Future Directions for Contingency Planning in European Air Traffic Management:

A Response to the April 2010 Eyjafjallajokull Volcano Eruption

Prepared by

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Overview: This report provides a survey of the events following the Eyjafjallajokull eruption in April 2010. National Supervisory Authorities (NSAs) and Air Navigation Service Providers (ANSPs) were faced with exceptional circumstances that justified the precautionary approach that guided their decision making processes following the initial eruption. However, a lack of coordinated scientific input into decision making processes at a European level arguably led to inconsistency, confusion and lack of communication with the public and with politicians after the first closures. This paper looks at guidance in a European perspective to study mechanisms that will form and maintain the core scientific knowledge needed to support European crisis management during future contingencies.

1. Introduction

This document focuses on the Eyjafjallajokull volcano eruption during April 2010 and its impact upon Air Traffic Services across European airspace. The intention is to encourage and direct future research into contingency planning both within the SESAR programme and more widely across European aviation[1]. The management of the Eyjafjallajokull event is considered from an academic perspective. Besides, an operational context is provided by individuals who were involved in contingency planning for EUROCONTROL and a number of ECAC states both before and during the incident.

The following pages draw upon literature that relates to four different aspects of this contingency:

1. insights from academia on the management of risks and crisis[2]. This is addressed in the following Section on 'The role of Scientific Input to Risk and Uncertainty in ATM Contingencies';

[1] Can M. Alpaslan, Sandy E. Green and Ian I. Mitroff (2009), "Corporate Governance in the Context Of Crises: Towards a Stakeholder Theory of Crisis Management", Journal of Contingencies and Crisis Management, vol. 17, Number 1, March 2009, pp. 38-49.

[2] For a general view on the perspective see in particular Olivier Godard, Claude Henry, Patrick Lagadec, Erwann Michel-Kerjan (2002) Traité des nouveaux risques: precaution, crise, assurance, Editions Gallimard, Paris.

2. the state of science on aviation hazards from volcanoes[3]. This is addressed in the subsequent section on 'The state of Scientific Research into the impact of Volcanic Eruptions on ATM';
3. the review of the events and crisis[4]. See 'Review of the Crisis';
4. decision-making processes and regulatory institutions[5]. This is addressed in the subsequent section on 'Regulation and Governance'
5. Report on the actions undertaken in the context of the impact of the volcanic ash cloud crisis on the air transport industry[6].

These orthogonal issues are then integrated into more general proposals for future research that might leave European Air Traffic Management better prepared to respond to future contingencies including, but not limited to, volcanic eruptions.

Contingency events and the Need for Scientific Input: Volcanic eruptions are part of a wider class of natural risks, including earthquakes, pandemics, and regional fires etc, the effects of which have to be managed collectively. These, in turn, form a sub-set of adverse events that also include man-made catastrophes, such as terrorist attacks, pollution etc. Natural and man-made risks are collectively known as contingency events. They are characterised by relatively low expected probabilities but extremely high potential consequences.

Increasingly, the public expect commercial and regulatory agencies to adopt sound a sound safety policy to potential contingencies. These expectations extend not just from the time before any incident occurs but also under the stress and time pressure that characterises decision making during a contingency. To meet these expectations, it is important to consider that operational decision making is informed by accurate scientific information on a wide range of issues. Although the management of crises are inevitably and legitimately is shaped by ad hoc contingency or political pressure, the line of inquiry stresses on the scope for scientific contribution.

The assessment and management of risk depends upon a clear understanding of the contingency under consideration. Without significant prior consultation, Air Navigation Service Providers

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[3] See in particular, Andrew Tupper, Simon Carn, Jason Davey, Yasuhiro Kamada, Rodney Potts, Fred Prata and Masami Tokuno (2004) "An evaluation of volcanic cloud detection techniques during recent significant eruptions in the Western 'Ring of fire'", accepted in Remote Sensing of Environment, 18 February 2004, p1-28, and the special issue of Natural Hazards of November 2009, on "Aviation Hazards from Volcanoes", A.J. Prata and A. Tupper (Guest Editors) (Springer, Netherlands, Vol. 51, Number 2, pp. 239-401.

[4] Eurocontrol/CND/STATFOR "Ash Cloud of April and May 2010: Inpact on Air Traffic" Doc394, V1.0, 28 June 2010 and Intelligent Risk Systems "Special Report: a Review of the Impact of the Volcanic Ash Cloud Crisis in Europe in April 2010", May 2010.

[5] See the academic journal Regulation and Governance, http://www.wiley.com/bw/journal.asp?ref=1748-5983, on management-based and performance based regulation, Coglianese Cary and Lazer David (2003), "Management-Based Regulation: Prescribing Private Management to Achieve Public Goals", *Law & Society Review*, Vol. 37, No. 4, pp. 691-730.; Coglianese C., Nash J, Olmstead T (2003) "Performance-Based Regulation: Prospects and Limitations in Health, Safety, and Environmental Regulation" *Administrative Law Review,* N° 55, pp.705–724, Mini Symposium on the Volcanic Ash Crisis (2010), *European Journal of Risk Regulation,* Vol.1, No. 2, pp.101-113 and C.W. Johnson, G. Amar, T. Licu and R. Lawrence, High-Level Architectures for Contingency Planning in Air Traffic Management. In R.J. Simmons, D.J. Mohan and M. Mullane (eds), Proceedings of the 26th International Conference on Systems Safety, Vancouver, Canada 2008, International Systems Safety Society, Unionville, VA, USA, ISBN 0-9721385-8-7, 2008.

[6] http://ec.europa.eu/transport/doc/2010_06_30_volcano_crisis_report.pdf

(ANSPs), regulators and government agencies are forced to gather what scientific advice they may find in response to an adverse event as it develops. This undermines decision making processes because prior scientific information is rarely available in an appropriate form. It may be based on limited laboratory studies or environmental observations, which hardly apply to a particular contingency as it develops.

