Institution: University of Westminster		
Unit of Assessment: 13 Architecture, Built Environment and Planning		
Title of case study: Delay Cost Management in European Aviation		
Period when the underpinning research was undertaken: 2011-2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Andrew Cook Graham Tanner Gérald Gurtner Luis Delgado	Professor; Senior Research Fellow; Senior Research Fellow; Senior Research Fellow	Sept 1993 ongoing; Sept 1994 ongoing; Nov 2015 ongoing; Jan 2014 ongoing
Period when the claimed impact occurred: Aug 2013 – Dec 2020		
Is this case study continued from a case study submitted in 2014? ~~Y~~/N		

1. Summary of the impact (indicative maximum 100 words)

The University of Westminster's ATM (Air Traffic Management) Group, led by Professor Andrew Cook, have designed, computed, and maintained the aviation industry's standard delay cost values that have been used across Europe by practitioners and policy makers since 2011 and have resulted in the following impacts during this REF period:

- Informing ATM business decisions – enabling NATS to avoid significant additional investment and operating costs; securing continuing maintenance cost savings at Australian airports.
- Highlighting the need for airport capacity expansion in the UK and informing the Government decision in which airport expansion scheme to invest.
- Informing EU airport safety regulations to accommodate value of time penalties that would be incurred by aircraft operations under severe weather conditions.
- Changing the strategic and tactical design of aircraft prioritisation rules within the Single European Sky ATM Research (SESAR) project to reduce delays for airspace users.
- Underpinning binding regulations on all EU states regarding en-route delays.

2. Underpinning research (indicative maximum 500 words)

The researchers developed, from first principles, a quantitative framework for calculating airline delay costs [1]. The core cost components considered in their work are those associated with aircraft maintenance, fleet financing, crew costs, passenger costs to the airline, and fuel burn. The report furnishes a set of **standard reference values relating to the cost of delay**, for use in both the calculation of operational/tactical costs (e.g. producing a set of quantitative rules for re-route trade-offs) and at the policy/strategic level (e.g. to inform airspace design). It formulates costs based on specific aircraft types, for multiple cost elements, under various cost scenarios, for all phases of flight, and as a non-linear function of delay duration.

The objective of report [2] is to provide users, including industry, with **updated reference values for the cost of delay** to European airlines. It updates previous reporting, which was based on the reference year of 2010. This new report presents costs for the reference year 2014 and extends the range of aircraft covered from 12 to 15, with the values being generated by a significantly updated model.

Journal paper [3] presents a model for **the economic value of extra capacity at an airport**. This is based on a series of functional relationships linking the benefits of extra capacity and the associated costs. It takes into account the cost of delay for airlines and its indirect consequences on the airport, through the loss or gain of aeronautical and non-aeronautical revenues. The model is highly data-driven and a range of data sources have been used. In particular, special care has been taken to incorporate the full distribution of delay at the airports, rather than average values only. The results from the simplified version of the model show the existence of a unique maximum for the operating profit of the airport in terms of capacity, which is clearly dependent on the airport and exhibits interesting behaviour with respect to the average number of passengers per aircraft and the predictability of the flight departure times. The researchers further show that there exists an important trade-off between increased predictability and punctuality at the airport. It is demonstrated that a more complex behavioural model for passengers can introduce several local maxima in airport profits that may drive the airport towards suboptimal decisions.

In another journal paper, the researchers tackle the lack of a **framework for modelling the cost of resilience during disturbance** in ATM research. There is no universally accepted metric for cost resilience. The design of such a framework is presented and the modelling to date is

reported [4]. The framework incorporates performance assessment as a function of differential stakeholder uptake of strategic mechanisms designed to mitigate disturbance. Advanced cost- and non-cost-based metrics, disaggregated by stakeholder sub-types, are described. A new cost resilience metric is proposed and exemplified with early test data.

