically, they were using *acceptable peak traffic count* for each sector based on practical experience (Welch et al., 2007).
14 Sector, as already defined, is a primary operational component of the airspace structure that can be considered as an elementary capacity reference of the ATM system. A sector is made up of one or more elementary sectors. Elementary sector is the primary component of the airspace structure, one or more of which may be combined to form a sector. In some cases, the elementary sector can be the same as the operational sector; in other cases, the elementary sector is never open operationally without being combined with one or more other elementary sectors (Eurocontrol, 2013).
15 That is, besides ATC and ATFCM.
16 However, lead times concerning more significant capacity improvements reach as much as five years. For example, 3–4 years have to be planned for recruiting and training of air traffic controllers (Hoefel, 2013); broadly similar timelines hold for airspace (re-)design actions, which belong to ASM.
17 In the European ATM context, the network manager is the body entrusted with the tasks necessary for the execution of 'ATM network functions', which have been created by the Single European Sky II legislation. The network functions are, inter alia, aiming to develop and create European route network design, and organise the air traffic flow management (ATFM). (European Commission, 2021) More specifically, 'the implementing rules for ATFM shall support operational decisions by ANSPs, airport operators and airspace users, and shall cover flight planning, use of routings and available airspace capacity during all phases of flight, including slot assignment' (Skybrary, 2021).

18 ICAO suggests that some ATC instructions or procedures (such as radar vectors or speed control instructions) can also be considered ATFM measures (ICAO, 2018).
19 For the sake of clear distinction between these two terms we remind that air traffic control (ATC) is a service provided by air traffic controllers, for the purpose of preventing collisions and expediting and maintaining an orderly flow of air traffic. ATFM, as already defined, is the ATM operational function which balances the traffic demand for ATC services with the capacities and capabilities of the ATC system (ICAO, 2018).
20 *Regional ATFM* aims 'to maximize the efficiency and effectiveness of ATM across the area of responsibility of more than one ANSP' (ICAO, 2018).
21 It should be underlined that the final decision for implementation or cancellation and 'ownership' of an ATFM regulation lies with the Flow Management Position (FMP) in the ACC in question. Nevertheless, the details on the regulation itself are, as a rule, to be coordinated with the NM (Eurocontrol, 2021).
22 A time calculated and issued by an ATFM unit, as a result of tactical slot allocation, at which a flight is expected to become airborne (ICAO, 2018).
23 The estimated take-off time taking into account EOBT (= the estimated time that an aircraft will start movement associated with its departure) plus estimated taxi-out time (ICAO, 2018).
24 The final decision for the regulation reason remains the responsibility of the relevant FMP (Eurocontrol, 2021).
25 A strategic airport slot gives an airline the right to operate at a particular airport on a particular day during a specified time window, over a given schedule season ('Summer' or 'Winter'; CANSO, 2019).
26 For more details on methodology of delay definition and assignment, interested reader is referred to Eurocontrol (2020b).
27 Departure delays can be classified as 'primary' delay (directly attributable) and 'reactionary' delay (carried over from previous flight legs, due to e.g. late arrival of aircraft or crew); (Eurocontrol PRC, 2019).
28 The relative shares of various contributing causes look very differently after the revised attribution made by the Performance Review Commission (PRC), with 'ATC staffing' taking over as by far the most dominant cause of en-route ATFM delays in Europe, responsible for more than 75% of all delay minutes in 2019 (Eurocontrol PRC, 2020).
29 That is, including the cost of reactionary delay (University of Westminster, 2015).

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7 Air navigation service providers and environmental performance

Marina Efthymiou

Introduction

Air transportation contributes to economic prosperity, facilitating growth, particularly in developing countries. Aviation facilitates the transportation of people and goods, improves living standards, alleviates poverty and increases revenues from taxes. Nevertheless, the rapid air transport growth has created a series of environmental problems, from noise pollution to climate change. Aviation's environmental efficiency remains a concern despite improvements in fuel efficiency, the introduction of market-based measures like the EU Emissions Trading Scheme (Efthymiou & Papatheodorou, 2019) and the Carbon Offsetting Scheme for International Aviation (CORSIA). It is important to coordinate policies and balance stakeholders' interests and actions, according to Efthymiou and Papatheodorou (2020). The focus of environmental policy attention has been on airlines and airports, but environmental policies have been introduced to air navigation service providers (ANSPs) in the last decade.

European ANSPs are estimated to consume 1,140 GWh of electricity annually, roughly equivalent to 55% of the annual electricity consumption of Malta. We estimate that switching to renewable energy and making energy-efficient investments could save ANSPs over 311,000 tonnes of CO_2 every year. Decarbonising this ground infrastructure by switching to and investing in renewable energy over the next decade could save 311,000 tonnes of CO_2 equivalent emissions annually, summing up to almost 6.2 million tonnes overall by 2050, according to Eurocontrol (2021). Apart from reducing the emissions of the ANSP, it is important to consider the airspace structure.

The European sky is one of the busiest skies globally, with 33,000 flights a day. Yet, its air traffic management is organised in a fragmented way. The European airspace system covers an area of 10.8 million km^2 managed by 37 ANSPs and 63 area control centres (ACCs). The estimated cost of this airspace fragmentation amounts to 4 billion euros a year (Efthymiou & Papatheodorou, 2018), and an average flight is 42 Km longer due to fragmentation inefficiencies: this results in longer delays, higher fuel consumption, higher level of emissions and increased burden on users. This fragmentation

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adversely impacts flight safety, limits capacity, increases costs and slows down decision-making. Thus, better coordination for transferring the responsibility of an aircraft among air traffic control (ATC) sectors in Europe is needed. Such an initiative to reform the architecture of the air traffic management (ATM), known as Single European Sky (SES), was first launched by the European Commission in 1999.

Airspace not limited by national borders allows the complete unification of European airspace and more direct flight paths (Kantareva et al., 2016). EC anticipates that with the implementation of the SES, safety will improve ten times, airspace capacity will triple, the cost of air traffic management will fall by 50%, and the adverse impact on the environment will fall by 10%. The first package of the legislative framework introduced in 2004 establishes the EC as the regulator for the civil sector and the Single Sky Committee to assist it in its regulatory activities, the provision of ANS, the organisation and use of airspace and the interoperability of the European Air Traffic Management Network (EATMN). The SES II package approved in 2009 introduced the performance scheme, a refocus of the functional airspace blocks (FABs) and a network manager (NM) to coordinate certain actions at a network level.

Regulation 390/2013 (known as the Performance Regulation) identifies four key performance areas (KPAs) in SES, namely: (a) safety, (b) capacity, (c) cost-efficiency and (d) environment. The performance scheme is developed for different periods, called reference periods (RP). An essential point in performance regulation (PR) is monitoring, including data collection and dissemination. If there is evidence that the targets will not be reached, then the introduction of corrective measures becomes necessary. Regulation 390/2013 considers key performance indicators (KPIs) necessary to monitor, benchmark and review performance schemes for ANS and network functions.

Performance

Performance is a complex concept that describes the capability of generating results. Performance can be expressed as a set of variables or indicators that are complementary or occasionally contradictory. Performance measures can be classified as follows (Parmenter, 2015):

1 Performance indicators (PIs) express what needs to be achieved.
2 Key performance indicators (KPIs) express what needs to be achieved to improve performance drastically.
3 Result indicators (RIs) express what has already been achieved in general.
4 Key result indicators (KRIs) express what has been achieved according to a certain perspective or critical success factor.

In general, a PI can be described as an additional metric that partially reflects the performance of an organisational unit. Regulation 390/2013 considers performance indicators as indicators used for performance monitoring, benchmarking and reviewing of performance schemes for air navigation services and network functions. Dobruszkes and Efthymiou (2020) suggest that environmental reporting is fundamental to environmental policy; thus, environmental indicators play a crucial role in achieving key policy objectives.

The performance in Single European Sky focuses on four KPAs: (a) safety, (b) capacity, (c) cost-efficiency and (d) environment. The four KPAs are part of the wider set of 11 ICAO KPAs, including efficiency, flexibility, predictability, security, access & equity, interoperability and participation. The implementation as of 1 January 2012 of the performance scheme aims to set and implement binding targets for the EU Member States through the adoption of European-Union wide performance targets and approval of consistent national or functional airspace blocks (FAB) performance plans.

Commercial aircraft operate at cruise altitudes of 8 to 13 km, where they release gases and particulates that alter the atmospheric composition and contribute to climate change. The effects of non-CO_2 emissions (which have no Kyoto Protocol equivalent values) are still scientifically less well understood, although there are indications that certain non-CO_2 emissions could have effects in some cases. In the case of contrails, the impact could be significant, but scientific understanding of the direction and magnitude of the impact is not currently well consolidated. To control the CO_2 emissions, environment is included in the key performance areas.

The air navigation system should contribute to protecting the environment by considering noise, gaseous emissions, and other environmental issues in implementing and operating the global air navigation system. According to Regulation 691/2010 'the performance scheme', the main objective is to reduce ANS related CO_2 emissions and local air quality (LAQ) through flight efficiency improvements, both in the air and on the ground.

The **first reference period (RP1)** focused on improvements on average horizontal en-route flight efficiency of last filed flight plan (KEP) in European network level (reduction of −0.75% of the route extension in 2014 compared to the 2009 baseline equal to 5.42%) only and not mandatory to national/FAB level and monitoring on effective use of civil/military airspace structures. The other objectives of RP1 are:

1 Develop and support the deployment of 500 airspace changes in 2012–2014.
2 Support the implementation of free route airspace (FRA) in 25 ACCs by 2014.
3 Increase the number of conditional routes (CDR) annually by 5% according to the flexible use of airspace concept (FUAC).
4 Increase the CDR1/2 availability and usage annually by an average of 5% (FUA).

5 Reduce the route unavailability (in time and quantity) by 10% in 2013 and 2014 (FUA).
6 Reduction of vertical flight inefficiency by 5% in 2014.

The FUA indicators (bullet 3–5) are reported quarterly. Flight efficiency (bullet 6) is reported only twice per year.

The main objective for the **second reference period (RP2)** is at the EU wide level and the national/FAB level. The focus of RP2 is on:

1 Average horizontal en-route flight efficiency of last filed flight plan (target is set at European Network level (KEP = 4.1%).
2 Horizontal flight efficiency of the actual trajectory (KEA) (target is set at EU wide level (KEA = 2.6%) and FAB level-different for every FAB).
3 Effectiveness of booking procedures for free use of airspace (only monitoring at EU wide level and national/FAB level).
4 Rate of planning of CDRs (only monitoring at EU wide level and national/FAB level).
5 Effective use of CDRs (only monitoring at EU wide level and national/FAB level).
6 Additional time in taxi-out phase (only monitoring at National/FAB level and airport level).
7 Additional time in terminal airspace (ASMA) (only monitoring at the national/FAB level and the airport level).

Monitoring of the ASMA and additional taxi-out time indicators has started during RP1, under the capacity KPA. The rationale for monitoring is to gain experience with the indicator and ensure an acceptable level of quality, both from a data and algorithmic perspective.

The **third reference period (RP3)** covers the years 2020–2024. The only KPI in RP3 is the average horizontal en-route flight efficiency of the actual trajectory. In contrast, the average horizontal en-route flight efficiency of the last filed flight plan trajectory, the average horizontal en-route flight efficiency of the shortest constrained trajectory, the additional time in the taxi-out phase, the additional time in terminal airspace, the share of arrivals applying Continuous Descent Operation (CDO) and local airspace structures are set as indicators for monitoring.

Eurocontrol conducted environmental impact assessment studies to evaluate the impact of the FABs creation on the environmental performance of SES. For instance, the DANUBE FAB Environmental Impact Assessment Study was carried out using the System for traffic Assignment and Analysis at a Macroscopic level (SAAM) fast-time simulation tool to calculate the changes in fuel use and CO_2 emissions in the Danube FAB airspace above FL09 (Kantareva et al., 2016). The study concluded that the annual fuel saving due to the FAB implementation will be 45,000 tonnes by 2020 and

Table 7.1 Estimated ANS-related benefit pool by phase of flight.

Phase of flight	*Estimated ANS-related benefit pool (CO2 emissions in Mtonnes)*
En-route airspace horizontal inefficiency	4.5
Terminal airspace: arrival path extension	2.4
Enroute airspace vertical inefficiency	2.1
Descent: inefficiency due to intermediate level off	1.1
Surface: Taxi-out	1.02
Surface: Taxi in	0.47
Climb: inefficiency due to intermediate level off	0.1
Terminal airspace departure path extension	0.0

Source: Eurocontrol (2021)

80,000 tonnes by 2030. The annual CO_2 savings are expected to be 143,000 tonnes by 2020 and 255,000 by 2030 (Kantareva et al., 2016).

Significant focus has been placed on flight efficiency, as inefficient flight trajectory contributes significantly to CO_2 emissions. According to Eurocontrol (2021), ANS can influence approximately 6% (11.6 Mt) of the total gate-to-gate fuel burn. Most of this (39%) is related to en-route airspace horizontal inefficiencies (Table 7.1).

Efficiency improvements

A higher increase in capacity than traffic growth was achieved during the last decade while maintaining safety standards. At the same time, more efficient routes were implemented. The European ATS route network distances are 3.6% longer than the Great Circle distances (for intra-European flights). An initial assessment of the European ATS route network design, availability and utilisation indicate that flight efficiency could improve further by enhancing route availability and utilisation. The restrictions imposed on utilising the European ATS route network contribute approximately 0.4% to the airspace utilisation inefficiency. In 2018, FABEC area control centres coordinated seasonal improvements concerning 117 different flows, saving 4.3 million kg of fuel and 13.4 million kg of CO_2.

Eurocontrol developed a flight efficiency plan (FEP) containing 5 Action Points that required immediate attention:

1 Enhancing European en-route airspace design.
2 Improving airspace utilisation and route network availability.
3 Efficient TMA design and utilisation.
4 Optimising airport operations.
5 Improving awareness of performance.

These action points could save the airlines 470,000 tons of fuel each year – the equivalent of 390 million euros and 1.5 million tons of CO_2 emissions.

Airframe design, weight, weather conditions and the airspace they are flying in influence the optimum cruise conditions. Flight management systems at an aircraft can determine the most efficient cruise altitude and speed to optimise fuel burn. ATM can assist in this process by enabling capacity in the en-route phase of flight to offer aircraft the cruise levels and speeds they request to burn less fuel. Furthermore, taking advantage of the wind can offer efficiency gains.

En-route flight efficiency

Flight efficiency can be measured horizontally or vertically. The KPI average horizontal en-route flight efficiency of the actual trajectory is calculated as follows (EC Reg (EU) 2019/317):

(a) This indicator is the comparison between the length of the en-route part of the actual trajectory derived from surveillance data and the achieved distance, summed over IFR flights within or traversing the local airspace;
(b) 'En-route part' refers to the distance flown outside a circle of 40NM around the origin and destination airports;
(c) Where a flight departs from or arrives at an airport outside the local airspace, the entry or exit points of the local airspace are used for the calculation of this indicator;
(d) Where a flight departs from and arrives at an airport inside the local airspace and crosses a non-local airspace, only the part inside the local airspace is used for the calculation of this indicator;
(e) 'Achieved distance' is a function of the position of the entry and exit points of the flight into and out of the local airspace. Achieved distance represents the contribution that those points make to the great circle distance between origin and destination of the flight;
(f) For the purposes of this indicator, 'local' means at national level or at the level of functional airspace blocks, depending on the level at which the performance plan is established;
(g) The indicator is calculated for the whole calendar year and each year of the reference period as an average. The ten highest daily values and the ten lowest daily values are excluded from the calculation when calculating this average.

The average horizontal en-route flight efficiency (indicator) is the difference between the distance of the en-route part of the trajectory and the optimum trajectory, which is, on average, the great circle distance. Thereby, 'en-route' is defined as the distance flown outside a circle of 40 NM around the airport. The flights considered for this indicator are:

- All commercial IFR flights within European airspace;
- Where a flight departs or arrives outside the European airspace, only that part inside the European airspace is considered;

- Circular flights and flights with a great circle distance shorter than 80NM between terminal areas are excluded.

The factors influencing horizontal flight efficiency are illustrated in Figure 7.1. The figure also describes the planning process of an optimised flight plan routing. States that do not have a central archive of surveillance data use indicator option A based on the last filed flight plan trajectory. If surveillance data are available (radar data, ADS-B data or other), States use the actual trajectory (indicator option B).

Furthermore, the desired outcome is not to achieve zero extra distance, creating operational and economic problems. The user-preferred trajectory rarely corresponds to the direct route. Computing the indicator for wind-optimum trajectories (assuming such data are available), for example, can produce an extra distance compared to the direct route. This is because more favourable wind situations (e.g. high wind speed bands over the Northern Atlantic Ocean) can increase the ground speed of an aeroplane and so reduce flight time-based costs (e.g. aircraft or fuel). Hence, reducing the horizontal en-route flight efficiency indicator towards its theoretical limit (zero) is not advised.

NATS has developed a flight efficiency metric called 3Di inefficiency score 3Di. The 3Di is an average efficiency rating for vertical and horizontal trajectories. It applies to domestic airspace for the airborne portion of flight only. It must be highlighted that because aircraft performance and fuel flow rates vary across the different phases of flight, the metric applies different weightings for level flight occurring in climb, cruise, and descent phases of flight. Combining those two factors (i.e. deviation from the optimal trajectory and flight phase related rating) gives the inefficiency score for each flight

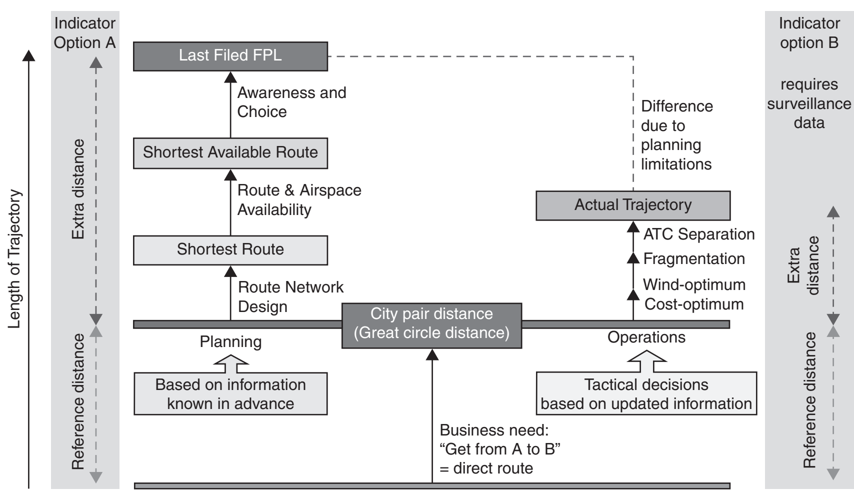

Figure 7.1 The planning process of an optimised flight plan routing.

in the considered airspace. Scores run from 0, representing zero inefficiencies to over 100, with most flights typically having a score between 15 and 35. The score can be improved by better airspace design, controllers' tools, flow management techniques, changes to procedures, awareness training, flexible use of airspace and optimised coordination across sectors. The score is also affected by the number of flights, the traffic demand on sectors, the weather, any unusual events (e.g. runway closure) and changes in the runway capacity.

The horizontal plane compares the actual radar ground track against the (most direct) great circle track – between the first and last radar point. Horizontal inefficiency is defined by the difference between these two distances, which describes the 'additional miles flown'. In the vertical plane, it compares the actual vertical profile from radar data against a modelled ideal flight, defined as a continuous climb to the aircraft's requested flight level (for cruise), and followed by a continuous descent approach. Inefficiency is the difference between the 'actual' and 'ideal' flight profile. The vertical inefficiency is defined by the amount of flight time spent in level flight and the deviation from its requested cruise level. Level portions of flight at low altitude are more fuel penalising than higher levels.

By providing the most direct possible routes, smooth continuous climbs and descents and optimum flight levels during the cruise phase, air traffic controllers aim to help reduce aircraft fuel burn and carbon emissions, earning a low 3Di score. Combining the 3Di airspace efficiency metric with the flight optimisation system or 'FLOSYS' enables the Air traffic controllers to analyse the environmental efficiency of flights in near real-time. By having access to this granularity of data for the first time, controllers and airspace managers will identify better opportunities for operational improvements that will save airlines fuel and cut carbon emissions.

Continuous descent operation and continuous climb operations

During normal approaches, air traffic control often requires aircraft to descend early and level off at intermediate altitudes (Figure 7.2). The flight phases at these lower altitudes are more fuel-inefficient than flights in higher altitudes. It aims to keep aircraft as long as possible at the cruising level and perform the succeeding descent with idle engine power to increase fuel and noise efficiency. Therefore. continuous descent operations (CDO) describes a descent technique whereby engines are as far as possible operated at idle thrust to reduce engine noise, fuel burn and exhaust gas emission during descent (Efthymiou et al., 2019).

In ICAO Document 9931 (2010) (the 'Continuous Descent Operations Manual'), CDO is defined as:

> an aircraft operating technique aided by appropriate airspace and procedure design and appropriate ATC clearances enabling the execution of a flight profile optimised to the operating capability of the aircraft, with

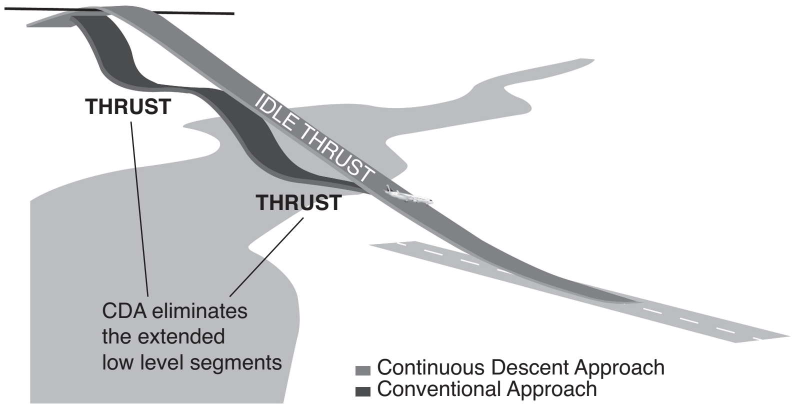

Figure 7.2 General CDO concept.
Source: Efthymiou et al. (2019)

low engine thrust settings and, where possible, a low drag configuration, thereby reducing fuel burn and emissions during descent. The optimum vertical profile takes the form of a continuously descending path, with a minimum of level flight segments only as needed to decelerate and configure the aircraft or to establish on a landing guidance system (e.g. ILS).

To achieve the maximum possible benefits of CDO in terms of fuel savings and noise reduction, the descent should be flown from the top-of-descent (TOD) to the final approach fix (FAF) close to the airport (ICAO Doc 9931, 2010). CDOs create measurable benefits concerning fuel burn and emission reductions even if they are not introduced or flown to the full extent starting at the TOD. Establishing some parts of continuous descent and removing only some level offs during descent can also create measurable benefits. The resulting of such optimised descents according to the ICAO CDO manual can provide the following advantages (ICAO Doc 9931, 2010):

- More efficient use of airspace and arrival route placement;
- More consistent flight paths and stabilised approach paths;
- Reduction in both pilot and controller workload;
- Reduction in the number of required radio transmissions;
- Cost savings and environmental benefits caused by reduced fuel burn;
- Reduction in the incidence of controlled flight into terrain (CFIT);
- Authorisation of operations where noise limitations would otherwise result in operations being curtailed or restricted.

Also, if the actual focus is on the descent phase of a flight, the principle of avoiding level offs at lower altitudes can be applied conversely to the climb phase of a flight. This method is called Continuous Climb Operations (CCO). ICAO Document 9993 (2013) defines CCO as:

> An operation, enabled by airspace design, procedure design and ATC, in which a departing aircraft climbs without interruption, to the greatest possible extent, by employing optimum climb engine thrust, at climb speeds until reaching the cruise flight level.

Conditional routes

Another aspect contributing to the environment's improvement is conditional routes (CDRs). A CDR is an ATS route that is only available for flight planning and is used under specified conditions. A CDR may have more than one category, and those categories may change at specified times:

- Category One – Permanently Plannable CDR: CDR1 routes are generally available for flight planning during times published in the relevant national Aeronautical Information Publication (AIP). Updated information on the availability following conditions published daily in EAUP/EUUPs. CDRs1 can either be established on an H 24 basis, fixed time periods, or fixed flight level bands.
- Category Two – Non-Permanently Plannable CDR: CDR2 routes may be available for flight planning. Flights may only be planned on a CDR2 following conditions published daily in the EAUP/EUUPs.
- Category Three – Not Plannable CDR: CDR3 routes are not available for flight planning; however, ATC Units may issue tactical clearances on such route segments. CDR3 are not subject to allocation the day before by airspace management cells (AMCs).

For instance, improving flight plan quality and utilising civil/military airspace structures can reduce emissions. If all the available routes were used at their full potential, annual savings of 30,000 tons of fuel/year or reduced emissions of 100,000 tons of CO_2/year could be achieved. Apart from improving airspace utilisation and route network availability, enhancing European airspace design and introducing a more efficient Terminal Airspace, by improving Terminal Airspace design and implementing continuous descent approaches (CDAs), or optimising airport operations, by implementing airport collaborative decision making (A-CDM) can lead to carbon offsetting.

Through collaborative decision making (CDM) procedures, airport and aircraft operators, ground handlers and air traffic control share information, creating a common situational awareness for all actors. CDM is a concept to be implemented in an airport environment by introducing operational procedures and automated processes.

Free route airspace

Free route airspace (FRA) is a specific airspace within which users can freely plan their routes between an entry point and an exit point without reference to the ATS route network. In this airspace, flights will remain subject to air traffic control. Although FRA aims for permanent implementation, it is used during specific time periods. In complicated airspaces like MUAC, [1] FRA plays an important role in its capacity.

The main benefit of FRA implementation is straighter routes and the consequent reductions in the total flown distance, carried and burned fuel, and emissions. This will reduce the aircraft's weight during flight and give a further benefit of reduced fuel burn and CO_2 emissions during the whole flight. Additionally, FRA will significantly reduce the route structure and flight planning complexity. Therefore, there are also opportunities to rationalise some legacy inefficiencies in the network.

FRA is based on full trajectory operations. Thus, the FRA concept brings increased flight predictability and reduced uncertainty for the Network, leading to capacity increases for ATM, which will also benefit the user. Several ACCs and ANSPs have already implemented fully or partially Free Route Airspace with further phased implementations planned by all FABs/ANSPs, including cross-border operations and full free route implementation. Free Route operations are already operational in Portugal (24hrs), Maastricht (24hrs, night and weekend in parts of the area of responsibility – AoR), Karlsruhe (24hrs in parts of the AoR), Ireland (24 hrs), Austria – night, Finland – night and weekend, Zagreb, Belgrade, the Former Yugoslav Republic of Macedonia and joint Free Route in Denmark and Sweden. The implementation is coordinated through the NM European Route Network Improvement Plan (ERNIP) and the Network Operations Plan following the Strategic Objectives and Targets set in the Network Strategic Plan and the Network Manager Performance Plan.

In Europe, there are many initiatives to implement free route airspace. The first states in which the FRA was implemented were Sweden, Portugal and Ireland. The introduction of the FRA is easier for Portugal and Ireland because their airspace extends above the Atlantic Ocean, which leads the transit flight paths Europe – America thus to almost zero climbing/descent to/from the defined FRA area.

In 2011, 142 'direct routes' became available to the airspace controlled by MUAC. Those routes contributed to the reduction of flight time and engine use, reduction of fuel use, CO_2 emissions, and the costs occurring from the high traffic density in the European airspace. Those routes were conducted during the night and the weekend for safety reasons. They are also the first step to the Free Route Airspace Maastricht (FRAM) programme that aims to implement those routes daily and 24hours scale. The benefit of this change is 1.16 million km less per year, meaning 3,700 tonnes of fuel less, 12,000 tonnes of CO_2 and 37 tonnes less NO_X compared to the previous routes.

In 2019, MUAC successfully transitioned to 24/7 free route airspace. The environmental benefits in MUAC airspace alone can be significant – an estimated 40,000 kg of fuel and 150,000 kg of CO_2 emissions saved per day if all flights make the best use of FRA (Eurocontrol, 2022).

Eurocontrol estimates that implementing pan-European free route airspace will reduce flight distances by 7.5 million nm annually. The main problem is an insufficient ATC system, which cannot cope with the requirements of the FRAs. For example, it can be expected that free-selected trajectories of a given number of aircraft will create a higher workload to Air Traffic Controller compared to adherence of predefined airways serving for the same amount of aircraft. Another example is that dynamic flight data processing (FDP) makes ordering sectors for flights more difficult. Therefore, today's ATC systems only support FRAs to a limited extent.

Flexible use of airspace concept

The flexible use of airspace concept (FUAC) uses airspace structures and procedures that are particularly suited for temporary allocation and/or utilisation, such as conditional routes (CDRs), temporary reserved areas (TRAs), temporary segregated areas (TSAs), cross-border areas (CBAs), reduced co-ordination airspace (RCA) and prior coordination airspace (PCA). To improve the airspace utilisation in both a fixed route network and a free route environment, these airspace structures will be implemented according to the specific requirements.

According to Commission Regulation 2150/2005, Flexible Use of Airspace is 'an airspace management concept, according to which airspace should not be designated as either purely civil or purely military airspace but should rather be considered as one continuum in which all users' requirements have to be accommodated to the maximum extent possible.' Airspace management cell (AMC) means a cell responsible for the day-to-day management of the airspace under the responsibility of one or more Member States. Airspace restriction is defined as the volume of airspace within which, variously, activities dangerous to the flight of aircraft may be conducted at specified times (a 'Danger Area'); or such airspace situated above the land areas or territorial waters of a State, within which the flight of aircraft is restricted following certain specified conditions (a 'Restricted Area'); or airspace situated above the land areas or territorial waters of a State, within which the flight of aircraft is prohibited (a 'Prohibited Area')'.

According to the Commission Regulation 2150/2005, the following principles shall be applied for the FUAC:

(a) Coordination between civil and military authorities shall be organised at the strategic, pre-tactical and tactical levels of airspace management through the establishment of agreements and procedures to increase safety and airspace capacity and to improve the efficiency and flexibility of aircraft operations.

(b) Consistency between airspace management, air traffic flow management and air traffic services shall be established and maintained at the three levels of airspace management enumerated in point (a) to ensure, for the benefit of all users, efficiency in airspace planning, allocation and use.

(c) The airspace reservation for the exclusive or specific use of categories of users shall be of a temporary nature, applied only during limited periods of time based on actual use and released as soon as the activity having caused its establishment ceases.

(d) Member States shall develop cooperation for the efficient and consistent application of the concept of flexible use of airspace across national borders and/or the boundaries of flight information regions, and shall in particular address cross-border activities; this cooperation shall cover all relevant legal, operational and technical issues.

(e) Air traffic services units and users shall make the best use of the available airspace.