At times of crisis, there is a need to scrutinise the chain of decisions, the situation ex ante, the dynamic of the crisis, the ex-post situation to comprehend to what extent it might have diverged from considering properly principles and the established knowledge. This creates further problems because contingencies are by definition rare and exceptional circumstances. It may be difficult to avoid the hindsight bias that identifies 'optimal' responses only well after any danger has past. Subsequent reviews may also be biased by psychological aspects of regret for any loss, even if it would have been unreasonable to expect anyone to avoid a similar adverse outcome in any similar situation.

Finally, remedies to improve the management of similar possible future events have to be considered. Previous research in decision theory has identified ways of going beyond hindsight bias and regret and these techniques offer some hope of identifying appropriate structures for regulatory intervention in contingency planning.

2. The Role of Scientific Input to Risk and Uncertainty in Air Traffic Management Contingencies

A number of general concepts might support a scientific analytical framework for contingency planning. Such concepts could define a general mode of reasoning that might be applied to a number of different natural and man-made hazards that are characterised by relatively low probabilities and extremely high potential consequences.

A starting point for such a framework is that individuals continually take risks in their everyday lives. Risks themselves are not to be viewed as negative. They simply involve ex-ante assessments of gains and losses about particular actions, set of actions, alternatives. For instance, informal risk assessments are made every time we select an airline schedule. We assess the probability of failing to make a tight connection and missing our plane. In such circumstances, contingency plans may be made by booking an alternate flight or using a carrier that supports alternate transfers to the destination. This approach can be characterised as an application of 'expert judgement' and results in a 'balance of risks' decision.

From this it follows that a distinction is to be introduced between situations where individuals assess possible outcomes according to 'more or less' accurate distributions of event probabilities and situations where the occurrence of outcomes cannot be objectively evaluated. By analogy, we assess the risks associated with airline connections because we have experienced previous delays on a particular route and we apply rules to what we know. However, it becomes more difficult to assess the likelihood of very rare outcomes for which there may have not been any previous direct experience within our lifetime and this is where expert judgement becomes the only viable approach. For instance, it is complex to make accurate assessments of probability distributions for pandemic flu.

For some contingency events, whose outcomes are reversible or whose consequences may be mitigated by different forms of insurance, measures to reduce the impact on various stakeholders may be introduced. In such situations, we may be less concerned by the risks because prior investments soften the impact of even relatively rare risks. Many ECAC states have adopted this approach, following the requirement in COMMISSION REGULATION (EC) No 2096/2005 of 20 December 2005; *"At the latest one year after certification, an air navigation service provider shall have in place contingency plans for all the services it provides in the case of events which result in significant degradation or interruption of its services"*. Some have built fall back systems that provide support in the event of earthquakes or terrorist attacks on their primary facility. At least one has used an actuarial approach by paying for financial insurance against the inability to provide ATM services during prolonged contingency. However, the events of April 2010 illustrate the limitations of these piecemeal strategies across European ATM; they also illustrate the need to recruit more direct scientific advice to inform policy and planning in this area.

Previous research has identified a number of decision making strategies and these are illustrated by ANSP responses to the EC Common Requirements, cited above. Some individuals may rationally choose to reject the mitigation strategies mentioned above. These 'risky' positions are usually justified by arguments such as *"it is impossible to adequately inform investments when we cannot be sure of the contingency events that we will face"* or *"even if we can identify potential hazards, it is* *impossible to ensure that any investments will be useful in the aftermath of an earthquake, pandemic, volcanic ash cloud etc"*. Problems arise because these 'risky' individual behaviours have a collective impact on any other states that rely upon those service providers to support their traffic. From this it follows that we have to understand the aggregate impact of European contingency plans. This requires collective action through the European Commission, via agencies including EUROCONTROL and EASA. It also creates a role for SESAR in the future guidance of contingency planning using the opportunities provided by network resilience techniques and future infrastructures such as the SWIM middleware, which may be used to increase future European ATM resilience.

Such collective actions help to improve disaster and emergency planning in a number of ways. For instance, CFMU worked with the EUROCONTROL Contingency Task Force to develop simulations of what might happen following the closure of air space across a number of ECAC states. These were still being refined at the time of the Eyjafjallajokull eruption. However, they provided important indications of the disruption that was in fact experienced. The events after April 2010 provide a significant opportunity for further research by calibrating the initial simulations with real data that was unavailable to the Contingency Task Force[7].

From a collective perspective, objectively assessed and predictable outcomes assume preventive actions or rules. In other words, if the outcome of a potential contingency is very likely then the collective response would be to identify actions that would help to mitigate any potential future adverse event. The CFMU simulations help with this. However, they are not a panacea. They rely on a host of assumptions about the residual capacity of neighbouring ANSPs to meet the service commitments of surrounding states. Many of these assumptions were shown to be incorrect after April 2010 where there was a concern that increasing traffic levels following the closure of adjacent airspace could increase the risk exposure if the ash cloud began to affect other service providers .

In contrast, uncertain outcomes, typically, force decision-makers to act with precaution *before* adverse events occur. Then steps are to be taken to reduce the likelihood of failure since there is no or little prediction or control of the likely consequences. Unfortunately, this classical approach to decision making is complicated within contingency planning because it is extremely hard to reduce the likelihood of natural disasters, including volcanic eruptions, or manmade contingencies, such as terrorist attacks. In consequence, a precautionary approach was adopted *during* the Eyjafjallajokull eruption by closing many areas of air space.

Moreno, Todt and Luján [8] have argued that decision making is complicated by social actors appealing to precaution in order to compensate for power and information asymmetries in communication. They distinguish two different perspectives on this precautionary principle in decision making. Firstly, it can be seen as a decision criterion in which precaution is more important than scientific knowledge. Alternatively, the precautionary principle can be seen as one element (among many others) in a process of decision making that is otherwise guided by scientific knowledge, which

[7] For more information about the work of the EUROCONTROL Contingency Task Force see http://www.eurocontrol.int/ses/public/standard_page/sk_sesis_guidelines.html

[8] Carolina Moreno, Olivier Todt and José Luis Luján (2010) "The Context(s) of Precaution: Ideological and Instrumental Appeals to the Precautionary Principle", Science Communication, vol.32, March 2010, pp. 76-92.

understands scientific uncertainty as a temporary lack of knowledge. It is clear that the events following the eruption provide an example of the latter application of the precautionary principle.