Journal paper [5] **presents the model developed within the H2020/SESAR 'Vista' project, studying the future evolution of trade-offs between ATM key performance indicators, such as costs and emissions**. This is a new, holistic model for the European ATM system. It is an agent-driven simulator, featuring various stakeholders such as the Network Manager and airlines. The model simulates changes that business and regulatory forces drive at a strategic, pre-tactical and tactical level, comparing future European scenarios for 2035 and 2050, drawing attention to several, future key performance indicator (KPI) trade-offs. The economic components of the model are underpinned by the Westminster team's cost of delay computations, which are essential for all the airline impact calculations. Future implications are presented and discussed, e.g. at the passenger, flight, and airline level.

3. References to the research (indicative maximum of six references)

[1] Cook A.J. and Tanner G. 2011. *European airline delay cost reference values*. Brussels: EUROCONTROL Performance Review Unit.

[2] Cook, A.J. and Tanner, G. 2015. *European airline delay cost reference values - Updated and extended values, Version 4.1*. Brussels: EUROCONTROL Performance Review Unit.

[3] Gurtner, G., Cook, A.J., Graham, A., and Cristóbal, S. 2018. The economic value of additional airport departure capacity. *Journal of Air Transport Management*. 69, pp. 1-14.

[4] Cook, A.J., Delgado, L., Tanner, G. and Cristobal, S. 2016. Measuring the cost of resilience. *Journal of Air Transport Management*. 56 (A), pp. 38-47.

[5] Gurtner, G., Delgado, L., Cook, A.J., Martin, J. and Cristobal, S. 2020. A multi-layer model for long-term KPI alignment forecasts for the air transportation system. *Journal of Air Transport Management*. 89, 101905

Funding:

Total funding incoming to the University as a result of ATM projects funded during the REF period is **EUR 6 028 025**. Example projects coordinated by Westminster include:

- EUROCONTROL, 'ComplexityCosts' (2013 – 2016): EUR 264 000.
- European Commission, 'Vista: Market forces trade-offs impacting European ATM performance' (06/2016 – 06/2018): EUR 211 250.
- European Commission, 'Domino: Novel tools to evaluate ATM systems coupling under future deployment scenarios' (01/2018 – 12/2019): EUR 303 750.
- European Commission, 'BEACON: Behavioural Economics for ATM Concepts' (07/2020 – 12/2022): EUR 267 688.

4. Details of the impact (indicative maximum 750 words)

Devising EUROCONTROL's standard reference documents

The March 2011 report [1], and its December 2015 update [2], were developed for and published by the Performance Review Commission (PRC) of EUROCONTROL, the European Organisation for the Safety of Air Navigation. EURCONTROL states: "The **University of Westminster (UoW) report** ... represents the most **recent and comprehensive appraisal of the cost of delays in the air traffic management system in Europe**. The report is designed as a reference document for European delay direct costs incurred by airlines, both at the strategic (planning) and tactical stages" [a-i, p.15]. The Westminster report is a dynamic document, by which the framework is updated with the most recent data and enhanced research methodology every few years, ensuring its accuracy and utility. This is further reflected in several industry reference documents, such as EUROCONTROL's annual ('ACE') benchmarking report for ATM cost-effectiveness, updated 2016 through 2020 [a-ii].

As the central organisation for the coordination and planning of air traffic control for all of Europe, EUROCONTROL's use and dissemination of Cook and colleagues' work is such that it reaches a range of aviation stakeholders (airports and airlines, and, through these, passengers and businesses) across the continent. Examples of direct impact arising from the applied use of the ATM Group's delay cost reference values, sometimes via their incorporation in the above EUROCONTROL reports, are described below.

Informing ATM business decisions

NATS (En Route) plc, NERL, is the UK's air navigation service provider (ANSP) providing air traffic control services over the UK and the eastern North Atlantic. In order to demonstrate how their measures can reduce the cost burden of delays, NERL's Business Plan 2020-2024 incorporates EUROCONTROL's Performance Review Unit's valuation techniques "to estimate the cost of delay to airlines ... the values used for this analysis are taken from Performance Review Report (PRR 2015), which itself draws on the latest University of Westminster report", i.e. output [2] [b-i, p. 38]. The use of these reference values has allowed NERL to make the strategic decision to retain previous targets: "We, and our customers, have a strategic interest in ensuring that there is sufficient air traffic control capacity to cater for traffic growth and changes to demand profiles and routings ... We do not believe that setting more stretching regulatory targets on average delay per flight in RP3 is cost effective" [b-i, p.39]. In this way, the ATM Group's work has enabled NERL to **avoid "significant additional investment and operating cost"** [b-i, p.39].