Some considerations

Incentive scheme

The EC gives air navigation service providers incentives to enhance their compliance and efficiency to the performance regulation. The risk-sharing mechanism of the charging scheme, i.e. the sharing of the financial risk between member states/ANSPs and airspace users, is seen as a meaningful economic incentive for ANSPs to be more cost-efficient, taking advantage of good management, economies of scale and productivity gains. This creates a regime close to a cost capping in a multi-annual framework. According to article 12 of Reg. 390/2013 with a link to Commission Implementing Regulation (EU) No. 391/2013, all stakeholders' incentives shall be part of the regulatory environment known ex-ante and be applicable during the entire reference period. Moreover, the incentives on environment and capacity shall be financial, and the NSA should enforce corrective actions if necessary. Safety is a KPA that does not have any incentives mechanisms due to its uncompromising nature. The maximum number of aggregate bonuses and the maximum amount of aggregate penalties shall not exceed 1% of the revenue from air navigation services in year *n*.

Trade-offs between the KPAs

Flight efficiency always involves trade-offs between the different areas, for instance, safety versus capacity, fuel cost versus time cost, ground versus airborne delay, noise versus emissions, etc. Excess fuel burn in the air traffic management system is primarily characterised by flight delay costs and flight efficiency costs. Flight delays occur when an airport or airspace resource (runway, gate, taxiway, or airspace sector) has greater demand than the available capacity. Flight delays tend to grow exponentially with increased levels of traffic. Flight efficiency is measured by increased flight time, distance, and fuel compared to an 'ideal' flight trajectory.

As per the DANUBE FAB Performance Plan section 3.3 – Description of KPAs interdependencies and trade-offs:

> **Safety**
> Safety KPA establishes mandatory requirements in ATM operations and represents the key element of ANS. No safety compromises should be made to improve other KPAs, especially the cost-efficiency. The Performance Scheme Regulation and corresponding targets for RP2 are more oriented on cost-effectiveness while focusing less on the safety key performance area. Thus, for the second reference period and the next to come, the biggest challenge for States and FABs will be to keep focusing on safety while trying to achieve the targets in different KPAs.
>
> **Capacity**
> The very good performance of ATFM delays recorded by the DANUBE FAB in the last five years and for RP2 implies extra cost through investments, staff and corresponding procedures. DANUBE FAB RP2 capacity targets followed the PRB expectations and indicative figures while contributing to the very challenging cost-efficiency objectives. We appreciate that having one of the most reduced FAB determined unit cost and ATFM delays represent a very challenging objective and should be carefully assessed.
>
> **Environment**
> Similarly to the capacity targets, flight efficiency requires extra cost through investments, staff, and corresponding procedures for reaching the targets.

Example of environment versus unit rate cost

The flight Milano–Brindisi can follow different routes. In Figure 7.3, two different routes are given. The green flight path is sorely within Italy, whereas the red path passes through Croatia. The Great Distance Cycle (GDC) are the dashed lines in the map. For the red flight path, i.e. the one passing from Croatia, the GDC is calculated firstly from Milano to the border of the FIR and then within Croatia for the other intersections of the flight plan with the charging zone and then to Brindisi. Compared to the flight plan contained entirely within Italy, the route through Croatia implies a reduction of 430 km in Italy and an increase of 477 km in Croatia.

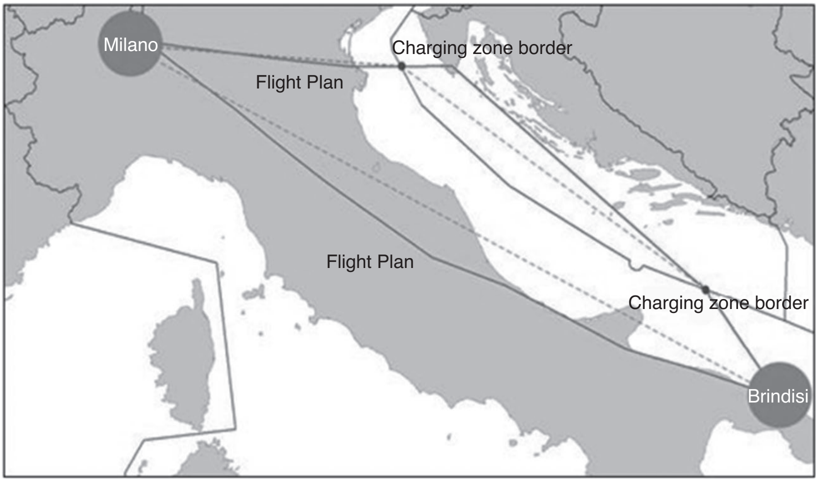

Figure 7.3 Two alternative routes between Milan and Brindisi.
Source: Efthymiou and Papatheodorou (2018)

For an aircraft weighing 80 metric tonnes, the price (for the unit rate) per kilometre (July 2013) is €1.00 in Italy and €0.53 in Croatia. Therefore, the longer route (through Croatia) is €177.19 cheaper (430km × €1.00−477km × €0.53). This significant difference in cost is the different Unit Rates in the two charging zones. The aeroplane might burn additional fuel by a longer distance, but the total savings are higher if the plane flies through Croatian airspace. In this specific example, the additional distance is 47km for the plan through Croatia. It is cheaper for the airspace user to file (and fly) the longer flight plan as long as its operating costs per kilometre are less than €3.77 (€177.19 ÷ 47km). This constitutes an incentive for airspace users to file longer routes with a detrimental effect on the horizontal flight efficiency indicator (KEP).

Avoiding expensive unit rates and asking for direct routing may negatively impact safety due to sector overload and capacity due to ACC under and overload. This is the argument used to implement a single unit rate per FAB, which is quite complex given the diverse local financial arrangements.

Conclusions

The SES general target is to reduce flights' environmental effects by 10%. SES brought many changes in how various countries collaborate in ATC management. The KPA of environment in the Performance Regulation is not exactly a separate target, but someone could argue that it benefits from improvements in the other areas. Moreover, the restructuring of the airspace and the creation of FABs contributed to the ATC management improvements in several areas. Despite these improvements, the SES has not delivered to the desired level environment-wise, mainly due to the lack of effective economic incentives for the ANSPs. Despite the societal pressure for improved environmental performance, there is a low priorit*is*ation in the environment KPA.

Significant focus has been placed on flight efficiency and airspace structure to mitigate climate change. Other environmental parameters are also of significant importance. More initiatives focusing on local air quality and noise pollution should be considered due to their high impact on local environmental issues. The trade-off between the different KPAs and the various environmental issues should be better balanced.

Finally, it is of fundamental importance to increase the environmental literacy of airspace users, ATCOs and all the stakeholders. The most effective action to increase environmental awareness is to change the mentality of ATCOs and ANSPs employees via training. In addition, airspace users are not making the best from SES. There are conditional routes available that the airlines do not use either due to the short notice or due to the difficulty from the AOC to change the flight plans as a system. The airlines should also be informed about the implemented solutions regarding the CDRs, and a better communication channel should be developed to make the change of routes a reality.

Discussion questions

1 To what extent can ANSPs contribute to climate change mitigation?
2 What are the trade-offs of KPA of sustainability?
3 How does the market environment and structure affect the environmental performance of ANSPs?

Note

1 Operated by EUROCONTROL on behalf of four States, EUROCONTROL's Maastricht Upper Area Control Centre (MUAC) provides civil and military cross-border air traffic control in the upper airspace of Belgium, Luxembourg, the Netherlands and north-west Germany (from 7.5 km or 24,500 feet).

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8 Air navigation service provider charges

Frank Fichert

Introduction

In the first years after the signing of the Chicago Convention, when commercial aviation was still in its infancy, the provision of air navigation services (ANS) usually was financed via the state budget. However, in line with the rapid expansion of the industry and the growing need for a more advanced (and also more costly) ANS infrastructure, the number of states that levied specific user charges increased. In 1958, the International Civil Aviation Organization (ICAO) held its first conference on 'charges for route air navigation facilities and services' (Jaworski, 1959), leading to ICAO's first statement on this issue, adopted by the Council in November 1958 (ICAO, 1959, pp. 36–37).

Today, following the 'user-pays principle', the provision of air navigation services is to a large degree financed by the airspace users via dedicated charges. Already more than twenty years ago, ICAO (1997, p. 9) stated that 'charges for route air navigation services are […] almost universally applied'. In 2003, 2005, and 2007, air navigation charges accounted for more than 90% of the total revenue of air navigation service providers (ICAO, 2007, p. 7).[1] However, in some countries, most notably the US, also specific taxes are levied on the air transport industry, with the revenues from these taxes being 'earmarked' for ANS provision (Oster & Strong 2007, p. 157). Since they are earmarked and linked to air transport activities, these taxes might be seen as an indirect way of user funding.

From the perspective of the airspace users, ANS charges are an important part of operating costs. However, it is difficult to determine their relevance since airlines usually do not distinguish between airport fees and air navigation charges in their annual reports.[2] On a global basis, the average costs per flight hour (instrument flight rules – IFR) in 2018 were 523 USD[3] (CANSO, 2020, p. 44), with a significantly lower amount for oceanic services. In addition, charges are levied for the use of approach and aerodrome services. Between the years 2000 and 2006, the share of air navigation service charges in airlines' total operating expenses varied between 2.4 and 2.8% (ICAO, 2007, p. 11).

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In this section, first some general charging principles are outlined based on the respective work of ICAO. The next subsection presents an overview of different design options for en-route charges, followed by a discussion of the pros and cons of different designs as well as potential alternatives. The following subsection deals with charges for approach and aerodrome services. Building upon the previous subsections, the interdependencies between different charges as well as selected administrative issues are discussed. Finally, some conclusions are drawn, discussing also challenges in applying the user-pays principle in times of a lasting industry-wide crisis.

Charging principles

If charges are levied for the use of air navigation services, some decisions on the cost basis (i.e. the overall amount that should be collected via charges) and on major charging principles have to be made. Based on ICAO's 'Policies on Charges' (ICAO, 2012), the four key charging principles are non-discrimination, cost-relatedness, transparency and consultation. Whereas the two last-mentioned principles are rather 'formal' (basically prescribing that charging schemes have to be published and airspace users should be consulted), the non-discrimination principle and the cost-relatedness principle directly affect the actual level and the design of the charges.

First, it has to be decided which costs should be passed on to the users.[4] ICAO (2012, p. III-1) recommends to allocate the full costs of providing ANS to the respective cost basis, including 'appropriate amounts' for the cost of capital and the depreciation of assets. Since the provision of air navigation services usually shows many features of a 'natural monopoly', it might be tempting for states (or commercial providers) to inflate the cost basis, especially if the majority of the airspace users are located in other countries. Consequently, ICAO (2012) stipulates that 'international civil aviation should not be asked to meet costs which are not properly allocable to it'. This implies, among others, a separation of costs between civil and military airspace users as well as between different types of flights (esp. domestic vs. international). In particular, the non-discrimination principle as laid out in Article 15 of the Chicago Convention prescribes that, for a given service, aircraft operated by foreign airlines should pay the same charge as those operated by a domestic airline.

The principle of cost-relatedness also implies that en-route services might be separated from approach and aerodrome services; a distinction that is recommended by ICAO (2012, p. III-1) and can be found in many ICAO member states. Thereby, in the European Union (EU) the term 'terminal services' is used,[5] referring to ANS provided during approach and departure,[6] whereas ICAO (2012) uses the term 'approach and aerodrome control' for this type of services. If separate charges are levied for en-route and approach and aerodrome services, rules for allocating costs have to be defined, preventing a cross-subsidisation between these activities. For example, under the assumption that domestic airlines have a higher share in the use of approach and aerodrome services than in the use of en-route services, states might have an incentive to cross-subsidise approach and aerodrome services by imposing higher charges in the en-route segment, thereby reducing overall costs of their domestic airlines.

Options for the design of charges – en-route

Key design options and examples

In theory, many options for levying en-route charges exist. Also in practice, a large variety of charging schemes is used by ICAO member states (see already Odoni, 1985, pp. 2–21). The following paragraphs focus on key design options and also provide some examples for illustration,[7] often omitting details of the sometimes quite complex charging schemes of the respective countries/ANSPs.

The most simplistic option is a 'lump sum' charge or 'flat fee' per flight, i.e. each aircraft using a particular airspace pays the same amount of money.[8] A distinction between overflights and flights arriving at and/or departing from an airport of the respective country might be made. Moreover, different levels of the flat fee might be set for different types of aircraft (e.g. turboprops and jets, as in the case of the Republic of Korea). Flat fees might be a suitable option for small countries or other regions where the distance flown by the various users within the respective airspace does not differ much (e.g. an oceanic airspace). Moreover, a flat fee might be appropriate if a more sophisticated charging scheme would create a disproportionate administrative burden when compared to the overall revenue. In practice, a fixed charge is used in several countries for flights operated with small aircraft, e.g. below a maximum take-off weight (MTOW) of 5.7 or 14 tonnes. Only few ICAO member states have implemented flat fees for larger aircraft, most of them only for overflights. In addition, flat fees are used for financing the provision of ANS in the oceanic airspace, e. g. oceanic charges levied by Canada, Iceland, Japan and the UK.

As a second option, the charge might solely be based on the distance flown within an airspace. Assuming that the speed of an aircraft in the en-route phase does not differ much between airspace users,[9] distance is to a large degree proportional to the time that the aircraft is controlled by the respective air navigation service provider (ANSP) which might serve as a proxy for the average workload caused by this flight (see already Odoni, 1985, pp. 5–7). However, given that the workload of the controllers is not proportional to distance, the tariff of the charge might be regressive (i.e. a decreasing average charge per distance unit). Also a two-part tariff (fixed charge plus proportional distance based charge) might lead to such a regressive effect.

Within a distance based charging scheme, several options for determining the distance exist, e.g., planned distance vs. actually flown distance, shortest distance between entry and exit point vs. sum of distances between waypoints, etc. Moreover, a continuous function might be used, or the ANSP might define distance classes (stepped scale), using either even or uneven intervals. ANS charges that are solely based on distance flown are not very widespread. One example is Iceland (Reykjavik flight information region – FIR); another one is the US (overflights only).

Neither the flat fee nor a solely distance based charge takes into account that different flights are of different 'economic value' for an airspace user. As a 'rule of thumb', one might argue that the (potential) 'economic value' of a flight increases with the capacity of an aircraft, and therefore its maximum take-off weight. Charges based on the MTOW (or the maximum take-off mass – MTOM) are common for airports, and sometimes considered to be a simplified form of Ramsey pricing (Morrison, 1982; Martin-Cejas, 1997; Hakimov & Mueller, 2014). However, it is quite easy to think of examples for flights with small aircraft that are of high importance to the user, leading to a high (potential) willingness to pay for ANS (e.g., transport of specific cargo (e.g. medicine), ambulance flights, but also some time-sensitive business aviation flights).

Box 8.1 Ramsey pricing

Usually, prices based on marginal costs are considered to be a first-best solution in order to achieve economic efficiency. However, if an industry is characterised by a high share of fixed costs and marginal costs are low (this describes the typical situation when controlling an uncongested airspace), marginal cost pricing usually leads to financial losses for the operator/provider of the service. On the other hand, prices based on average costs lead to welfare losses since users will be excluded even if their willingness to pay for that service exceeds the marginal cost of providing it. Ramsey pricing is a ('second best') concept that maximises overall welfare subject to the condition that total revenue covers the total cost of providing a service. The basic idea is that the price (or charge) paid by a user should be negatively correlated to the user's own price elasticity of demand (inverse elasticity rule). In other words, if the maximum price that a potential (user) would be willing to pay is rather high (in order words, demand is rather inelastic) this user will be charged a rather high price, whereas a user with a low willingness to pay will be charged a lower amount. In a nutshell, just like average cost pricing Ramsey pricing leads to full cost recovery, but the number of users is larger (and therefore welfare is higher) in a Ramsey pricing scheme when compared to an average pricing scheme. However, users have no incentive to reveal their willingness to pay to the providers of the service. Consequently, in practice some 'proxies' for a user's own price elasticity have to be used if Ramsey pricing should be applied. A more formal description of Ramsey pricing can be found in basically every textbook on regulation.

Together with distance, ICAO (2012) suggests aircraft weight as a potential base for charging. Again, many options for a weight-based tariff exist. Similar to a distance based tariff, the ANSP might use a continuous function based on aircraft weight (proportional, progressive, or regressive)[10] or define weight classes.

In practice, several countries have implemented en-route charges that are solely based on aircraft weight classes. The number of classes ranges from only two (e.g. Lebanon) to nine (Laos). A class based charging scheme leads to a high marginal charge at the thresholds of the classes ('jumps'). However, if the average weight within the respective classes is taken as a basis, the average charge per tonne of MTOW usually decreases. Table 8.1 shows the weight based charge of Uganda as an example.

The most common design of en-route charges is based on distance as well as aircraft weight (ICAO, 2013, pp. 5–41). Again, classes or a continuous tariff might be used for both criteria. For example, the Asecna[11] member countries use a charging scheme comprised of four distance based and ten weight based classes, leading to a total number of 40 coefficients which are multiplied by the charging rate. Thereby, the smallest multiplier is 1 (flight distance below 750 km and aircraft weight between 15 and 20 tonnes), the highest one is 52 (flight distance above 3,500 km and aircraft weight above 540 tonnes). Similarly, for Oceanic charges Cabo Verde uses three distance classes and nine weight classes.

Several countries multiply distance with a rate factor based on weight classes,[12] with different weight classes used in different countries. Table 8.2 shows two examples of countries using five and six classes, respectively.

Table 8.1 Air navigation service charge in Uganda.

Class	*Aircraft weight (MTOW) in kg*	*Charge (USD)*	*Charge per tonne MTOW (USD)*
1	Up to 2,000	10	5.00 or more
2	2,001–4,000	20	5.00–10.00
3	4,001–10,000	25	2.50–6.25
4	10,001–20,000	40	2.00–4.00
5	20,001–95,000	125	1.32–6.25
6	95,001–150,000	200	1.33–2.11
7	150,001–273,000	280	1.03–1.87
8	Over 273,001	330	1.21 or less

Source: Civil Aviation Authority (Uganda) (2012), own calculations

Table 8.2 Distance based charging schemes using weight classes (examples).

Kazakhstan		*Malaysia*	
Class definition (MTOW)	*Rate factor (USD per 100 km)*	*Class definition (MTOW)*	*Rate factor (Ringgit per mile)*
Up to 50	49	Up to 2.5	0.05
50.1–100	66	2.5–5	0.10
100.1–200	82	5.1–45	0.15
200.1–300	89	45.1–90	0.20
Over 300	93	90.1–135	0.25
		Over 135	0.30

Source: Kazaeronavigatsia (2021), Civil Aviation Authority of Malaysia (2021)

Whereas most countries use a single-digit number of classes, in some countries the number of classes is rather high, e.g. 181 in Indonesia, leading to a charging scheme with only small 'jumps' between classes.

A large (and growing) number of countries calculate en-route charges by multiplying a continuous distance factor with a continuous weight factor. For most countries, the distance factor is proportional to the actual distance, either the distance itself or the distance multiplied by a fixed factor (e.g. 0.01). In few cases, the distance factor is not proportional to distance, e.g. in India which uses the square root of the distance.

In 1970, Eurocontrol developed a charging scheme which is based on a proportional distance factor and a less than proportional weight factor (see equation (1)), using the term en-route 'service unit' for the product of the distance factor and the weight factor. This charging scheme was implemented based on a multilateral agreement of the Eurocontrol member states and extended to other European countries based on bilateral agreements (McInally, 2011, p. 108). Today, this charging scheme can be found in Annex VIII of the EU's Commission Implementing Regulation (EU) 2019/317, laying down a performance and charging scheme in the single European sky.[13] Moreover, the formula is also used in several other countries, e.g. Brazil, China (aircraft over 200 tonnes MTOW), and Nigeria. In Europe, the unit rate (r_e) is set separately by each country.

$$(1)\ C = r_e \star \frac{d}{100} \star \sqrt{\frac{w}{50}}$$

with C = charge, r_e = unit rate, d = distance in km and w = MTOW.

Whereas in the Eurocontrol scheme aircraft weight in divided by 50 before taking the square root, other countries simply use the square root of the weight (e.g. Australia, Canada). However, as also shown in Table 8.3, this only affects the absolute value of the weight factor but not the relation between the weight factors of different aircraft. Other formulas are possible, e.g. the third or fourth root of weight (Odoni, 1985), but have not been implemented in practice.

The design of the weight factor determines the relative share of one flights' contribution to the overall financing of en-route services in a region. Assume, for example, an aircraft with a MTOW of 74 tonnes (e.g. an A320) and an aircraft with a MTOW of 395 tonnes (e.g. a B747-400) travelling the same distance in different countries. Table 8.3 shows the quotient of the charge paid by the operator of the B747 and the charge paid by the operator of the A320.

As an intermediate summary, Table 8.4 shows possible groups of design options for en-route charges, leading already to a total of 36 theoretical options. Especially with respect to distance and weight classes, the delineation used in Table 8.4 is to some degree arbitrary and other classifications are possible.

In addition to the en-route ANS charge, in some countries additional charges are imposed, e. g. a communication service charge or a meteorological service charge, often as a fixed charge without further differentiation.

Finally, charges might also be used to provide incentives for airspace users. ICAO (2012) demands that the charging scheme 'should not be imposed in

Table 8.3 Effect of different charging scheme designs on the relation between charges paid by different aircraft travelling the same distance.

Design type	*Example*	*Quotient of B747 charge divided by A320 charge*
Flat fee / only distance based	US overflights	1
Weight based classes	Uganda	2.64
	Kazakhstan	1.41
	Malaysia	1.2
Continuous weight based tariff	Eurocontrol	2.31
	Australia	2.31

Table 8.4 Overview of design options for en-route charging schemes. Examples: (1) Japan Oceanic, (2) US overflights, (3) Kazakhstan, (4) Uganda, (5) Asecna, (6) Eurocontrol.

				Distance based					
					Yes				
				No	*Distance classes*		*Continuous tariff*		
					5 or less	*6 or more*	*Regressive*	*Linear*	*Progressive*
Weight based	*No*			1				2	
	Yes	*Weight classes*	*5 or less*					3	
			6 or more	4	5				
		Continuous tariff	*Regressive*					6	
			Linear						
			Progressive						

such a way as to discourage the use of facilities and services necessary for safety or the introduction of new aids and techniques'. Moreover, differentiated charges might be used to foster the use of safety and/or efficiency increasing services or equipment. For example, the Canadian flat fee for 'International Communication Services' is smaller for aircraft using datalink than for those using voice. The potential use of congestion charges will be discussed in the next sub-section.

As mentioned earlier, the US only levies charges for overflights. In addition, airlines have to pay taxes on domestic as well as international flights (in particular a fuel tax as a quantity tax, a passenger tax as an ad valorem tax based on the airfare for domestic flights, a passenger tax as a quantity tax for international flights, and some other excise taxes). The revenue of these taxes is used for financing the airport and air navigation infrastructure. There have been some debates on changing the US financing system (US GAO, 2007) but so far, apart from the overflight charge which was introduced in the year 2000, the US financing scheme still relies on excise taxes rather than on user fees. With respect to the idea of Ramsey pricing, the ad valorem tax on domestic airfares might be seen as a better proxy for the 'economic value' of a particular flight than a charge based on the MTOW. Assume two airlines (A and B) operating the same type of aircraft on the same domestic city-pair, and a higher total revenue of airline A (e.g. due to a higher load factor and/or higher airfares). Whereas in a MTOW based charging scheme both airlines would pay the same amount, in the US airline A pays a higher tax than airline B.

Discussion

The design of en-route charges gives room for many controversies (Odoni, 1985). If charges are supposed to reflect the (average) costs of service provision, the MTOW of an aircraft does not matter at all, and one might rather refer to the time an aircraft spends in a particular airspace than the distance it travels. Moreover, the technical equipment of the aircraft and some characteristics of the flight (e.g. level changes) might be determinants of a controller's workload. However, given that a large share of an ANSP's costs are fixed (and consequently the marginal costs of controlling one additional flight are small), one might question more fundamentally whether a cost-based approach is suitable or whether other economic concepts might be more advantageous.

If some kind of Ramsey pricing should be applied for financing ANS provision, which is a common recommendation if capacity is sufficient, an airline's revenue generated through a flight is probably a better proxy than the MTOW of the aircraft. Consequently, an ad-valorem tax on airfares and cargo rates (as an indirect application of the user-pays principle) might be preferable to a direct user charge. However, for overflights (and to a large degree also for arrivals) this is hardly feasible from an administrative point of view (unless one assumes a worldwide uniform system of taxes that are earmarked for ANS provision and a scheme for revenue distribution that all states can agree on). Moreover, an isolated approach, as in the US, has some limitations as well, basically resulting in a different treatment of domestic and international passengers. Finally, for other airspace users, e.g. a business aviation aircraft operated by its owner, separate schemes would have to be implemented.

Like any other price (or fee), charges for the use of air navigation services create incentives for airspace users, some of them intentional, others unwanted. This is of particular relevance if there are large differences in charging rates between neighbouring states. Today, airlines typically use flight management software to calculate the most efficient trajectory between their origin and destination airports. It might be a cost minimising strategy to take a longer route (leading to additional fuel burn and CO_2-emissions), if a rather 'expensive' airspace can be avoided or the distance flown in this airspace can be reduced (Delgado, 2015). This is of particular relevance in Europe, with its (on average) rather small countries and large differences in unit rates of neighbouring countries. For example, in January 2021 the unit rate was 44.03 Euro in Poland, 67.09 Euro in Germany, and 99.55 Euro in Belgium. Moreover, for those countries that are not member states of the European Monetary Union, exchange rate fluctuations can lead to significant changes in unit rates, which are billed in Euro and adapted on a monthly basis (e.g., due to exchange rate fluctuations the Swiss unit rate for en-route services, which is fixed for one year in Swiss Francs, was 96.08 EUR in June 2018 and 97.94 EUR in July 2018).

Depending on the specific characteristics of the charging scheme, airlines might use two different strategies. Until 31 December 2019, charges levied by Eurocontrol were calculated based on the last filed flight plan. It has been reported that sometimes airlines filed a flight plan that avoided an expensive airspace, but during the flight pilots asked air traffic controllers to give them a 'direct', i.e., to allow them to fly the shortest distance between two points. Of course, since the airlines could not be sure that their flight would be granted a 'direct', there is some kind of 'gambling' involved. Nevertheless, in those cases in which 'directs' were granted, the revenue distribution between ANSPs deviated from the traffic distribution, and in general air traffic became less predictable because airlines had an incentive to file flight plans for which they were hoping that the actual route would not be the one that they had filed. Since 1 January 2020, Eurocontrol's charges are based on the actual route flown, avoiding the problems sketched above (Eurocontrol, 2020).

However, even if airspace users (have to) stick to the flight plan that they have filed, it might still be a cost minimising strategy for an airline to fly longer routes with a higher fuel consumption if the additional fuel (and time) cost is outweighed by savings in ANS charges. One example referred to in the literature (Steer Davies Gleave, 2015, p. 200) are flights avoiding the Italian airspace (unit rate 62.97 euros in January 2021) and using the airspace of neighbouring Croatia instead (unit rate 37.97 euros). In theory, several options exist to avoid those incentives and their detrimental effect on the environment. First, country specific unit rates might be replaced by a uniform unit rate for a group of adjacent countries, for all EU member states, or even for a larger group of countries. However, the different unit rates reflect differences in ANS provision cost (e.g. ATCO wages in Germany are much higher than in Poland) and a uniform unit rate for all EU member states would, for example, reduce the ANS costs for domestic flights in Germany and increase them in Poland, which might not be in line with equity considerations. Consequently, a uniform unit rate in (large parts of) the European airspace is probably not a realistic option in the short and medium term. As an alternative, uniform city-pair/airport-pair charges (depending only on MTOW) might be implemented (at least for Intra-European flights) that take into account the different cost levels of European ANSPs (Verbeek & Visser, 2016; Pavlović & Fichert, 2019). Within such a charging scheme, airlines would have an incentive to file and use the most efficient route (which in most cases will be the shortest one).

In Europe, but also elsewhere, parts of the airspace are congested at least during peak periods, leading to delays and deviations from airspace users' preferred trajectories. In parts of Europe, this problem was already observed during the 1980s (Commission of the European Communities, 1985) and remained to be an issue also in the late 2010s. From an economic point of view, peak-load pricing might be an option for congested parts of the airspace and during busy periods. There are several options for introducing differentiated en-route charges (Jovanović et al., 2014; Steer Davies Gleave, 2015; Bolić et al., 2017). In principle, priority will always be given to those airspace users that have the highest willingness to pay for using a given part of the airspace at a given time (one reason might be a rather high cost of delay, e.g. if many transfer passenger are on board an aircraft that otherwise would miss their connecting flights). However, the different phases of flight planning as well as ANSP capacity planning have to be taken into account (i.e., strategic, pre-tactical, and tactical). Demand as well as available capacity might be subject to effects which are hardly foreseeable (esp. weather, but also military needs for the use of airspace). Consequently, peak-load pricing will have to be dynamic instead of simply setting higher (static) charges during predefined 'peak periods'. Moreover, at least with respect to the European situation the use of monetary incentives as a means of demand management also requires a more centralised capacity management (Ivanov et al., 2019).

Options for the design of charges – approach and aerodrome services

Key design options and examples

With respect to approach and aerodrome ANS, the theoretical options for the design of a charge are quite similar to the options for the en-route segment (of course, without the distance factor). The charge could be a flat fee (e.g. India) or it might be based on aircraft weight, again using weight classes (e.g. Cabo Verde) or a continuous function which might be proportional (e.g. in Azerbaijan and Belarus) or regressive with respect to aircraft weight (see below for several examples). In a small number of countries, the charge per movement is based on the number of aircraft seats rather than the MTOW of the aircraft (e.g. Bahamas, with six classes).

In the EU, Commission Implementing Regulation (EU) No 2019/317 prescribes that for airports above a certain threshold (80,000 IFR movements per year) the unit rate for terminal services (r_t) is multiplied by a weight factor which is calculated as shown in equation (2).[14] This scheme is also used by some other Eurocontrol member states.

$$(2)\ C = r_t \star \left(\frac{w}{50}\right)^{0.7}$$

with C = charge, r_t = unit rate and w = MTOW.

Other non-linear tariffs are, for example, applied in Canada (weight factor = $w^{0.8}$), Morocco (weight factor = $w^{0.5}$), Egypt (using the Eurocontrol weight factor for en-route services) and China (weight class based scheme with a fixed unit rate within each weight class and a higher unit rate for higher weight classes). In Switzerland,[15] a distinction is made between airport types: the weight factor at the two largest airports is defined according to equation (2) and for the other airports it is $w^{0.65}$. With respect to cost-relatedness or incentives, some countries have different approach and aerodrome service charges for IFR and VFR flights; others include an environmental factor, based on the noise emissions of the aircraft.

Again, the design of the weight factor determines the share that operators of different types of aircraft contribute to the financing of ANS provision. Based on the Eurocontrol weight factor, the operator of a B747-400 pays a 3.2 times higher charge than the operator of an A320 (compared to a relation of 2.3 for en-route services in the Eurocontrol region; see Table 8.3). In Canada, the relation for these two types of aircraft is even 3.8.