Scientific research has undoubtedly a key role to play in being associated with decision making both in planning for, and in response to, contingency events. Crises may occur in many different operational contexts. They may take place in 'stabilised' or ideal conditions when ANSPs have all the necessary decision making processes, financial resources and technical infrastructures. In such situations, it appears relatively easy to coordinate and recruit scientific expertise needed to resolve any ambiguity in assessing the risks posed by a contingency event to the continued provision of air traffic services.

However, adverse events also occur in less optimal conditions, for example during economic downturns when financial resources are scarce or during major changes in higher levels of management or during periodic system upgrades. Then, decision making processes operate in a confused environment where industry bodies have to recruit scientific advice at a time when the media, public and politicians are also trying to influence operational decisions. At such times, a lack of clear responsibilities both at a national and a European level interferes with the management of any crisis. Under such interference, social and political controversies may overwhelm technical considerations. At such circumstances decisions are unlikely to be based on a clear scientific rationale. Diverse representations of the risk and possible outcomes compete, which may lead to an ill considered application of the precautionary principle minimising risks towards zero with significant social, political and economic costs.

At time of crisis, sound decisions have to be tailored in proportion with the assessment of potential risks but with consideration of the worst plausible consequences. This approach has been endorsed by financial institutions in the aftermath of recent liquidity problems, for example by extending Monte Carlo approaches to Value at Risk computations. This is an instructive parallel because the previous risk assessments employed by the banks had often failed to consider the impact that an emerging crisis would have upon the individuals and teams who had to assess the risks associated with the crisis. The available time for reaction was reduced unsettling the chain of responsibilities and creating external pressures on those financial decision makers. They became preoccupied with meeting short term objectives and ignored the longer term impact of the loans that were being made. By analogy, this is precisely what seemed to happen to safety managers in ECAC states during the ash crisis. They suddenly found themselves caught between a host of demands that went well beyond the usual safety considerations.

In such context, the more sudden the crisis, the more scientific knowledge is required to inform rapid decision making, thus making available a body of expertise as an input needed to realise expert judgement decision-making. Previous research is unlikely to provide an answer to every question. However, it is important that service providers develop sufficient links to know where to begin an informed dialogue with external experts across several different domains. If these links do not exist then delays will occur when management try to find coherent and credible advice. Where ambiguity exists over the available expertise, communication is likely to become difficult with contradictory advice being offered with little relevance to the contingency at hand. Following any contingency, it seems therefore important to reinforce links between service providers and the scientific community in order to identify appropriate lessons for future intervention. In that regard, it appears critical to identify effective procedures so that those lessons would not be ignored as time passes.

The previous section has considered the role that scientific advice might play both in planning for and in mitigating the adverse outcomes of future contingencies. Our analysis has been informed by the impact of the April 2010 volcanic eruption on ECAC states and has addressed the following issues:

- The complexity of anticipating the nature of the crisis a priori and then identifying the characteristics of the risks once a contingency has occurred.
- The difficulty of assessing the costs and benefits of competing strategies in contingency planning, considering the scope for individual versus collective decision making.
- The challenges of establishing and maintaining links to necessary scientific advice before a contingency occurs and then of using that advice when communication channels can be undermined by wider political and public pressures.
- The need to sustain scientific input after a contingency, not only to identify appropriate lessons but also to ensure that they continue to be implanted and revised in the light of new scientific and research evidence.
- The importance of developing a wider scientific base to provide input from other industries and regions where experience in crisis management can usefully be applied to European Air Traffic Management.

3. The State of Scientific Research into the Impact of Volcanic Eruptions on Air Traffic Management

A number of scientific studies have been conducted into volcanic eruptions and their potential impact on air transport. Much of this work was motivated by concerns over the loss of power experienced during flights into ash clouds by British Airways in 1982 and KLM in 1989[9]. A series of symposiums, workshops and seminars have been held in many different areas of the world during 1987, 1991, 2004, 2007, and ongoing in 2010[10] These were sponsored by agencies including the International Civil Aviation Organization (ICAO), the International Airways Volcano Watch (IAVW) and Volcanic Ash Advisory Centres (VAAC). As might be expected, this level of interest has been outstripped by the increase in attention since the disruption of April 2010 with further meetings hosted by a number of University and research organisations, sponsored by individual member states as well as international organisations such as EUROCONTOL, NASA, ICAO and the World Meteorological Organisation.

A number of common concerns can be identified across the previous scientific work in this area. For instance, there remain inherent difficulties in distinguishing hazardous volcanic clouds from more mundane meteorological clouds. Further concerns may be summarised as follows:

- What is the concentration of ash required to damage different types of aircraft?
- How can we detect or predict those eruptions that are likely to create significant ash clouds?
- What observational techniques provide the most accurate/cost effective estimates of ash dispersion?
- What meteorological conditions (wind, precipitation, pressure) has to enter into consideration in modelling and predicting future dispersions?

These issues are intertwined. They are influenced by the scale of the eruption; by the quantities of volcanic ash projected into the atmosphere at different altitudes, by the specific gravities of different particles and by the range of volcanic gases that travel at different speed, height and directions according to different meteorological conditions etc. Each of these factors increases the difficulty in predicting the consequent impact of volcanic eruptions and the associated ash clouds on aviation operations. However, a range of observational techniques, simulation tools and pattern analysis algorithms have been developed to address these various concerns. These include ground-based, airborne[11] and satellite sensing technologies as well as 'reverse absorption' models for handling the residual data. However, none of these technologies provides perfectly accurate predictions. The precautionary approach described in the previous section remains a significant challenge when airlines and ANSPs need working together to formulate a proportionate response in the presence of false positives.

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[9] For summary accounts see witness statements included in the transcript of United States Senate Committee on Commerce, Science and Transportation, Volcanic Hazards—Impacts On Aviation, US Senate Commerce Committee hearing in 2006. Available on http://www.cusvo.org/docs/volcanichazards031606.pdf, last accessed August 2010.

