Controller Time and Delay Costs

- a trade-off analysis

L. Delgado and A. Cook
Department of Planning and Transport
University of Westminster
London, United Kingdom

S. Cristóbal
The Innaxis Foundation and Research Institute
Madrid, Spain

H. Plets
Belgocontrol
Brussels, Belgium

***Abstract*— Air traffic controller shortages remain a significant challenge in European ATM. Comparing different rules, we quantify the cost effectiveness of adding controller hours to Area Control Centre regulations to avert the delay cost impact on airlines. Typically, adding controller hours results in a net benefit. Distributions of delay duration and aircraft weight play an important role in determining the total cost of a regulation. Errors are likely to be incurred when analysing performance based on average delay values, particularly at the disaggregate level.**

Keywords-controller hours; cost non-linearity; cost of delay; regulation

I. INTRODUCTION

This paper reports on early analyses supporting the ‘ComplexityCosts’ project. The primary objective of the project is to better understand European air traffic management (ATM) network performance trade-offs for different stakeholder mechanisms. We define such mechanisms as those designed to afford resilience for one or more stakeholders during disturbance, and to which we may assign a monetary cost.

One such mechanism is adding controller hours to Area Control Centre (ACC) regulations in order to avert the delay cost impact on airlines. This paper focuses primarily on the cost effectiveness of such actions. The wider project modelling and application of the disturbances have been described earlier [1] and are on-going.

Overall, capacity and weather-related issues are the main reasons for Air Traffic Flow (and Capacity) Management (ATF(C)M) regulations [2]. From our analyses, ATCO (air traffic controller) staff shortages were the sixth most common reason for implementing ATFM regulations, the fifth highest by ATFM delay costs generated, and the fourth highest by total minutes of delay. In 2014, average, daily en-route ATFM delays increased by 17.4% mainly due to: ATC capacity (+27.8%), en-route ATC staffing (+44.9%) and en-route weather (+23%) delay [2]. Staff shortages thus remain a significant challenge in European ATM.

In this paper, Section II presents an overview of the state of the art. In Section III, the methodology is presented. The analysis of the results and main findings are described in Section IV. Conclusions and planned further work are presented in Section V.

II. STATE OF THE ART

Increasing ATCO hours to alleviate delay is a complicated issue. Challenges facing ANSPs with regard to the strategic planning of ATCOs include the unpredictability of future traffic and fairly long (approximately 3 year) lead times for ATCO training. From a tactical perspective, the assignment of ATCO hours depends on two major factors: (i) flexible rostering; and, (ii) controller mobility. With regard to rostering, some ANSPs are constrained by rigid staffing policies, which do not take account of traffic variations during the day. This leads to over-staffing during off-peak periods and controller shortages during periods of greatest demand, whilst, crucially, the total ATCO hours required to obviate or optimise delays might actually be available.

ATCO workload is recognised in the literature as one of the main capacity bottlenecks for en-route airspace [3]. When demand cannot be accommodated by opening further sectors (i.e. the airspace is already at its maximum number of operational sectors or there is a lack of staff), ATFCM measures, and hence delays, are introduced. Staff-related disruptions can be produced due to insufficient planning, but the tactical management of resources during the day of operations also plays a significant role (*ibid.*) As reported in [4], in general, there is also an overstaffing effect associated with seasonal cycles. During periods where demand is low, e.g. winter, ATCOs are still often called on duty due to contractual agreements.

En-route ACCs sectors are commonly managed by a team of two ATCOs: an executive and a planner controller [5]. This assignment could change during exceptionally low or high demand, e.g. with both roles carried out by a single ATCO or adding a third controller to a team [5, 6].

Dynamically optimising the number of ATCOs required has been addressed in previous research, such as [6]. However, various limitations to dynamic management exist (e.g. ATCOs should have two hours' break per shift) [3]. The process typically begins months in advance, the objective of the ANSPs being to provide sufficient workforce through the day whilst minimising the associated cost. This operational plan evolves until the publication of the final ATCO rosters. Some ANSPs, instead of using rigid master planning, implement a strategic planning process approach with progressive refinement as more information becomes available, as typified by the following sequence of phases [7]:

(1) *Master* (or *strategic*): e.g. from twelve to three months prior to execution day. An analysis based on economic conditions, available staffing and future traffic is carried out to produce the master plan for the sector opening scheme and the roster pre-publication. At this stage, the maximum amount of time all ATCOs can work during a single day is considered. (2) *Planning*: until two weeks or so prior to execution, the master plan is monitored and the roster is published. (3) *Pre-tactical*: the master plan is updated and an optimisation of the flexible shifts is carried out up to the day before operations. (4) *Tactical*: the day before execution, the master plan is updated based on short-term information and becomes the day of operations plan. (5) *Execution*: dynamic information is considered during the execution phase. (Often, (4) and (5) are both considered as 'tactical'.)