Discussion

As most countries are equipped with more than one airport, one crucial element in the design of approach and aerodrome charges is the unit rate. On the one hand, it could be a uniform rate for the entire country. On the other hand, there might be a separate rate for each airport (or at least different rates for certain 'groups' of airports). This decision is to a large degree linked to the overall organisation of the airport sector in a country and the role of the respective ANSP (Arblaster, 2018, pp. 178–183). If airports are responsible for providing approach and aerodrome services, which they might outsource to ANSPs (e.g. via a tendering procedure), the unit rates (and potentially also the overall design of the charging scheme) usually will differ. This decentralisation of terminal ANS provision can be observed, for example, in the U.K., leading to different charges at different airports that might also include incentives, e.g. a peak/off-peak differentiation at Manchester airport.

In other countries, a uniform rate is used for all airports or at least for all 'major' airports (e.g. Germany).[16] Given that also the provision of approach and aerodrome services is characterised by a high share of fixed costs, average costs for these services will usually be higher at smaller airports. Consequently, a uniform rate leads to a cross-subsidisation of ANS provision at smaller airports which may not only have an effect on the competitive position of these airports but also on the competition between airlines which are to some degree 'bound' to specific airports based on their business model. However, one might also argue that at least for very large airports with a high traffic volume and a rather complex design of flightpaths, average costs for approach and aerodrome services might exceed those of medium sized airports. Therefore, the direction as well as the magnitude of cross-subsidisation in this segment can only be identified with the help of a thorough empirical analysis. For example, in January 2021, the (regulated) unit rate for the two Paris airports was almost 18% lower than the unit rate for the other 56 French airports; the unit rate at Warsaw was even less than half of the unit rate applied to the other 18 Polish airports. On the other hand, the unit rate for Rome airport is about 2% above the rate for four other large Italian airports.

Interdependencies between charging schemes plus some administrative aspects

Regarding the use of different types of air navigation services, the distinction between domestic flights, international flights, and overflights is crucial. Whereas a domestic flight uses approach and aerodrome services at two airports in the same country, international flights use these services only once, and overflights by definition only need en-route services. Moreover, from an air traffic control perspective overflights are usually the least complex ones, whereas domestic flights probably show the highest level of complexity since they include all phases of a flight. There are different ways how states/ANSPs deal with these different types of flights within their respective charging schemes.

First, several states apply different charges for domestic and international flights. In those cases, the en-route charges for domestic flights are usually below the charges for international flights and overflights (e.g. Algeria, Chile, Ecuador, Iran, Kenya, Maldives, Namibia, Peru and South Africa). Also the approach and aerodrome charges for domestic and international flights differ in some countries. For some other countries, the charges for international and domestic flights are difficult to compare, in particular if different charging schemes and/or different currencies[17] are used. It might be subject to further analysis, whether the lower charges for domestic flights in the respective countries are justified by higher costs for controlling international flights (e.g. use of specific equipment not needed for domestic flights), whether the costs for controlling domestic flights are subsidised via the state budget (e.g. full cost recovery for international flights but not for domestic flights), or whether there is some kind of cross-subsidisation between international and domestic flights involved. The International Air Transport Association (IATA, 2019) states that 'sometimes' cross-subsidisation occurs in favour of domestic airlines/flights, but without giving specific examples.

Second, some charging schemes only differentiate between overflights and flights to/from an airport within the respective country, with no specific approach and aerodrome charges being levied. One might argue that in these cases the cost of providing approach and aerodrome services is included in the ANS charge. However, in many cases the charges for flights landing at or departing from an airport in the respective country are below the overflight charges, again possibly indicating some cross-subsidisation between those types of services.

Finally, several countries only differentiate between charges for en-route and for approach and aerodrome ANS. This is a rather transparent approach. Usually, for flights arriving and/or departing in the respective country, the distance for which the en-route charge is levied is reduced in order to take into account that the operator also has to pay for the approach and aerodrome ANS which covers part of the approach. In particular, in the Eurocontrol member states as well as in many other countries, distance within the en-route charging scheme is reduced by 20 km if the aircraft arrives at or departs from an airport in the respective country. A different distance value is used only in a few countries, e.g. 25 nm in Botswana, 50 nm in Papua New Guinea, and 100–220 km in Iceland (airport dependent).

From a transaction cost perspective, airspace users serving international markets are faced with a potentially large number of charging schemes and billing institutions. In some parts of the world, states are cooperating in order to reduce the administrative burden to airspace users. In particular, Eurocontrol's Central Route Charges Office (CRCO) collects en-route charges for all Eurocontrol and for some non-Eurocontrol members, and terminal charges for some Eurocontrol member states as well as for some non-member states (Eurocontrol, 2021). Other cooperative institutions are Asecna and Cocesna,[18] but they do not collect charges on behalf of their member states.

If approach and aerodrome services are provided by the ANSP that is also responsible for en-route services in the respective country, the charges are in general collected jointly by this institution. If approach and aerodrome services are provided by or on behalf of an airport (e.g. UK airports, some regional airports in Germany) the charges might be levied either by the airport or by the respective provider. There are also some examples for airports that do not have a dedicated charge for approach and aerodrome services but state that the costs for providing these services are covered by the (movement related) airport charges (e.g. London Gatwick, or the German low cost airport Hahn).

Conclusions

Within the legal framework set by the Chicago Convention and based on the standards as well as guidelines provided by ICAO a rather diverse set of charging schemes has emerged throughout the world. However, with respect to the largest aviation markets the picture is more homogenous, with the Eurocontrol scheme as a role model for several other countries. Probably the most notable exception is the US, relying on excise taxes rather than on charges for domestic and international traffic.

In general, most current charging schemes are composed of different elements that are taking into account the average costs of service provision and the broadly estimated 'economic value' that a service is generating for the airspace user. Depending on the specific design of the charging scheme, the emphasis is set more towards the one or the other. As long as the airspace is not congested and airspace users have few options for strategic behaviour that 'outsmarts' the charging scheme, it is unlikely that an ANS charging scheme that basically refers to average costs leads to noteworthy distortions. However, especially in the European airspace significant levels of congestion (before COVID-19) as well as inefficiencies due to large differences in en-route unit rates of neighbouring countries can be observed. Given the complexity of air navigation service provision and the numerous, often quite volatile determinants of traffic flows, designing a suitable alternative for the current charging scheme is a much greater challenge than in many other infrastructure sectors, giving room for further research.

Moreover, any funding system that either depends on direct user charges or on earmarked taxes levied from airspace users (or their customers) is vulnerable in times of an industry crisis. The COVID-19 pandemic is the so-far most dramatic example of a plunge in air transport demand and ANSP revenue. Eurocontrol Performance Review Commission (2021, p. 66) estimates a reduction in en-route service units in 2020 of almost 58% when compared to 2019, leading to a revenue loss of 4.8 billion euros. Within the current regulatory framework, the largest part of these revenue losses might be recovered from the airspace users in later years. However, this might put additional financial pressure on the airlines, which are already heavily affected by the crisis. Therefore, some stakeholders argue in favour of an at least partial replacement of current user funding with (general) tax revenues (Barbero & Laursen, 2021). However, this might considered to be a subsidy for the air transport industry, and one might also discuss whether policymakers have an incentive to provide a sufficient amount of tax revenues to finance ANS operation as well as investment. It is not without reason that the independence on discretionary political decisions is often considered to be a major advantage of funding schemes based on user contributions.

Discussion questions

1 Please discuss the pros and cons of applying the user-pays principle to ANS provision.

2 Please discuss why it might be necessary to not only regulate the overall level but also the structure/design of ANS charges.
3 Please discuss the pros and cons of ICAO's recommendation to take aircraft weight into account in a 'less than proportional' way, when designing ANS charges.
4 Please discuss potential options of introducing peak-load pricing into ANS charging schemes as well as their pros and cons.
5 Please discuss whether all airports in a given country should have the same or a different unit rate for approach and aerodrome services.

Notes

1 This number is based on surveys covering up to 70 states.
2 One exception is the European low-cost carrier (LCC) Easyjet. In 2019, the airline paid 409 m GBP 'navigation charges', approximately 6 percent of total cost. However, given that Easyjet as a LCC has a rather low-cost base (e.g. staff) and to a large degree operates in Western Europe with its rather high ANS charges, its share of ANS costs is probably above the industry average.
3 This number refers to the states that are participating in the CANSO benchmarking.
4 This is also relevant for the regulation of air navigation service providers. In particular, many states allow for a full cost recovery, whereas in the European Union the total revenue permitted is based on the determined costs, which are set ex ante for so called 'reference periods' and are linked to a target for cost efficiency improvements. This issue is discussed in more detail in Chapter 9 of this volume.
5 Also other countries/ANSPs refer to 'terminal services', e.g. NAV Canada.
6 As a peculiarity, the London approach service combines features of en-route and terminal services. A separate charge is levied for this service covering aircraft arriving at or departing from five airports in the London metropolitan region.
7 Unless stated otherwise, information on charging schemes is based on ICAO (2016).
8 In some countries, owners/operators of small aircraft pay a monthly or annual fee for the use of ANS.
9 This of course is not true for jets when compared to propeller aircraft.
10 ICAO (2013: 5–39) recommends a less than proportional consideration of aircraft weight.
11 Agency for Aerial Navigation Safety in Africa and Madagascar (18 member countries, including France).
12 As an exception, Mexico uses the wingspan of the aircraft instead of its weight for class definition.
13 The definition of the en-route service unit can also be found in the predecessors of this regulation, esp. Commission Implementing Regulation (EU) No 391/2013 (Annex IV), and Commission Regulation (EC) No 1794/2006 (Annex IV).
14 The weight factor is based on an empirical analysis of the relation between the MTOW and seating capacity. For a comprehensive discussion of this weight factor see PricewaterhouseCoopers (2001, pp. 50–57).
15 Switzerland uses MTOM instead of MTOW.
16 The grouping of airports for which a uniform rate should be applied is a political decision. In Germany, the uniform rate is not only applied to large hubs like Frankfurt and Munich, but also to airports like Erfurt and Saarbrucken with less than 200,000 passengers p.a. (passenger numbers before the COVID-19 pandemic).

17 Usually the local currency is used for domestic flights and USD for international flights.
18 Corporacion Centroamericana de Servicios de Navegación Aerea, with six member states in Latin America.

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9 Regulation of air traffic control services

Principles and European experience

Hans-Martin Niemeier and Peter Forsyth

Introduction

Liberalisation of air transport has been a success story. Competition between airlines has brought down air fares and created gains in economic welfare. This liberalisation is still far from perfect. So called 'open skies' are restricting cross border consolidation of airlines and slots are creating barriers to entry for newcomers. In spite of this, the far from perfect market has led many industry experts be very optimistic about markets. Compared to airlines, air traffic control remains one of the most and heavily regulated industries. This chapter analyses the proper role of the markets and the proper role of regulation in organising air traffic control. The liberalisation of air transport has taught us many lessons, as did the regulation of public utilities and in particular airports. These lessons are taken on board in outlining how those parts of the air traffic control value chain can regulated. This is the contrasted with current form of regulation of ATC.

The chapter is organised as follows. We start by contrasting the performance of the liberalised airline market with the performance of the ATC. We then ask if the ATC value chain could be organised by separating into distinct markets, and if so to what extent. We argue that more activities can be liberalised but there remains a core which needs to be regulated.[1] How this can be done will be discussed thereafter. The chapter ends with a summary and conclusions.

The performance of liberalised airline markets and the performance of ATC

Liberalisation of air transport started in the 1970s in the US. At that time it was a politically controversial issue. There were a number of studies criticising the Civil Aeronautics Board for regulating air fares and causing substantial inefficiencies. The CAB set the air fares at average costs of the airlines and allowed designated private airlines to compete. Entry was not allowed. The airlines competed not on price but in terms of service frequency, which led to half-filled flights. The low productivity led to higher operating costs, which

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in turn were accepted by the CAB, as air fares were set on average costs. Economists criticised this and argued for an open market for competition, as this would lead to market entry forcing the incumbents to cut costs and lower air fares. Another aspect of inefficiency was that there was very little variation of service quality and fare levels – low-cost carriers were unable to compete. In the end after deregulation market prices fell substantially. This was not only textbook economics, but as Winston (1993, p. 1286) pointed out, 'microeconomists' predictions that deregulation would produce substantial benefits for Americans have been generally accurate'.

Air traffic control is regarded today by many observers in a similar situation to the airlines before deregulation. In many countries, ATC has been for a long period of time regulated by the principle of full cost recovery. As this principle allows cost increases to be passed on to the users, there are no incentives for cost efficiency. On the contrary, it gives incentives to build empires. The more controllers and the more capital used, the better the manager. There is no incentive for labour saving and cost saving technologies. Gold plating and cost padding are all rational strategies for ATC managers, as these increase their rewards, the increased costs of which can be passed on to the users. There are incentives for excess capacity and cost inefficiencies. Likewise, there are no incentives to manage capacity shortages well. Peak and congestion pricing is generally not practised (it is also opposed by airlines).

Airlines are officially critical of ATC inefficiencies. This has intensified with the liberalisation of aviation. In regulated times, the ATC cost could just be pushed on to the consumer easily. Liberalisation has changed this a little, but not so much, as for airlines ATC charges are similar to a tax. They do not like it, but as long as higher ATC charges do not change the competitive position, they accept it in the end. Furthermore, the fixed cost nature of ATC leads to productivity gains with higher traffic. Only in a crisis, when ATC charges increase because of the full cost recovery principle, do airlines become very critical, or when delays occur which hit all airlines but to different degrees.

The empirical evidence for substantial inefficiencies is reflected in benchmarking studies. Since 2008 Eurocontrol and the Federal Aviation Administration of the US have compared operational key performance data of the EU and US system. The comparison showed that overall the US system is performing much better than the Single European Sky. In 2015 the FAA handled 57% more flights than the EU system with 17% fewer air traffic controllers and 44% fewer total staff. The unit costs for 2014 of the FAA were 35% lower than in Europe. These comparisons are based on partial indicators and do not give a precise picture of the difference in terms of cost efficiencies. Unfortunately, there are no academic studies offering a more comprehensive analysis, but the differences are so great that precision is not needed. The evidence clearly indicates a large gap. Academic studies have analysed the EU system. Bilotkach et al. (2015) found that Western European countries perform better than Eastern for the period 2002 to 2011. Button and Neiva (2014) also found large differences among the ANSPs in terms of cost efficiency and in another study Neiva (2015) showed that the performance of an ANSP depends also much on the performance of the others. There is a substantial interdependency among the ANSPs in the Single European Sky. Bilotkach et al. (2015) and Button and Neiva (2014) also found evidence that productivity grows slowly and cost efficiency improved over time. These productivity gains are very often driven by growing traffic and less by reducing inefficiencies. European ANSPs are operating under increasing returns to scale (Dempsey-Brench & Volta, 2018). Adler et al. (2018) analysed the efficiency of ANSPs of the European Union with total benchmarking methods for the year 2016 and stress that 'ANSPs could save between 25 and 30% of total costs on average by adjusting to best practices' (ibid., p. 2) and that 'potential cost savings of one billion euros was possible in 2016 in the en-route sector and another 300 million in terminal provision.' (ibid., p. 3). These are conservative and robust estimations.[2] Benchmarks are always relative. If the US ATC system were included in the benchmark of Adler et al. the inefficiencies would increase. Add to that that the US system has also been criticised for having to high costs, the potential for cost savings grows even further.

In summary, the performance of airlines and ATC is strikingly different. Airlines have been forced by competition to become more and more productive and price their products to what the market will bear. Competition, even when not perfect, lets productivity gains be passed on to the consumer. ATC has made only very slow productivity gains and has not used the potential gains from new technologies. Pricing is based on full cost recovery or average costs, and does not reflect market conditions. Only small productivity gains have been passed on to the airlines. Given these experiences, the demand to let the market also work in ATC is easy to understand. To determine whether it is feasible for ATC markets to work in the ways that airline markets work, it is necessary to examine cost conditions. Economies of scale are insignificant in airline markets, and competition can thrive. By contrast, if a market is dominated by natural monopoly, competition will not survive.

How do ATC markets work?

Economics has developed an elaborate theory under which conditions markets work efficiently and under which markets fail to do so (Bator, 1958; for a recent textbook treatment see Church & Ware, 2000). There are several possible market structures, ranging from competition to monopoly. A perfectly competitive market allocates resources efficiently and maximises economic welfare. Perfect markets are rare, as the conditions for such markets are rarely met. Real world markets are usually imperfect and that is why the state sometimes intervenes with various policies, such as for example environmental policy. Competition policy tries to prevent firms from monopolising markets and abusing their market power. This is an ex-post measure. Regulation acts ex-ante in case competition is not possible and a monopoly leads to persistent power. Regulatory economics tries to identify these monopolistic situations by analysing the structure of an industry, and detects those areas which are not contestable, and hence a natural monopoly exists.

There are two conditions for a natural monopoly. The investment must be relation specific, that is it has only value in a specific exchange relationship. If the investment is done and the relationship does not work anymore, then the investment is useless and the capital is sunk. This is the first condition. The second is that the cost function must be sub-additive. A natural monopoly is an industry 'whose cost function is such that no combination of several firms can produce an industry output vector as cheaply as it can be provided by a single supplier' (Baumol et al., 1977, p. 350). For the case of a single product (see Figure 9.1) this is the case if the demand curve D intersects the long run average cost curve (LRAC) in its decreasing part. In such a case, the larger firm has a cost advantage which would enable it to drive out the other firms with a lower output, and thus create a monopoly. As a new firm requires specialised investment while the capital costs of the incumbent monopolists are sunk, the incumbent cannot be challenged by a new entrant. Such a natural monopoly is efficient as two or more firms would lead to higher average costs, but the efficiency gains might be lost due to the use of market power. A profit maximising firm would charge prices well above average costs. The use of market power by the natural monopolist can be reduced by regulation. Also note that the solution of a perfect market with prices set at marginal costs is not feasible as the marginal costs are below the LRAC. This gap can be closed at best by differentiating prices. ATC charges do this by being weight related (see below).

Not all parts of the ATC industry can be characterised as natural monopoly. As with other industries, such as telecommunications, the ATC industry consists of distinct parts, some of which are natural monopolies, but others might have the potential to be competitive.

Disaggregating the vertical structure of air traffic control leads to the following model (see Table 9.1). This model is quite general and explains the vertical structure of ATC in Europe, the US and other countries well.[3] In order to find out which parts of the vertical structure of ATC production have the character of a natural monopoly with sunk costs, we have to answer two questions:

- Is there evidence on the cost side for a natural monopoly?
- Are the investments relation specific? Are costs sunk once investment had been made?

Table 9.1 provides evidence of natural monopoly. With current technology, ATC services are offered over a specific location by combining the activities shown in the table. The location can be divided into the terminal area and the en-route area. For a given air space, the costs are lower if this area is exclusively managed by one provider because, with two or more providers,

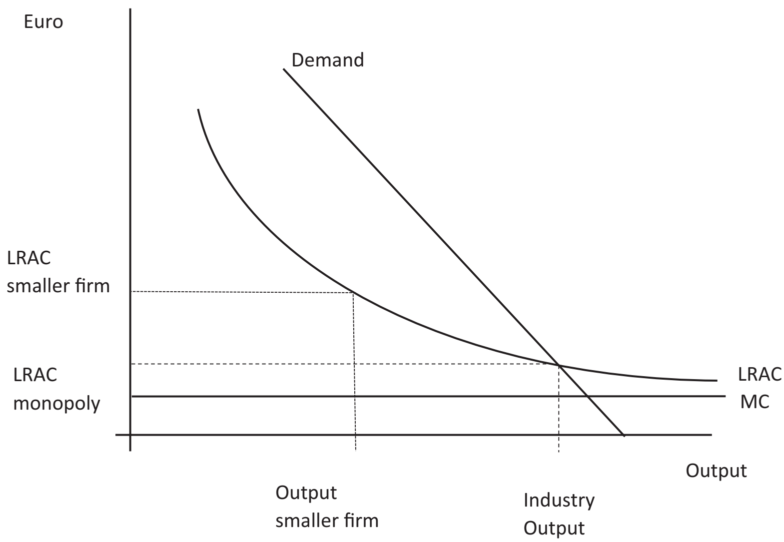


Figure 9.1 Natural monopoly.

Table 9.1 Evidence of natural monopoly in the vertical structure of ATC.

Activity	*Natural monopoly*	*Evidence*
Exclusive right of disposal over a defined airspace	Yes	not empirical proven
Communication navigation and surveillance service	Yes	not empirical proven, but alternative technology might change this
ATM system	No	decreasing average costs plausible, but no relation-specific investment; hence, contestable market
ATM service	No	learning economies, but no natural monopoly; mobility of air traffic controllers

coordination costs would increase. In addition, some scale economies in the vertical chain would be lost as well (see below). Self-separation of aircraft would change this, but under current conditions the terminal area and the en-route area have natural monopoly characteristics. Extending the air space should also lead to lower costs, in particular, if the space is defined arbitrarily by national boundaries, as in Europe. It is intuitively plausible that economies of scale could be realised with larger ANSPs as the fixed costs for example of an ATC centre are spread over a larger area.[4] The Single European Sky initiative was supposed to deliver these economies, but up to now there remains too much fragmentation and unrealised economies of scale (Bilotkach et al., 2015; Dempsey-Brench & Volta, 2018). At what level these economies will run out has not been analysed empirically. Similar considerations also hold for the terminal area. Competition among different providers at an airport is inefficient, but competition for the market through tenders is possible and practised with promising results in terms of efficiency (Arblaster & Zhang, 2020).

Computer navigation services (CNS), such as radar technology, were the backbone of the air navigation services (Knieps, 1990). Under a radar system, CNS have a natural monopoly as it would be extremely costly to duplicate such network. However, radar, first developed in the 1930s, has become outdated. Satellite systems offer higher quality at a lower cost, turning the former natural monopoly into a competitive market, at least in principle (see the discussion of the potential gains and implementation problems by Arblaster, 2018, p. 30ff).

The data from CNS services are processed by ATM Systems to the air traffic controller. These ATM Systems require large investments which could be a source for decreasing unit costs. However, the ATM Systems market is in principle, contestable, as the CNS data can be processed on a global basis.

The ATM services are provided by the air traffic controllers. As it takes a number of years to educate an air traffic controller, there are substantial economies of learning-by-doing which are a source for lower average costs, but do not cause market failure. It also takes time for an air traffic controller to switch countries and learn the specificities of a new controlling area. Nevertheless, such changes are possible so that these services could be left to the market (ibid.).

How to regulate and how not to?

In the following sections we define the goals of regulation. Thereafter we discuss institutional aspects of regulation and then review the regulatory instruments. For all three issues we compare the theory with the actual practice of regulating ANSPs.

Goals

Economic regulation is guided by the basic idea is that regulation should lead to firms which maximise economic welfare as far as possible (Baldwin & Cave, 1999; Forsyth, 1997; Kunz, 1999). Competition is not feasible if there is natural monopoly, but regulation seeks to induce firms to price and produce as efficiently as possible.

Ideally ANSPs should maximise economic welfare, which would involve operating the following conditions:

- Airlines and other users should be protected from prices above the minimum efficient levels. Charges should be set as close as possible to marginal cost. Given that, with natural monopoly, the marginal costs are below average costs, prices which cover costs should be differentiated if possible, minimising the welfare loss.

- ANSPs should produce in a technically and cost-efficient way; that is, they should use only the minimise inputs to produce a given level of output, and should select from these technically efficient combinations those which minimise the cost of producing this output level.
- ANSPs should ration demand efficiently. If demand exceeds temporarily or permanently capacity, output should be distributed to those with the greatest willingness to pay.
- ANSPs should invest up to the point where the marginal benefit of additional capacity equal the marginal costs of providing the extra capacity.

ICAO principles on ATC, and the EU Directives, as well as regulation in Australia and UK have accepted these conditions, at least to some degree. Protecting users from monopoly power is a goal widely shared. Charges should be non-discriminatory. Allocative efficiency, especially when rationing demand, is contentious and has led to many deviations by policy makers from the above principles.

Regulatory Institutions for public and private ANSPs

Unlike airlines and airports, many of which have been privatised in whole or in part, most ANSPs have not been privatised. The UK provider NATS and the Italian provider ENAV are notable exceptions, but both are only partly privatised, so private investors have only a minority share. In the case of NATS, airlines and airports hold a minority share. This is not the case for ENAV. In many other European countries ANSPs have often been corporatised so that commercial interests gained importance. Given this rather strong role of the state we have to develop regulatory institutions for private and state-owned ANSPs which are independent of ownership.

Both economics and political science have developed rationales for effective regulatory institutions for public utilities which we can use for regulation of ANSPs (Niemeier, 2010).[5] The economic rationale is to ask how to effectively correct for market failure which – as we argued above – is relevant for parts of the ANSP value chain which have the character of natural monopoly. From this line of thought, we can adopt instruments and institutions to regulate a private monopoly. The political rationale asks if and how politics should delegate power to independent institutions, such as a regulator or a commission. Democratically elected governments only have power for a short period of time and cannot bind future governments, but they can assign limited discretionary power to independent regulators which have expertise and are committed to long-term political goals. Both approaches have much in common (Bartle & Vass, 2007). Actually, both face the same problem. The owner, either a private or public body, has to invest in a relation-specific long-term asset. In theory, they both could write a long-term contract that covers all contingencies, but this is not possible in the real world in which we face risks of uncertain probabilities. COVID-19 is one of the many black swan events which air transport has seen in recent decades. Furthermore, there is the risk that the partner for which a certain investment is tailored behaves opportunistically after the investment is made. For example, an airline might announce an expansion of its flights so that it is profitable for the ANSP to invest in additional capacity. Once the investment is made the airline knows that it could offer just the marginal cost of such a service, which will not cover the high fixed costs. Similarly, there are many investments in new technology which only realise their full potential if all parties adopt them. This makes opportunistic behaviour profitable. The problem of ANSPs, either private or public, is described by Gomez-Ibanez (2003, p. 3) and is indeed the central problem for all public utilities: 'The expensive, durable and immobile investments help make all parties – the company, its customers, and the government – vulnerable to opportunism and desirous of stability and commitment'.

How can stability and commitment be achieved? The answer to this question is the same from the viewpoint of economics and political science. Economists like Levy and Spiller (1994), Stern (1997) and Stern and Holder (1999) argue that stability and commitment can be best achieved by an independent regulator, an institution with limited discretionary power which provides long term credibility and trust, expertise and flexibility without arbitrariness. Political scientist like Majone (1997, p. 152) point out that 'independent agencies enjoy two significant advantages: expertise and the possibility of making credible policy commitments'. From both of these strands of theory it follows that an independent regulator with discretionary power provides a good governance model for public utilities.

These theories have also defined principles and criteria for effective regulatory institutions adopted by the OECD (2005) and by a number of high-income countries (for example the UK) and other countries (for example Brazil, Chile):

- *Legislative mandate from elected legislature.* Regulators should have a well-defined set of objectives from their parliament. The legal framework should separate the roles and responsibilities and define principles of good regulation.
- *Independence and accountability to democratic bodies.* Independence can be undermined directly by the regulated firm or by users; this is termed regulatory capture. For independence it is necessary to separate the function of regulation from the function of ownership and management of public utilities.
- *Fair, accessible and open process.* Public hearings and consultation should be part of any good regulatory approach. Results should not be predetermined.
- *Cost effective regulatory processes.* The legislative mandate should be effectively implemented avoiding high bureaucratic costs.

- *Well targeted and temporary.* The causes of market power are not immune from change over time. The questions of which firms should be subject to regulation should be answered an investigation in which the regulator and the stakeholders participate, but the final decision should be taken by a third party.

Table 9.2 provides an overview of the independence of regulators of selected ATCs. Historically ATCs were organised as a government department. This

Table 9.2 Governance of selected air navigation service providers.

Country	*ATC Name*	*Ownership*	*Regulator*
Australia	Airservices Australia	Government corporation	Regulatory Commission
Canada	NAV CANADA	Not-for-profit private corporation	Legislated principles/ appeals
New Zealand	Airways Corporation of New Zealand	Corporation	Self-regulating/ appeals
South Africa	Air Traffic and Navigation Services Ltd.	Not-for-profit joint-stock corporation	Transport ministry committee
European Union			
European Union	ANSPs of all EU member states	N. A.	Performance Review Body advising the EU Commission
France	Direction des services de la navigation Aérienne (DSNA)	State department	DGAC (French CAA) Approved by transport ministry
Germany	Deutsche Flugsicherung GmbH (DFS)	Government corporation	Bundesaufsichtsamtes für Flugsicherung (BAFG)
Netherlands	Luchtverkeersleiding Nederland (LVNL	Not-for-profit government corporation	Approved by transport ministry
Ireland	AirNav Ireland	Government corporation	Irish Aviation Authority[a]
Italy	ENAV	Minority private	ENAC
Switzerland	Skyguide	Not-for-profit government corporation	Approved by transport ministry
United Kingdom	National Air traffic System, Ltd.	Public/private partnership	Civil Aviation Authority Independent regulator
United States	FAA's Air Traffic Organization	State department	Financing from taxation

[a]The IAA was the name of the Irish ANSP until 2021. In 2022, the ANSP was separated under the name AirNav Ireland from the remainder of the IAA which will be the name of the combined aviation safety and economic regulation. This reorganisation, designed to make ANSP regulation independent of the service provider, was first proposed in 2004.

Source: based on Button and Dougall (2006); updated from various ATC websites is still the case in the US. In 2005, the US formed the Air Traffic Organization (ATO), an organisation within the Federal Aviation Administration. According to Oster and Strong (2007) and Puentes and Neiva (2017) the ATO suffers from organisational dependence, lack of accountability and a disconnection between cost and revenue drivers. The ATO is financed through excise and general taxes, while other countries rely on user charges. In short, the US has not applied the model of an independent regulator.

In Europe air traffic control was done by each state individually. This led to large delays and to the Single European Sky initiative. There are two levels of regulation – a European one which sets the level of charges overall and checks the consistency of plans of the ANSPs of each member state, and the regulation at the level of each member state. On the European level, the regulator is the European Commission which is advised by the Performance Review Board (PRB). The PRB is a group of independent experts. Initially it was designed to become an independent regulator, but the PRB was dependent on cooperation with Eurocontrol, which in itself fulfils many functions like setting standards and providing air navigation services. This cooperation did not work and led to many conflicts, undermining the effectiveness of the PRB. It proved that the theoretical reasons for independence were real (Aviation Advocacy, 2017). The Commission conceded, and reorganised the PRB so that it remained a group of independent experts acting under direct control of the Commission. In parallel the Commission set up a Wise Persons Group (2019) to propose reform. This group recommended

> a strong, independent and technically competent economic regulator at European level … which could be accommodated within EASA, would have permanent staff. The Commission would elaborate new legislative proposals. The independent economic regulator would provide evidence and advice to the Commission in relation to the definition of performance targets and approval of performance plans. It would establish Acceptable Means of Compliance, monitor performance and support national authorities to oversee the performance of service providers. Its decisions should be subject to an appeal mechanism (mediation body, ultimately access to the European Court of Justice/Court of First Instance in case of disagreement with its decisions).
>
> (Wise Persons Group, 2019, p. 24)

The implementation of this proposal is currently being discussed by all parties. It meets a number of the criteria for an effective regulatory institution, in particular the appeal mechanism. There seem to be three critical aspects:

- If EASA, which regulates safety and security, becomes also the economic regulator then this might create conflicts between the different goals. This conflict could be resolved within EASA if it were organised like the UK CAA where both divisions are independent from each other with control over budget, and personnel and are not subordinated under a common director.