[10] Among them, "Volcano Ash Crisis Seminar", Belgrade, 7th September 2010 and "Atlantic Conference on Eyjafjallajökull and Aviation", Keflavik, 15th-16th September 2010

[11] Examples include the well publicised AVOID infra-red technologies being trialled by Easyjet and the Norwegian Institute for Air Research.

The scientific input to such a proportionate response cannot simply focus on the dispersion of volcanic products. It has also to take on board contribution from the risk-based perspective adopted within decision theory. In particular, it is important to consider a wide range of operational concerns. No human casualties have yet been caused by volcanic ash. However, the use of modern aircraft built with two engines instead of four arguably aggravates the risk. Traffic growth, especially over areas of volcanic activity in the Pacific and North Atlantic also exacerbates the potential hazards.

Risk assessments also consider a host of lesser consequences. An aircraft crossing ash clouds that may or may not have been accurately detected will suffer some reduction in the expected life of its engines even if this does not cause one or more of its engines to stall. In that respect, airlines incur significant increased maintenance costs. Any scientific analysis of operational decisions during volcanic activity has to target offsetting each of these factors against the obvious costs of disruption from a precautionary approach that would leave many flights and stranded passengers on the ground.

Previous sections have argued that the recent eruptions and subsequent disruption to Air Traffic have illustrated a break-down in communications between scientific bodies and the operational and regulatory decision makers. There is a pressing need to distil the mass of research often scattered and described in previous paragraphs so that it is in a form that can be used to rapidly address future crises. Academic research papers are, typically, not an appropriate means of informing strategic management decisions. For instance, the findings from these studies need to be assessed against multiple channels of information providing real time data about rapidly changing situations. These observations illustrate the relevance of other branches of research into knowledge management. This work provides ways of optimising interaction with distributed and diffuse knowledge sets that integrate data from monitoring and observations, from airlines tests, VAACs, volcanologists, meteorological services etc. This is partially recognised within the European Commission's Transport Work Programme for 2011 within FP7:

> *"These integrated travel information services shall ensure co-operation between transportation modes and improve the ability of the system to cope with unexpected scenarios. In particular, research should develop solutions to compensate for a sudden decrease of the traffic capacity in one transportation mode to ensure continuity of mobility services (for example, following unexpected hazards and natural phenomena, such as the recent volcanic ash clouds across Europe)".*

(**GC.SST.2011.7-6. Integrated intermodal traveller services**)

In that, knowledge management goes well beyond the development of integrated travel information services. Computational research also offers techniques for identifying and resolving the contradictions or omissions that arise in both scientific and operational data. This is a significant strength given that different scientific opinions are often provided in different ECAC states. Such differences may, in turn, lead to radically different approaches to same hazards whose effects extend across national borders.

The events following the eruption confirm Boin's analysis[12] in the editorial that opened a recent special edition of the Review of Policy research on crisis management; "The contributions in this special issue strongly suggest that the crises of the future will be increasingly transboundary in nature….. The potential for crossing boundaries sets this new class of adversity apart from its traditional brethren. A transboundary crisis can easily cross geographical borders, threatening multiple cities, regions, countries, and continents…..A transboundary crisis also jumps functional boundaries. For instance, it can cross from a financial system into an industrial; from private to public; from one sector of industry to another (a crisis in the car industry affects the steel industry)".

These observations reiterate the European dimension in knowledge management. Knowledge management techniques are likely to develop promising tools in helping to ensure that different service providers all benefit from the best possible scientific advice. Without this, there is little hope of achieving consensus in a coordinated response to a shared problem. Risk management depends on knowledge management. Without risk management it is likely that there will be little benefit to be gained from the collection and integration of diverse information sources. These two technologies together provide with potential for integrating scientific and operational knowledge in a manner that would enable network optimisations during contingency events.

[12] Arjen Boin "Introduction to the Special Issue. Special issue on "The New World of Crises and Crisis Management: Implications for Policymaking and Research", Review of Policy Research, vol. 26, issue 4, July 2009, pp. 367-531

4. Review of the Crisis

A number of reports have been issued into the events that took place from the 14th to the 22nd April 2010. Many of these accounts disagree about the significant meetings and decisions that helped to shape the response across ECAC states. Further caveats may be raised over the reliability of any estimates about the total costs of the disruption; these range from €1 billion to €3 billion, and beyond. Most accounts recognise the lack of coordination across Europe. This undermined network optimisation as airspace was closed at relatively short notice. Further concerns may be raised on tailoring scheduling information to the broader needs of the aviation industry, especially for airports and airlines.

Also many of the reports published in the aftermath of the Eyjafjallajokull eruption agree on the domino effect that propagated the impact of cancellations, diversions and airport closures well beyond national airspace. Above all, criticisms have been made about the need to develop a coherent methodology to assess the risks for Air Traffic service provision. It was difficult, if not impossible, for ANSPs to use existing risk assessment tools to determine whether or not it was safe to fly at various concentrations of ash. Existing guidance provided a framework for considering likelihood and consequence but not how to resolve inconsistent and competing scientific advice. Similarly, regulatory documents did not address the problems created by a lack of evidence that might be used to validate particular hazard analyses for contingency events. In the absence of this information, ANSPs adopted the precautionary approach described in previous sections.

Further problems have been identified in distributed knowledge management for travellers. Members of the public were often poorly informed about the impact on their plans, especially in the first few days of the eruption. In consequence, they could not reschedule flights even where these were available. Uncertainty created bottlenecks as travellers tried to book alternate modes of transportation. This lack of information exacerbated the impact of the cancellations and closures. It also created a host of communications problems for ANSPs who were, typically, viewed as being responsible for the inconvenience caused to members of the public.

Many of the problems had been anticipated by members of the EUROCONTROL Contingency Task Force, mentioned in the opening sections of this paper. Unfortunately, their work was only completed a few months before the eruption. In consequence many ANSPs had not had time to act on the Task Force guidelines.