In another example, PricewaterhouseCoopers (PwC) were commissioned by Airservices Australia (the Australian ANSP) to assess the costs and benefits of Metron Traffic Flow (an air traffic flow management system) following its implementation at Sydney, Perth, and Brisbane airports in 2012 and at Melbourne Airport in 2014. The analysis featured in a December 2014 report that used the ATM Group's cost reference values [1] in respect to: marginal maintenance costs and marginal crew costs, per minute and by aircraft type [b-ii, p.7-9, and 18]. The former is important because: "Marginal maintenance costs incurred by aircraft increase with airborne time (and therefore with airborne delay)", while under the latter it was cited that: "Airline stakeholders are all in favour of including the effects of ground delay in the analysis as it is overall delay that has the most significant effect on their metrics and operations" [b-ii, p.18]. PwC state that: "the airborne delay savings contributed to an estimated maintenance **costs savings of $27.3 million** over the appraisal period" [b-ii, p.12], further concluding that the data "provide support for the continued rollout of Metron across domestic airports, in agreement with the positive feedback received from stakeholders" [b-ii p.15]. The evaluation, drawing extensively on the ATM Group's cost reference values, enabled the Metron software to become fully integrated into Airservices Australia's ground delay programme [b-iii], a decision driven by the cost savings cited [b-ii, b-iv, p.51].

Informing policy decisions on airport capacity in the UK

The ATM Group's work has also played a role in setting the agenda for the expansion of airport capacity in the UK, by **highlighting the need for airport expansion and informing the Government decision on which airport expansion scheme should be invested in**. The Airports Commission (AC) was set up by the coalition government in 2012 and undertook "one of the most comprehensive assessments of any infrastructure project ever undertaken in the UK" [c-i]. In their 2014 *Business Case and Sustainability Assessment* of the Heathrow Airport North West Runway scheme, the AC conducted an analysis of delay costs on five specific demand scenarios using output [1], the 2011 version of the ATM Group's reference values [c-ii, p.37-38]. The AC found that: "The benefits of reduced delays from the scheme range from £0.8 billion to £2.2 billion, depending on the demand scenario under consideration. Under the *global growth* scenario, benefits experienced by airlines account for 56% of the total benefits" [c-ii, p.38]. On the basis of the AC data, which included an *Economy: Final Delay Impacts Assessment* that also used the ATM Group's cost reference values [c-iii, p.43], the Department for Transport (DfT) chose the Heathrow Airport North West Runway scheme in Oct 2016 [c-i]. The DfT augmented support for this option by using the ATM Group's updated cost reference values (output [2]) "to produce estimates for the annual and total costs to airlines of delays" in their *Upgrading UK Airspace: Strategic Rationale* document of Feb 2017 [c-iv, p.67-69]. The results, as seen in the table below [c-iv, p.68], demonstrated the need to expand the capacity of UK airports. This Heathrow expansion plan has gained legal approval, thus allowing a planning application, subject to its alignment with climate commitments [c-v].

Year	NATS 'Do Minimum' outputs		DfT estimates
	No. of flights	ATFM delay minutes	Cost to airlines (2016 £)
2016	2,455,770	147,632	£4,860,000
2020	2,686,917	1,001,492	£32,900,000
2025	2,981,144	2,838,274	£93,400,000
2030	3,252,840	4,408,638	£145,000,000
Present value: 2016-30	42,941,893	32,182,664	£762,000,000