- The regulator just gives 'evidence and advice to the Commission'. If the final decision is left to the Commission – which, in effect, is then the regulator – the member states who are managing directly or indirectly the ANSPs can pressurise the Commission to decide in their interest.
- The independent regulator should report to the parliament as to how it fulfils his duties and obligations.

At the level of the member states most countries have separated ATC management from regulation in some form. The European Parliament (2004) asked its members to separate these functions:

> The national supervisory authorities shall be independent of air navigation service providers. This independence shall be achieved through adequate separation, at the functional level at least, between the national supervisory authorities and such providers. Member States shall ensure that national supervisory authorities exercise their powers impartially and transparently.
>
> (Article 4)

The problem with this recommendation is that it is not enough to have only some functional separation as this fails to meet the conditions for independence. An unambiguous separation was adopted in the UK when the UK was still a member of the EU, and in Italy. The partial privatisation of NATS with a minority share for a consortium of airlines was combined with a reform of regulation along the lines of British public utility price cap regulation[6] (Steuer, 2010). NATS is regulated by the CAA which is organisationally and legally separated from the DfT, and is responsible to parliament. Italy has followed this model, but only half-heartedly. The Italian Transport Ministry has a 51% share in ENAV and can directly influence the decisions of ENAC which is a subordinated authority of the transport department. This purely functional separation does not guarantee independence and does not resolve the conflict between ownership and regulation. Privatisation was also discussed in Germany in 2005. The German provider Deutsche Flug Sicherung (DFS), a limited corporation fully owned by the federal government, was planned to be privatised and price capped in 2005/6 and a consortium of airlines was planning to bid for a substantial share of it. However, the privatisation law was not signed by the German President for legal reasons. Since then, privatisation has been postponed. In 2009 a new regulatory authority was implemented in accordance with the EU directive. The Bundesaufsichtsamt für Flugsicherung is a separate regulator, but not as independent from the transport department as the CAA is.

Australia and Ireland have also organised their ATCs as government owned corporations and have given the regulator a more independent status. Independence is clearly missing in France. The DNSNA is an autonomous entity and regulated by the DGAC, the French civil aviation authority, which belongs to the transport department.

Other countries restrict the profit-maximising behaviour and combine this with elements to include consultation with airlines. This is the case in Canada where a club of airlines owns and manages ATC and in the UK where a group of airlines and airports hold a minority share. Giving a group of ATC users a share in ownership is akin to vertical integration. This might have positive and negative effects, which largely depend on the extent to which the interests of the shareholders approximate the interests of the users as a whole. In the case of NATS, in the beginning BAA represented the interests of airports and a group of 8 airlines represented roughly 30% of all airlines. This has changed. Today London Heathrow Airport represents the airports and a group of 6 airlines among them BA, easyJet, Virgin and Lufthansa represent the airlines. No group has a controlling influence. The danger might be that users discriminate against each other through the fee structure (although this is limited by the legal framework of the charges directive) and by providing a sub-optimal trade-off between cost and services. The Netherlands and Switzerland have also corporatised their ANSPs and try to limit profit maximising motives by applying the non-for-profit principle.

Overall, there is a general trend towards commercialising ATC services. Privatisation has been very limited and only partial. Private investors and shareholders have found the risk of a relationship investment only attractive if the state keeps a majority share, thereby guaranteeing that the investment remains profitable. The lack of independence prevents the regulators from setting strong incentives for efficiency. The EU Commission has experienced this in the last decade with the PRB, but the attempted reform falls short of creating a democratically controlled, independent regulator at the European level. At the level of the member states regulators are dependent, opening the door for regulatory capture. Such an institutional setting can set only weak incentives for efficiency and might be even worse than systems which keep ATC organised as state department.

Regulation and the objectives of the firm

The theory of regulation was originally designed to apply to private sector monopolies, such as railways or electricity utilities in the US. Left to the market, these firms were expected to use their market power to make large profits, and charge high prices, if unregulated. Being private with shareholder owners, these firms were assumed to be profit maximisers. However, most ATCs are government owned entities, with no clear objective or requirement to maximise their profits. How appropriate is it to apply the theory of private sector regulation to them?

There is no generally established theory of the public sector firm. For many years, it was assumed that they would act as welfare maximisers. These firms would minimise their costs, choose welfare maximising price structures, and only make efficient investments which passed the cost benefit analysis test. Over time, it became evident that this was an unrealistic assumption. The move towards privatisation was encouraged, in part, by the growing view that public sector firms were inefficient. They were seen as not minimising their costs, making poor quality choices, setting up inefficient price strategies and using their market power to fund excessive investments. 'Government run' was a byword for inefficiency and incompetence.

Once this was recognised, many governments sought to address the problem. In some cases, notably in the UK, privatisation was seen as the answer. An alternative was to reform from within. Government firms were instructed to become more commercial, and many were corporatised, which involved setting up the firm to be as close to a private sector firm as possible. This could involve a requirement that the firm maximise its profits, though this was not always set as the objective. When the firm is a natural monopoly, there is the risk that it will misuse its market power. If this is so, there is a case for regulation. In fact, there are many regulated government firms around the world. For example, many governments owned, but corporatised, airports, like Amsterdam Schiphol, are regulated. As noted before, many ATC providers in the EU, UK and Australia are corporatised and regulated.

The objectives of the ATC firms will determine how they respond to market situations and in particular, to regulation. The difficulty is that it is often not clear what the objectives of public ATCs are. External indicators are not necessarily good indicators of likely behaviour. Glossy annual reports and CEO salaries set at ten times the salary of the country's Prime Minister are not a good indicator of whether an ATC is truly corporatised. Some corporatised firms have the trappings of the corporate sector, but underneath they remain as old-style government firms. This is therefore a particular challenge in designing good regulation for ATC firms.

Methods of regulation

Ideally, the independent regulator should be free to determine which methods it uses to reach the regulatory goals. However, there is not one method which fits all purposes. Regulatory economics offers more of a toolbox, and certain instruments can be used to tackle specific problems. This is very useful and regulators make use of it. They also face new problems and come up with useful solutions. Regulators are confronted with the problem that the regulated firm knows more about costs and demand of their services than the regulator ever will (i.e. information is distributed asymmetrically). Moreover, the regulated firm has every reason not to share cost and demand information with the regulator where provision of that information would act against the firm's own goals. The regulator needs to design regulatory contracts to make it profitable for the firm to behave efficiently. These contracts differ in as much as some contracts set strong incentives for efficiency and others do not. The regulated firm will provide some information but will keep other information where that facilitates the company earning rents. In the following. we discuss the main methods of regulation (for an overview see Table 9.3), from which the independent regulator can choose, and see how they are actually in the regulation of ANSPs. In the penultimate section of the chapter, we evaluate ATC regulation under the Single European Sky which was introduced to improve efficiency in European ATC.

In the remainder of this section of the chapter, the following aspects of regulation are considered in turn:

- Cost-orientation versus incentives for firms that are profit-oriented and for those that are not;
- Service quality such as flight delays;
- Investment decisions;
- Management of capacity via (peak and congestion) pricing;
- Light-handed regulation; and
- Auctions: competition for the market.

This discussion is then applied to a critical assessment of the EU system of regulation of ATC providers.

Cost based versus incentive regulation under profit maximisation

The first choice a regulator faces is to choose between the possible types of regulation, cost based, incentive regulation, or light-handed regulation. The last of these is relatively new, and we postpone discussion of it till later in the

Table 9.3 Regulatory methods and results.

Issues	*State of the art*	*Practice*	*Main results*
Incentives with profit maximisers	Price caps	Cost based	Too high costs
Incentives for not profit maximisers	Modified price caps	Cost based	Too high costs
Quality/delays	Penalties pricing opportunity costs	Ineffective penalties	Too high delays
Investment and standards	Regulated asset base and constructive engagement	Consultation and controlling at high level	Overcapacity and silos with incompatible technology
Rationing	Peak and congestion pricing	Modulation with revenue neutrality	Allocative inefficiency with too high delays
Threat of regulation	Light handed regulation with arbitration	Hardly used	Too high regulatory costs

chapter. Traditional public utilities were regulated according to principles of cost relatedness. The regulated charges were set create just high enough revenues to cover total costs including the depreciation of capital and a normal rate of return on capital. This determined the level of charges. The principles also applied to the structure of charges – each charge was set to reflect its costs (at least in principle). This approach is clearly reflected in the Article 15 of Chicago Convention of 1944 and in the subsequent ICAO policy leading to the 'Manual on Air Navigation Services Economics' which is regularly updated (ICAO, 2013).

The advantage of cost-based regulation is that prevents the ANSP from restricting output and charging monopoly prices – in theory. However, cost-based regulation has unintended consequences and these disadvantages can easily outweigh the advantages. These problems are well known (see for example Sherman, 1989) and are even acknowledged, to some extent, in the Manual on Air Navigation Services Economics (ICAO, 2013). Firstly, the incentives are set for too costly a choice of inputs. If the regulated rate of return on capital is above the cost of capital, the ANSP has an incentive to invest too much in order to expand the capital base to increase profits – the Averch Johnson effect. In addition and irrespective of investment, there are strong incentives for gold-plating and cost-padding. These can lead to substantial productive inefficiency, as research in other industries has shown. Secondly, cost-based regulation leads to an inefficient price structure. Cost-based regulated firms usually practise uniform pricing without peak and congestion pricing. It is quite telling that the ICAO Manual just mentions the Averch Johnson effect[7] and not the other negative effects on cost and allocative efficiency.

Given these unintended consequences Beesley and Littlechild, in the 1980s, argued for price cap regulation, which over time has become the most widely practised form of incentive regulation of public utilities. Price cap regulation sets charges over a certain period – very often 5 years – in accordance with the rate of inflation (CPI/RPI) minus expected productivity gains (X). Unlike cost-based regulation, price caps do not regulate profits, but set incentives for cost reduction. The gains from cost reduction can be kept by the regulated firm within the regulation period and are then to be then passed to the users via lower charges in subsequent periods. There are pure and hybrid price caps which differ in the way that the X is determined. The X should reflect the productivity growth of the regulated industry in excess of the rest of the competitive industry. As ANSPs can realise economies of scale, their productivity should grow faster than other industries, other things equal. Pure price caps set the X without reference to the costs of the regulated firm by benchmarking to other firms in the industry, while hybrid regulation sets the X with reference to the regulated cost base of the regulated firm itself (this has also been called the building block method). This has implications for the regulated firm. Under pure price caps, the regulated firm cannot influence the cap strategically, but under a hybrid regime it can. In the former case, therefore, the incentives to cut costs are 'high powered'. The regulated firm could have high costs during the regulation period in order to raise regulated prices, and hence profits. Therefore, hybrid price caps provide weaker incentives for cost reduction. Nevertheless, hybrid price caps have become the dominant form of price caps. For example, the airport industry, the regulated UK airports, and an increasing number of European airports have been regulated using hybrid price caps; and for a short time, Australian airports were regulated using a system which approached a pure price cap. Overall the experience in terms of efficiency is positive, certainly better than cost-based regulation (Forsyth et al., 2020, 2021). Price cap regulation is also superior to cost-based regulation because it is forward looking, while cost plus regulation relies on historic costs, though the regulatory lag of typically 5 years is sufficient to set at least some incentives towards cost reduction. In addition, price cap regulation does not regulate the charges structure according to some arbitrary cost allocations based on historic costs. A well-defined price cap sets incentives for approximately Ramsey prices, as well as for a reform of weight related charges for air navigation services in case of excess demand. It sets incentives for allocative efficiency of air traffic management (see below).

The ICAO Manual (2013, 1.37) does not even mention pure price caps and their positive effect on allocative efficiency. It acknowledges the cost efficiency effects, but excessively stresses a 'potential shortcoming' as that the effect would fade out if the ANSP becomes efficient and that ANSPs might overstate investment to increase the cap which they later do not deliver on, unless the regulator scrutinises this, which in turn makes price caps 'increasingly complex and hence expensive for the regulator, the regulated companies and all users' (ibid). The first argument is clearly dubious as it depicts success as a problem. The argument of gaming with investment is a problem, but it is also a problem of cost-based regulation. It can be minimised with good investment regulation (see below).

The scepticism about price caps for ANSPs, combined with a rather rosy assessment of cost-based regulation, is also in line with actual practice of regulation. In spite of this, there has been some movement towards incentive regulation in a number of jurisdictions. The UK adopted a revenue cap. At the European level, incentive regulation has been established, but in a very heavy handed and ineffective way (see below).

In conclusion, the ICAO Manual shows some bias not shared by research, and we interpret this as a sign for the scepticism in actual regulator policy towards reforming traditional cost-based regulation and adopting incentive regulation or even light-handed regulation, which is discussed below. Unlike with airport regulation, where many states have slowly but continuously reformed regulation towards some form of imperfect incentive regulation, no such a trend is detectible in the regulation of ANSPs.

Cost based versus incentive regulation under non-profit maximisation

Price caps are designed to regulate private profit maximising firms. They create profit incentives so that the firm performs well in minimising its costs, and choosing efficient price structures. This is particularly the case when a pure price cap is imposed, but it also holds true for hybrid price caps, albeit with weaker incentives.

What should be done if the firm is not a profit maximiser? Good results will not necessarily follow if this is the case. This is a serious question when the regulation is to be applied to public firms, and the majority of ANSPs are public firms. It is true that some public firms are corporatised, but this does not necessarily mean that they behave as profit maximising firms. Corporatised firms may have some of the characteristics of private profit maximising firms, but they may behave in a quite different manner. They may behave like traditional public firms (which most have been until recently).

There is only a limited literature on the public firm. There has been some literature on their productivity performance, which concluded that this was very often not good. There was a developing literature on how to improve the performance of public firms (Loeb & Magat, 1979; Finsinger & Vogelsang, 1982) but the move towards privatisation somewhat bypassed it. As a result, the theory of public sector firm's performance remained incomplete. In particular, there has been little theory on how to regulate a public firm which cannot be assumed to be a profit maximiser.

How best to regulate public sector firms, such as most ANSPs? What do they maximise? Many do not seem to act as profit maximisers. An alternative assumption is that they may be size or sales maximisers. This is a rough assumption, and some would argue that public firms do not maximise anything in particular. Nonetheless, the term 'empire builders' is often used when public firms are being considered, and this is close to the more formal size maximiser hypothesis. For present purposes we shall work with this.

Suppose that a price cap is set and there is some slack (the regulator is imperfectly informed about the potential costs of the firm). A profit maximising firm will take advantage of this, by keeping its costs to a minimum, and enjoy high profits. By contrast, a size maximising firm will allow output to expand (subject to still covering its costs) and allow costs to rise – essentially it converts the potential profits into higher costs and output. It is not obvious that it will have any incentive to set prices efficiently. In short, it cannot be trusted to produce efficiently. The experience of the ANSPs in Europe, many of which have poor productive efficiency, bears this out.

What alternatives are there to price caps, which fail to induce good performance with public firms? We suggest a modified form of price cap will be an improvement. The regulator can set a price cap which is designed to achieve cost recovery at what it thinks is the minimal feasible cost. The informational asymmetry which bedevils all regulation will still be present. However, this can be mitigated by extensive use of benchmarking. Benchmarking is useful when regulating a private sector, profit maximising firm. But good benchmarking is much more important when regulating a public sector firm – it is essential. There are no simple ways of inducing the firm to set efficient price structures. In the ANSP case, this would involve setting efficient peak prices or delay penalties. In this case the regulator would have to use its own information to set them. This actually happens with ANSP regulation in Europe. The current delay penalties are widely regarded as too low, but if there is information about the costs of delay, as there is, better delay penalties can be set. The delay penalties are set by the regulator, rather than set by the firm responding to price cap incentives. With investment the regulator needs to evaluate investment proposals submitted by the firm, assessing its costs and benefits, and allows price adjustments consistent with the costs of the investment. This all does involve a much more 'hands on' approach by the regulator. But this is inevitable if the firm does not maximise profits – and the mechanisms suggested by Loeb and Magat (1979) and by Finsinger and Vogelsang (1982) to induce the firm to maximise profits are not in place.

Does this amount to a radical shift in regulation? Not necessarily. The regulation of public airports in some jurisdictions such as Ireland is similar to that suggested here. Dublin airport is price capped, but the regulator makes a substantial effort to estimate possible costs, and relies on benchmarking to a significant degree. Price cap regulators recognise that all price capped firms have an incentive to under-provide quality (and allow delays to mount) and thus they over-ride the firm to set quality standards. Finally, with most price capped airports, the regulator has a major role in evaluating investments and in setting prices which cover the costs of the investment.

This is a relatively heavy-handed approach to regulation. It is, however, one which is used particularly when public firms are regulated. In the case of ANSPs, it is not enough to simply set a price cap and leave the firms to produce, set prices and qualities, and invest efficiently. The experience of the European ANSPs indicates that doing this leads to poor results, and improvements to this system are needed.

Quality regulation and reduction of delays

The importance of quality for price regulation has always been stressed. While cost based regulation could lead to excessive quality, price cap regulation sets incentives to increase profits by reducing cost through excessively low quality. Hence there is a need to regulate quality. There have been two ways which have been practised with success. Quality can be monitored with user involvement. The threat to tighten regulation in the next period can be sufficient to prevent the regulated firm to produce with too low quality. This approach has been used with price capped airports in the first regulatory periods in the 1990s in the UK and at Hamburg airport. In both cases the airports did not need to expand runway capacity. If investment becomes an important factor, airport regulators prefer to regulate the services by standards and financial incentives (bonus malus or penalty systems).

In air traffic management, on-time service is crucial. Quality is mainly defined by a flight arriving on time without delays. Delays are relatively expensive for airlines and passengers. Given the high cost that delays have, the regulator would prefer to regulate this effectively by financial incentives.

Delays have always been important for air traffic control. In Europe it has led to a debate among stakeholders on how to regulate delays. ANSPs argued that there is interdependence between capacity and cost efficiency, and that the price cap should be relaxed. The delays were supposed to be caused by excessively tight caps, and future caps should be lifted in order to provide the capacity needed to reduce delays. Airlines objected to this argument, as the delays occurred mainly at a few ANSPs (among them DFS with the Karlsruhe centre), and were due to mismanagement.

There is a trade-off between quality and cost for an efficiently producing ANSP. However, most ANSPs are far from this efficiency frontier. The so called 'Academic Study' on behalf of the PRB (Adler et al., 2018) estimated, with rigorous benchmarking methods, that most ANSPs were at least 30% away from this frontier. If ANSPs are operating with so much slack, then the quality/cost trade-off is not binding and relevant. Delays might be the result of poor management of resources. There are incentives for keeping delays within the regulated threshold and penalties for exceeding the thresholds. However, these penalties are so low and below the pay for overtime work, that it is not profitable for an ANSP to reduce delays. The EU Commission reacted after this experience by increasing the penalty, but it is far below the level of the delay cost for the airlines. An independent regulator would increase the penalties so that they reflect the real costs of delays.

Regulation of investment and standards

In public utility regulation, regulation of investment has been a major challenge, and this is also so in air traffic control. Characteristics such as the long-term nature of investment, the lumpiness, the relations specificity and the network effects with its problems of interoperability and standardisation are all present. ATC investment differs from other forms of investment, not in principle, but some of the characteristics are more important than others. Regulators use approaches such as the regulatory asset base, explicit investment contracts and user involvement (in particular constructive engagement) for regulation.

Arblaster (2018) differentiates between investments that enhance capacity and investments that increase efficiency of the network without benefits for ANSPs, but for users, and analyses how this is regulated in different jurisdictions. We follow this analysis and point out some additional problems. Investments in new capacity which come very often also with new technology can either reduce or increase the costs of ANSPs. If the investment is cost saving, the regulator can simply keep the price cap as the ANSP will deliver the investment. If the investment increases costs then it needs to raise the cap. If the regulator uses the regulated asset base model the investments are scrutinised (also by user involvement) and, if found to be desired by users and efficiently provided, are added to the asset base. Consultation with users becomes also very important to identify user support and the value of the investment/capacity to users. Arblaster (2018) shows that the CAA in the UK is doing a much better job here than many other regulators, because they are employing the model of constructive engagement. In this model, the regulator does not only consult the users, but it structures the dialogue between ANSPs and airlines. Constructive engagement becomes even more important for the projects with an externality, that is where the positive effects accrue to the users or are realised if all partners of the network coordinate their investments. These investments are often those investments with new technology which would create interoperability and thereby increase overall efficiency and performance. More constructive engagement and a strict form of regulatory asset base regulation, in which investment are controlled ex-ante and checked for delivery and outturn cost ex-post by an independent regulator, could be an effective way to regulate.

Capacity management by peak and congestion pricing

One of the major advantages of incentive regulation over cost-based regulation is the idea of introducing peak and congestion pricing in public utilities. However, this assumes ANSPs are profit maximisers, which as we discussed above is problematic. Nevertheless, we start with this assumption and discuss at the end the implications if ANSPs behave differently.

Peak and congestion pricing lead to efficiency gains compared to a uniform price structure. Lowering the off-peak price increases traffic and welfare unless demand is completely inelastic, which is unlikely. Increasing the peak price reduces delays. Changing the price structure from a weight-based system (see Chapter 8 of this book by Fichert) to a price per movement sets incentives for better use of capacity through large aircrafts in times of excess demand. Peak Pricing is a form of congestion pricing for the case that the traffic varies over time. It internalises the externality of which an additional flight imposes on other flights in terms of delays. Peak and congestion pricing tests the elasticity of demand (prior to costly capacity expansion) and provides guidance for optimal investment. The advantages have been discussed intensively and economists have recommended peak and congestion pricing for a long time in general, and particular for air traffic control (Knieps, 1990, 1992).[8]

An ANSPs which is not profit maximising would not respond to these incentives and would not implement peak and off-peak pricing. In such a case the regulator has to be more intrusive. In the early 2000s, the Irish regulator imposed peak pricing on Dublin Airport by prescribing a low off-peak price so that the airport would have been forced to adopt peak prices in order to collect all the allowed revenue.[9]

In practice, economists have found that these recommendations have little impact on pricing in ATC. A regulator would follow these recommendations and set strong incentives using a simple price cap which sets incentives to modulate charges and price capacity efficiently. The price cap limits the average charges, but would allow the ANSP to increase charges in the peak and reduce charges in the off peak. In order to work, these so-called modulations (that is peak and off-peak pricing) must be profitable for the ANSP. The regulator would face resistance from ANSPs and also from airlines, although the latter practise peak and congestion pricing on a daily basis.

The resistance to adopting congestion charges has been a long practice in ICAO, but the latest edition of the manual opens the option for congestion pricing. After outlining the benefits and costs of congestion charges, ICAO (2013, 5.171) concludes:

> Furthermore, given the fact that congestion costs are not directly associated with the cost of air navigation facilities and services, it is difficult to reconcile this pricing practice with the principle of cost-recovery. Consequently, the use of congestion pricing should be done with great care, and revenue derived from such charges should be reinvested in the air navigation services system in order to expand capacity to better address the congestion problem.

It remains to be seen if States take this road.

Light-handed regulation

An alternative to ex-ante regulation is light handed regulation, which can take several forms. One form is that of monitoring, which is a system of oversight, combined with the threat of sanctions for poor behaviour. Monitoring differs from abolishing ex-ante regulation insofar as the behaviour of the firm is closely followed. The most interesting examples of light-handed regulation of airports of this form are Australia and New Zealand (Forsyth, 2008). The strength and weaknesses depend on three aspects. Firstly, monitoring needs to be combined with a credible threat (Kunz, 1999). This is first of all an institutional question about an independent regulator. Without it, the regulated firm can hope to influence the decision and the threat is not credible. Secondly, the guidelines have to be clearly and precisely stated. This has not always been the case (Forsyth, 2008). Thirdly, the incentives towards efficiency depend on whether the guidelines follow the principles of cost based or incentive regulation. An alternative form of light-handed regulation is the negotiate/arbitrate form, which is used in North American rail regulation. Here the parties negotiate about price or other aspects of service, and if the parties are unable to reach agreement, they have recourse to an arbitrator which will decide the issue.

The ICAO Manual (2013) discusses this form of regulation briefly. It has not been practised much in regulating ANSPs (see Arblaster, 2018), as the institutional conditions have been generally not met. Regulators of airports and other industries usually started with 'heavy' handed regulation and then phased it out after gaining credibility and power. This could also be an option for regulating ANSPs. This works well if there is a credible threat of stronger regulation.

Auctions: competition for the market

Creating competition for the market by auctioning of the monopoly right is one of the tools of regulatory economics. Initially, after the seminal paper by Demsetz (1968) auctions were thought of as a more market based and less bureaucratic approach than regulation of a monopoly. Williamson (1976) criticised effectively this optimism because franchising through auctions does not work so smoothly with long term relation specific investments. The length of a contract is important and franchising contracts have to be carefully designed to prevent investors from under investment, from offering lower quality and from renegotiating contracts. In the ANSP world, competitive tendering has been used for terminal services. The overall results are encouraging and show that costs can be reduced substantially (Arblaster, 2018, p. 220; Arblaster & Zhang, 2020).[10] Terminal services are characterised by less relation specificity than en-route services. So, it remains to be seen if auctions for en-route services will work. Adler et al. (2020) argue that the benefits of price caps are reaped by unions and that auctions are a better way to reform the SES.

The EU system of ATC regulation and the need for reform

ANSPs in Europe and in other jurisdictions have been traditionally subject to the full cost recovery principle (FCRP).[11] FCRP sets charges so that in a certain period (typically a year) the revenues cover the fixed and variable costs. If the revenues fall short in a year, the positive or negative difference can be recovered in the next one or two years (and vice versa for above-forecast revenues). The charges are calculated by dividing the total cost by the output (irrespective of the state of the economy) with the result that charges and traffic move in opposite directions: charges increase with decreasing traffic (including in a recession) and decrease with rising traffic (such as in a boom). FCRP is applied, for example in Canada and in those non-EU European countries which are part of Eurocontrol (for example, Norway, Turkey, Serbia and more recently the UK). Full cost recovery has similar incentives for cost efficiency as cost-based regulation. Cost savings do not accrue to the ANSP so there is no reward for finding efficiencies. Cost based regulation typically equates the price of the services for one year at that level where the planned costs are equal to the planned revenues. The price is set at average costs including a normal rate of return. Very often the regulated price changes if output increases and the regulated firm realises lower average costs. If input prices increase, the regulated firm will ask the regulator to increase prices. If demand decreases, the firm knows that the regulator will increase prices, but may also ask why the firm has not reduced costs. FCRP makes sure that the regulator does not ask this question, but automatically increases the price to cover the full costs. Pricing is just an instrument to finance the services irrespective of cost efficiency and the effects of prices on demand. Besides these disadvantages FCRP is supposed to have the advantage that with traffic growth, economies of scale are realised and then passed on to the users via lower prices. This is a possibility, but it overlooks that regulated firms have no strong incentive to realise scale economies and thus little penalty for being far from the efficiency frontier. In the case of ANSPs, productivity growth can be surprisingly low.[12]

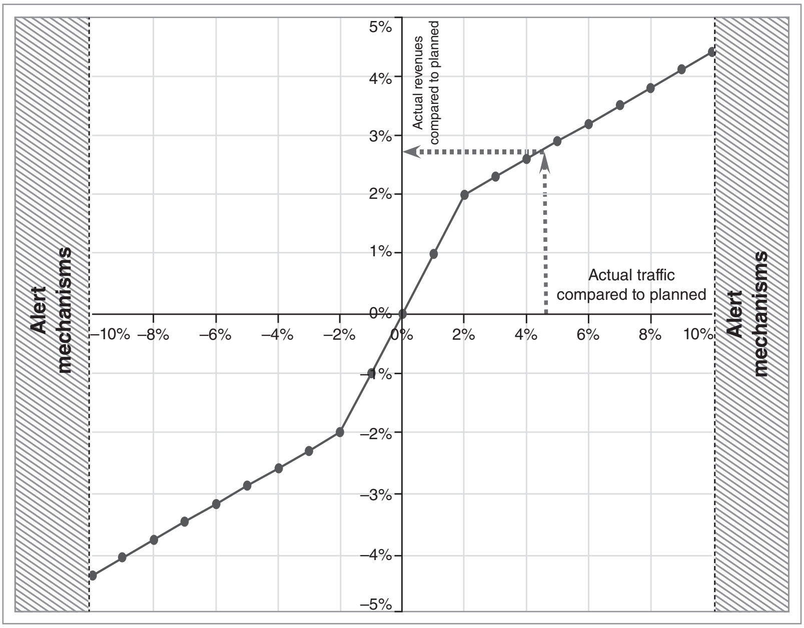
The Single European Sky (SES) initiative was fully aware of the pitfalls of the FCRP and wanted to break away from it in order to set incentives for cost efficiency. The discussion led to a compromise between the stakeholders. It was agreed on a system of incentive regulation which regulates the determined costs adjusted by a Traffic Risk Sharing Mechanism (TRSM) so that the revenues are relatively stable over the regulatory period. It is in a way similar to revenue caps. The FCRP rule is no longer operative except for very special cases which at the time of reform was seen as very unlikely, but which then happened in the COVID crisis.

The TRSM was established with the reform of regulation in 2010 (EU Regulation, 1191/2010). In the EU directive of 2006 on a common charging scheme for air navigation services, the traffic risk sharing mechanism was not defined, and only the idea of incentive schemes was mentioned as an option for member states (EU Regulation 1794/2006). At that time charges were based on the FCRP. The full cost recovery principle led to an increase of charges in the financial crisis of 2007/8. This was seen as a real problem for airlines which suffered from the crisis, as charges were, on average, 10% of their operating costs. The idea of the reform was to establish a forward-looking incentivising performance and charging scheme (Huet, 2011). Instead of setting charges to cover full costs, the charges were set on determined unit costs corrected by a traffic risk sharing mechanism (and other factors).

The traffic risk mechanism defines risk as the risk that the actual traffic volume differs substantially from that forecast. The forecast is done by Eurostat. In the performance review period the ANSPs were allowed to choose one of the three scenarios. Not surprisingly, this was always the lower scenario. This has been changed with RP3 where the base scenario was prescribed.

The traffic risk sharing mechanism has five zones, each defined with respect to a traffic forecast:

i. A ‘dead band’ of plus/minus 2 percentage points of traffic compared to the forecast (EU Regulation, 1191/2010, par 11, 3.).
ii. Above-forecast demand of between 2% and 10%. In this case, 70% of the additional revenue needs to be returned to the users within the next two years.
iii. Below-forecast demand of between 2% and 10%. Here 70% of revenue loss shall be borne by the users within the next two years.
iv. Demand above 110% of the forecast. All additional revenue must be returned to the users within the next two years.
v. Demand below 90% of the forecast. All losses of revenues shall be borne by the users ‘in principle no later’ than in the next two years’ time. But



If traffic is 4.3% more than planned: ANSP gets 2% more revenues and 30% of the remaining 2.3% (i.e. 2.69%)

Figure 9.2 Traffic risk sharing mechanism.
Source: Fron (2017)

> note: 'However, Member States may decide to spread the carryover of such losses in revenues over several years with a view of the stability of the unit rate' (par, 11, 6).