Further problems stemmed from the focus of this planning work. The guidelines were narrowly intended to support ANSPs and did not extend to the airline and airport operations that were most directly affected by the disruptions. Although the EUROCONTROL guidance seemed to have anticipated many aspects of the crisis, it did not anticipate the speed with which the ash cloud spread through the air space of Northern Europe. The rapid propagation of cloud imposed unexpected demands on the chain of decision making that extended both within and between ECAC states. In that, the national focus of individual NSAs created priorities that often exacerbated the coordination of multi-lateral approaches.

Previous paragraphs come in support of a more authoritative account from many of those who were most directly involved in the response to the Eyjafjallajokull eruption. However, it is possible to develop a high-level summary of the major developments making use of the Eurocontrol STATFOR report and the Intelligent Risks Systems 'Special Report' on the European volcanic crisis. The UK Meteorological Office's London Volcanic Ash Advisory Centre issued an initial warning following advisories from the Icelandic Met Office. The VAAC alert triggered a swift reaction from EUROCONTROL; CFMU sent warnings to individual ANSPs around Europe. They also prepared for worst case scenarios with zero rate regulation, assuming there was a possibility of prolonged closures to national airspace. This decision was taken after an emergency video conference with UK NATS.

The second day saw the consequences of the precautionary approach, mentioned in previous sections, as many areas of airspace around Europe were closed. CFMU acted as an information exchange passing data and information between ANSPs, coordinating with EU Commission and national meteorological services. However, the crisis imposed considerable stress upon key members of staff. The challenges of keeping these communications channels open and updated over time left little opportunity to identify the underlying scientific research that might have helped to inform or direct subsequent risk-based decision making.

The work of CFMU was complicated by the need to respond to decisions made in each member state. Sectors were often open or closed with relatively little warning in the early stages of the contingency, created few opportunities to optimise the revised traffic flows and creating complex knock-on effects across European air space. The lack of agreed tools for risk assessment undermined attempts by coordinating bodies to anticipate the likely impact of changing meteorological conditions. In consequence, there was a 25% reduction in air traffic across ECAC states on the first day of closures.

Over the next three days, the ash cloud expanded south. This triggered additional airspace closures. However, there was still little consistency in the decision making processes that were advocated and followed by individual NSAs. For example, Ireland initially opened her Southern sectors to transatlantic flights. This decision was later reversed. Across Europe, Airport operators were often left to decide whether or not to remain open while airspace closures were in place. This led to further confusion as members of the public did not know whether they should try and check-in for their flights.

Similarly, airlines used different algorithms to determine which flights would be cancelled and which would remain scheduled as closures extended beyond the first days of the eruption. Each organisation had to assess its own operational risks in terms of the costs of cancellation and the likelihood of meeting any schedule once airspace was reopened.

At a more strategic level, the Common Requirements had created a framework in which individual ANSPs and their respective National Supervisory Authority (NSA) were responsible for assessing the safety of the services that they provided. In the consultation with national regulatory organisations, there was a considerable concern to avoid any potential casualties. Most states, therefore, responded to lack of clear data and scientific uncertainty over the impact of ash on aircraft engines by adopting the precautionary principle.

Airlines and airports initially struggled to cope with the impact of the closures, mentioned above. Over time, however, more and more questions were raised about the evidence that might be used to justify what they perceived to be the 'risk averse' approach of ANSPs. Partly in consequence, ANSPs authorised more than 30 test flights into the ash cloud over different areas of Europe during the 18th April. However, the results from these tests took time to analyse. It was also difficult for scientists to convince the public that a small number of successful flights in particular regions of the ash cloud did not provide a sufficient sample upon which to assess the risks of opening European air space. This does not imply that the scientific studies supported the conservative approach that led to the closure of airspace. There was insufficient evidence to make recommendations.

By the 19th April, direct ground observations indicated that the eruption was beginning to diminish. There were signs that the emission of ash was declining. However, operational decision making continued to be complicated by a lack of consensus amongst many of the scientists who made very different predictions about the extent of the ash cloud. Traffic disruption created political pressure from the media who raised concerns about the fate of thousands of stranded passengers. These concerns were mirrored by mounting financial pressures as the airlines struggled to meet legal obligations to support their customers. It is against this background that the EU Transport council held an extraordinary videoconference meeting. It was decided to allow governments to reopen airspace on a limited basis. In order to do this, the meeting introduced a three tier categorisation for airspace restrictions: fully restricted; partially restricted at the discretion of national authorities and unrestricted. ANSPs gradually began to respond by opening sectors at reduced capacity. The next 24 hours saw an 80% increase in traffic volumes up to almost 30% of normal capacity.

From the 19th April, airlines were suddenly allowed to operate in air space that would previously have been closed under the initial precautionary approach that had been adopted by ANSPs and their regulators. Special operating procedures and permits enabled some airlines to operate under VFR rather than IFR restrictions. These measures created considerable confusion for many members of the public who legitimately asked whether or not it was now safer to fly than it had been over the previous 48 hours. Between the 19th and 22nd, many sectors reopened but others closed with shifting patterns in the ash cloud and changes in the local risk assessments across ECAC states.

The previous paragraphs have provided an extremely high-level summary of the dynamics that influenced decision making processes across Europe. From this a number of issues are identified that are relevant for the integration of scientific advice in anticipation of future contingencies:

- *Need for Scientific Input into 'Real Time' Risk Assessment and Decision Making*
  As mentioned, the early stages of the eruption illustrate how many ANSPs implemented the precautionary approach. However, by trying to achieve zero safety risks in closing airspace, they also increased business risks as passengers and airlines sought alternate routings. There was also a significant loss of support from politicians and the public, with a growing perception that ad hoc decisions were being made without any proper justification. While the precautionary principle was applicable in the hours following the eruption; subsequent events showed the need for closer cooperation between scientific agencies and service providers. Such cooperation would present the public and politicians with a proportionate view of the risks involved from opening the skies.