Changing EU Airport Safety Regulations

In 2018, the Møreforsking Molde AS research group was commissioned by Avinor AS, a state-owned, limited company that operates most of the civil airports in Norway, to conduct an economic impact assessment of implementing the International Civil Aviation Organization's (ICAO) regulations of minimum friction on contaminated runways [d-i]. These regulations were likely to affect aircraft operations under specific weather conditions – such as those in Norway that are severely exposed to snow and ice – and were anticipated to "entail a larger number of cancelled or diverted flights because of reduced aircraft maximum landing weight" [d-i, p.9]. As such, the March 2018 report analyses, in particular, the economic costs of reduced regularity for the passengers at four Norwegian airports, and makes its calculations by using the ATM Group's updated delay cost reference values (output [2]), with particular reference to its value of time calculations [d-i, p.15]. The findings were that the economic costs of the delays that would be incurred from implementation of the aforementioned ICAO regulations would be significant, "rais[ing] the question of whether the winter services will remain sustainable under the new regulations" [d-i, p.21]. Avinor AS provided this case study to ICAO as part of their submission on potential impacts of the new regulations to the European Union Aviation Safety Agency (EASA) Rulemaking Group RMT.0704. **EASA issued a proposed amendment to the aforementioned ICAO regulation, "as regards runway surface condition assessment and reporting which will be applicable worldwide by November 2020",** which specifies "the introduction of new requirements for runway surface condition assessment and reporting, aerodrome snow plan […] as well as performance standards for runway surface friction measurement devices" [d-ii, p.1]. It is notable that this proposed amendment document features a case study summary of the Møreforsking report across several of its pages, demonstrating its contextual importance in informing the EASA regulation amendment [d-ii, p.197-200]. The corresponding Implementing Regulation (EU) 2020/469, of 14 February 2020, was adopted in July 2020, explicitly citing the foregoing stakeholder consultation [d-iii].

Changing the strategic and tactical design of aircraft prioritisation rules in SESAR:

SESAR's role is to define, develop, and deploy applied research needed to increase ATM performance and build Europe's intelligent air transport system [e-i]. The size of this undertaking is such that the current (2016 to 2024) programme budget is EUR 1.6 billion. By explicitly quantifying the non-linear relationship between delay duration and delay cost (e.g. two 15-minute delays will usually cost less than one 30-minute delay) in their delay cost reference values, the ATM Group has **changed the strategic and tactical design of aircraft prioritisation rules within SESAR**.

This has occurred, for instance, through the User Driven Prioritisation Process (UDPP), a SESAR project led by EUROCONTROL, which minimises the impact of delay in capacity-constrained situations by attributing ground delays based on airspace user preferences [e-ii]. As the former leader of the UDPP project writes: "Prof Cook input into the early, general design of UDPP through mutual project collaborations, especially during the 'UDPP Credits' project (for SESAR Project 07.06.02), in the period 2014 – 2016, and in collaborations on subsequent papers. Of particular value was establishing the important principle of the non-linear relationship between delay duration and delay cost, expressed, for example, through the concept of step cost functions, as reflected in the standard reference values published by the University of Westminster: an important concept common to both the UDPP and Westminster cost models" [e-iii].

On the basis of UDPP validation simulation data, researchers at EUROCONTROL and Think Research Ltd estimate that **UDPP can reduce the impact of delays on airspace users on the additional cost by more than 40%, and on passengers' connections, whilst not reducing**

the performance of the airport [e-iv]. A shadow-mode trial at Zurich Airport in Oct. 2019, marked the project's phase-1 implementation [e-ii; e-v, p.94] and full rollout across Europe is being evaluated [e-v]. This work is being pursued in the H2020/SESAR project 'BEACON', led by the University of Westminster, with EUROCONTROL as a partner.

Directly driving binding regulations on all EU states regarding ATC service provision:

The European Commission's Implementing Regulation (EU) No 390/2013, of 3 May 2013, laid down a performance scheme for air navigation services and network functions. These regulations applied until 31 Dec. 2019 (since updated) and imposed **binding targets on European states** regarding, *inter alia*, average en-route delays [f-i]. Citing [f-i], each functional airspace block across Europe has its own targets, and for 'reference period 2' (2015-2019), the Single European Sky area (European) network average target was set at no more than 0.5 minutes/flight, on 11 March 2014 [f-ii]. This value was determined as a trade-off between the cost of capacity and the cost of delay, the latter being "estimated based on a study commissioned by the EUROCONTROL PRU by the University of Westminster, UK" (referring to output [1]) within the methodology developed by EUROCONTROL [f-iii, p.20].