An example is the Maastricht Upper Area Control Centre where demand-based rostering is deployed, in conjunction with monthly efficiency monitoring. Various tools developed in-house are used in the rostering process, including 'TimeZone' [7]. This tool is used primarily strategically (around 12 months in advance) to determine the most efficient *number* of shifts required, and then pre-tactically (D-14 days) to tactically, for finely-controlled, optimised position planning and shift time allocations in the ops room. Fully integrated with this tool, and deployed between the strategic and pre-tactical phases, is the 'Ops Roster Tool', which takes ATCO personal preferences into account and builds individual controller assignments.

Various constraints are taken into consideration when developing such planning processes, such as: shift durations, breaks, multiple-tasking, ATCO's qualifications, rotations to maintain skill levels and an ability to re-roster in the event of unexpected occurrences, demand and workload [8]. Buffers may also be introduced at the different planning stages to cope with uncertainty; in [3], the inefficiency of these buffers along with airspace execution performance is considered as a measure of the operating cost efficiency of the ANSP.

Capacities may also be increased, limiting the impact on the number of ATCOs required, with solutions such as multi-sector planning (MSP). The implementation of MSP offers medium-term strategic solutions, planning trajectories over several sectors. This has been demonstrated to have significant potential to improve the efficiency of ATC resource utilisation (see, for example, [9]), and although validated in Europe with plans for implementation in progress, has hitherto not been substantially applied.

With many such technology solutions presented above readily available, the main reason why some ANSPs have not adopted them, and maintained less flexible rostering, is lack of social acceptability. Another influencing factor is that single-manned sectors during peak hours are not permitted in Europe (whereas they are in the US, for example). Furthermore, regarding ATCO mobility in Europe, forecasting the required ATCO numbers is undertaken at the individual ANSP level, due to licencing heterogeneity and the absence of any supra-national pool of controllers. This variously contributes to staff shortages (e.g. causing delays) or over-staffing (e.g. causing cost inefficiencies).

Tactical optimisation of resources is out of scope for this paper; nor do we consider at this stage issues such as sector complexities, workload evaluation and non-linear allocation effects. For the evaluations presented, we assume that in order to increase the capacity of the ACC, the number of ATCOs available is incremented in two-controller steps. This aspect of the methodology is elaborated in Section III(B). A key focus of our paper is the explicit trade-off between the cost of additional controller provision and the associated, disaggregate delay costs incurred by airlines, not hitherto explored in the literature.

III. METHODOLOGY

A. Data

Regulation and airspace data were sourced from the Demand Data Repository 2 (DDR2) [10], using all days in the period AIRAC 1313 – AIRAC 1413 (12DEC13 – 07JAN15). All flights that operated in Europe (European Civil Aviation Conference area) during that period with a trajectory through a regulation were initially in scope (1 349 217 flights). Commercial passenger flights were selected for the estimation of the cost of delay. Aircraft types with an MTOW (maximum take-off weight) of less than 15 tonnes were thus excluded, along with those that corresponded to military or cargo operations and business aviation. 1 304 607 flights remained in scope. Some over-estimation of commercial flights may have resulted (e.g. commercial aircraft operators flying a cargo flight). ATFM regulation data (duration, location and reason) were also obtained from the DDR2 database.

B. Adding extra ATCO hours

Some simplifying assumptions are applied at this stage of the modelling. If, by adding ATCO hours, the regulation could not have been avoided, we assume it should have been reported as a different cause (e.g. capacity). Instances with (non-capped) overflows from adjacent sectors due to an airspace closure, or ATCOs being unable to report for work due to bad weather, are potential examples of issues associated with the reporting of accurate causes. These are also reflected in airline delay reporting (especially for reactionary delays). Indeed, the allocation of the 'reason' code for the regulations is defined at the local FMP level and may be somewhat subjective, especially were several factors pertain. However, taking the DDR2 causes as recorded, we assume that by adding ATCO hours to regulations caused by staff shortages, the delay generated and associated airline costs would be averted.

As mentioned, the number of ATCOs available is incremented in two-controller steps, thus allowing the use of a sectorisation with one additional sector. Such potential increments in the number of ATCOs operating in the ACC are deployed up to the maximum number of staff reported in the same ACC during the AIRAC (Aeronautical Information Regulation And Control) period under study, through supporting analyses of the DDR2 data.

Again, notwithstanding some limitations of the approach, the modelling in this paper is focused on **understanding the impact** of increasing ATCO hours on regulation delay costs, rather than the *mechanics* of implementing such hours *per se*. Two rules have been defined for the addition of staff.

Rule 1, 'fractional-shift ATCO costs': Extra controller time is only added between the start and end of the regulation. The extra ATCO effort assigned is represented by the coloured shaded areas of Fig. 1. In some cases, the number of controllers will be limited by the maximum possible at the ACC. For example, adding a further two controllers to an existing four extra (i.e. six in total), leads to an effective net increment of fewer ATCO hours than adding two further controllers to an existing two extra (i.e. four in total). This is because during the periods 1400 – 1600 and 1700 – 1800 the maximum number of controllers in the ACC is already attained with four extra ATCOs. In general, Rule 1 assigns the *minimum* number of ATCO hours required to increase the capacity, also allowing fractional hours to be added. It should thus be considered as a minimum possible ATCO cost baseline.