Who should bear the risk of traffic variations? One consideration is which side of the market (producers or consumers) is better placed to bear risk? In utility regulation, the regulated firm, often being a natural monopoly, is generally considered to be in the stronger position to bear demand risk. Furthermore, in general suppliers know better than the consumer how many products they can sell and at what prices. This should be also the case for ANSPs and airlines, as ANSPs serve many airlines which do not know the plans of their competitors. The ANSPs are in contact with their airlines. It is not the task of airlines to add up the different demands for such services.

The rationale for the 70 to 30 sharing is supposed to reflect the share of fixed to variable costs (Huet, 2011). This highlights the thinking behind a traffic risk mechanism: charges should be based on unit costs as in full cost recovery. The only difference is that the costs are now scrutinised to some extent and that they are forward looking. These predetermined costs will then always be financed fully by the charges. Such average cost pricing has the following problems:

- Allocatively inefficient pricing. Prices should be set at short run marginal costs, (which will not cover total costs). If traffic falls and charges are increased over the next two years, such a price movement would only be efficient if short run marginal costs are falling. The main goal of the inversely related traffic mechanism is to stabilise revenues (see Figure 9.2). This implies that price signals are set in the wrong direction.
- The traffic risk sharing mechanism stabilises revenues in a very narrow range. The realised revenues cannot diverge by more than 9 percentage points from the forecast (with a time lag of up to two years). This safeguard has unintended effects on management of ANSPs. With above-forecast growth, the ANSP is not rewarded for additional traffic, so it may under provide capacity. With below-forecast growth management has less incentives to cut cost and adjust flexibly as it is largely compensated for revenue losses. A revenue shortfall of 10%, reduces ex-post revenues by only 4.5% and any larger shortfalls are fully recovered. Management has only a limited interest to demand cost cutting and unions would correctly argue that the revenue losses are too limited to justify any substantial changes in wages or employment.
- In the Great Financial Crisis, demand did not fall below 10% below forecast (Huet, 2011). But this did happen in the Covid Crisis. For such a case, the modified full cost recovery principle is prescribed in the EU Regulation. This means that if demand recovers, charges will rise faster than under a price cap or a hybrid cap. Given this, the incentives to adjust supply to demand are low as the losses can be recouped later on.
- The traffic risk sharing mechanism also gives incentives for strategic behaviour and political gaming. Strategically, the ANSPs lobby for a low demand forecast so that they can keep all the additional revenues within the range of the death band of four percentage points of traffic. This shifts risks to the airlines but is regarded by airlines as unfair.[13] Furthermore, TRSM rewards political gaming. In summer 2018 when traffic grew fast and delays built up in Germany, the CEO of German DFS argued that the EU Commission and the regulation have caused DFS to use a too low forecast and so DFS could not provide the necessary capacity. Although the premise was wrong, and DFS was warned by the EU Commission of using a too conservative forecast, it allowed the DFS to seek to shift responsibility to Brussels.

The abolition of the traffic risk sharing mechanism has been evaluated by Steer Davies Gleave (SDG) in the study for DG MOVE in 2017 and 2018. The airlines preferred to abolish the traffic risk sharing mechanism. SDG (2018) argued against abolition on the grounds of increased risk, which in turn would lead to a higher required rate of return and higher charges. While higher risks have an effect on the required rate of return, SDG's evaluation did not include the negative effects on ANSP costs of the contribution of the TRSM to gaming and allocative inefficiency, instead using the debatable argument that reduction in efficiency incentives and risks would increase economic welfare. At that time, nobody thought that traffic could fall below the outer bounds of the TRSM. Two years later exactly this happened. The Covid-19 Crisis exposed two problems.

Firstly, the SES rules did not allow the EU Commission to lower charges or to keep charges constant. The Commission had to apply the modified FCRP, which meant that the losses can be spread out over the next few years. This risks that charges will increase too early and too fast. Among ANSPs there is a widespread belief that the share of ANSP charges in airline unit costs is so low that it has no influence on airline recovery. This belief seriously underestimates the effects. In a crisis airlines do not cover their full costs. They are reducing their prices to short run marginal costs, which are only a portion of the full costs since they do not include any fixed costs. A better measure is the share of ANSP costs in 'operating costs', although these also include some fixed elements like depreciation and insurance costs. Berrittella (2009) writes that 'en-route traffic control charges are based on the size of an aircraft approximated by its weight and the distance flown, and range from 2 to 6% of operating costs.' This is based on 2004 to 2006 data, when crude oil prices were at a level of about 60 US dollars per barrel and fuel had a share of about 20% of operating costs. In 2020, at the start of the current crisis, oil costs only about 40 US dollars per barrel in 2020.[14] Therefore, ANSP pricing matters for airline costs, particularly in a crisis and in the phase of recovery.

Secondly, the ANSPs reacted in exactly the way the incentives as forecast. The ANSPs of the SES reduced their total costs by 1% relative to 2019 (PRB, 2022). Most ANSPs have adopted some cost reduction measures, but the bottom line is a marginal reduction which cannot be explained by a relatively high share of fixed costs. The PRB (ibid.) criticised this mismanagement only very gently. 'ANSPs were aware of the sharp drop in traffic as early as March 2020, meaning that they had enough time to adapt and lower costs for most of the year' (ibid., p. 4) and calls for a 'more sustainable response from ANSPs' (ibid., p. 3)

In addition to problems with the TRSM and FCRP there are the following problems with the regulation of SES:

- The regulatory period of three years instead of the common 5 years is relatively short and limits the incentives for cost reductions, as these profits are retained by the ANSP only for 3 years and then have to be passed on to users.
- Resetting or rebasing the cap every three years opens an avenue for strategic behaviour for ANSPs. There is the incentive to allow costs to escalate every three years so that regulators 'observe' a high cost base on which the determined unit costs are based so that they can obtain from the regulator a relatively generous cap. The regulators are aware of this, but face the information asymmetry problem which they can overcome only partially with benchmarking. It also increases the regulatory costs.

Compared with the pure price caps, the incentives for cost efficiency are far less strong and are blurred by the incentives for strategic behaviour.

- The Single European Sky project was prompted by the 'unprecedented increase in the incidence of delay' (Schulte-Strathaus, 2011, p. 39) at the end of the 1980s. The SES regulation has reduced delays to levels not thought to be possible twenty years ago. However, in 2018 and 2019, delays increased again quickly and substantially because ANSPs mismanaged their resources and were able to use the rising delays to lobby for more generous price caps. Although the EU Commission increased the penalty for delays the incentives for managing the traffic with low levels of delays are not sufficiently strong.
- In managing delays, peak and off-peak pricing are not used. The resistance against pricing tools is clearly revealed in the SDG study (2015) 'Policy Options for the Modulation of Charges in the Single European Sky' prepared for the European Commission, which acknowledges the academic support for modulation of charges and raises practical problems of implementation, some of which merit discussion. However, the whole exercise of the study is of rather limited use because the SDG study argues that modulation should follow the objectives of 'economic efficiency' and 'revenue/cost neutrality: the scheme should not have the effect of increasing or decreasing ANSP or FAB revenues' (Ibid. p. iii). Under a regime of cost/revenue neutrality, the incentives are clear. The ANSP cannot gain, but faces resistance from the airlines for its efforts to operated efficiently and price efficiently. ANSPs will not do so and will prefer the status quo. This will hardly change in the current discussion about a reform of regulation, in which Eurocontrol's Heerbaart (2021) stresses the revenue neutrality principle, and argues that all modulations would just lead to additional administrative costs.
- The regulation of the SES tries to regulate investment through the regulated asset base as part of the calculation of determined unit costs. However, it faces the problem that it can do this only at an aggregate level and has to trust that the national regulators are checking on the investment of individual national ANSPs. Given the lack of regulatory independence, this cannot be really done well at all. Observers such as Bekier (2017) have shown that investments are often claimed but are not delivered. Consultation with users is also not working effectively as this presupposes independence of the regulator.
- The Single European Sky lacks interoperability between ANSPs. The technology are very often 'island solutions' for a particular state. Investment in the network is crucial, but projects with an externality, that is where the positive effects accrue to the users or are realised if all partners of the network coordinate their investments, might not be undertaken. These investments are often those investments with new technology which would improve interoperability and thereby increase overall efficiency and performance. The ATM Masterplan should foster the implementation, but so far it is not integrated into the performance regulation. More constructive

engagement and a strict from of regulatory asset base regulation, in which investment are controlled ex-ante and ex-post by an independent regulator, would be a more effective way to regulate this.

Summary and conclusions

In this chapter we argued that ATC performs rather poorly compared with the deregulated airline market. There is evidence that most ANSPs are producing at too high a cost. This is in particular the case for European ANSPs, which suffer from fragmentation and unrealised economies of scale. Thirty per cent of total costs could be saved and this seems to be the lower bound of saving potential. We then analysed the vertical structure of ATC and distinguished the competitive part from the monopolistic. The en-route and terminal services under current technology are natural monopolies, while other services can be left to the market. The monopolistic bottleneck should be regulated, which lead us to consider how best to do this in terms of institutional setting and regulatory methods.

Institutionally, it is critical that the natural monopoly is regulated by an independent regulator. The relation specific nature of the investment makes it risky for private and public investors to commit themselves to long-term projects. As the future is risky and uncertain, discretion is needed to solve problems. This discretion should be practised by an institution which has no conflict of interest and is competent. Hence the need for an independent regulator. However, the vast majority of regulators are not independent. In Europe the UK and Irish regulators are, but not the German or regulators in other EU member states. Also, the EU Commission as the policy maker should not be the regulator.

In terms of regulatory methods, we contrasted what regulatory economics views as best practice with the actual regulation. Most countries do not follow best practice and this was in particular the case with the SES. Instead of setting incentives through price caps, cost-based regulation is dominant. Quality is foremost for the aviation industry, but delay minimisation is not incentivised effectively. Instead of regulation of investment through the regulated asset base on the basis of 'constructive engagement' with airlines, very often investments are just monitored at an aggregated level. Peak and congestion pricing are also not encouraged, which results potentially in allocative inefficiency. Elements of light-handed regulation are missing because there is no regulatory threat to reregulate. The European regulation is widely regarded as being too complex, but this is not its real weakness. The regulation hardly sets any incentives for efficiency but safeguards ANSPs from any cost-control responsibilities and from risk. In the COVID crisis this became very evident, because the traffic-sharing mechanism allowed for full cost recovery, so that the ANSPS had no incentives to cut costs because they can recoup the losses in the near future. It remains to be seen if attempts to 'build back better' will lead to a reform of regulation of the SES. In terms of economic performance, reform can be regarded as absolutely essential.

Discussion questions

1 Are ATC systems natural monopolies?
2 Would it be better to have a single ATC system for the whole of Europe rather than around 30 country-based systems?
3 Can designing better regulation resolve the problem of interoperability?

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Notes

1 Regulation here is defined as rules which limit contractual freedom and thereby determine price, quantity, quality, investment and access. Environmental and safety regulations are not covered in this analysis.
2 This study has been critically discussed and accepted in the consultation for setting the price cap in 2019. Standfuss et al. (2020) have discussed the study by Adler et al. (2018). They 'hint at the danger of biased results which might lead to decisions of regulatory authorities that do not contribute to an improved performance' (p. 58). They point our data issues and heterogeneity – factors which have also been pointed out by Adler et al. Because of these issues Adler et al. have used two benchmarking methods and applied the principle of doubt, that is they have taken the estimation with the lower inefficiency in case the two estimations differ. Standfuss et al. have surprisingly overlooked this in their assessment. They have only shown that benchmarking is not precise, but the claim of biased results is unfounded.
3 For a more detailed analysis of the value chain see the chapter in this book by Bekier on business models.
4 If two separate regional natural monopolies without any reorganization for example by not closing abundant centres were merged economies are not realised.
5 Niemeier (2010) discusses which part of the value chain of air transport should be regulated by which institutions. The following builds on this discussion and updates it.
6 NATS is supposed to operate, not only on a purely commercial basis, but also reflect the interest of users. The CAA discussed whether this might be a reason not regulated NATS, but decided against it as the non-profit orientation was not legally binding.
7 The Manual concludes: 'However, rate of return regulation may provide the ANSP with a strong incentive for over-investment in order to increase the volume of its profit' (ICAO, 2013, 1.39).
8 Arblaster (2018) provides an excellent review of the latest scientific literature.
9 Indicative of the suboptimality of a price structure imposed by regulation, the scheme was later withdrawn because sudden changes in the structure of demand (prompted by 9/11) caused a change in peak/off-peak times that no longer matched those set by the regulator.
10 One of the problems extending the range of competitive tendering is that in many cases public firms are bidding. For example, the state owned DFS and the state owned AustroControl might compete for terminals services at an airport in

Germany. Assume that AustroControl won the contract but has underestimated the costs so that this creates losses. On a small scale this is not a problem, but on a large scale it leads to the question if the Austrian taxpayer is willing to take such risks.

11 Arblaster (2018) provides a good overview of different risk sharing mechanisms in Australia, New Zealand and Canada. The New Zealand TRSM is similar to the European, but avoids the FCRP, as does the Australian.

12 Note that price cap regulation might also try to set a price path which allows the ANSP to recover the total efficient costs in the long run. The difference is that charges are set mechanically each period or each period with a delay so that the charges are covering average costs irrespective of demand and irrespective of cost efficiency concerns. There are similarities with cost plus regulation, but not with incentive regulation except that the charges should also cover cost over a long period provided that cost is efficiently incurred.

13 Actions consistent with the incentive to under- and over-forecast demand are also observed in price reviews of airport charges where industry submissions (and commissioned demand forecasts) may sometimes be inspected – and contrasted – on regulators' websites.

14 In 2021 the oil price rose substantially.

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10 The business framework for air navigation service providers

Marek Bekier

Introduction

Following the Second World War, the entire civil aviation industry experienced a continuous strong growth, which was enabled through the technological advancements made during the war. A steady and robust increase in global economic activities with an associated increase in wealth – seen in a significant growth of purchase power for emerging middle classes – fuelled the societal appetite for air travel and transformed the aviation industry from a niche transport sector into a multi-billion network of businesses that transported around 4.5 billion passengers in 2018 (IATA, 2019). The growth in air travel and air cargo activities required an alongside development of a civil aviation regulatory framework and an improvement of the general aviation infrastructure, which includes mainly airports and the provision of air navigation services (ANS).

The Chicago Convention in 1944, towards the end of a long global war between national states, resulted in a regulatory framework for Civil Aviation that was built on national ownership of, practically, the entire aviation value chain. Article 1 of the Convention, which recognises – exclusively – sovereignty of a state over its airspace is seen as the prompt for the states to establish national organisations – the air navigation service providers (ANSPs) – that were mandated to operate and control the airspace over their national territory. In line with the general focus on national ownership and sovereignty, control over airports and air carriers was predominantly regulated through national governments and led to the concept of strongly regulated bilateralism in air services between countries (Kaul, 2008).

In Europe, the adoption of the first aviation package by the European Commission in 1987 signalled a re-organisation and a first step in liberalisation of the European aviation sector, which was characterised by a barrier-less market entry for competition. Since then, from a commercial perspective, although airlines, airports and ANSPs have developed in different directions, the civil aviation industry is generally seen as a highly competitive and low-margin industry.

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Airports have developed into shopping and service hubs in their attempt to attract more airline customers and increase retail revenues by transforming travellers into shoppers. Airlines in their constant competition for fare paying passengers generate pressure on the traditionally low sector profit margins, a process that has been amplified through the rise of new business models (low-cost carriers: LCC), innovative cooperation agreements and M&A activities.

The liberalisation of the airline and airport sectors has altered the physiognomy of the aviation industry and enabled commercial and profitable business models, the emergence of joint-stock companies, while national ownership of carriers has largely been replaced by private sector ownership (Efthymiou & Papatheodorou, 2018). The lowering of entry barriers for competitors, a more strategic approach to network optimisation and the consequent capacity expansion have contributed to turn the industry into a highly competitive sector with new cooperation and alliance models and a constant increase in customers (Calzada & Fageda, 2009).

In this wider industry context, ANSP and their business concepts are outliers, as the service provision today is still predominantly done in national monopoly markets without competitive pressure and with only limited commercial orientation (Efthymiou, 2016). ANSP's today are still largely under governmental control and have, so far, deviated from other similar public utility service and network industries (such as railroad, telecom, energy or postal services), which today are mostly operating in competitive markets freed from governmental governance and ownership.

The main motivation for liberalising previously monopolised markets and de-regulating public service utilities is seen in a more critical view on the role of the state in the economy in general and the recognition that governmental owned and controlled public utilities are usually underperforming when compared with sector companies with private ownership and governance models and access to capital markets, which is often needed for necessary investments in the infrastructure upgrades (Nestor & Mahboobi, 1999). Concerns regarding the safety of ATC operations in a more competitive environment are most often voiced when a reduction of governmental ownership is discussed, although there is no evidence to back this often-cited assumption (Adams, 2005).

Why liberalisation has not occurred in the ANS industry and the reasons behind the continued governmental presence in this sector are commonly seen in its legacy. In accordance with the Chicago Convention's principle of national airspace sovereignty, arguments to prevent a more liberalised framework for the provision of air traffic management (ATM) usually include concerns in respect to the military usage and the sovereignty of the airspace, the view that ANS is essentially a public good and its provision therefore an inherently governmental function and, based on the cost-inefficiency of a duplication of infrastructures, a natural monopoly (Neiva, 2015).

In such a perception of the role of an ANSP, the main focus of such an agency must lie on the safe provision of air traffic control (ATC) and associated support services, the maintenance and operation of the aviation infrastructure and only to a lesser degree on commercialising these services and optimising their respective business models. This traditional view on the role of an ANSP is also reflected across the academic literature, where the notion of a 'business model' in connection with the provision of ANS was hardly found until around 2009, when several countries started to liberalise selected service areas for competition. However, compared with other aviation related industries, the concept 'business model' is still much less commonly used within the ANS segment (Materna, 2019), which can be seen as reflecting the traditional business attitude within the ANS industry. While there are numerous definitions of business models that describe how ANSP products, services, revenues, and costs relate to each other, in this chapter the following definition, suggested by Materna (2019), is used: 'The business model of ANSPs describes the method of creating services and products for customers on market(s) with ANS and/or markets with supplementary services.'

According to this definition, the focus in the provision of ANS lies on the efficiency of the production of the services and products, but focuses less on the cost or revenue perspective. This can be seen as a result of the statutory monopoly character of the industry and the vertical integration of the ANSP, a concept that is discussed in the next section.

The vertically integrated air navigation service provider

The Chicago Convention in 1944 established – among others – the legal framework for the establishment of ANS and mandated the contracting states to define obligations under the umbrella of national sovereignty. With the mandate from ICAO, the responsibility of the management of the airspace fell to nation states and governments established national monopoly ANSPs as the entities to be in charge of the following services:

- air traffic management, which includes the main function ATC;
- communication, navigation and surveillance (CNS) systems, which form the technical infrastructure for the provision of ANS;
- meteorological services (MET);
- search and rescue services (SAR); and
- aeronautical information services (AIS), which today is usually referred to as aeronautical information management (AIM).

This service portfolio covers infrastructure and service provision and ANSPs that provide all of the above are also referred to as 'vertically integrated ANSP'. The vertical integration describes an organisational structure, whereby the ANSP has control over the entire product/service chain that is required to deliver the product. While this has the advantage that an ANSP can secure control on its supplies (including the technical infrastructure), it is anti-competitive in nature and prevents the establishment of a 'market' situation. A vertically integrated ANSP can, in the present context and for the purpose of this chapter, be defined as: 'an ANSP that owns and maintains the entire infrastructure required for the purpose of ANS provision and is the sole provider (often as a statutory monopoly) of ANS services within the borders of a national state'.

The vertical integration suggests that the provision of ANS is in fact several businesses or business areas under one umbrella and in absence of market structures for individual services, economies of scale and density can be aggregated. A recent study, however (Buyle, 2020), revealed that the larger European ANSP actually generated diseconomies of scale over the past decade and that their ability to achieve scale effects in general was very limited.

The financing of the system costs, which include Infrastructure and services, is based on a charging system that does not reflect actual effort (costs) per flight and is discussed in the next section.

Economic components of the air navigation service provider business

ICAO DOC 9082 contains the ICAO Policies on Charges for Airports and Air Navigation Services and provides the contracting states with a framework concerning the financing of their ANS infrastructure. The proposed charging system, as the central component for the financial compensation of the ANSP, is built on a 'cost-coverage' or 'cost-recovery' principle. The intention behind this cost-recovery philosophy is simply to levy charges for the users of the ANS infrastructure within a frame that covers the operating costs (system costs) of that system. While this financing mechanism has been accepted by airspace users and worked reasonably well in the past, its vagueness concerning what can be considered 'system costs' leaves room for different interpretations.

ANSPs have cost structures that are characterised by high fixed costs, a very limited short-term scalability and are challenged 'to maintain high standards of safety, security and quality of service while aircraft operators seek to reduce the charges they pay' (ICAO, 2012). This leads to the scenario that in times of suddenly falling demand, the prices for the ANS service should – according to the mechanism of the cost-recovery principle – increase significantly.

However, such a collapse of demand in air travel presents a situation when the airlines themselves are confronted with a corresponding collapse in revenues and they would therefore suffer disproportionately from an increase of service charges. The International Aviation Transport Association's calculation for the pandemic year 2020, in which the global airline industry is losing around 84,3 billion USD, highlights this dilemma.

Another shortcoming of the cost-recovery principle lies in the absence of incentives for the ANSP to increase service quality, innovate new technologies and focus on cost efficient provision of services. Furthermore, the absence of market pressure to optimise the production lines can lead to a behaviour of applying 'gold-plated' solutions and allow an organisational build-up (overhead) that goes beyond the size of comparable organisations operating in a competitive market (Arblaster, 2018). To prevent the ANSP from abusing their monopolies and to mitigate these short-comings of the cost-recovery principle, some form of economic regulation is usually implemented (and will be discussed later).

As the revenues of the vertically integrated ANSP are mainly, and in most cases fully, generated through the application of different service fees which are levied to the users, there is a symbiotic relationship and a mutual dependency between ANSP and the airline industry.

Recently it has been observed that ANSP add commercial revenues generated through services or products in less regulated areas such as CNS or aviation consulting to a slightly more diversified revenue side of the ANSP. The commercial revenue generated is usually, in comparison with the revenues generated through fees and charges, negligible, however and as the ACR case study will show, with the extension of the commercial business area to include Terminal ANS (see Figure 10.1), this no longer is the case. Additionally, the change of service provision from the UK government-controlled provider NATS to Air Navigation Solutions (ANSL) at the London Gatwick airport demonstrates that the T-ANS market is not restricted to the provision of ANS at regional airports and that the creation of new provider interfaces, even in very complex and busy airspaces, does not negatively impact on performance and capacity.

Figure 10.1 shows a standardised airspace structure with the main distinctions between en-route ANS and terminal ANS. While the main source of revenue is generated through the collection of the (en-)route charges, the second main charge adding to the ANSP revenues are the terminal charges, which are levied for the ANS services that are provided within the terminal

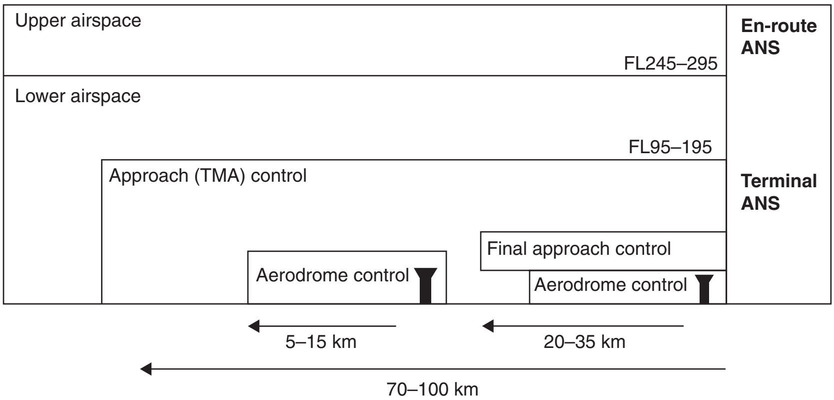

Figure 10.1 Standard Airspace – distinction between en-route ANS and terminal ANS.

airspace, typically arrivals and departures from airports on their path towards and from the en-route airspace. The charging mechanism used for aircraft in the en-route airspace (see Chapter 8) cannot be applied in the terminal airspace for mainly two reasons. While the distances flown in the terminal area are – in comparison with the en-route segment – very short and would not generate sufficient revenues, the associated operational ATC workload is often un-proportionally higher. The smaller terminal airspaces are located around airports and cities and typically utilised by a wider range of airspace users and activities (general aviation, schooling-flights, sport-aviation), operating in more complex airspace structures and drive – from an operational ATC performance perspective – a significantly higher ATC workload, as individual flights require more ATCO attention and intervention.

There are numerous differences between individual countries' methods on how the terminal charges are calculated and levied in the attempt to price the costs fairly, as a 'golden formula' has not been found yet. An explanation for this could lie in differences of airspace structures and ratios between terminal airspaces and en-route airspaces. With the ambition to cover system costs through user charges, a country with a small en-route segment and many terminal areas requires a different calculation key than a country with large en-route airspace and few terminal areas.

The terminal charges systems across Europe have raised concerns among the airlines. They have been highlighting the inconsistency of charging methodologies between states, which results in perceived unfair discrimination between airlines, a lack of transparency in cost information, including attribution methodologies, and as well instances of explicit price discrimination (PWC, 2001).

In the context of the provision of T-ANS as a commercial service in a competitive market, a fair terminal charging system is the enabler that prevents the formation of unjustifiably high entry barriers or internal cross subsidisation by the incumbent monopoly ANSP. A provider of T-ANS does not have the possibility to allocate revenues achieved in the 'cash cow' en-route segment to cover the costs of infrastructure and services in the terminal area, a behaviour also referred to as cross-subsidisation. While ICAO or the European Commission do not support cross subsidisation, such a cross-subsidisation between air navigation services within an ANSP as well as between users is in reality common practice (Oster & Strong, 2007) and is, as long as it is a monopoly market, also not problematic.

A good way to understand ANSP costs is to look at industry averages. The ATM Cost Effectiveness (ACE) Benchmarking Report offers the most comprehensive set of data for the European ANSP, as it summarises annual factual data and analysis on cost effectiveness and productivity for ANSP in Europe. This benchmark report contains self-reported data concerning staff: costs, assets and revenues in accordance with generally accepted accounting principles and provides a useful overview on ANSP productivity.

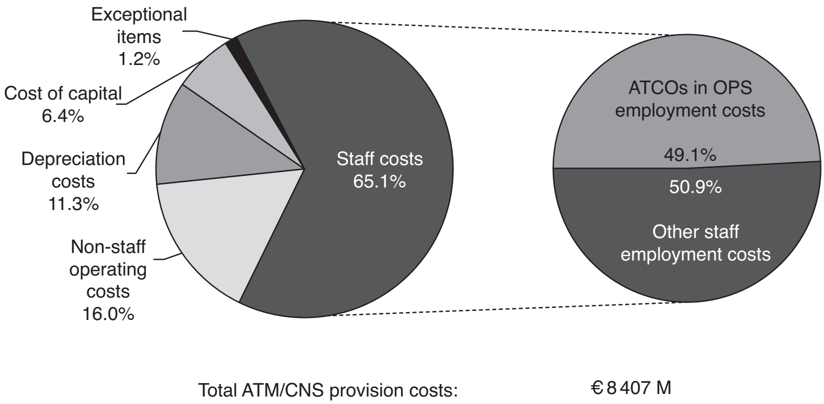

Figure 10.2 Breakdown of ATM/CNS provision costs in 2018.
Source: Eurocontrol (2020)

According to the latest data available data from 2018 (Eurocontrol, 2020) the total gate-to-gate costs, which is the sum of the en-route costs and the terminal ANS costs as reported by the member states, amounted to 8.4 billion EUR and Figure 10.2 depicts the European average cost distribution.

Even though there is a variation among the different ANSP, it shows that the by far largest cost item concerns staff costs (65%), but only half of these costs concern operational ATCO costs. This high percentage of fixed staff costs explains the limited short-term scalability of services on the one hand and hints towards why productivity increase through technology has been seen as crucial for next generation operational concepts such as Remote Tower technologies or virtual centres.

For the calculation of charges in general and the unit rate in particular, every ANSP has to determine the overall cost-base for the provision of all ANS services. This cost determination must follow generally accepted accounting and costing principles and must also include costs that are not incurred by the ANSP itself, but that are essential for the provision of ANS. This includes training costs for operational staff and safety, security and economic oversight costs that are provided by other government agencies. Equally, costs from the facility and equipment inventory from the ANSP as well as such costs from agencies supporting the ANS production process can be included in such a cost base. Based on the determination of the cost base, the regulatory authority then determines the effective unit rate that will be charged to the airlines using the airspace. Although this process and its details is defined, it grants an ANSP still with a large amount of flexibility (as to what to include into the cost base) to impact the revenue side and assure all costs will be covered.

To prevent abuse from the monopoly status and in absence of taming market forces, it is the state's responsibility to oversee and regulate the ANSP economically.

Economic regulation as way to prevent monopoly abuse

Economic oversight is manifesting itself through the application of economic regulation and is defined as the function by which a State supervises the commercial and operational practices of an ANSP (ICAO, 2013). In absence of a functioning market that assures appropriate pricing for services and generates incentives for innovation and customer focus, measures must be taken with the goals to prevent the ANSP from using anti-competitive practices and ensure that the level and application of service charges is non-discriminatory and transparent.

A regulating authority can choose from a selection of different regulatory 'tools' from their toolbox. These types of economic regulation can range from being relatively light-handed (for example the application of competition law) to being rather heavy, whereby the commercial freedom of the ANSP to make economic decisions is directly impacted (for example a 'rate-of-return' regulation). The appropriate level of economic regulation applied to an ANSP depends on the several factors and includes according to ICAO (2013):

- the degree of competition in each market;
- the applicable legal, institutional and governance frameworks;
- the roles, rights and responsibilities of the different parties involved; and
- the costs associated to specific oversight forms.

The goal of economic regulation is to emulate market conditions, therefore the type of economic regulation selected should not be chosen to 'penalise' an ANSP, but should ideally provide with incentives to structure its pricing, quality and costs in a way that will optimise its market outcome (Arblaster, 2018). When a monopoly market opens to competition, targeted economic regulation becomes, at least according to market theory, largely obsolete. However, even in a competitive market, an economic regulator is required to settle disputes between competitors in economic matters, to prevent abuse of monopoly power to erect entry barriers or tilt the level market playing field by cross-subsidising between different service lines.

Economic regulation can be exercised by either government departments or independent regulatory authorities, which is often seen as beneficial as they typically operate in a neutral and independent way from potential political influence or a too close relationship with the regulated entity. Especially the ANS industry where the 'arms-length' distance between government and ANSP is often rather a hands-length, regulatory independence is strongly recommended.