- *Need for Exchange of Scientific Expertise in Contingency Planning Around the Globe*
  There is a suspicion that the impact of the Eyjafjallajokull eruption was exacerbated by a sense of complacency in some areas of the European aviation industry. Ash clouds were a

problem in other areas of the world but were not considered to be a significant threat for most ECAC states. This left Europe vulnerable to the events of April 2010. This potential complacency undermined attempts to transfer scientific and engineering practices that already supported aviation operations in other parts of the globe that were more accustomed to volcanic activity. It is important to stress that this response is understandable given the relative frequency of ash clouds. From October 2008 to March 2010, the London Volcanic Ash Advisory Centre (VAAC) did not report any volcanic activity in its area of responsibility. In a comparable period, the Buenos Aires VAAC issued just under 500 ash advisories associated with four different volcanoes. The Wellington VAAC issued 76 warnings for ash clouds emanating from Tonga and Vanuatu while the Tokyo VAAC gave out 76 warnings for a single Russian volcano.

- *Need for Integration of Scientific Input into Proportionate Responses*
  Previous sections have argued that the insights from previous research are seldom published in a form that can be used to inform operational decision making by ANSPs and regulators and that, partly in consequence, service providers fail to learn from the results of the most recent experimental work. From this it follows that communication mechanisms have to be established to help decision makers obtain authoritative advice in the immediate aftermath of any contingency event. Unless such channels are created before an emergency then there is little chance that external scientific input will be able to reduce the uncertainty and confusion that characterise many responses to the eruptions of April 2010. There is, of course, no guarantee that closer cooperation between scientific bodies and service providers will be able to provide a panacea for all future contingencies. However, such an engagement should deliver mechanisms for ensuring a proportionate response based on scientific evidence where uncertainty persists. Decisions may then be grounded in evidence and revised as more data becomes available. For example, flight tests could have been coordinated in conjunction with the use of satellite visualisation, ground volcano observations and simulation algorithms. In contrast, many of these activities were rapidly scheduled by different agencies around Europe with relatively little coordination and with little direct involvement from the operational teams who had to make decisions based on the data that was obtained. Not only is it important that, for instance, Regulators and ANSP business and safety managers should be informed of the scientific studies being conducted to reduce uncertainty during contingency events, it is also certainly important for the public and for politicians to be informed. It is striking that during the Eyjafjallajokull eruption, most European citizens were completely unaware of the scientific appraisal of the situation. In the future, a scientific advisory body might be established by the Commission to help communicate this perspective both to the public and the media.

- *Need for Scientific Input into European Crisis Management*
  The events of April 2010 raise many research questions about the formation and maintenance of the core scientific knowledge needed to support European crisis management. It was clear at many stages of the contingency that scientific input was needed to support a host of operational decisions. However, each NSA and ANSP looked to different national and international agencies. In consequence, confusion, inconsistency and rumour led many states to adopt a precautionary approach. There were few clear

mechanisms for translating VAAC warnings into policy decisions. These caveats should not obscure significant contributions at a European level. The interactions between the warning centres, CFMU and individual member states provided a clear starting point for a coordinated response. The subsequent intervention of the European Extraordinary Transport Council also provides a clear template for the future when they took measures to coordinate the easing of the precautionary approach. However, major stakeholders including the airports, airlines and the travelling public felt isolated from the decision making processes. In many cases, they had little or no information about the risk mitigation strategies that justified the reopening of European airspace. This creates significant opportunities for future regulatory guidance across member states, these opportunities are discussed in the closing sections of this report.

- *Need for Scientific Input to Inform Media and Political Influence*
  Many ANSPs faced considerable problems in justifying the closure of their air space to the travelling public and to politicians. These difficulties were exacerbated when neighbouring states kept most of their sectors open. The consequent inconvenience to the travelling public combined with uncertainty over the grounds for closing air space and rising financial losses across the industry. These different pressures were created against the background of global economic problems for which politicians were being held accountable in elections across many ECAC states. The lack of clear scientific advice created a situation in which many service providers were publically forced to justify their operational decisions against contradictory input from different research teams and some scepticism amongst politicians. The intervention of the European Extraordinary Transport Council provided some resolution to a growing conflict in which service providers were seen to oppose public and political consensus. However, the need for such an 'extraordinary' intervention arguably illustrates the importance of reforming the ways in which Europe responds to crises, with responsibility distributed between a host of intersecting European and National agencies including but not limited to ANSPs, NSAs, Airlines, Airports, Government Ministries of Transport and the Economy, EUROCONTROL/CFMU, EASA, ICAO etc. Of particular relevance to crisis management is how far communication of the technical approach might be open to debate and the speed of information diffusion to give grounds for optimal individual behaviour, i.e. by airlines and the travelling public, and collective responses, i.e. by national regulatory authorities and European agencies.

5. Regulation and Governance

Many aspects of the Eyjafjallajokull response raise wider questions about the resilience of European regulation and governance in the face of international contingencies. Similar questions have been posed by previous adverse events in many different industries, ranging from recent problems across the financial services industries through to the Blackouts in electricity distribution across France, Italy and Germany. The experience from these rare, high consequence failures has helped to identify a distinction between two different issues that are inextricably linked: the need for European coordination and the need to create appropriate organisational structures for that coordination. These concerns create a requirement for supranational regulatory coordination in drawing scientific and operational lessons from previous contingencies. They also suggest a framework to coordinate the future European response to potential adverse events, which could be based on structures that are already in place as part of the SESAR programme.