Rule 2, 'full-shift ATCO costs': This second rule has been designed to best reflect operational requirements. Whole ATCO shifts of 7 hours are used as increments, i.e. 14-hour blocks for the ATCO pairs. Limited rostering flexibility is allowed, in that a regulation of up to 8 hours is deemed resolvable by adding effort over 7 hours. Beyond this time, another 7-hour block is added, which might sometimes resolve a subsequent, separate, regulation, although we have not quantified such impacts, nor better optimisations which might be achievable within the applied blocks. No *optimisation* is performed regarding the time when the controllers should start and end their shifts, as long as the regulation period is covered by the additional shifts.

C. *Cost of extra staff*

Full service provision costs can be broken down into three economic factors [11]: ATCO-hour productivity, employment costs per ATCO-hour, and support costs per composite flight-hour. Support costs represent 70% of the total provision costs, including the employment costs of non-duty staff (e.g. ATCOs on other duties, trainees, technical support), non-staff operating costs (e.g. energy, communications), exceptional costs, and capital-related costs (e.g. depreciation and financing). As we are here considering the measure of adding ATCO hours at the (pre-)tactical level, only duty ATCO hours are applied. Costs

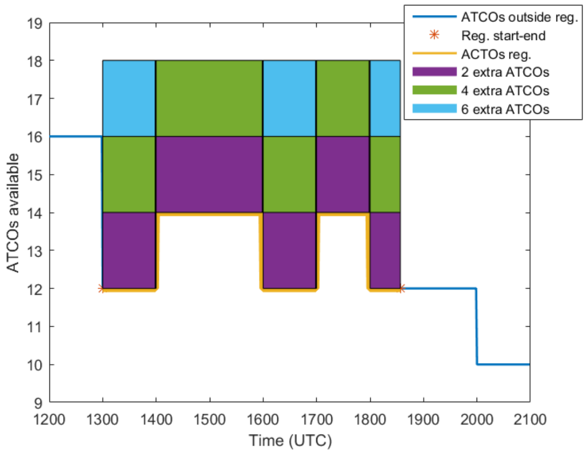


Figure 1. Rule 1 example: shaded areas indicate ATCO-hour increments.

such as training and strategic re-sectorisation are not accounted for. We have used individual costs per ANSP, as defined in [12]. The average cost of an ATCO duty-hour for 2014 was EUR 108.

D. *Cost of delay estimation*

The cost of delay to the airlines has been computed using provisional, at-gate 2014 costs, building on the team's earlier work for EUROCONTROL [13][1]. Explicit values have been calculated for fifteen 'core' aircraft, by delay duration, representing a range of weights and covering 63% of movements in the ECAC area. For non-core aircraft, good fits of cost with √MTOW were used ($r^2_{min} = 0.98$).

Although the passenger cost of delay is often a dominating delay cost for operators, there remains relatively limited evidence supporting the calculation of such costs. A key feature is the impact of Regulation (EC) No 261/2004, which establishes the rules for compensation and assistance to airline passengers in the event of denied boarding, cancellation or delay. In February 2014, a proposed strengthening of such air passenger rights passed its first reading in the European Parliament [14]. Furthermore, a number of national rulings have impacted the interpretation and application of the Regulation, mostly in terms of extending the scope in favour of the passenger [15]. Revisions to our passenger cost estimates have also taken into account a 2012 study by Steer Davies Gleave in support of a Commission Impact Assessment [16].

The costs used are primary delay costs, to avoid double-counting in the network. It is also important to note that such delay costs are non-linear as a function of delay duration. For example, the average cost *per minute* at 60 minutes of delay is just over fourfold the value for 5 minutes of delay.

[1] Our passenger delay cost estimations have gone out to airline consultation. Other costs, relating to fuel, maintenance and crew, are more readily quantifiable from (published) data sources. It is planned to publish our full 2014 estimates and supporting methodology, in December 2015.

IV. ANALYSIS AND RESULTS

A. *Regulations and delay cost*

In the period under study there was a total of 22 850 ATFM regulations issued, which generated a total of 9.8M minutes of delay (6.6M ATFM minutes en-route; 3.2M ATFM minutes airport). As a comparison, in [11], for 2014, 9.0M minutes of delay were reported (5.6M ATFM minutes en-route; 3.4M ATFM minutes airport). These EUROCONTROL-reported data (*ibid*.) cover only the Single European Sky Performance Scheme area, and the calendar year 2014, whereas our data extend somewhat further geographically and temporally (see Section III(A)).

From the 9.8M minutes of delay in our model, 8.8M minutes of delay generated cost (i.e., after excluding cargo, military and business aircraft), leading to an estimated cost of EUR 489M for the commercial flights (EUR 333M ATFM en-route; EUR 156M ATFM airport), which gives an average *primary* ATFM delay cost of 55 EUR/min. (Of note, such averages vary by cause, ranging from 48 EUR/min for aerodrome capacity to 96 EUR/min for industrial actions.) In comparison, in [11], the total cost of ATFM delays for 2014 is estimated at EUR 710M (EUR 440M en-route; EUR 270M airport) in the SES area. An average cost of 79 EUR/min is used (*ibid*.) for the costing of these ATFM departure delays in 2014, using EUR_{2009} prices, at the full tactical cost (i.e. including reactionary delay). Our calculations (not shown) show these costs to be fully consistent, the differences being mainly attributable to passenger cost variations and inclusion or exclusion of reactionary costs.