The airline umbrella organisation IATA (2020) identified, aside from the independence of the regulatory authority, additional elements that are central in any effective economic regulation on ANSP. These include a neutral dispute settlement mechanism for appeals against the regulator's decisions and a regulatory review period that ideally covers time periods of 3–5 years, as these period cycles should provide sufficient time for a regulated company to develop procedures, implement changes and extract cost efficiencies, which can be passed on to the customers. Furthermore, an effective stakeholder engagement process must ensure the early and timely involvement of airlines and airports in negotiations on business plans, future investments and operational expenditures, that could affect the cost-efficiency of the ANSP. The final frame of effective ANSP economic regulation should consist of clearly defined and measurable cost efficiency targets, and operational performance standards.

The expected transformation from the ATM industry to a more competitive environment, as experienced in most other industries of the aviation value chain and similar public utility industries, must consider numerous aspects and requires prerequisites. While there seems to be general agreement that more market mechanisms within ANS are highly desirable, there is currently no common view on the scope or the pace of such a liberalisation process. László (2018) observes that certain elements of the ATM service provision are already partly privatised, while others are only liberalised in some states, which indicates an absence of a general and well-structured approach towards liberalisation in ATM.

The intention to introduce more competition into a market requires, on the highest level, a choice between opting for 'competition for the market' versus allowing competition in the market. Competition for the market describes the situation, whereby several companies compete to obtain the right to operate a monopolistic market, whereas competition in the market describes the scenario, where several companies are – within a market – competing against each other. In connection with the provision of ANS, a competition for the market is favoured by the view that economies of scale, scope and density make competition untenable (Button & McDougall, 2006) and appears to be the more realistic choice for ANS services in the en-route segment, where a duplication of today's surveillance infrastructure and costs makes no economic sense. However, with a more widespread application of satellite-based navigation infrastructure and the establishment of a commercial ATM Data (ADS) market, this is not necessarily the case in the future.

A competition in the market on the other side requires a market partition for selected services and with that, an unbundling of the vertical integration of the ANSP is required in order to allow for a fair market environment. The ANS market can be split into different market segments and the European Commission (2020) in their proposal to amend the SES regulation proposes commercial markets for the following services: aeronautical information (AIS), ATM data (ADS), CNS, MET and T-ANS. Such a progressive opening of support services to competition is seen to provide new business opportunities within the ATM industry, but also enable a faster and less expensive implementation of new technologies (European Commission, 2013).

As mentioned, pockets of such markets have already developed and contribute to the growing pressure on the legacy ANSP to develop a more commercial approach towards the provision of ANS. In Europe, this pressure combined with the institutional drive towards a more harmonised and integrated Single European Sky has forced most states to review the ownership and governance model of its ANSPs.

Governance models of air navigation service providers

The ANSP in the past have been typically established and operated by governmental institutions, often governmental departments that were funded by the national treasury and staffed by government civil servants. The management and operation of these entities through governmental structures however yields some issues such as a limited access to capital markets for the financing of the necessary infrastructure, cumbersome governmental procurement and decision-making mechanisms and growing labour costs and staffing levels in absence of disciplining market forces (Dempsey et al., 2006).

To counter these inefficiencies, there has been a trend in the ANS industry, in line with other public utility service industries, to allow the ANSP more freedom from government ownership. Several notions to describe such a process are – often interchangeably – used and include 'corporatisation', 'privatisation' or 'autonomisation'. Privatisation is understood as the change in ownership from government/state-owned to private ownership while corporatisation refers to the process of transforming state assets, government agencies, or municipal organisations into corporations.

Commercialisation is a process in which the management style of an organisation is assessed and re-organised to assure its efficiency, enhanced productivity and profitability (Dempsey-Brench & Volta, 2018). It describes a process that typically involves the introduction of new funding methods, new governance arrangements and new mechanisms for safety and economic regulation (McDougall & Roberts, 2008). However, 'commercialisation' is not a defined notion that has the same meaning for all, and it is often used to describe an ambition or a process to reduce the government involvement with the ANSP and indicate a more business-oriented approach towards the provision of ATM. Its goal is to transform the ANSP to behave more like a company that operates in the private sector and within a competitive environment.

By granting the ANSP more freedom and distance from the government and by adjusting the ANSP governance structures to resemble private corporations, a more private sector management should be encouraged. The desire to reform ownership and governance of an ANSP does not only stem from increased commercial pressures for some ANS service areas but Dempsey et al. (2006) have identified some fundamental problem areas that arise when governmental institutions provide ANS, these include:

- problems of governmental institutions to keep pace with the capital needs in times of growing traffic demands.

- limited ability of government institutions to borrow money in capital markets when infrastructure upgrades are needed.
- inefficient governmental procurement and decision-making policies leading to bureaucratic inefficiencies.
- staffing levels and labour costs that not moderated by market forces.

In the bandwidth between a fully state-owned public entity with no degree of commercialisation to a fully privatised for profit company with publicly traded shares, several intermediate models of organisational types can be formed. An overview on different form of organisational models is shown in Table 10.1 (ICAO, 2000) and listed according to their degree of commercialisation, whereby a state authority, for an example a CAA, has no commercial orientation and a fully privatised for profit company with publicly traded shares presents the most commercial version.

A commercialisation of ANSP is therefore not an all-or-nothing choice as many different, intermediate and hybrid, forms of ownership and governance can be chosen from. A change in ownership structure and governance of an ANSP however does not 'automatically' translate into a more commercial way of looking at the ANS business or break up the vertical integration, but is primarily an attempt to solve governmental financing and budget constraints (Efthymiou, 2020).

According to Eurocontrol (2020), in Europe today a number of different ownership and legal forms can be found and varies from state agencies usually connected to the transport department, to government-owned corporations to semiprivate firms with for-profit or not-for-profit motivations. A full privatisation of a state owned ANSP has not occurred as of today and is not likely to happen within the near future, as the national ANSP today still executes a row of activities that are seen to be connected to public powers and are closely related to state sovereignty. These include activities related to the defence of the airspace and associated coordination with military authorities, aviation safety and security and other obligations that are mandated to a state through the Chicago Convention agreement (for example: to ensure provision of air navigation facilities and aids) (László, 2018).

Table 10.1 Degree of commercialisation of different ANS organisation types.

ANS organisation type	*Degree of commercialisation*
State authority (CAA)	0%
Autonomous state entity	
State-owned corporation (Crown corporation)	
Concession/lease (all or part of the facilities)	
Partial privatisation (e.g. non-aeronautical)	
Not-for-profit (stakeholder owned) corporation	
Fully privatised company (publicly traded shares)	100%

Source: ICAO (2000)

Blondiau et al. (2016) noted that, independent of the legal form or the ownership structure of an ANSP, often a strong association of ANSP to their governments can be observed, and which is usually reflected in the governance structure and processes. A good example of such a closeness can be seen in the Swiss ANSP skyguide. Skyguide is formally a semi-private joint stock company, bound to the requirement that the Swiss government must hold 51% of the shares. While this ownership and legal structure indicates a certain distance from government and a well-advanced commercialisation, in reality the Swiss government owns 99% of the shares and the Board members overseeing the management are politically appointed.

Two countries, the UK and Canada, have gone furthest in their attempt to separate ANS from governmental functions and in both cases the commercialisation of the ANSP resulted in cash injections to the federal budgets (Neiva, 2015). In the UK, NATS, the British ANSP is a public-private partnership, where the government owns only 49% of the shares, retains the 'golden share', but where the management control lies fully with the private sector. The share majority of NATS is in private hands and distributed between a pension fund and actual stakeholders and customers, namely Heathrow Airport and the Airline Group representing a group of airlines with a significant market share in the UK.

In Canada, the government decided to privatise its ANSP, NAV Canada, in 1996 and created a self-funded non-share capital corporation. Like the NATS governance, the board of directors of NAV Canada is composed of central stakeholders and users of NAV Canada services and includes employee representation, a governance structure, which resembles the structure of a user cooperative (Neiva, 2015).

The selection of the state concerning the organisational format of their ANSP is dependent on the specific situation of the state in regard to overall government policy and stand towards new public management in general, but can also be affected by the legal, institutional and governance frameworks in place. According to ICAO (2013) further factors such as the general market conditions in each country, the degree of competition, the requirements of the aviation industry in general and the contribution of the civil aviation sector to the state's overall economic and social objectives play a pivotal role in determining the appropriate form of organisational format.

However, regardless of the ownership and independence of the organisational format selected for the national ANSP, the Article 28 of the Chicago Convention, which states pointedly that the state is ultimately responsible for the safe and efficient provision of and operation of Air Navigation Services and associated infrastructure, still applies. Equally it is in the State's responsibility to assure that all the obligations and Annexes stemming from the Convention as well as all ICAO policies and practices are observed.

Furthermore, commercialisation does not imply that safety or other social considerations will no longer be subject to governmental regulation and regardless of the ownership or governance structure, the regulatory framework in its totality, in particular all the safety and economic regulations, apply and need to be complied with.

McDougall and Roberts (2008) note that commercialisation of ANSP has generally been a success, as safety of operations and service quality has improved, while costs could – to some extent – be reduced and no public interest considerations, such as a deterioration of labour relations or a decline of accountability to governments, have been violated. Advantages of commercialised ANSPs compared with state agencies are mainly seen in an improved understanding of client needs and a more expeditious decision making and implementation processes, factors which yield positively on project delivery or implementation of new technology.

Others argue that ownership structures do, in reality, not impact on the cost structure or the cost efficiency of the ANSP (Dempsey-Brench & Volta, 2018) and suggest that the impact of regulation outweighs the impact of ownership structure. It can be argued that compliance with all regulations and frameworks, such as the SES envelope in Europe, leaves the individual ANSP with little room to manoeuvre and its role as a node within a larger network industry limits its ability to impact on the revenue side. Additionally, while the ownership and governance model can mirror a private sector organisation, the cultural and business DNA of an ANSP originates from being a governmental agency and a monopoly organisation protected from market realities. Critics of privatisation efforts in ANS also, based on experience of airport privatisations in the US, opine that the cost of increased (insurance) liability in a transfer from public to private ownership could outweigh the promised economic savings (Airline Financial News, 2003).

Independent from ANSP ownership and governance, the ANS market is expected to, at least partially, liberalise for a number of ANS services. This development is on-going and has given space for new entrants to these ANS service markets.

The case of ACR – a private terminal ANS provider

One of the ANS industry segments that has seen partial deregulation and has developed a more competitive and commercial market, is the provision of T-ANS. This specific market, which – until recently – has received comparatively little focus from the national ANSP is usually not connected to any national sovereignty interests, cannot be considered a natural monopoly market and is served by dedicated T-ANS companies. The ANSP customer in this ANS segment is not the airspace user, but an airport that requires ANS to serve its customer base, the airlines, and that subcontracts ANS from a provider typically through the definition of a service level agreement.

In Sweden, Aviation Capacity Resources (ACR) was founded in 2004, in a time characterised by an industry recovery following the 9/11 downturn, the rise of the low-cost carriers (LCC) and with the emerging view that focus on cost-efficiency and customer focus should also be introduced into the regulated ANS industry. In the absence of an open market for the provision of any ATM services, ACR initially focused on the training of ANS staff and the provision of consultancy services, while the Swedish ANS landscape required legal and institutional changes in anticipation of an announced partial deregulation of the market.

While competition between airlines and a full commercialisation of the airports was seen to yield many benefits for the industry, competition in the ANS market for airports was eyed with suspicion and met with opposition. Legal changes that were required to enable competition need to be supported by the political and institutional levels and in the ACR experience the pressure on these lawmaking structures could only be exercised by the customers. Many airports were not content with the service and pricing framework provided by LFV, and the increasing communal and private ownership of these airports increased the pressure on the system to allow for competition. Aside from removing the legal barriers, ACR needed to overcome scepticism among regulators and stakeholders and obstruction by the incumbent monopolist.

This process, following a first and unsuccessful attempt in 2005, finally succeeded in 2010 and in that year, Sweden lifted the statutory monopoly of Luftfartsverket (LFV) for the provision of ANS at all airports and opened a selected segment of the Swedish regional airports for competition.

Instantly, 3 airports, in their struggle to operate profitably, while burdened with high ANS costs through the monopoly provider LFV, launched a tender process for the provision of ANS. This tender process was won by ACR and in October 2010, a historic contract – the first of its kind – between ACR and these three airports (Västerås, Örebro and Växjö) was signed. Within the next 6 months, ACR received the ISO Quality Systems Management certificate and was certified with the Single European Sky (SES) ANSP certificate through the Swedish CAA, enabling ACR to offer their services in the entire European Common Aviation Area. Operations in the first airport units started in March 2011 and since then ACR has grown and – as of January 2021 – provides ANS (ATC or AFIS) at 17 airports in Sweden, which compares to 80% of the deregulated market.

The establishment of a competitive market for the provision of ANS turned out to be a win-win situation for all involved. On smaller regional airports that are dependent on ATC to operate their commercial routes, the ANS cost element is often the largest budgetary cost item (up to 50%) and following the change to ACR, a service cost-reduction of – on average – around 40% materialised. The dimension of the savings achieved in Sweden is in line with cost savings in comparable provider change processes in other countries (ATM Policy Institute, 2017), while ACR instantly became a profitable company. At the same time, the emergence of competition forced the incumbent LFV to increase its focus on customer orientation and cost-efficiency, a development that ultimately benefits all its customers.

To understand how such a significant cost reduction for the airports can be achieved, while service and quality levels remain unchanged, requires an examination of the ACR business model. Inspired by the successful LCC philosophy to focus on business and operational practices that drive down costs, ACR focuses solely on the provision of T-ANS without adding organisational and service elements not needed for the execution of the main business process, to its service portfolio. Such a targeted approach to service provision to a defined customer segment contrasts with the service scope of the legacy ANSP and allows for a very lean organisational and overhead structure. While the European ANSP on average employs between 1 to 3 staff per operational Air Traffic Controller, which is a ratio of 1:1 up to 1:3 (Performance Review Unit, 2020), this ratio at ACR lies at 0.1 (one non-operational staff per 10 ATCO). The cost savings achieved by such a lean organisational structure are sufficient for ACR to be otherwise fully in line with common industry compensation frameworks.

ACR's revenue model reflects its nature of being a focused 'niche' ANSP and not vertically integrated. The ACR customers are airports that require ANS as a service to their customer base and ACR is therefore a sub-supplier to the airport. The commercial agreements with the airports are usually negotiated through the definition of Service Level Agreements that define the type of service (AFIS or ATC) and the volume of service (usually in service hours per year) as well as costs for additional services that the airport can require (for example: additional service hours outside the planned opening hours).

Services and corporate functions not considered vital (for example: ATCO training, the provision of technical support services or IT) are procured on the market rather than provided inefficiently in-house. However, once the organisational size justifies an integration of such services in a more cost-efficient way, the organisation is adjusted accordingly.

The reported increase in customer satisfaction (ACR, 2020) can be explained with the targeted organisational focus on its key customer base and is confirmed in the fact that, until today, no ACR customers have changed the provider after ACR has taken over. ACR today looks at expanding its service and customer portfolio outside the Scandinavian market and is meeting a European T-ANS market that is fragmented and not mature yet. Although the European Commission encourages the introduction of market mechanisms through the SES legislative process, the opening of the ANS market for T-ANS is still very fragmented and often fully protected through national regulations. The reasons for the reluctance of member states to deregulate their T-ANS segment are not researched, but the unhealthy closeness of ANSP to their national governments could be a reason for this protectionism. The observed reluctance to open ANS segments for competition is in line with a more general observation that, despite the on-going integration processes concerning a European airspace architecture and the technological developments promising fundamental changes in the way ATM is provided, the sector continues to tend towards monopolies that are organised within national borders (László, 2018).

Conclusions

This chapter provided an overview on the business framework for Air Navigation Service Providers, a topic that only in recent years has gotten more attention and focus. While the Chicago convention framework binds the nation state to ultimate responsibility over the organisation of the airspace and its infrastructure, there is an increasing pressure on the ANS industry to liberalise and de-regulate in line with other industries in the aviation sector, public utility and network industries.

Liberalisation in the ANS industry in Europe is not expected to be a fast process, but will impact on the organisational structures of ANSP, the ANS market and the regulatory framework. Legacy ANSP will need to re-adjust their organisations to mirror the distinction of regulated monopoly services and commercial services that are offered in a competitive environment. This is likely to require some form of unbundling of the vertical integration and a further commercialisation of these organisations.

Driven by technological developments, a 'post pandemic' increased focus on scalability of services and their cost-efficiency and a regulatory framework that encourages market mechanisms, competitive markets for ANS services are expected to expand. In a first step this is likely to be limited to services such as CNS, AIM, T-ANS, ADS, MET, but at a later stage, enabled through new – less location dependent – technologies, it can also include en-route ANS.

The role of the economic regulator in a liberalised ANS landscape is expected to transform from purely executing economic regulation on the ANSP in order to prevent monopoly abuse and pricing discriminations, to a role that liaises between competitors in economic disputes and assures a fair market environment without unfair entry barriers or cross subsidisation.

The benefits of market liberalisation such as increased cost efficiency, innovation and customer focus appear to outweigh the concerns connected to sovereignty (air defence) and safety and within a more integrated European airspace architecture, fuelled by digitalisation and automated ATM technology, a more competitive ANS environment is likely to manifest. Even when considering all political, legal and regulatory concerns, it appears that the ANS industry is on a trajectory, in line with other network industries, to become another liberalised public utility.

Discussion points

1 Competition in T-ANS has yielded measurable and significant cost savings for airports: can competition be expanded into the en-route segment? Where do you see obstacles?
2 Is the provision of ANS another public utility (like Energy, Telecom, Railroad) that should be commercialised or not? Discuss and compare to another industry

3 Does a commercialisation of ANSP without a change of the market monopoly status make sense? What's your view?
4 What is – in your view – the best ownership and governance model for ANSP? Support your view with examples.
5 Where do you see additional business opportunities for ANSP in the future?

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11 The potential of unbundling air traffic management services in Europe

Keith McEvoy and Marina Efthymiou

Introduction

An air traffic management system is designed to provide safe and efficient aircraft movement both on the ground and in the air. Lawless (2020) highlights that an ATM system is classed as a critical infrastructure that allows for the safe movement of people and goods. An ATM system can be looked at from a national and international perspective as several agencies are involved in ATM service provision (CAA, 2020). In the European context, the ATM network is formed by the interaction of numerous organisations and agencies. These range from the national and private air navigation service providers (ANSPs), who provide the air traffic control service, to governing bodies such as Eurocontrol and the European Aviation Safety Agency (EASA).

As Eurocontrol (2006) stated, the fragmentation of the European air traffic management system has long been of concern. Lawless (2020) stresses that the modern European ATM network is still vital for the safe and efficient functioning of European aviation. However, it is still marred by cost and environmental inefficiencies and continuing criticism from airspace users. Eurocontrol released a statement that inefficiencies in the network contribute to an average additional fuel burn of 8.6–11.2%, compared to the most fuel-efficient flights in the European network (Eurocontrol, 2020).

Inefficiencies still exist in the European ATM network despite reform initiatives like the Single European Sky and SESAR. The Single European Sky (SES) initiative was first proposed in the late 1990s, following a period where the safe operation of civil aircraft in close proximity to heavily active military areas was seen as problematic (Lawless, 2020). In 2004, the European Parliament passed the first iteration of the Single European Sky. SES 1 enacted regulations to transcend national borders and re-shape the European ATM network. This initiative has since evolved into SES II and SES II+.

The next stage of reform that has come to the fore in recent years is the unbundling of ATM services. As mentioned above, the ATM network suffers from large scale duplicity of services. The European Commission has now proposed that the ATM network be subject to a full unbundling of services (Lawless, 2020). The unbundling of Terminal ATM (controlled airspace in

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the vicinity of an airport) has already occurred in small pockets throughout Europe. For unbundling to have a large-scale positive impact on the network, full liberalisation of European ATM services will likely be required.

Current European air traffic management

The European Union has attempted to liberalise the air transport industry since 1993 (Hiney et al., 2020; Efthymiou & Papatheodorou, 2018). However, and despite the introduction of the Single European Sky, the liberalisation of European airspace, in the ATC context, is currently in a state of gridlock (Baumgartner & Finger, 2014). As Adler et al. (2020) state, ATC provision is one of the last elements of the aviation supply chain to be considered for liberalisation.

ANSPs connect airlines and airports by providing safety-critical services while promoting efficient traffic flows (Dempsey-Brench & Volta, 2018). ANSPs are continually being criticised for not being cost-efficient and costing airlines millions of Euros in delays. The Director of Eurocontrol, Eamonn Brennan, said that ‘airlines are charged billions of Euros for ATM services but are they receiving billions of Euro worth’ (CAPA, 2019). This raises the question of why European ANSPs are not deemed cost-efficient. The first important aspect is how European airspace has evolved.

Following on from the Chicago convention, which took place in 1994, several rules were implemented concerning the provision of air navigation services. Importantly, it was stated that ‘each state is required to provide air navigation services for their own state’ (ICAO, 2013). This ICAO regulation has created a European air traffic management architecture that is far from ideal as a direct result. European airspace is fragmented and comprises numerous Flight Information Regions (FIRs). Generally, each FIR is controlled by a specific sovereign state, over which the FIR lies.

This fragmented approach to European ATM has created the situation whereby ANSPs operate as natural monopolies (Grebensek & Magister, 2012). Europe has a staggering 37 ANSPs controlling approximately 1000 different airspace sectors. Because of this fragmented approach, delays in these European airspace sectors cost airlines a vast amount of money (Grebensek & Magister, 2012).

In 2019, the European ATM network handled over 11.1 million flights, an average of 30,427 flights daily. This also equates to a 0.9% increase in daily traffic compared with 2018, an upward trend since 2014 (Eurocontrol, 2019b). Despite these large numbers of aircraft moving through the ATM system daily, the Network Manager reported a reduction of en-route ATFM delay of approximately 9%. This is quite a reduction, considering traffic numbers increased on 2018 levels. However, the reduction was mainly due to fewer weather disruptions in en-route airspace, more so than related to any ANSPs directly (Eurocontrol, 2019b).

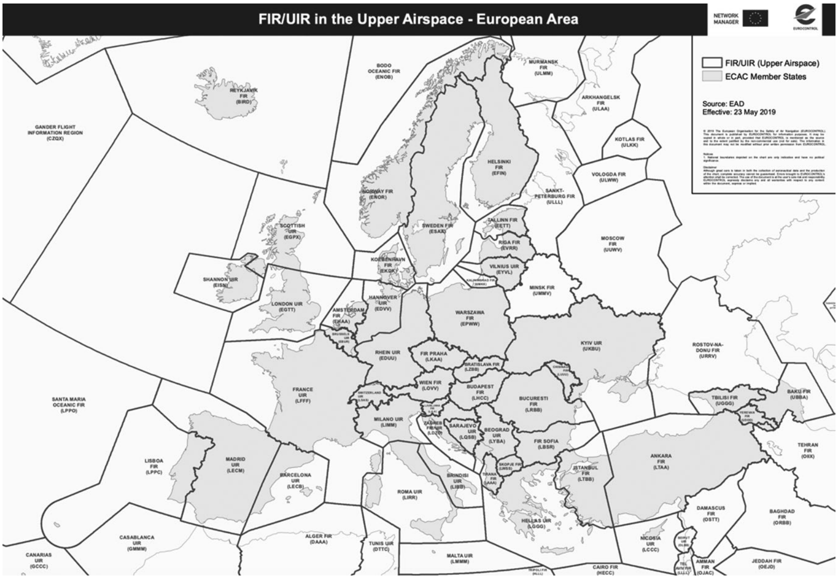

Figure 11.1 European flight information regions.
Source: Eurocontrol (2019a)

Even though a reduction of delays in the order of 9% was observed and reported, airline groups are not happy with the en-route performance of the European ATM network. Ryanair, one of the most vocal airlines in Europe, argues that these continuing ATFM delays are unacceptable, and changes must be made. CANSO (2019) have long argued that ATM leaders are continuously making changes and reforms to address the capacity and cost efficiency issues. This highlights that ANSPs are open to reform while not allowing an open ATM market.

As well as delays to air traffic, the cost-efficiency of the fragmented European airspace is continually being highlighted by airline lobbying groups, such as IATA and Airlines4Europe. IATA (2010) argues that airline groups feel that Europe is continually taking two steps forward and one step back in terms of cost-efficiency. Likewise, Airlines4Europe (2020), a lobbying group for European airlines, has recently stated that ''European ATC remains inefficient, expensive and unreliable for millions of passengers''. The reality is that the costs imposed on airlines by an ANSP, called 'unit rates', are highly regulated by the European Commission. Therefore, an ANSP cannot charge an airline a unit rate that has not been approved. However, it is important to note that before the introduction of performance and risk-sharing charging regulation, the situation existed in which European ANSPs were seen as natural monopolies (Artblaster, 2018). Essentially, this meant that revenues generated for ANSPs were done so within a captive market with a cost-recovery charging mechanism and airlines had no other choice but to use the services of a particular ANSP. Thus, the motivation for ANSPs to have a good economic performance was particularly weak (Artblaster, 2018). This would suggest that a performance and charging scheme regulation was required to keep control of ATC unit charges and ensure a cost-effective ATM network for airspace users.

The current cost-efficiency and performance monitoring regulation is commission implementing regulation 2019/317 (European Commission, 2019). Castelli et al. (2005) state that a specific policy governing ANSP performance and cost-efficiency was an important move by the European Commission. They highlight that to guarantee maximum efficiency at minimum cost to all airspace users and help realise the goals of the Single European Sky (which will be discussed later), ANSP operations must be monitored and controlled. It is important to note that this formal performance regulation only came into force in the EU in 2009; however, a performance review framework had already been in existence since 1997 (Eurocontrol, 2019c).

Under the 2019/317 regulation, all national supervisory authorities of each state must supply the performance review board with the planned unit rates for the subsequent 5 year period – called reporting periods. This is performed by the national supervisory authority (which is generally the aviation regulator in most states), allowing for a level of independence from the ANSP and the unit rate charged (European Commission, 2019). However, the ANSP can put forward their predicted costs for the relevant period to aid the NSA in determining the correct unit rate.

The provision of gate-to-gate ATM/CNS is costly. There are significant costs at both en-route and terminal levels (see Table 11.1). Despite the aim of performance regulation to reduce the cost for airspace users, inefficiencies continue to exist. Castelli et al. (2005) have said that whether the performance regulation has achieved its cost-efficiency goals is very much up for debate. It is even the case that CANSO, the representative group of ANSPs, agrees that the performance regulation has not lived up to its aim and does

Table 11.1 Breakdown of ATM costs for an unnamed European ANSP, 2017.

Gate-to-gate ATM/CNS provision costs (European Level) €8,213M		
	En-route ATM/CNS costs (European Level) €6,387M	*Terminal ATM/CNS costs (European Level) €1,825M*
Staff costs	€4,098M	€1,244M
Non staff operating costs	€1,011M	€305M
Depreciation costs	€785M	€158M
Cost of Capital	€407M	€89M
Exceptional costs	€85M	€29M

Source: Performance Review Commission (2019) not assure airlines of an ANSP being as cost-efficient as possible (CANSO, 2012). Interestingly, both IATA and CANSO have issues with the performance scheme regulation. Perhaps it is now timely to review or adopt the regulation and move into a more modern and interoperable ANSP framework within Europe. Artblaster (2018) argues that having a performance scheme that does not work lends great weight towards the benefits of creating an open ATM market.

ATM reform initiatives

Limitations of SES & FABs

As Baumgartner and Finger (2014) indicate, the SES programme was due to have been delivered by 2020. This has not happened yet. Remarkably back in 2012, the vice-president for transport in Europe made the stark announcement that the Single European Sky initiative was not delivering. $5 billion a year were being lost by airlines due to a drastically inefficient ATM network (Kallas, 2012). This was backed up by Blondiau, Delhaye, Proost and Adler (2006), who had illustrated that the whole SES process would only work if a performance scheme was introduced. However, as we can see, even after the introduction of performance regulation, the aims of the SES have still not been realised. To date, this has been largely unsuccessful, with 2019 being a record year for both traffic numbers and delays.

Lawless (2020) indicated that FABs were used to transcend national borders; however, they also state that FABs were still conformed to the traditional national borders. Also, although the creation of FABs played a fundamental role in SES, it is well known across Europe that most ANSPs feel that FABs have not worked (Efthymiou, 2016). For example, the UK and Ireland still operate independently despite the UK – Ireland FAB (Lawless, 2020). As Nava-Gaxiola and Barrado (2016) state, following a review of the southwest FAB, state boundaries limit the operational improvements proposed in the SESAR programme to modernise the Single European Sky. It indicates that something other than FABs needs to be considered to defragment European airspace.

From the environmental perspective, FABs have also been shown to have been of no real benefit (Efthymiou & Papatheodorou, 2018). Environmental concerns are very real in today's aviation industry, and elements such as en-route flight efficiency need to be addressed. However, Efthymiou and Papatheodorou (2018) study found that ANSPs and FABs lack a strong environmental ethos. Indeed, it was said that FABs have generally failed to address the issue. For example, FABs introduced the concept of conditional airways to reduce track miles flown and hence fuel burn, but the conditional routes are massively underutilised (Efthymiou & Papatheodorou, 2018).

Interestingly, Buyle et al. (2020) suggest that ANSPs as individual entities are already operating in the most cost-efficient manner possible. Therefore, they argue that there is nothing concrete to definitively say that Reg. 371 and the consolidation of ANSPs through FABS would be of any benefit whatsoever to the ATM network (Buyle et al., 2020). Baumgartner and Finger (2014) stated that the SES and SES II projects were the latest and likely to be the last attempt to harmonise European airspace.

Air navigation service providers

ANSP business models

It is important at the outset to mention that there are many different types of ANSP business models. Before introducing any performance review regulations, ANSPs in Europe could be considered natural public monopolies (Artblaster, 2018). However, because of the introduction of performance regulation, they are now seen as regulated monopolies – albeit still monopolies (Blondiau, Delhaye, Proost & Adler, 2016). As Artblaster (2018) indicates, airlines have no option but to use the services of an ANSP. Essentially, they are a captive market. Artblaster (2018) believes that the time is right to look beyond individual ANSPs and start the liberalisation of the en-route European ATC network. Following the Chicago convention, when each state was required to provide a national air traffic control service, it was the status quo that these early ANSPs were state-controlled. Although that has not changed fully, within European ANSPs, there are now different models of ownership. Indeed, NATS in the UK were the first part-privately owned ANSP that operated on a 'for profit' basis (Dempsey-Brench & Volta, 2018).

Blondiau et al. (2016) performed interesting research, using a public utility approach, into the business models of ANSPs, considering they are heavily regulated entities. In doing so, they identified four key aspects of ANSPs that must be considered when researching their business models. They are:

1 The semi-public nature of ANSPs.
2 The heterogeneity of ANSPs.
3 Monopoly nature of en-route ATM.
4 Likely emergence of special interest groups.