5.1 Coordinating the European response to Contingency Events

A number of different approaches have been taken to structuring the European response to contingency events in different industries. Each technique has strengths and weaknesses; a complete analysis is omitted for the sake of brevity[13]. However, the different approaches may be summarised as follows:

- *A network of national entities* that coordinate through interaction[14]. This is observed in the direct operational coordination that, for instance, characterises adjacent states within the European energy distribution market. Each neighbour establishes common letters of agreement and may act collectively to develop regional plans for emergency response, for instance by authorising transmission loading relief to assist their colleagues. Networks of national entities are built-up over time and, typically, are sensitive to the local, legal, political cultures between neighbouring states. Entities interact according to cross-border issues either by pair when only two of them are involved or more widely when regional issues are involved. This local focus creates problems for establishing European consistency at a higher level. Opinions and decisions within the network may converge or diverge. These issues may be addressed by European agencies that provide mediation or guidance across local initiatives. Additional complexity arises when one member state occupies a central position either because of the issue under scrutiny or because of her recognised expertise. In such situations, other partners may feel overlooked in regional policy formation. Further problems arise in areas where there are continuing political tensions between neighbouring states. This approach has some superficial similarities with the organisation of Functional Airspace Blocks (FABs) as part of the Single European Skies programme. However, these

[13] C.W. Johnson, G. Amar, T. Licu and R. Lawrence, High-Level Architectures for Contingency Planning in Air Traffic Management. In R.J. Simmons, D.J. Mohan and M. Mullane (eds), Proceedings of the 26th International Conference on Systems Safety, Vancouver, Canada 2008, International Systems Safety Society, Unionville, VA, USA, ISBN 0-9721385-8-7, 2008.

[14] A parallel and lessons might be drawn from literature characterising the structure of networks in biology, Strogatz Steven H. (2001) "Exploring complex networks", *Nature*, Vol. 410, pp. 268-276

groupings seem to have had little or no influence on the coordination of the scientific or operational response to April 2010 beyond informal dialogues between member states;

- *A European meta-organisation* that coordinates through semi-binding guidance[15]. This is observed through the processes of commitology that govern many aspects of European life. Examples include the Standing Committee on the Food Chain and Animal Health that provides authoritative guidance on contingencies affecting food production and distribution. These meta-organizations are composed from members who themselves represent national agencies. These individuals represent the views of their respective organisations. Hence the meta-level organisations may be viewed as a consortium of national regulators. These structures are established because it is too costly or complicated to ensure consistency through a series of bi-lateral and multi-lateral agreements at a regional level. The work of these organisations critically depends upon a search for consensus. The limitation is the scope of intervention and enforcement of the Meta-organisations. In particular, it is clear that different member states often progress at very different speeds towards the implementation of guidance issued by European meta-organisations. These differences persist where guidance has been enshrined in both European and national legislation. The more that views diverge on key issues and enforcement, the less confidence is to be placed upon the intervention of such organisations in response to major contingencies and often their response can be perceived as slow and inappropriate. This caveat is particularly important when the decisions made by European meta-organisations are seen to be detrimental to the independence and interests of national entities;

- *A central independent body*. In some respects this characterised a single European independent agency granted powers of regulation and enforcement, steered by a board of chosen individual members. The creation of EASA appears a step in that direction that is a single independent supranational authority outside the usual structures for European governance. Here the issue is that it creates considerable questions about the responsibility and authority of such an organisation. It would, typically, be constrained in terms of its scope for action and its enforcement powers. However, the perceived independence of the organisation may help to establish a more focused approach between industry stakeholders outside the wider political context that complicates some aspects of European decision making[16].

Many of the problems that complicated the response to the Eyjafjallajokull eruption were created because the governance and regulation of European Air Traffic Management was based on elements of all three approaches at the time of the contingency. The Common Requirements devolved many aspects of policy and decision making to NSAs in conjunction with their ANSPs. As mentioned previously, there were also fledging attempts to establish regional groupings around Contingency

[15] See seminal work by Göran Ahrne and Brunsson Nils (2008) *Meta-organizations*. Edward Elgar Publishing, Cheltenham UK and Northampton, Massachusetts

[16] Dumez H.et Jeunemaitre A. (1999), "Les institutions de la régulation des marchés: étude de quelques modèles de référence", Revue Internationale de Droit Economique, Vol.1, p. 11-30 and C.W. Johnson, B. Kirwan, T. Licu and P. Statsny, Recognition Primed Decision Making and the Organisational Response to Accidents: Ueberlingen and the Challenges of Safety Improvement in European Air Traffic Management, Safety Science, (47)853-872,2009.

Planning Teams within several FABs. At the same time, EUROCONTROL's Contingency Task Force had recently developed guidelines that had no regulatory status for member states.

5.2 Governance and Organization Structures

Governance is multifaceted. The term encapsulates decision making, the acceptance and assignment of responsibility, the supervision and implementation of procedures and of enforcement actions. It is impossible to provide an exhaustive analysis of each aspect of the response to the Eyjafjallajokull eruption across each European state. However, it is possible to focus on the constitution of decision making bodies and the interfaces between those bodies both within and between different nations. In most cases, ANSPs and NSAs formed ad hoc committees that prepared tactical and operational responses to the changing threat posed by the ash cloud. These groupings often lacked scientific representation. In some cases, they did not regularly interact with members of the travelling public or even with other stakeholders, including the airlines and airports. In consequence, these stakeholders did not talk directly to ANSPs. Instead, they turned to the media, who sought the opinions of other scientific agencies. This led to the conflict, identified in previous pages of this report. It is important not to blame the media in this respect; they play a central role in the provision of public information for future contingencies. The experience of the ash cloud during 2010 has illustrated the need for more coherent media strategies in communicating a European scientific perspective to problems that extend across international borders.

A number of alternatives may be put forward. For instance, many ANSPs currently support in-house Research and Development organisations. Financial considerations have curtailed the scope of their work in recent years. In consequence, some ECAC states have appointed external scientific advisory boards that help to identify new areas of research that might have a long term impact on the strategic direction for their organisation. Recent examples might be the use of novel radar techniques to help identify the coming generation of small composite aircraft or on control techniques that might enable ANSPs to intervene in the operation of UAVs. The work of these scientific groups is seldom visible to the public or even to other ANSPs. However, they provide a template for the integration of leading researchers to support decision making during contingency events. It is clear from these existing contacts that such relationships are unlikely to be built up during the time pressures and political or economic tension that characterises an on-going contingency. Similarly, a number of scientific organisations have been specifically developed to provide advice to European agencies – the work of the VAAC is a specific example here. However, there is a need for a more systematic approach to provide detailed and authoritative scientific support to European regulatory organisations during contingency events.