The use of the dynamic Westminster report across the applicable period of the regulations is evidenced, for example, in the *PRB Annual Monitoring Report 2015* [f-iv]. Explaining how the "KPI used for Union-wide en-route capacity is the average minutes of en-route ATFM delay per flight", as per Implementing Regulation (EU) No 390/2013, the PRB cites output [2] (2015) to calculate the cost impact of the average value of 0.76 achieved that year: "additional delay of 0.26 minutes per flight equates to an additional cost to airspace users of an estimated 240M€ per annum of indirect cost exposure (Delay Calculation 25,321 flights/day x 365 x €100)" [f-iv, p.32]. On the basis of this cost of an additional 0.26 minutes of delay, on average, it is recommended that "the European Commission should consider interventions under Article 18 (2) of the Performance Regulation", i.e. **to ensure that delays are limited to 0.5 minutes/flight and additional cost to airspace users is avoided** [f-iv, p.32].

5. Sources to corroborate the impact (indicative maximum of 10 references)

[a] EUROCONTROL: (i) Business Case Team. *Standard Inputs for EUROCONTROL Cost-Benefit Analyses,* ed. 08 Jan. 2018 (ii) Performance Review Unit (PRU) with the ACE Working Group. "ATM Cost-Effectiveness (ACE) Benchmarking Report" yearly May updates, e.g. 2016, 2017, 2018.

[b] (i) NERL. *Appendices RP3 Business Plan 2020-2024*. Oct. 2018 (ii) PricewaterhouseCooper. *Airservices Australia Metron Traffic Flow Benefits Realisation*. Dec. 2014 (iii) Airservices Australia, *Air traffic flow management, software: Harmony* Accessed Feb. 2020 (iv) Airservices Australia, *Airservices Annual Report 2014-15*. 2015

[c] (i) DfT, *Airports: The Government's View*, Summary document. Oct. 2016 (ii) Airports Commission, *Airports Commission: Heathrow Airport North West Runway: Business Case and Sustainability Assessment*, Nov. 2014 (iii) Airports Commission, *Economy: Final Delay Impacts Assessment*, Jul. 2015 (iv) DfT. *Upgrading UK Airspace: Strategic Rationale*. Feb. 2017 (v) BBC "Heathrow expansion: What is the third runway plan?" Dec. 2020

[d] (i) Bråthen, S., Hoff, K.L., *et al. Economic impact assessment of the new ICAO standard for contaminated runways. A case study of four Norwegian airports*. Report 1804. Møreforsking Molde AS. 2018. (ii) EASA. "European Union Aviation Safety Agency, Notice of Proposed Amendment 2018-14: Runway safety RMT.0703 (includes also RMT.0704 'Runway surface condition assessment and reporting)" 17 Dec. 2018 (iii) EASA. "European Union Aviation Safety Agency, Explanatory Note to Decision 2020/007/R" 02 Jul. 2020

[e] (i) SESAR About page [link] (ii) EUROCONTROL on UDPP [link] (iii) Testimony: former leader of UDPP project, EUROCONTROL (iv) Pilon, N., et al. "Reducing Impact of Delays using Airspace User-Driven Flight Prioritisation: User Driven Prioritisation Process Validation Simulation and Results", SESAR Innovation Days, 2019 (v) EUROCONTROL. "LSSIP 2019 - Switzerland Local Single Sky Implementation: Level 1 – Implementation Overview" Apr. 2020

[f] (i) Commission Implementing Regulation (EU) No 390/2013, 03 May 2013 (ii) Commission Implementing Decision, 11 Mar. 2014 (iii) EUROCONTROL, *Capacity assessment and planning guidance document*, ed. 2.8, 2013 (iv) Performance Review Body, *PRB Annual Monitoring Report 2015,* vol 1, 2016