The study found that cost-plus regulation, also known as 'cost-recovery' (for example, setting unit rate charges as per 2019/317), does not act as an incentive for ANSPs to reduce costs. It was found that with this type of regulation, excessive costs and capital investments have occurred (Blondiau, Delhaye, Proost & Adler, 2016). This has occurred because, according to the performance regulation, ANSPs will be compensated for fixed investment costs, therefore ANSPs will invest more, thus raising the unit charge. However, a positive from this is that ANSPs are more inclined to adopt newer and more efficient technologies (Blondiau et al., 2016). Adler, Delhaye, Kivel and

Proost (2020) concluded that ANSPs with public-private ownership, such as NATS, have higher cost efficiency and productivity levels. However, these ANSPs are only a small subset, so in reality, there would need more public/privately owned ANSPs to get 'the real picture'. They also determined that those ANSPs under semi-state ownership (such as the Irish Aviation Authority) are inclined to look after the national interest than reduce the airspace users' cost base. The research shows these ANSPs to be more inefficient than privately owned ANSPs.

Contrary to the results from Adler et al. (2020), Dempsey-Brench and Volta (2018) argue from their research that the ownership state of an ANSP does not impact cost-structures or cost-efficiencies. Therefore, we can see that no one conclusion is drawn concerning European ANSP business models. More research needs to be conducted.

Tomova (2016) looks at ANSPs business models from a different perspective to Blondiau et al. (2016). She argues that the discussion at the European level regarding how ANSPs operate is generally focused purely on how their business operates in terms of performance regulation. Commercial revenues of European ANSPs are generally ignored. Tomova (2016) suggests a couple of reasons as to why this is the case within Europe:

1 Privatisation is still very rare among ANSPs.
2 Within Europe, the focus on commercial revenues has been on airports and airlines and rarely on ANSPs.

Compared to the other parts of the world, Europe seems to be lagging. Tomova (2016) highlights that in other fragmented airspaces (non-European), there is now competition for an open en-route market. This sharpening of competition among ANSPs has driven costs down and encouraged ANSPs to operate with more commercial business models. This is not yet the case in Europe, apart from some liberalisation of terminal airspace (to be discussed later). One ANSP can provide ANS services to another; however, there is little research in the European context. Europe needs to adopt more radical changes towards more liberalisation (Tomova, 2016).

Materna (2019) describes the liberalisation of ATM in greater detail. She describes a situation whereby state-owned ANSPs were publicly funded historically. It is now the case that ANSP business models have adapted to take advantage of more commercial revenues that can be generated (Materna, 2019). However, low-level terminal airspace has been somewhat liberalised, not quite on a global ATM network level (Materna, 2019).

Buyle et al. (2020) investigated the economies of density and economies of scale in European ATM and found no cost complementarity between en-route and terminal services. This is particularly important as this could pave the way for future unbundling of ATM en-route services and creating an open ATM market.

Reform of ATM services in Europe

Unbundling of terminal ANS

Materna (2019) discusses terminal airspace's liberalisation or 'unbundling'. She stated that the UK pioneered the liberalisation of the ANS market. Thompson et al. (2016) undertook a Porter's five forces analysis of the UK Terminal ATM (see Figure 11.2). They highlight that while the CAA established targets under the SES performance scheme, they discovered that they could do it in two ways. One was to deliver a performance target for the en-route service (which the CAA described as monopolistic). Rather than establishing targets for terminal airspace, the second option decided to liberalise that element of the UK ATM network and create a competitive market. Under the performance scheme at the time, nine UK Terminals fell under the rules governing the scheme, and all were under the control of the UK ANSP, NATS. To use London Gatwick as an example, following a competitive tendering process, the air navigation service company called ANS solutions won the contract and is currently providing the service at London Gatwick. ANS are a subsidiary of the main German ANSP, DFS. Importantly for the future of ATM, Thompson et al. (2016) concluded that creating competition at nine UK airports has had the effect of realising high cost and service benefits. By entering negotiations to win ATM contracts, ANS providers have become more customer-focused and developed strong interoperability with NATS. These are key findings and highlight what could be achieved should liberalisation occur in en-route airspace.

However, as soon as the issue of Brexit was raised, the CAA commenced a review of TANS operations in the UK. The issue that the UK has now run into is whether or not TANS at UK airports is still subject to what is referred to as 'market conditions' (CAA, 2017). Under the reporting period structure, the UK were granted exemptions from RP2, as the EU had considered that market conditions existed in the UK. However, with RP3 submissions now in process and following on from the UK's departure from the EU, the CAA are unsure if they can continue TANS operations under RP3 (CAA, 2017).

Following the UK example, Spain was another country to look at the liberalisation of its Terminal airspace. Comendador, Valdes and Sanz (2012) stated that the main aim of the liberalisation process in Spain was to break up the current monopolistic situation and reduce ANS costs. In Spain, the control of Terminal airspace was put forward for tender for 20 different airports. They identified an important comparison between the liberalisation of ANSPs and airlines. As we know, the airline industry was liberalised many decades ago, and it is still the case that new private airlines attempt to enter the market all the time. The ATM world has been very slow to catch up. Comendador, Valdes and Sanz (2012) make a key observation that could be very important as the liberalisation of ATM continues. Comendador, Valdes and Sanz (2012) found that companies that plan to avail of these opportunities must:

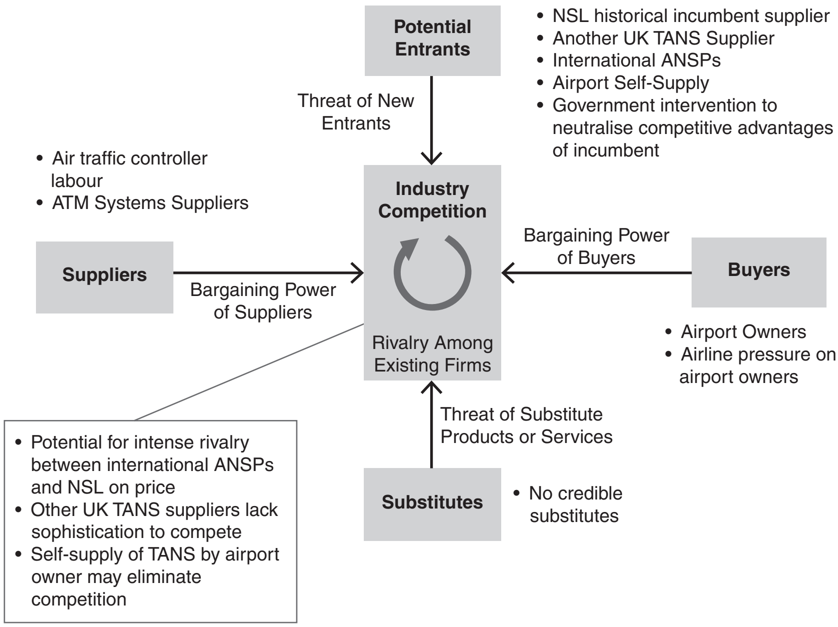

Figure 11.2 An industry analysis of United Kingdom TANS at nine largest airports.
Source: Thompson et al. (2016)

- Plan the process in detail;
- Obtain the relevant certification first;
- Ensure adequate selection and training of personnel; and
- Effectively organise the service within current regulations.

Sweden has also been a pioneer in terms of TANS. Sweden began to deregulate its terminal airspace in 2010 and has opened up for any certified ATS providers to tender for terminal airspace. The Swedish company, ACR, have taken great advantage of this open market and have won the tender for 17 of Sweden's regional airports, with an 18th likely to come on stream quite soon (ATC Network, 2021). ACR's business model has been described as a monopoly breaking business concept. This approach by ACR has been seen as a 'game changer' within the industry. ACR focus on creating a lean business while also focussing on innovation. Indeed, since ACR has entered the Swedish TANS market, the cost of terminal ATS has been reduced by 30–40% (ATC Network, 2021).

En-route unbundling

The 'unbundling' or liberalisation of en-route airspace is at a more embryonic phase. In Europe, en-route ATM services are still provided by the ANSPs for each sovereign country, as per the original ICAO regulation. Despite the lack of literature, that is not to say that the unbundling of en-route airspace has not been mentioned in different aspects. Artblaster (2018) states that now is the correct time to fully liberalise the en-route ATM market if Europe wants to create a cost-efficient environment. However, Nava-Gaxiola and Barrado (2016) stated 'state boundaries are the barriers to reform'. Traditional boundaries need to be fully overcome to harness an open ATM market.

However, while full en-route liberalisation is yet to be achieved, there have been a lot of advancements in cross-border activities between ANSPs. As we saw above, the European ATM masterplan sets out cross-border initiatives and improvements that need to be made to reduce the fragmentation of the EU airspace and develop a level of interoperability. It will be interesting to observe how these cross-border initiatives may lead to full unbundling of services.

To take an example from elsewhere in Europe, Baumgartner and Finger (2014) suggest that the liberalisation of European airspace should be compared to other European initiatives, such as creating a single European power and telecommunications market. The liberalisation of the telecommunications market is quite an interesting example, as it compares quite well with that of aviation. They are similar in that they started with creating a framework of interoperability (much like modern ATM) and progressively moved towards a fully liberalised telecommunications market. However, the liberalisation of the telecommunication market was difficult to achieve due to national boundaries and certain countries that were not initially willing to take part (Waverman & Sirel, 1997). At that point, the European Commission could use its power and ultimately, a fully open telecommunications market was realised. As more and more competitors entered the market, alliances began to form between many operators (Waverman & Sirel, 1997). This could well be a blueprint of what will occur in European ATM.

Push and pull factors for ANS unbundling

Singh (2011) identified that cooperation between organisations in the air transport industry is essential for strategic performance. Singh (2011) suggests that the same cooperation models adapted by airlines could be applied to ANSPs. For example, Airline alliances have led to a seamless network, cost efficiencies, improved service quality, strategy for growth and new technology motives (Singh, 2011). These are all aspects that are relevant to the ATM industry also. Therefore, if airline alliances have achieved positive momentum in terms of those items listed above, then perhaps alliances could be as equally fruitful for ANSPs.

The way forward in ATM is to create cross-border air traffic services. Cross-border data flow, dynamic airspace configuration, and ''capacity on demand'' are needed to enable this. These require strong ANSP interoperability and collaboration. Also, as Baumgartner and Finger (2014) indicate, the technology providers all feel like ATM should now be borderless.

An example of interoperability and collaboration that may become key in an open ATM market is COOPANS. COOPANS is an Air traffic control system that several European ANSPs developed in conjunction with the service provider, Thales (Kearney & Li, 2015). COOPANS is a cross border alliance of 6 ANSPs. One of the COOPANS objectives is to lower costs by harmonising the air traffic control system between the 6 ANSPs. This level of interoperability and collaboration between ANSPs can act as a competitive advantage when or if there is ever an open ATM market.

Apart from COOPANS, there are some examples of collaboration between ANSPs, with Borealis being the most successful one. Borealis has a track record of ANSP cooperation for the mutual benefit of ANSPs and airline customers. The flagship project of the Borealis alliance was that of Free route airspace. Free route airspace now accounts for fuel savings of 3,000 tonnes a day and as much as 10,000 fewer CO2 tonnes a day in the European ATM network. Cooperation among ANSPs is essential to surviving in an open market environment. The collective negotiating power is higher than the individual; ANSPs share resources and expertise, leading to cost reductions and economies of scale.

Moreover, Aeronautical Data Service Providers (ADSPs) can play an important role in unbundling. Outsourcing this service can provide significant cost savings. The move towards CNS unbundling and the provision of services through third-party ADSPs is already evident in Europe. For example, the Spanish ANSP ENAIRE has teamed up with INDRA, a technology company, to launch satellites into space, ultimately resulting in the provision of space-based aeronautical data, reducing reliance on traditional RADAR but also covering large volumes of airspace. This can give ENAIRE a competitive edge in an open market environment.

The technology and system interoperability are already sufficiently developed, and ANS can be provided remotely from any other ACC. However, one of the major barriers to ATM liberalisation is political will or the lack of it. The proposal to unbundle ATM en-route services has very strong support at European Parliament and European Commission levels; however, this is not the case for the European Council.

There are several reasons why the full liberalisation of ATM is unlikely to pass the European Council stage. The ever-present issue of sovereignty continually arises. Sovereignty is certainly not a new issue in the world of ATM as it dates to the Chicago convention in 1944 when each state was to be responsible for Air Traffic service provision. It is very difficult to relinquish sovereignty over their airspace for states because sovereignty is intrinsically linked to security and military.

Moreover, some ANSPs are 'scared' of potentially entering an open market, so ANSPs and states do not want a full liberalisation of services. State-owned ANSPs do not have the required competencies and resources to operate in a market environment. Risk-averse ANSPs would also not invest in technologies and implement market dominance strategies. Natural monopolies' current market environment has not created the incentives to act competitively. For an ANSP to be ready for market conditions, they need to develop solid market knowledge and position themselves to gain a competitive edge.

Full liberalisation of the ATM network will create some legal issues. First, the topic of who will actively regulate the ATM service arose. For example, EASA is considered the European aviation regulator. However, each state is still required to have their own National Supervisory Authority. Secondly, the social aspects of such a move must be considered. If an ANSP takes over another member state's upper airspace, will it be the case that staff will provide the service remotely or will the ANSP take over the local ACC units? Also, the Transfer of Undertakings (TUPE) law will need to be considered.

The risk to an ANSP is very real. Smaller ANSPs would likely disappear, and rationalisation of the medium-large ANSPs would occur under market conditions, similar to airlines merging. When viewing such a rationalisation of ANSPs from the top down, it is perhaps not such a bad situation to occur as it reduces the fragmentation of the ATM network. However, from an ANSPs perspective, this may be undesirable. Nevertheless, in the case of ANA, Luxembourg's ANSP, despite all the reforms that have been attempted within the ATM network, including the small pockets of terminal unbundling that has already occurred, the smallest state-owned ANSP has still survived.

Conclusion

The European ATM network is fragmented, with numerous ANSPs operating various ownership models. Based on this inefficiency, reforms have been attempted, including unbundling. Terminal unbundling has already occurred in small pockets throughout Europe. ANS solutions, for example, a subsidiary of DFS, is offering Terminal Air Navigation Services (TANS) in Gatwick airport in the UK. En-route unbundling has not progressed, but it is a potential future for the European network.

While it appears that a full unbundling of ANS is not quite there at the moment, it is prudent for an ANSP to prepare for the forthcoming liberalisation of the European ATM network. The key strategic characteristics that an ANSP must adopt in the event of an open en-route ATM market are: (a) strong technological capabilities, (b) excellent customer service quality, (c) adaptability and flexibility, (d) mature Safety Management System, (e) strong presence in an ANSP alliance and ATM groups, (f) financial independence, (g) commercially driven mindset and (h) strong link to CNS data providers.

The global COVID-19 pandemic has undoubtedly wreaked havoc on European aviation. The pandemic impact has not yet been realised. Fundamentally, any reform is at the behest of the EU member states. Until the European Commission can enforce liberalisation on the EU nations, we are still decades away from the full ANS unbundling and reform.

Discussion questions

1 In the event of full liberalisation of ATM services, what key strategic characteristics should an ANSP have?
2 What are the implications of an open market?
3 How do market structures affect ATC liberalisation?
4 What are the conditions for ATC unbundling, and what are the potential impacts?

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12 Multiple remote tower operations

Air traffic controllers' attention distributions and task performances

Peter Kearney, Wen-Chin Li and Graham Braithwaite

Introduction

The initial concept of remote tower operation (RTO) was for air traffic services (ATS) to be delivered remotely without direct observation from a local tower (Kraiss & Kuhlen, 1996). Based on the concept of remote tower operations, multiple remote tower operations (MRTO) offers further opportunity for cost efficiency of air traffic services for small and medium sized airports (Efthymiou, 2020), especially if a single controller could provide air traffic services to two (or more airports) at the same time. Remote tower technology allows one air traffic controller (ATCO) to control one or more airports at the same time, a significant consideration of course are the appropriate traffic volumes for a single air traffic controller to manage (SESAR Joint Undertaking, 2013, 2015). ATCOs use Out the Window (OTW) visualisation media supported by radar data processing (RDP), electronic flight strips (EFS) and a voice communications network (VCS) to provide air traffic services (Moehlenbrink & Papenfuss, 2011). This Multiple Remote Towers research project was sponsored by the Single European Sky ATM Research Program (SESAR) and the ATM Operations division of the Irish Aviation Authority. The remote tower centre (RTC) was located at Dublin Air Traffic Services Unit, 150 miles away from both Shannon and Cork airports where the services were provided simultaneously. Cork airport is a H24 international airport with aircraft types up to medium weight category such as Boeing 737 and Airbus 320. The motivations of this MRTO project are to understand the limitations of controlling parallel traffic at two airports by a single ATCO, to demonstrate how the implementation of the new technology impacts safety, capacity and human performance in order to secure regulatory approval.

The innovative concept of multiple remote tower operations (MRTO) is principally suitable for lower traffic density airports. The visual cues and objects which ATCOs routinely use for safe operations must be provided by the surveillance cameras; the data-communication links and the systems must support the provision of air traffic services at two (or more) different

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airfields simultaneously (Van Schaik, Roessingh, Lindqvist & Falt, 2016). Groundbreaking technology enables precise image-video resolution for signal detection and recognition. The crucial factor to assure aviation safety is the cooperative interaction between the human and the technical systems being used (Onken & Walsdorf, 2001). ATCOs visual attention and situation awareness are the main safety concerns of human–computer interaction in MRTO, as the expectation of MRTO is for 'a single ATCO to perform the tasks originally designed to be executed by up to four ATCOs'. Therefore, the development of enhanced video resolution for remote air traffic services is not sufficient, it must integrate human-centred design in MRTO systems (Friedrich & Mohlenbrink, 2013; Kearney et al., 2017).

Objectives of Single European Sky ATM operational steps

The EU Single European Sky initiative (SES) was introduced to restructure European airspace and propose innovative measures for air traffic management to achieve the objectives of enhanced cost-efficiency and improved airspace and airport capacity while simultaneously improving safety performance. The main driver of the implementation of the remote tower concept is cost-efficiency and the safety criteria to be applied should ensure that the level of safety after the introduction into service of the remote tower concept is at least not reduced compared to current conventional tower operations (European Aviation Safety Agency, 2015a). Many air navigation service providers (ANSPs) have developed automated systems using video-panorama cameras for synthetic outside views (Leitner & Oehme, 2016). Research into remote tower operations increased over the last 20 years (European Aviation Safety Agency, 2014; SESAR Joint Undertaking, 2015). The emerging technology of RTO developed slowly during the initial stages but in recent times has taken a leap forward with virtual tower operations based on EUROCAE WG-100 standard 'Remote and Virtual Towers' (EUROCAE, 2016). Research on multiple remote tower operations directly contributes to the objectives of the simultaneous provision of remote air traffic services for multiple aerodromes. This research activity falls under SESAR Operational Step 3 for multiple remote tower operations based on Dublin airport simultaneously provided ATS to Cork and Shannon airports (Figure 12.1).

Operations from Dublin Airport simultaneously control Shannon and Cork airports

Due to budget reduction measures under the sequestration cuts in the Budget Control Act, FAA closed 149 ATC towers at small airports and faced major financial constraints in the building and maintenance of control towers. There is a need to develop an innovative technology which will be able to provide alternative solutions to address such financial issues in ATM provision.

Figure 12.1 IAA demonstrated the SESAR ATM project for multiple remote tower operations from Dublin Airport simultaneously control Shannon and Cork airports.

Remote tower technologies offer benefits to existing towered facilities and under testing in Leesburg and Loveland by FAA. It offers the future potential to both save money and enhance performance. The concept of remote tower operations has been addressed as a suitable solution and is being developing in many countries. Furthermore, a centralised remote tower facility could supplement the work of existing controllers at several different airports, potentially enabling several airport services to stay open longer hours and provide increased access and safety for late night shifts (Van Beek, 2017).

The development of multiple remote tower operations

Innovative systems development requires careful assessment of human information processing at the initial design stage to assure effective operators' situation awareness, safety and cost-efficiency (Kearney et al., 2016). The cognitive match between an ATCOs information processing and external information presentation is a key requirement for effective monitoring performance in multiple remote tower operations. A well-designed interface should provide sufficient cues to rapidly direct the operator's visual scanning to desired objects with the least fixation duration. Therefore, highlighting the importance of the design of controller's working position (CWP) for presenting information via out the window visualisation (OTW), radar data processing (RDP), electronic flight strips (EFS) and a communications network (VCS) to provide air traffic services, which is an emergent theme of human–computer interactions on MRTO (Hollan, Hutchins & Kirsh, 2000).

The US NextGen program (Federal Aviation Administration, 2012) also investigates the diverse aspects of tower control including human–computer interaction, situation awareness, cost of airport control tower, safety management and capacity variation. Similarly, NASA has examined remote tower operations for improving runway safety (Dorighi & Rabin, 2002). Preliminary research found that RTO can provide substantial economic benefits compared with traditional operations of local physical air traffic control towers, as NextGen proposed an innovative concept to address airport capacity problems by introducing more integrated tower information, providing weather conditions and surveillance data as well as decision support tools to ATCOs (Nene, 2008). The results of human-in-the-loop experiments demonstrated that the concept of remote tower operations exhibited encouraging improvements in communications and departure rates with no differences in perceived workload, effort, safety and situation awareness (Nickelson, Jones & Zimmerman, 2011). Learnings from multiple remote tower operations are not only beneficial in understanding the performance of innovative systems but will also assist in how these advanced systems can impact on safety, capacity and cost-efficiency (Irish Aviation Authority, 2016; Van Lancker et al., 2016).

Interface design impact to ATCOs' cognitive processes

Working with advanced automated systems, human operators not only have to monitor multiple displays with efficient distributed attention, but they must also intervene if automation fails by relocating their attention to the area requiring immediate attention (Bruder et al., 2014). The path of visual attention can reveal the cognitive process of human–computer interaction between operators and machines (Allsop & Gray, 2014; Kearney, Li & Lin, 2016). Therefore, an operator's eye movements on the displays can reveal human information processes and how the interface design impacts operator's performance (Goldberg & Kotval, 1999). For example, saccades (rapid movements between fixations) may reflect the operator's direction of an attention shift (Katoh, 1997; Kowler, 2011; Salvucci & Goldberg, 2000), the distribution of one's fixations on an interesting area is related to attention allocation (Henderson, 2003), and can facilitate mechanisms to construct situation awareness (Johnson & Proctor, 2004). In this way, an ATCOs eye movement parameters can be treated as a window into the cognitive system, allowing interface designers to capture ATCOs cognitive process (Henderson, 2003). Pupil dilation increases as a function of cognitive demand. ATCOs are constantly scanning the progress of aircraft in order to provide a safe separation and expeditious service. Observing ATCOs' eye movement patterns reveals that pupil dilation after alert activation is significantly bigger than before alert activation (Kearney, Li & Lin, 2016).

Visual attention is a precursor to initiating the cognitive process involved in attention distribution, situation awareness, and real-time decision-making (Lavine et al., 2002). Since the air traffic management system in Europe often operates to its limits, new operational concepts and technologies are constantly required to enhance capacity, safety and cost-efficiency. Future ATM systems must increase capacity and improve safety standards while at the same time deliver economic improvements (Muller, Giesa & Anders, 2001). The duration of human visual scanning is more related to processing complexity than to visual search efficiency (Robinski & Stein, 2013), as much more time is spent in fixations than in saccades. A saccade amplitude is computed from the sum of the distances between consecutive fixations with the units of pixels or visual angle degree between each successive fixation (Goldberg & Kotval, 1999). That means the more saccade amplitude deployed in visual scans on an specific display, the more attentions distributed to the instrument related to task performance (Katoh, 1997). On the other hand, saccade amplitude could be an index to observe if the interface design increases operator's cognitive process or not (Liversedge & Findlay, 2000). In addition, effective saccades play an important role in scanning the elements, which could in turn be used to identify whether the elements being scanned are relevant or irrelevant based on the saccade velocity (McColemana & Blair, 2013; Remington, Wu & Pashler, 2011). It appears that saccade velocity might be associated with how fast the operator's attention shifts and cognitive process (Rayner, 1998).

Visual parameters related to human–computer interaction

The path of fixations is associated with selective attention and accurate judgments for perceptual targets (Henderson, 2003). Saccadic eye movements are controlled by top-down visual processes, which are coordinated closely with perceptual attention (Zhao et al., 2012). This indicates that saccadic paths are intentional and meaningful, and are based on the requirements of the task and trajectory prediction to the near future (Kowler, 2011). However, Wickens et al. (2001) proposed that attention allocation is determined by the bottom-up capture of salient stimulus, inhibited by the effort required to move the focus of attention, and driven by the expectancy of seeing valuable stimulus in the traffic environment. To apply eye tracking technology in the context of monitoring tasks, it is necessary to understand the pattern of ATCOs monitoring is reflected by eye movements, such as how ATCOs guide their eye movements during monitoring phases and how eye scan patterns change during the monitoring process (Hasse & Bruder, 2015). Most eye movements are in the form of saccades and fixations which are fast eye movements followed by a period of remaining relatively stationary in the same position. The features of slower saccade velocity over the relevant areas of interests (AOIs) could be associated closely with the knowledge-based visual scan process (Hoffman & Subramaniam, 1995). AOIs were defined as ATCOs fixations gathered together closely on a specific display which suggests there is some information in the closeness of these fixations that attracts ATCOs attentions. Saccadic eye movements are proven as top-down visual processes relating to ATCOs perceptual attention (Zhao et al., 2012). This indicates that saccadic paths are intentional and meaningful, and are based on the requirements of the task in hand (Kowler, 2011).

ATCOs not only have to distribute their attention to detect potential conflicts among aircraft, both in the air and on the ground, but also have to monitor several radio frequencies to maintain situation awareness to prevent critical events. Condensed monitoring tasks and an augmented visual channel is foreseen as the most promising way to increase the capacity and safety of air traffic services (Beier & Gemperlein, 2004). Visual parameters are related to different operational content (Yu et al., 2016), which could explore the interaction between human operator and the innovative technology of remote tower (Koenig & Lachnit, 2011; Komogortsev & Karpov, 2013). Monitoring performance is the most critical aspect related to safety in multiple remote tower operations. By applying eye tracking technology, ATCOs' eye movements and attention distributions can be investigated either bottom-up (stimulus-driven) or top-down (goal-driven) cognitive processes, the nature of the monitoring task will feed back to system design and ATCOs' training in the future. The eye tracking parameters are well suited for calculating the outcome of monitoring tasks (Hasse, Grasshoff & Bruder, 2012). Based on literature reviews, there are four null hypotheses regarding ATCOs' visual parameters on performing MRTO which will be tested as follows:

1. H_0: ATCOs' fixation counts on the AOIs would have no significant interaction effect to perform MRTO tasks.
2. H_0: ATCOs' fixation duration on the AOIs would have no significant interaction effect to perform MRTO tasks.
3. H_0: ATCOs' saccade amplitude on the AOIs would have no significant interaction effect to perform MRTO tasks.
4. H_0: ATCOs' pupil dilation on the AOIs would have no significant interaction effect to perform MRTO tasks.

Method

Scenarios

The SESAR Safety Case for certification of multiple remote tower operations has distinct safety requirements for live trials. This approach outlines the activities of safety assessment to be conducted for the entire multiple remote tower systems including people, procedures, and equipment. Thirty-two scenarios were recorded using an eye tracking device to investigate human–computer interaction and use of the supporting camera systems of a single ATCO performing live exercises of multiple remote tower operations. The recordings consisted of tracking ATCOs' visual parameters across display systems while performing real and realistic multiple remote tower operations.

All scenarios contained three different air traffic control tasks: surface movement control (SMC), which is the air traffic control service provided to aircraft, vehicles and personnel on the manoeuvring area of an aerodrome excluding the runway in use at both Shannon and Cork airports; air movement control (AMC) which is the air traffic control service provided to aircraft in the vicinity of an aerodrome and to aircraft, vehicles and personnel on the runway in use in at both Shannon and Cork airports; and SMC plus AMC involving both Shannon and Cork airport. The approval of the Cranfield University Research Ethic Committee was granted (CURES/1506/2016) in advance of the research taking place. All collected data were only available to the research team and stored in accordance with the United Kingdom Ethical Code and the Data Protection Act.

Apparatus

Remote tower module

The remote tower module (RTM) accommodates SMC and AMC working positions equipped with identical display systems including (1) the out of the window (OTW) visualisation with fourteen active screens and one standby unit in the event of equipment failure. The displays match the pan (360 degree), tilt (up 90 degree, down 80 degree), zoom (30 times) camera resolution of 1920 × 1080 pixels with a refresh rate of 60Hz in a 220 degrees configuration. These screens are sufficiently flexible to permit an ATCO to arrange the airports view to be split evenly between the two airports or if the operational situation requires, to have a larger view of a particular airport; (2) electronic flight strip (EFS) system which is divided into two parts; one for Shannon airport and one for Cork airport; (3) radar data processing (RDP) which can be used as a distance indicator to touch-down and is divided into two parts one for Shannon and one for Cork airport; (4) a voice communication system (VCS) which was equipped with a Schmid Communications Panel. It is used for both GND-AIR and GND-GND communications comprising all necessary frequencies and intercom direct dial buttons. These four displays on RTM are the areas of interest (AOIs) for human–computer interaction analysis in multiple remote tower operations. These four AOIs are the main sources of information related to ATCOs task performance. To increase ATCOs situation awareness, the borders of the display systems of OTW, RDP and EFS were distinguished by colours: purple indicated Shannon airport, green indicated Cork airport. Each of the RTM is configured with the appropriate Shannon AMC/SMC and Cork AMC/SMC ATC VHF frequencies, the frequencies of Shannon on the top and the frequencies of Cork on the bottom. They are also colour coded to provide additional situation awareness to ATCOs (green for Cork and purple for Shannon) (Figure 12.2).

Eye tracking device

A wearable and light-weight eye-tracking device 'Pupil Pro', which consists of a headset including two cameras for eye movement data collection and analysis (Figure 12.2). The headset hosts two cameras, one facing the right eye of the participant (eye-camera) which has a resolution of 800 × 600 pixels and a frame rate of 60 Hz, the other camera capturing the field of vision (world-camera) which has a resolution of 1920 × 1080 pixels with a frame rate of 60 Hz. These two cameras can be synchronised after calibration. The 'world-camera' is mounted on the right top of the headset showing the orientation and view of the ATCOs view of the area of interests; the eye-camera is mounted offset right and low and is adjustable to suit different wearer's facial layout and track their pupil parameters accordingly (Kassner, Patera & Bulling, 2014).

Research design

Thirty-two live exercises providing ATS for both Shannon and Cork airports from the remote tower control centre located at Dublin airport were analysed by eye tracker. The participants were all qualified ATCOs, holding operational licences for both Shannon and Cork airports. The assessment of human–computer interactions is based on ATCOs visual attention among AOIs while performing SMC and AMC tasks. Therefore, these 32 scenarios comprised three types of operation as between-subject variables, (1) SMC on both Shannon and Cork airports simultaneous; (2) AMC on both Shannon and Cork airports simultaneous; (3) AMC plus SMC on both Shannon and Cork airports simultaneous. The definition of 'simultaneous' is where the spacing between two aircraft arriving or departing at Shannon and Cork airports is less than that required if the two aircraft were landing or departing at the same airport. It means that the activities of AMC, SMC and AMC plus SMC on both Shannon airport and Cork airport are simultaneously being monitored and controlled by a single ATCO.