Although the focus here has been on the interface between scientific bodies and air traffic management organisations, similar comments may be made about the need to make decision making processes more transparent for the travelling public. Communication problems both created and compounded political pressure following the initial air space closures. Schäfer[17] identifies three different dimensions that characterise relationships between science and the media:

1. *Extensiveness:* Science is said to be increasingly represented in the mass media.
2. *Pluralization:* Media coverage on science is said to be increasingly diverse in terms of actors and content.
3. *Controversy:* Media coverage on science is seen as increasingly controversial."

In the aftermath of the eruption, each of these dimensions can be observed as many different scientists presented evidence both for and against the continuing restrictions. In the absence of any coordinated source of scientific information, the public debate evolved over network information systems including the Internet, television and the radio, press, airlines communication departments, airports, etc. Some of the information provided by these sources was incorrect. In other cases, the distributed information sources provided contradictory views. In most cases, they only provided partial information about the impact of the ash on aviation operations. This added to the sense of frustration felt by many individuals and groups over the continued closures.

[17] Mike S. Schäfer (2009) "From Public Understanding to Public Engagement: an Empirical Assessment of Changes in Science Coverage", Science Communication, vol. 30, June 2009, pp. 475-505

6 Scientific Input in Post-Crisis Thinking

There is a danger that the inconsistency and lack of coherence that characterised some aspects of the scientific response in the immediate aftermath of the eruption will extend into longer term responses to this contingency. Reviews have been commissioned in many different regions of Europe and at a host of different levels by individual organisations, Parliamentary committees, industry bodies etc. These have helped to trigger a large number of conferences and workshops that are often the result of local initiatives rather than any more sustained or coordinated action plan.

The proliferation of research interest following the contingency is positive; it encourages further reflection on the technical problems that led to uncertainty during the initial response. However, the multiplicity of distributed events creates further challenges for ANSPs and other industry organisations that must try and synthesise the key lessons from all of these various meetings. Anyone attending a significant number of these events will also realize that many of the contributions remain in a form that cannot easily be used to inform subsequent operational decision making.

Further problems arise because many of the submissions to these meetings are based on a partial understanding of the events as they unfolded across Europe. They, typically, focus on the problems faced by an individual nation or by a particular region. They lack the European perspective that can only be provided by an authoritative analysis of the distributed response across ECAC states. For example, the problems and information needs for NATS were radically different from those facing individuals in NAVPortugal during different phases of the eruption.

The need for an authoritative account of the handling of the ash cloud during April 2010 extends to the role that scientific bodies played in decision making across member states. As we have seen, there were significant differences in the degree of engagement both at a European level and within individual ANSPs. The future analysis of the Eyjafjallajokull response has to review these differences in the hope that lessons are drawn for sharing across Europe. Ideally, it may be possible to synthesise several different generic approaches that could then be adopted by member states in the same way that EUROCONTROL and EASA have promoted safety management techniques and more general risk assessment tools across the aviation industry.

The future analysis of the Eyjafjallajokull response must also consider the ways in which responsibilities were divided between different European organisations. In particular, In terms of technical and decision making processes, a number of entities have been involved with airspace legitimacy that does not geographically coincide: the two European VAAC London and Toulouse covers an airspace that does recoup with CFMU Eurocontrol and the EU, and neither with ATC and Meteorological national airspaces. Different degrees of legitimacy either through national sovereignty, multilateral agreements are attached to airspace, which weigh on decision making processes. On political grounds and power of legal enforcement, stakeholders involvement in regulatory processes, similar observation can be made when considering the EU Council of Transport and ECAC or national sovereignty powers and delegation rights.

Such considerations might provide with a basis upon which scientific input and governance alternatives might be looked at where it can have the greatest impact upon a coordinated approach to any future contingency. As we have seen, the EC Common Requirements place responsibility for contingency planning on individual ANSPs in consultation with their NSAs. The response to the events of April 2010 has shown that more may be done to promote a coordinated response to pan-European crises.

7. Conclusions

This report has surveyed events following the Eyjafjallajokull eruption in April 2010. It has focused on identifying how scientific uncertainty, localised assessments, opaque decision making processes and poor communication mechanisms impaired a coordinated response. These factors combined over time to undermine public and political confidence in the decision to close many European sectors. The communications problems can be illustrated by the observation that the European VAACs in London and Toulouse each cover areas of airspace that do not equate with any structures used by CFMU or individual ANSPs. Many stakeholders felt excluded from the subsequent decision making processes, leading to the intervention of the European Extraordinary Transport Council. However, further action is now needed to ensure that lessons are learned for any similar contingency both within and beyond the Aviation industry.

From that perspective, it is to note that key elements and expertise through CFMU, EUROCONTROL contingency planning, SES2, EASA are already in place to think developing a more coherent and coordinated response. SESAR might also provide useful scientific and technical input. However, it remains to identify the detailed national and regional decision making structures that would help to implement a more consistent approach to the hazards that might be faced in an uncertain future. On these grounds, the sharing of risk management, individual and collective, among stakeholders, of liabilities and redress, the choice of collective governance models are key issues to help defining a sound approach.

Parallel to these considerations the contingency events have shown that NSAs and ANSPs were faced with exceptional circumstances, which ruled out to depart from not applying a full precautionary principle, which guided the decision making processes following the initial eruption. Yet, a lack of coordinated scientific input into decision making processes at a European level arguably led to inconsistency, confusion and lack of communication with the public and with politicians after the first closures. It also raises issues in terms of governance framework. In that, further work and reviews about thinkable decision making processes and structures alternatives would certainly help to improve the management of future comparable contingencies. In particular, the European Commission through her research work programme might be the sound and adequate receptacle to foster developing such mechanisms that would form and maintain the core scientific knowledge needed to support European crisis management during these future contingencies.

Today there is tension between a zero-risk safety first approach and a balance of risks business approach and the result is a conservative safety dominated position. This needs to evolve to seek a more informed decision based approach using the best scientific knowledge applied consistently to the problem in hand and available to empowered decision makers. This approach needs to ensure that scientific opinions are co-ordinated, the likely impact to European Aviation and the travelling public is minimised and the approach is transparent.