In our calculations, 5.7% (1 317) of all the ATFM regulations had staff shortages as the main cause. Of these, 1 151 regulations were en-route and 166 airport-related. The ATCO staff shortage regulations generated 671 746 minutes of delay (6.8% of the total ATFM delay) and a total cost of EUR 30M.

The regulations applied within an ACC that had more than one airspace configuration were analysed further. A total of 1 112 regulations thus remained (96.6% of all the regulations due to en-route ATC staffing shortages). 80 935 flights crossed these regulations, of which 33 648 had delays assigned (596 525 minutes in total) – an average of 18 minutes of delay per delayed flight. After the non-commercial exclusions, there were 30 095 such flights generating 528 757 minutes of delay and EUR 26M of delay cost – an average of 50 EUR /min. Of the 1 112 regulations reported, there were 64 that did not generate any delay.

Since we are interested in the cost generated by the regulations, only delay which generated cost will be considered in the following analyses. Fig. 2 shows the top ten ANSPs and ACCs that generated the maximum delay along with the percentage of the total cost generated within that top ten. Note that Deutsche Flugsicherung (DFS) (ED code) is the ANSP that generated the maximum percentage of delay, very closely followed by Cyprus DCAC (LC). However, the *cost* generated was higher in the Cyprus airspace than in the German case. There were more flights affected in the ED airspace than in the airspace of LC (7 229 and 4 979 flights with delay assigned, respectively), hence the average delay per delayed flight in Germany was 14 min/flight, whilst in Cyprus it was 21 min/flight. The non-linearity of the relationship between cost and delay accounts, partially, for the extra cost of the lower total delay of LC, compared with ED. Another factor (as presented later) is the weight of the aircraft affected by the regulations.

Focusing on the ACCs, it is observed that with DFS as the ANSP generating the overall maximum amount of delay, that delay was generated by several ACCs, while in Cyprus, all the delay was generated by a single ACC. This means that the ACC centre of LCCCCTA was the single greatest contributor

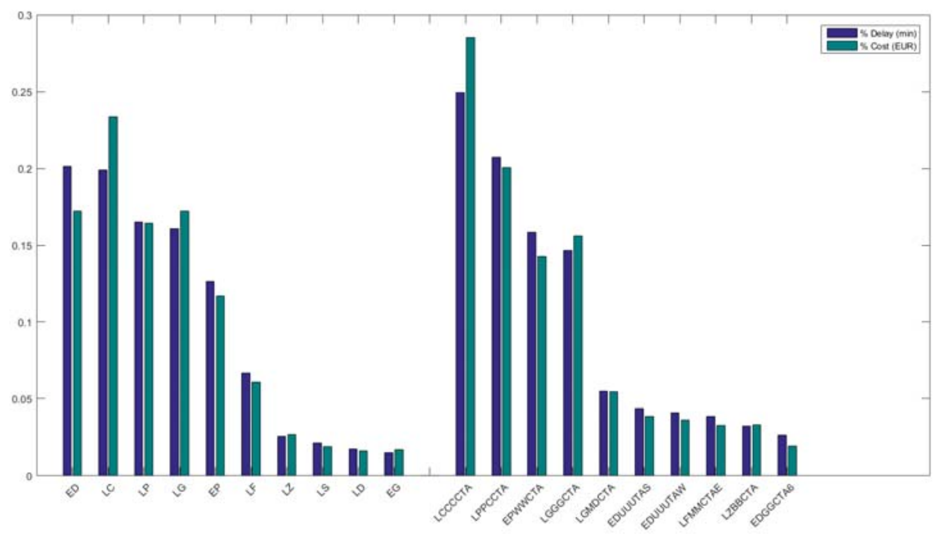


Figure 2. Delay and cost by top 10 ANSPs and ACCs by ATFM delay due to ATC staffing. (Only delay that generated cost considered.)