The eye tracking device collected and analysed ATCOs' visual parameters including fixation count, fixation duration, saccade amplitude and pupil dilation across the different interface displays (OTW, EFS, RDP and VCS) on the RTM. The definition of fixation in this research is when the ATCO constantly maintains a gaze in a direction over 100 milliseconds. Due to different time frames for completing each scenario, all of 32 scenarios of eye tracker data are analysed for chunks of 60 seconds. The time frames of recorded eye movements contain the most critical visual parameters which reflect ATCOs cognitive processes and visual attention shifting among OTW, EFS, RDP and VCS.

A period of 60 seconds for analysing ATCOs visual attention was supported by the consensus of experienced controllers. The live trial exercises related to remote control of over 500 live dynamic aircraft activities between Shannon and Cork airports. A project team was established to ensure that all aspects of relevant aviation activity were represented in the project. The project team consisted of a project manager, an ATM specialist, a human factors expert and two appropriately rated controllers who were present for the live trials. To assure the safety of operations during the provision of service from

Figure 12.2 ATCOs using Pupil Pro Eye Tracker interacted with RTM comprised OTW, RDP, EFS and VCS (left-hand side are Shannon airport, right-hand side are Cork airport) for multiple remote tower operations.

the remote tower centre, both local towers were fully manned and operating in so-called shadow mode, capable of intervening in operations as required.

Results

The core concept of MRTO is to improve cost-efficiency and capacity of air traffic service, and maintain or improve the level of safety. The regulator's concerns on safety and human performance regarding ATCOs attention distributions and operational performance had to be investigation before implementation. The complexity of MRTO involves organising the traffic flow, providing information, and maintaining separation rules to both aircraft and ground vehicles between Shannon and Cork airports for SMC and AMC by interacting with OTW, EFS, RDP and VCS on monitoring tasks. The safety back-up of shadow operations never needed to intervene in the work of the single ATCO during the live demonstrations of multiple remote tower operations. When dealing with safety critical work contexts, the most suitable approach for cognitive processes assessment relies on unobtrusive techniques (Marchitto et al., 2016). This is the reason of applying eye tracking technology in this research. The results demonstrated that there are some substantial differences on ATCOs' visual parameters on different AOIs while performing AMS and SMC by remote tower module.

Sample characteristics

Thirty-two scenarios of multiple remote tower operations included 11 SMC, 11 AMC and 10 SMC plus AMC were recorded by using an eye tracking device. ATCOs' eye movements across the displays on CWP including RDP, EFS, VCS and OTW were analysed while performing SMC, AMC and SMC plus AMC at both Shannon and Cork airports. A series of mixed ANOVAs with AOIs (four levels: RDP, EFS, VCS, and OTW) as within-subject

Table 12.1 Descriptive statistics of mean and standard deviation of four eye movement parameters among three tasks and four AOIs.

Tasks	*Visual parameters*	*N*	*RDP*	*EFS*	*VCS*	*OTW*
SMC	FC	11	19.18(11.7)	17.09(14.08)	3.36(3.91)	64.91(18.31)
	FD	11	0.239(0.079)	0.247(0.105)	0.200(0.202)	0.307(0.084)
	SA	11	70.35(26.58)	66.57(42.09)	49.60(46.34)	113.45(28.73)
	PS	7	76.22(3.41)	69.81(9.12)	81.01(6.04)	75.99(3.74)
AMC	FC	11	32.27(10.49)	43.36(25.2)	12.00(14.33)	38.82(14.85)
	FD	11	0.263(0.041)	0.262(0.060)	0.156(0.137)	0.258(0.038)
	SA	11	43.07(18.96)	43.94(20.53)	15.85(19.15)	137.57(28.92)
	PS	7	84.91(4.65)	83.70(10.41)	94.64(22.09)	85.86(10.83)
SMC+AMC	FC	10	23.50(16.64)	56.80(39.28)	2.20(3.82)	26.40(19.95)
	FD	10	0.339(0.182)	0.238(0.104)	0.154(0.266)	0.303(0.104)
	SA	10	52.60(25.17)	36.00(34.01)	20.81(41.54)	141.00(38.43)
	PS	3	79.54(9.24)	77.82(10.58)	87.42(21.80)	77.84(11.28)

factor and operational tasks (three levels: SMC, AMC, and SMC+AMC) as between-subject factor were performed to assess single ATCOs eye movement patterns on human–computer interactions in multiple remote tower operations. The response variables are fixation count (FC), fixation duration (FD), saccade amplitude (SA), and pupil size (PS). The assumption of sphericity was verified by using Mauchly's test, and the Bonferroni was applied to perform pairwise comparisons after a significant overall test. Effect size of factors and interactions were quantified by partial eta square (η_p^2). The descriptive statistics of sample characteristics were shown in Table 12.1.

Fixation counts (FC) among interfaces on CWP for tasks performance

There is a significant interaction between different interfaces (AOIs) and tasks, F (3.20, 46.40) = 7.496, $p < 0.001$, $\eta_p^2 = 0.341$. A significant main effect of AOIs, F (1.60, 46.401) = 23.205, $p < 0.001$, $\eta_p^2 = 0.445$ was found, but main effect of tasks is insignificant, F (2, 29) = 2.426, $p = 0.106$, $\eta_p^2 = 0.143$. Post-hoc comparison on AOI revealed that fixation counts on the communication system (FC_{VCS}) are less significant than on the radar data (FC_{RDP}), the strips (FC_{EFS}), and the outside view (FC_{OTW}), $p < 0.001$. Moreover, FC_{RDP} is smaller than FC_{EFS} ($p < 0.05$) and FC_{OTW} ($p < 0.001$). Post-hoc comparison revealed FC_{SMC} is smaller than FC_{AMC} ($p < 0.05$) (Figure 12.3). The results demonstrated that ATCOs exhibited the highest fixations numbers (64.9) at OTW and the lowest fixation numbers at VCS on SMC; however, EFS has the highest fixation numbers in both AMC (43.4) and AMC plus SMC (56.8). The SMC operation results in the highest usage of the outside camera view as indicated by the high fixations counts. The AMC operation scores high on flight

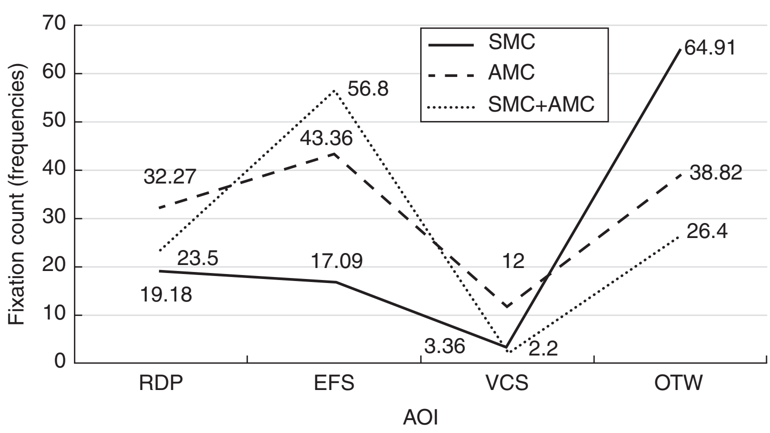

Figure 12.3 The differences of fixation count among AOIs and distinctive patterns of three tasks.

strips and the outside camera (Table 12.1 and Figure 12.3). Combining the two increases the usage of the strips to the highest levels, while the ATCO interaction with the camera system is decreased to the lowest levels. The controller is adapting task strategies to the situation and enhances their preparation by using flight strips data intensively while performing AMS plus SMC. Therefore, the first null hypothesis 'H_0: ATCOs' fixation counts on the AOIs would have no significant interaction effect to perform MRTO tasks' is rejected.

Fixation duration (FD) among interfaces on CWP for tasks performance

There is no significant interaction between different interfaces (AOIs) and tasks, F (3.702, 53.680) = 0.705, $p > 0.05$, $\eta_p^2 = 0.046$. A significant main effect of AOIs was found, F (1.851, 53.680) = 5.070, $p < 0.05$, $\eta_p^2 = 0.149$, but no significant main effect on tasks, F (2, 29) = 0.406, $p = 0.670$, $\eta_p^2 = 0.027$. Post-hoc comparison on AOIs revealed FDVCS is smaller than FDRDP ($p < 0.05$) and FDOTW ($p < 0.01$) (Figure 12.4). Fixation duration has a significant main effect on AOIs and revealed that ATCOs distributed the longest fixation duration on the RDP on both AMC (263 ms) and SMC plus AMC (339 ms). However, the longest fixation duration of SMC is on OTW (307 ms). Again, the shortest fixation duration is on VCS across three tasks (Table 12.1 and Figure 12.4). The item of interest is held approximately stable on the retina during fixations with the majority between 154 ms and 339 ms depending on the complexity of information being processed and current cognitive load of ATCOs (Table 12.1). Task and strategy related trends can be observed. Fixation duration is the lowest on the communication device. Combining SMC and AMC (high task load situation) results in longer fixation duration on radar data and similar levels for the using the cameras as during SMC. The effects are

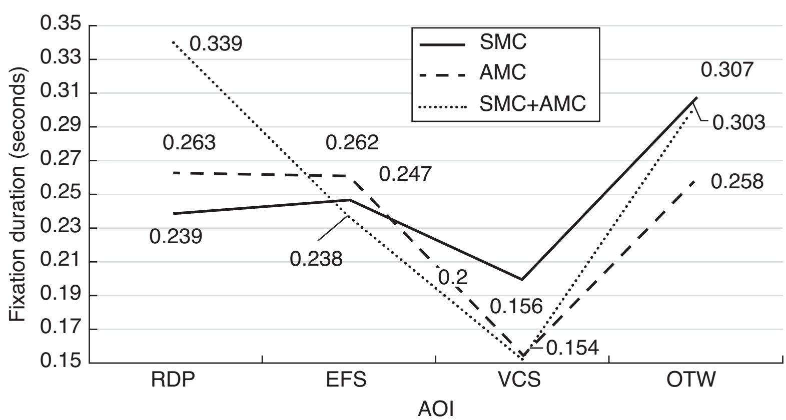

Figure 12.4 The differences of fixation duration among AOIs and distinctive patterns of three tasks.

relatively small as fixations duration are bound by a minimum and in fact has no significant interaction between AOIs and tasks. Therefore, the second null hypothesis 'H$_0$: ATCOs' fixation duration on the AOIs would have no significant interaction effect to perform MRTO tasks' is accepted.

Saccade amplitude (SA) among interfaces on CWP for tasks performance

There is a significant interaction between different interfaces (AOIs) and tasks, F (6, 87) = 2.437, $p < 0.05$ $\eta_p^2 = 0.144$. A significant main effect of AOIs, F (3, 87) = 57.752, $p < 0.001$, $\eta_p^2 = .666$ was found. A significant effect of tasks, F (2, 29) = 3.578, $p < 0.05$, $\eta_p^2 = 0.198$ was found as well. Post-hoc comparison on scenarios revealed participants' SASMC is higher than SAAMC ($p < 0.05$). Post-hoc comparison on AOIs revealed SAVCS is smaller than SARDP ($p < 0.01$), SAEFS ($p < 0.05$), and SAOTW ($p < 0.001$). Moreover, SARDP and SAEFS are smaller than SAOTW ($p < 0.001$) (Figure 12.5). The VCS is the smallest saccade amplitude consistent with SMC (49.6 degree), AMC (15.85 degree) and SMC plus AMC (20.81 degree) (Table 12.1) compared with EFS, OTW and RDP. The VCS Is the smallest saccade amplitude consistent with SMC (49.6 degree), AMC (15.85 degree) and SMC plus AMC (20.81 degree) compared with EFS, OTW and RDP. However, the OTW is the highest saccade amplitude across SMC (113.45 degree), AMC (137.57 degree) and SMC plus AMC (141 degree) (Table 12.1 and Figure 12.5). It revealed that OTW comprised of 14 visual reproduction display screens is a good human-centred design to facilitate ATCOs searching required information to perform MRTO. Therefore, the third null hypothesis is 'H$_0$: ATCOs' saccade amplitude on the AOIs would have no significant interaction effect to perform MRTO task' is rejected.

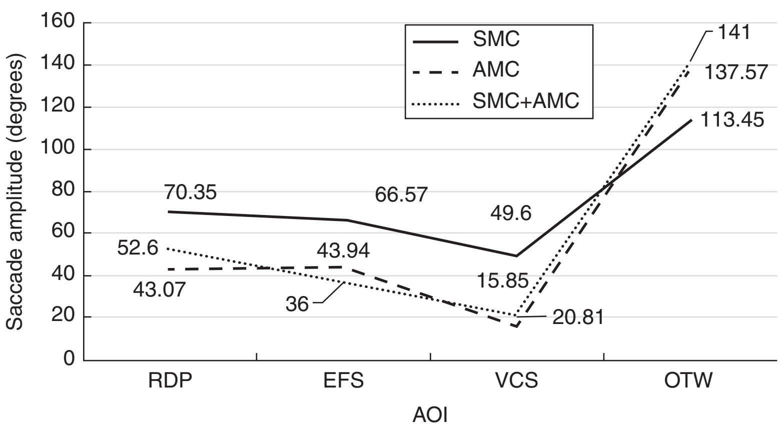

Figure 12.5 The differences of saccade amplitude among AOIs and distinctive patterns of three tasks.

Pupil size (PS) among interfaces on CWP for tasks performance

Results indicated the interaction between different interfaces (AOIs) and tasks is not significant, F (3.05, 21.35) = 0.307, $p > 0.05$, $\eta_p^2 = 0.042$. A significant main effect of AOIs, F (1.53, 21.35) = 5.790, $p < 0.001$, $\eta_p^2 = 0.293$ was found, but no significant main effect on tasks, F (2, 14) = 2.765, $p = 0.097$, $\eta_p^2 = 0.283$. Post-hoc comparison on AOIs revealed participants' PSVCS is higher than PSEFS ($p < 0.01$) and PSOTW ($p < 0.01$). The results revealed that ATCOs pupil dilation has significant main effect on AOI (Table 12.1 and Figure 12.6). The VCS is the highest pupil dilation consistent with AMC (94.64 pixels), SMC plus AMC (87.42 pixels) and SMC (81.01 pixels) compared with EFS, OTW and RDP. On the other hand, the EFS is the lowest pupil dilation across AMC (83.7 pixels), SMC plus AMC (77.82 pixels) and SMC (69.81 pixels). Therefore, the fourth null hypothesis is 'H_0: ATCOs' pupil dilation on the AOIs would have no significant interaction effect to perform MRTO tasks' is accepted.

Discussion

These live demonstrations of multiple remote tower operations represented all aspects of AMC and SMC including vehicle manoeuvres and aircraft arriving and departing from Shannon and Cork airports. Previous visual science research found that increased challenge levels in tasks could increase the frequency of long fixations (Van Orden et al., 2001). The result of this research has demonstrated that a single ATCO by the assistance of advanced technology is able to perform multiple remote tower tasks without compromised operational safety. Furthermore, ATCOs' eye movement parameters

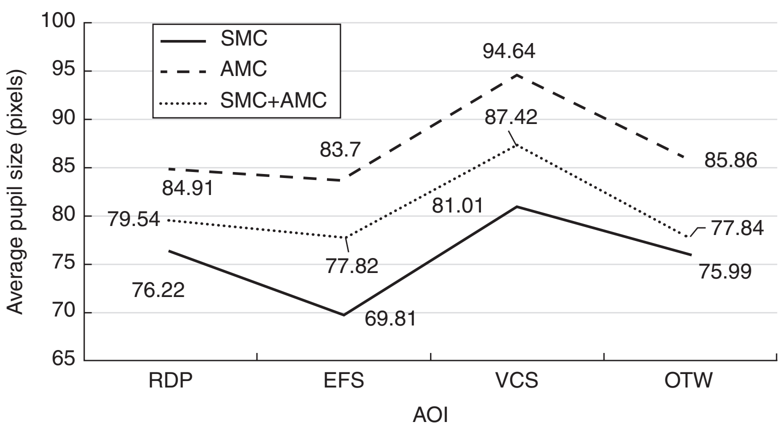

Figure 12.6 The differences of pupil size among AOIs and distinctive patterns of three tasks.

(fixation counts, fixation durations, saccade amplitude and pupil dilation) can be measured in live operations and had significant interactions effects between performing tasks (AMC, SMC or AMC plus SMC) and interfaces (EFS, OTW, RDP and VCS) on CWP while conducting monitoring tasks for multiple remote tower operations. This research reflected that design of innovative air traffic management systems involving human–computer interactions requires an understanding of ATCOs cognitive processes and the operational deployment context in order that safety and capacity can be enhanced (Langan-Fox, Canty & Sankey, 2009). The results of this research can provide a basis for future training and design for multiple remote tower operations.

ATCOs visual scan patterns related to tasks demanding

The design of visual presentation on interface displays is the substantial factor to be considered from human–computer interactions and safety perspective for multiple remote tower operations. ATCOs tend to spend more time looking at interesting objects in the interface displays, as their fixations are drifting over the critical visual stimuli on the screens for tasks performance. The length of fixation duration can reflect difficulty in extracting information, and the number of fixations indicates the importance of the areas of interest (Kotval & Goldberg, 1998). RTM provides detailed information which enables ATCOs to maintain continuous observation of all flight operations by using visual reproduction display screens (European Aviation Safety Agency, 2014, 2015b). It is an interesting finding and demonstrates that ATCOs distributed their fixations and shifted their attention in order to maintain situation awareness between two different airports based on the priority of dynamic tasks (Figure 12.7). Given that multiple remote tower is an innovative technology in the field of air traffic management, corresponding interface design should be evaluated so that ATCOs' workload could be minimised (Goldberg & Kotval, 1999). The analysis of eye movement data found that ATCOs' scanning patterns were influenced by the performing tasks (SMC, AMC or SMC plus AMC). Multiple remote tower operations at two airports is achieved through the support of advanced technology, however an increasing visual monitoring tasks might induce perceived workload as a potential cost based on visual parameters. This is the reason both EFS and OTW have high percentages of fixation counts in these three different tasks, 79.2% at SMC, 65.3% at AMC and 77.4% at SMC plus AMC. SMC is focused on the ground movements of vehicles and aircraft, ATCOs relied heavily upon OTW by using PTZ to track the positions of aircraft and vehicles, therefore, the highest frequency of fixation (64.9) is on the SMC for both airports. VSC showed the lowest fixation counts across three tasks, as there is not much operational requirements to select the frequency of voice communication system on MRTO.

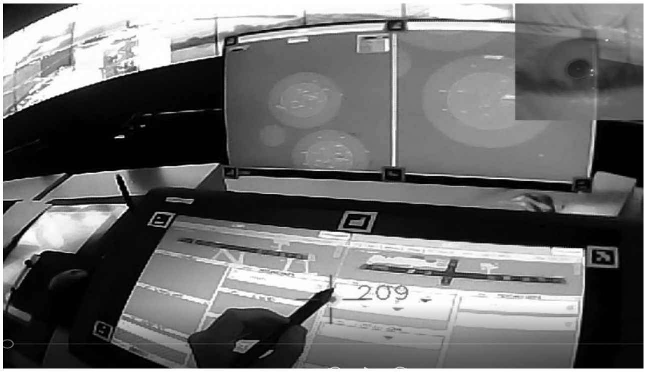

Figure 12.7 ATCO shifting attention from Shannon to Cork airport to pay attention on the runway activities on the EFS (fixation shown as red-cross recorded by eye tracker).

Visual behaviours reflecting complexity of multiple tasks

Fixation numbers and fixation duration are closely linked to each other and related to cognitive process and human performance (Yu et al., 2016). Short fixation durations primarily indicate operators encoding an element into working memory, and a longer fixation is more likely to signal deeper processing (Ballard et al., 1997). The results demonstrated that visual attention relating to human performance when performing multiple remote tower operations did not exceed the 1,000 millisecond of end-to-end delay, and fitted the requirements of safety assessment (European Aviation Safety Agency, 2015a). To ensure the safety of operations while a single ATCO performing multiple remote tower operations at two different airports and while fulfilling the roles of SMC and AMC at both airports, ATCOs found that it would be appropriate to add additional time and lateral spacing between aircraft cleared for take-off so that ATCOs can monitor the roll and initial rotation of the first aircraft before clearing and monitoring the second aircraft for take-off or landing. This finding is important for subsequent operational procedure design.

Eye movements are influenced by the interface design, as information presented by RDP becomes conceptually more difficult, fixation duration increases, and the frequency of regressions increases to process the distance of aircraft for safe separation. Regressions will allow ATCO revisiting previously fixated stimulus such as the texts of aircraft call-sign, the figures of flight levels, or images of symbols on the interface displays, and physically returning the eyes to the location of stimulus could cue the ATCOs memory for that stimulus, effectively aiding the comprehension process (Booth & Weger, 2013). There is a close connection between fixation duration and amount of information processing (Rayner, 1998; Singh & Singh, 2012). When an

AMC is managing two simultaneous arrivals into two different airports, ideally the first landing aircraft should be stable on the runway before the second arrival aircraft is 1NM from touchdown at the other aerodrome. However, OTW is the longest fixation duration for SMC due to the nature of complexity of aircraft and vehicle movements in two airports simultaneously. A Single ATCO performing simultaneous AMC and SMC functions is the biggest challenge within MRTO, as RDP and OTW show long fixation durations on SMC plus AMC tasks (Figure 12.4). It requires further investigation to develop effective human-centred design to mitigate the potential risks on multiple monitoring and controlling tasks.

Human-centred design of CWP sufficiently support multi-tasks performance

Visual activity is the objective method for assessing an ATCOs cognitive process related to real-time decision-making (Ayaz et al., 2010). The concurrence of excessive fixations, long fixation duration and less saccade duration is the precursor of tunnelled attention (Johnson & Proctor, 2004). ATCOs visual behaviours provide an opportunity to investigate the relationship between eye movement patterns and information processing. Eye scan pattern is one of the most powerful methods for assessing human beings' cognitive processes in human–computer interaction. For example, saccade is defined as fast eye movement between fixations and generally it declines as a function of increased mental workload (Ahlstrom & Friedman-Berg, 2006). Saccade plays an important role in indicating workload imposed by different tasks among EFS, OTW, RDP and VCS. The results reveal that saccade amplitude has significant interaction between AOIs and tasks (Figure 12.5). ATCOs performing MRTO not only have to distribute their attention to detect potential conflicts among aircraft in the air and on the ground at both Shannon and Cork airports, but also have to resolve unexpected events under time pressure through radio telephony communications with pilots and others.

The VCS is the smallest saccade amplitude among EFS, OTW and RDP consistent with three different tasks. The VCS display consists of a screen with buttons and small digital numbers of radio frequencies used by all moving aircraft, vehicles and other parties on both Shannon airport (on the top of VCS) and Cork airports (on the bottom of CVS). ATCOs must pay attention to select the correct frequency, should an ATCO select an incorrect frequency they may miss transmissions from aircraft/vehicles and may not be able to transmit crucial information to aircraft/vehicles. It demonstrated that ATCOs have more mental workload while interacting with VCS for radio telephony communications compared with EFS, OTW and RDP. On the other hand, the OTW is the highest saccade amplitude across tasks. It can be explained that OTW is a good human-centred design to facilitate ATCOs searching required information to perform MRTO by selected ratio of screens to enlarge the images by PTZ. There are lots of human–computer

Figure 12.8 ATCO using PTZ camera to enlarge the visual perception to enhance situation awareness during B-737 landing.

interactions related to the usages of PTZ, as the OTW screens are sufficiently flexible to permit an ATCO to have a larger view of a particular dynamic target to enhance situation awareness (Figure 12.8).

Integrated visual characteristics with interface design reduced cognitive loads

Eye tracking technology offers profound insights into human–computer interaction and the cognitive processes of ATCOs monitoring tasks. The measurement of pupil dilation has been used to investigate the status of cognitive processes and mental workload, as pupil diameter increases as an indication of cognitive demand (Ahlstrom & Friedman-Berg, 2006). The VCS is the highest pupil dilation compared with EFS, OTW and RDP consistent with AMC, SMC plus AMC and SMC. It is the evidence that VCS has induced significant cognitive loads to ATCO on monitoring tasks and selecting frequencies for communications, as ATCOs pupil dilation is the highest and the saccade amplitude is the smallest. This finding supports Ahlstrom and Friedman-Berg's (2006) proposal that 'saccade decreasing mental workload increasing, and pupil dilation increasing cognitive load also increasing'. ATCOs must pay attention on selecting the correct frequency to provide effective ATS. Based on the eye tracking data analysis, there are two scenarios (6.25%) where an ATCO selected an incorrect frequency on the VCS then realised the errors and corrected them. This indicates a need to investigate how to deal with VCS design to enhance the safety of MRTO. On the other hand, the EFS is the lowest pupil dilation across AMC, SMC+AMC and SMC (Figure 12.6). This finding implies that ATCOs had the lowest cognitive load while interacting with EFS compared with OTW, RDP and VCS. The different colour borders and runway layout on EFS are very good human-centred design, as it delineates different airports reducing ATCOs' cognitive load and facilitating task performance by clearly defined areas of aircraft information including arrivals, pending, control zone, runway, taxiway, pushed and cleared. The dotted-red border on the runway indicates the runway is occupied by a vehicle or aircraft, is used to enhance the ATCOs' situational awareness of activity on the runway and aid in preventing runway incursions. Furthermore, ATCOs are allowed to interact with EFS making notes for intensifying working memory and serve as reminders for secondary priority of communication with pilots/ vehicle drivers on both Shannon and Cork airports for the deferred responses due to performing multiple tasks (Figure 12.9).

Limitation of visual representation on OTW

This research may demonstrate that aerodrome control service could be provided by the RTC for Cork and Shannon in multiple airport modes by one controller 'in sequence' during periods of low aircraft movements. The 'simultaneous' aircraft operation was possible during these periods but spacing would be required when the arrival/departure times at the two airports coincided. The provision of 'in sequence' of MRTO demonstrated no issues for the ATCOs monitoring tasks and providing ATS for both Cork and Shannon airports by using OTW, PTZ and OTW. Although the benefit of remote tower provision of ATC services for multiple remote towers was predicted increasing efficiency, it might have trade-off effects by increasing ATCOs perceived workload (Kearney et al., 2019). The observation of live exercise revealed that two 'in sequence' arrival flights into these two airports were manageable but it was recorded that there was potential for delay at one airport due to focusing on the activities at the other airport (exercise 41:

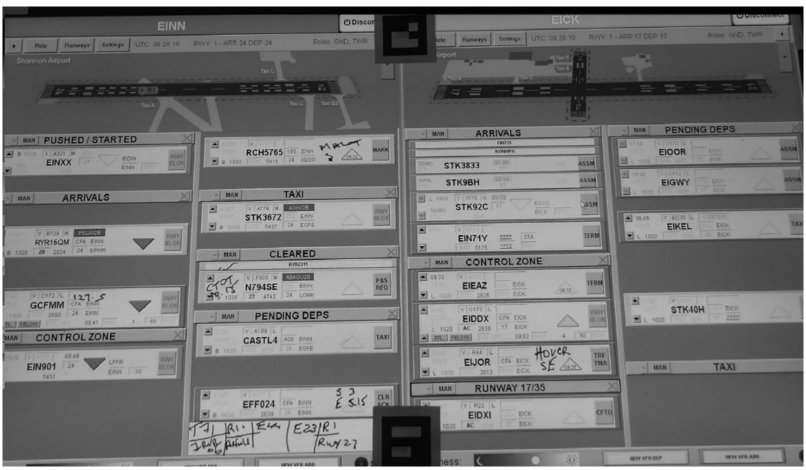

Figure 12.9 The use of colour on the border of EFS increases ATCOs' situation awareness. Although the colours are not visible in this monochrome photograph, the heading on the top left (indicating Shannon airport) is in purple on the screen, while a green colour on the top right indicates Cork airport.

Figure 12.10 The visual representation on OTW for runway on Shannon distorted from straight line to curve; on the other side, the PTZ overlapped with OTW on the Cork airport provided better visual clues for air movement control.

control of SNN & CRK AMC and SMC combined in RTM-A2) particularly if that activities are unexpected. ATCOs have to learn managing his/her workload by the supports of innovative technology, such as PTZ, EFS and OTW. However, there is a limitation on visual representation of the innovative technology. The visual representation on OTW for runway on Shannon distorted from straight line to curve which related to the PTZ camera function provides the capacity up to 30 times optical zoom, 90 degrees up and 80 degrees down with 360 degrees panning displayed in a 220 degrees of OTW screens. On the other side, the PTZ overlapped with OTW on the Cork airport provided better visual clues for air movement control (Figure 12.10). Application of innovative technologies always have positive and negative impacts to human operators' task performances.

Operating innovated technology of MRTO is not only an issue of technical task performances but also of real-time decision-making involving attention distributions and human–computer interactions (Li et al., 2018). While there were a number of comments during the debrief of these exercises in relation to increasing workload impacted task performances. Based on the observation to live exercises, there were a number of occasions where there was a delayed response (< 60 seconds) to a vehicle and occasions where an aircraft was slightly delayed because the controller was dealing with unexpected traffic at the other aerodrome. For future application, ATCOs workload capacity related to task performance must be monitored to ensure that unplanned pop up aircraft such as Search and Rescue Helicopters can be accommodated without delay. ATCOs have to learn to prioritise different tasks which work had to be done and which work could wait. To deal with ATCOs workload and increasing capacity, the additional technical functions on CWP will have significant improvement, such as automatic PTZ tracking, fixed PTZ cameras on critical areas, enhancing radar tracking, and the usability of mouse cursor on the RTM.

Conclusion and recommendation

ATCOs worked with innovative technology and display systems with outside views provided by PTZ camera while performing multiple remote tower operations. This research indicates that increased pupil dilation and decreased saccade amplitude in a visual search task are related to strategic adaption to the demands of the tasks for a single ATCO to perform MRTO. The distribution of visual attention among display systems is the key human–computer interaction issue in single ATCOs performing multiple monitoring tasks. Information presentation on the remote tower module and information interpretation by the ATCO are crucial elements in assuring aviation safety and optimal human performance. Current OTW and EFS on RTM demonstrate that good practice of human-centred design on information presentation can simplify ATCOs' cognitive processes by reducing the volume of visual searching thereby alleviating cognitive load. Furthermore, innovative remote tower technology will facilitate staffing and equipment cost-efficiencies including communications, navigation, surveillance and flight data processing systems. There is potential to save €2.21 million Euro per annum per installation. ATCOs visual attention and monitoring performance can be affected by how information is presented, the complexity of the information presented, and the operating environment in the remote tower centre. To achieve resource-efficient and sustainable air navigation services, there is a growing demand to improve the design of human–computer interactions in multiple remote tower technology deployment. These must align with high technology-readiness level, operators' practices, industrial developments, and the certification processes of regulators.

Discussion questions

1 How can the objectives of Single European Sky be achieved?
2 What are the strengths and weaknesses of multiple remote tower operations?
3 How can ATCOs' monitoring performance be evaluated?
4 What are the best practices for human-centred design on multiple remote tower modules?

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