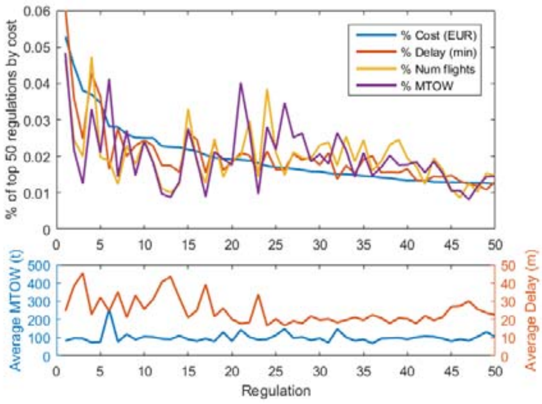


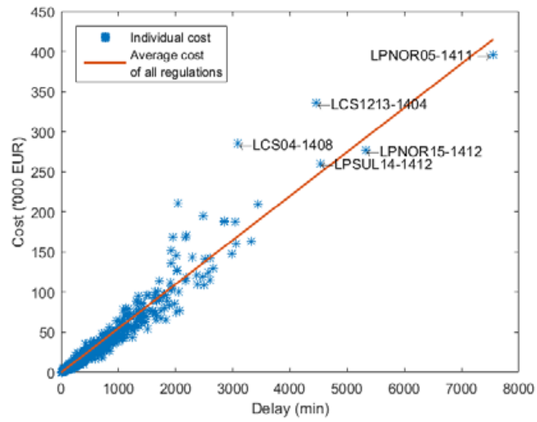
Figure 3. Top 50 regulations by cost generated due to ATC staffing.

of delay and delay cost for the network during the period of study. Further analyses are required, but this suggests that the Cyprus regulations have higher than average delays assigned to aircraft, thus leading to higher costs.

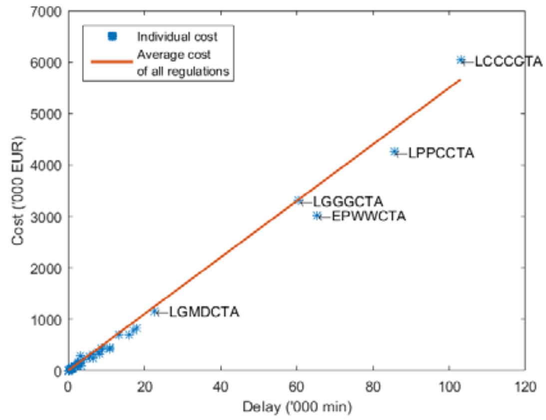
Note that even with the total number of minutes of delay higher in the German airspace, the non-linearity of the cost with the delay duration means that the distribution of that delay plays a role in the total cost generated. Similar principles are observed between the Portuguese and Greek ANSPs: higher delays in Portugal led to lower costs than the delays generated by Greece due to ATC staffing problems.

Fig. 3 presents the percentage values of delay cost, delay minutes, number of flights affected and aircraft weight, for the top 50 regulations that generated the highest delay costs. The plot is ordered by delay cost, from highest (left) to lowest. Once again, we note how in some cases, the total delay generated does not relate directly with the delay cost of that regulation. For example, the sixth regulation by cost has a lower amount of delay that the seventh regulation, however, the average weight of the aircraft going through that regulation was higher (average MTOW of 259 tonnes, c.f. 77 tonnes), even with a lower average delay (25 mins/flight, c.f. 35 mins/flight). Thus, both the parameters delay duration and aircraft weight play a role in determining the total cost of a regulation.

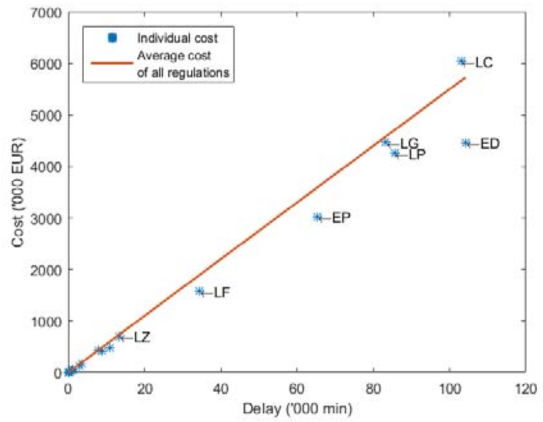
Fig. 4 summarises the relationships between the delays generated by the ATCO shortage regulations and the costs that the associated flights incurred due to those delays. The cost that would be generated by using the *average* value instead of computing the actual cost for individual flights is also shown in the figures. By the ‘average’ value, we are referring to the average cost over all regulations of 55 EUR/min cited above. Note that there are a significant number of regulations (panel (a)) that have a total cost higher than the value obtained using the average values. As the data are aggregated by ACCs and ANSPs, this variability with respect to the average value is reduced (panels (b) and (c)), as the average cost is then closer to the average value of the subset of flights analysed. However, even at the ANSP level there is a deviation from the average of 55 EUR/min. For the regulations that were issued due to en-



(a) by regulations



(b) by ACCs



(c) by ANSPs

Figure 4. Delay and cost of delay relationship.

route ATCO staff shortages, this average value is reduced to 50 EUR/min. This shows the error that is incurred when analysing performance based on average delay values alone. In general, assessing the cost individually by particular regulations, ACCs or even ANPS, might well generate lower or higher costs for similar amounts of delay. Hence, individual flight cost computations should be used when deciding which areas might have a higher return from a given set of investment mechanisms, since a higher delay does not always represent a higher cost. When using average values, such effects may often be obscured.

B. Extra staff mechanism analysis

In this section, the effect of adding extra ATCOs to mitigate the regulations due to ATCO staff issues is analysed. The average difference between the average number of ACTOs available during the regulations and the maximum number of ATCOs available at the ACC where the regulation was implemented is 4.3 ATCOs. Therefore, there is, on average, the possibility of adding four controllers during such regulations. If a window of four hours before and after the start and end time of the regulation is considered, the difference of the average number of ATCOs present during the regulation with respect to the maximum number of ATCOs seen in that window period is 2.4 ATCOs. Thus, in a window close to the regulation it would be possible, on average, to increase the number of ATCOs by two.

Two particular types of case have been identified when analysing the ATCOs declared as being assigned. 198 (17.8%) regulations in scope had, during the regulation, some period of time during which the number of ATCOs available was the maximum (ever) available for the ACC. Of those, for 60 regulations (5.4% of the total number) this applied during the whole duration of the regulation. In the former case, it was assumed that the regulation could be averted by adding controllers, while in the latter it was considered that since the maximum number of ATCOs was already achieved, adding further ATCOs would not avert the regulation. Since the categorisation of regulations is carried out at a local FMP level, we do not have access to the reasons behind the decision to assign such regulations to ATCO staff shortages. Nevertheless, those 60 regulations generated a total of 18 111 minutes of delay to 1 037 flights, representing EUR 0.9M.

In the other cases, the cost of adding controllers has been computed and compared with the cost of the delay generated by the regulation. It is assumed that the regulation would not be required after adding such additional staff and, therefore, its delay cost would be averted. Fig. 5 presents two regulations as examples.

Regulation KWUR1C20 of AIRAC 1410 generated 121 minutes of delay (EUR 5 251). As shown in Fig. 5 (panel (a)), Rule 1 adds controllers only during the period of time of the regulation, and, as presented in panel (c), the cost of the delay generated is high enough such that there is always a net gain by adding controllers. Even if the maximum number of controllers that the ACC can have in operation is deployed, the net gain is EUR 3 800. We note that when controllers are added, at some point the maximum number of controllers at the ACC is attained and therefore the effort and cost increments are not uniform in the plot. If a more operational approach is taken, and 7-hour shifts are deployed (Rule 2, panel (e)), then there is a break-even point. When the regulation can be resolved by adding four controllers in one shift (i.e. 28 extra ATCO hours in total), with one group of two controllers there is a net gain. However, if more than four controllers are required, then the cost of those controllers is higher than the cost of the delay of the regulation, and a net loss results.

Fig. 5 (panels (b), (d) and (f)) presents another example (regulation EPJR14N in AIRAC 1407) where, by applying Rule 1, it is possible to find a set of increments of ATCO hours that leads to a net gain, but, since the delay and the cost of the regulation were low (9 minutes and EUR 390), if full shifts were added (Rule 2), a net loss results.

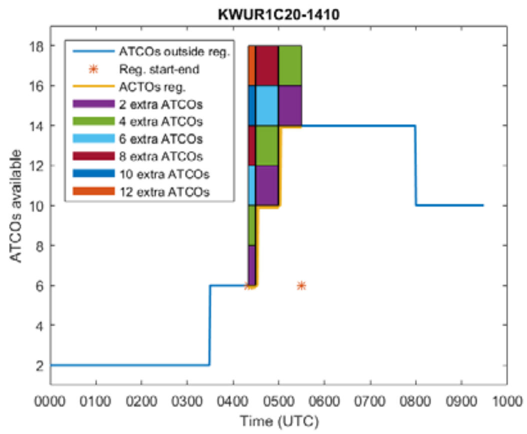
As shown in the previous examples, when adding ATCO hours, assuming that the corresponding regulation could be averted, three outcomes are possible:

i) **net gain:** the cost of the delay is high enough to justify adding ATCOs up to the maximum available at the ACC;

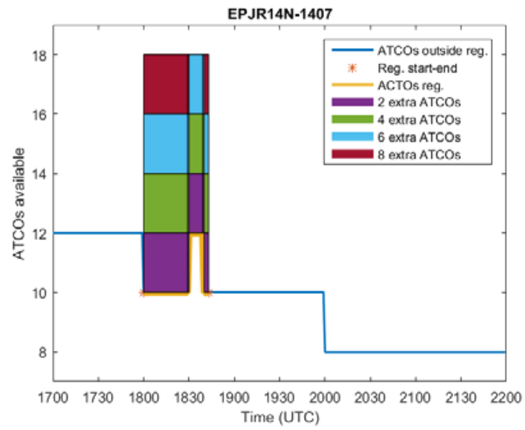
ii) **net loss:** adding controllers leads to higher costs than the delay costs;

iii) **trade-off:** with a smaller number of controllers their cost is off-set by the cost of the delay avoided, whereas adding more controllers leads to a higher net cost than the avoided delay.

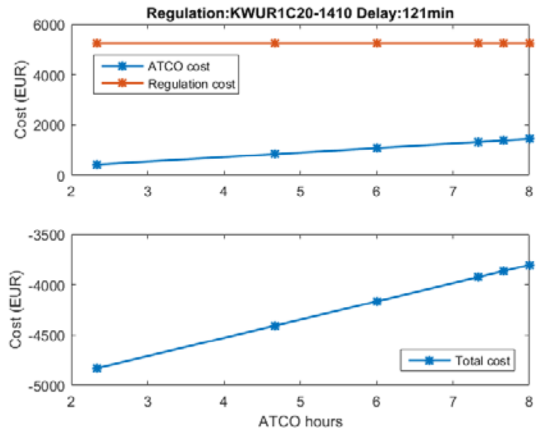
Table I shows the number of regulations, as a function of the above outcomes, under Rule 1 and Rule 2. Under Rule 1, 87.1% of all the regulations benefit from adding ATCOs, even if this represents having the maximum available for the ACC during the period of the regulation. For 64 regulations (5.8%), adding ATCOs represents a higher cost than the cost of the delay generated by the regulation. In 1.7% of the cases, there is a trade-off as a function of the number of controllers required. Adding operational constraints to better reflect practice, under Rule 2, the number of regulations that benefit decreases, but still comprise over 70%. In 8.5% of cases a trade-off now exists. In 13.4% of cases, adding controllers represents a higher cost than the delay potentially averted. In total, there were 66 regulations that did not generate any reported delay, possibly since they were not the most penalising regulation. In summary, in the majority of cases, the cost impact on airlines due to the regulations are high enough to justify the addition of extra ATCO staff.



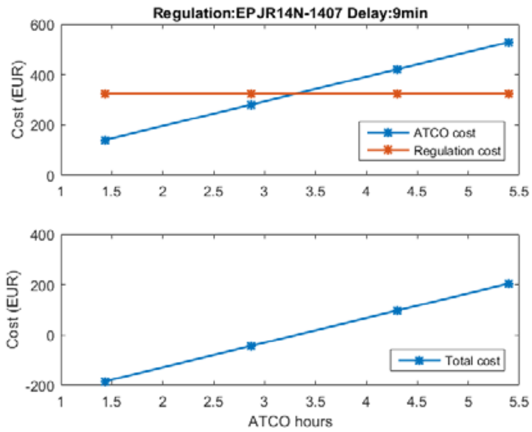
(a) Regulation KWUR1C20 in AIRAC 1410



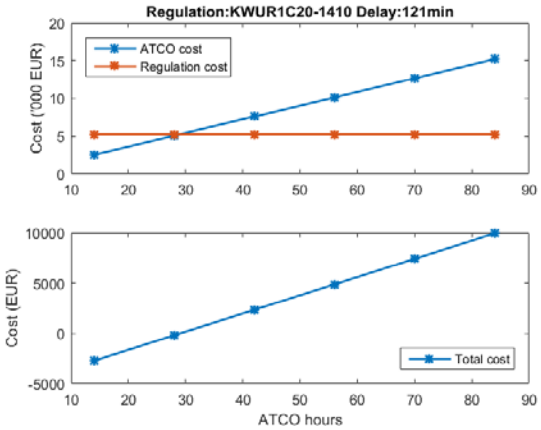
(b) Regulation EPJR14N in AIRAC 1407



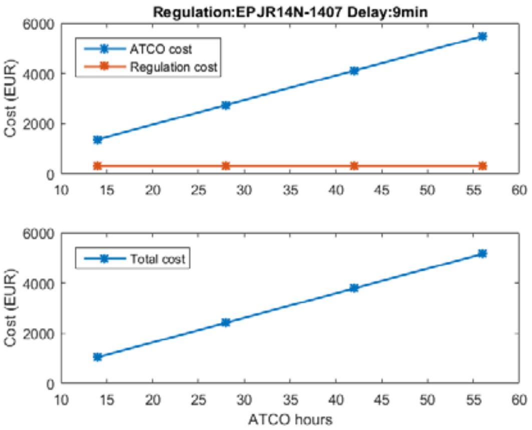
(c) Regulation KWUR1C20 in AIRAC 1410 – Rule 1



(d) Regulation EPJR14N in AIRAC 1407 – Rule 1



(e) Regulation KWUR1C20 in AIRAC 1410 – Rule 2



(f) Regulation EPJR14N in AIRAC 1407 – Rule 2

Figure 5. Example costs delay and extra staff for Rule 1 and Rule 2, for two regulations.

TABLE I. RELATIONSHIP BETWEEN RULE APPLIED AND ADDING ATCOS

Rule	Net gain	Net loss	Trade-off
1	**87.1%** (969)	**5.8%** (64) [a]	**1.7%** (19)
2	**72.7%** (808)	**13.4%** (149) [a]	**8.5%** (95)

a. 56 regulations in these categories do not have delay.

V. CONCLUSIONS AND FURTHER WORK

If average costs of delay are used per minute of ATFM delay, close approximations to actual values (i.e. computed by individual delay durations) may be obtained for aggregated data (e.g. at an ANSP level). However, for smaller samples (e.g. at a regulation or ACC level) the variability of cost values around that average, due to different distributions of delays and aircraft weights traversing the airspace, renders estimates made through averages more prone to error. Therefore, when deciding on areas that might benefit from improvement mechanisms (adding extra ATCOs, in this case), the characteristics of the delays and costs should be considered, and not only the total delay generated.

Results show that, in the majority of cases, the cost of a regulation's delay is sufficiently high to justify adding extra ATCO resources, even if that means that the maximum number of controllers possible at the ACC are on duty. This controller cost is below the delay cost of the regulation in 73% of the cases when full 7-hour shifts are added. Note, however, that in such cases, the stakeholder bearing the cost (the ANSP) is different from the stakeholders obtaining the benefit (the airlines and passengers). It is not surprising that one of the key points raised by the airspace users in [2] was that continued work must be undertaken to address staffing and capacity issues. This effect will probably be greater still in future, considering the evolution in average aircraft size (and weight) in Europe. In 2014, the number of flights was still below 2008 levels, however, there has been a continuous increase in average aircraft weight and passenger numbers [11] – thus driving up unit delay costs. This extra cost burden on the ANSPs to provide additional resources might also have an impact in terms of lower reported productivity, with more resources required to handle similar traffic.

In this research, we have not explicitly established if a regulation could actually be averted by adding extra ATCO hours. The assumption has been made that if the regulation reason indicated was ATCO staff shortages, then by adding staff resources, the regulation could be avoided. More detailed modelling should be carried out to estimate the impact of such extra staff on the capacity that can be provided. For example, information on the capacity of different sectorisations could be considered. (In future, initiatives such as dynamic sectorisation, MSP, mobility of ATCOs, virtual ATC centres, improved ATM systems, or merging ACCs and/or ANSPs, may contribute to improving ATCO productivity, and these may all benefit from improved impact modelling.) In some cases, regulations might not be completely averted, but reduced in duration and/or intensity. Thus improved trade-offs between adding/managing resources and delay could be established.

Future work should also consider modelling the parameters that affect the distribution of delays generated by regulations (e.g. regulation duration, capacity declared, demand, etc.). In this manner, it would be possible to analyse what characteristics of a given regulation are more important when generating delay and, especially delay cost, since cost increases non-linearly with delay duration. It might be preferred to have greater total delay distributed between more flights than higher individual delays.

ACKNOWLEDGMENT

This work is co-financed by EUROCONTROL acting on behalf of the SESAR Joint Undertaking (SJU) and the European Union as part of the SESAR Exploratory Research programme. Opinions expressed in this work reflect the authors' views only. EUROCONTROL and/or the SJU shall not be considered liable for them or for any use that may be made of the information contained herein. We are grateful to Imperial College London for insights in Section II.

REFERENCES

[1] Cook, A., Delgado, L., Cristóbal, S., Blanch, A., 2014. What cost resilience? Schaefer, D. (Ed.) Proceedings of the fourth SESAR Innovation Days, Madrid.
[2] EUROCONTROL, 2015. Annual network operations report 2014.
[3] Tobaruela, G., A Framework to assess the ability of automation to deliver capacity targets in European airspace, PhD dissertation, Imperial College, London, March 2015.
[4] Grebenšek, A., Magister, T., 2012. Effect of seasonal traffic variability on the performance of air navigation service providers. Journal of Air Transport Management, 25, 22-25.
[5] Transportation Research Board, 2010. Air traffic controller staffing in the en-route domain – A review of the Federal Aviation Administration's task load model. National research council, Washington D.C., 2010.
[6] Tien, S.L., Hoffman, R., 2009. Optimizing Airspace Sectors for Varying Demand Patterns using Multi-Controller Staffing. Eighth USA/Europe ATM Research and Development Seminar Napa, CA.
[7] Tobaruela, G., Majumdar, A., Ochieng, W.Y, Schuster, W., Hendrickx, P., Enhancing cost-efficiency and reducing capacity shortages: Strategic planning and dynamic shift management, 10th USA-Europe ATM Seminar, Chicago, 10-13 June 2013.
[8] Conniss, R., Curtois, T., Petrovic, S., 2014, Scheduling Air Traffic Controllers, 10th International Conference of the Practice and Theory of Automated Timetabling, PATAT 2014, York, United Kingdom, 26-29 August 2014.
[9] Williams, A., Rodgers, M.D., Mondoloni, S., Improving ATC efficiency through an implementation of a multi sector planner position, 7th USA-Europe ATM Seminar, Barcelona, 02-05 July 2007.
[10] EUROCONTROL, 2015. DDR2 Reference manual for generic users, v. 2.1.2.
[11] EUROCONTROL, 2015. Performance Review Report 2014 – An assessment of Air Traffic Management in Europe during the Calendar Year 2014. Performance Review Commission.
[12] EUROCONTROL, 2014. ATM Cost-Effectiveness (ACE) 2013 benchmarking report with 2014-2018 outlook.
[13] Cook, A., Tanner, G., 2011. European airline delay cost reference values. Commissioned by EUROCONTROL Performance Review Unit, Brussels.
[14] European Commission, 2014. European Parliament votes on air passenger rights, Press Release IP/14/119, Brussels, 5 Feb. 2014, 1-4.
[15] Correia, V., Rouissi, N., 2015. Global, regional and national air passenger rights – does the patchwork work? Air & Space Law, 40 (2), 123-146.
[16] European Commission, 2013. Commission staff working document – impact assessment, Brussels, 13 March 2013