Evaluating the efficiency of functional airspace blocks

Paula Rachel MARK
TTCAA
Port of Spain, Trinidad and Tobago

On ledges, one sees troll paths (rifts)
The dream, an iceberg - Tomas Tranströmer (translated from French)

Abstract: Functional airspace blocks are like icebergs. They have a two-fold significance in their activity. Evaluation of their efficiency will not be complete without investigating the impact of inherent latent effects associated with hybridization and air traffic management. A generalized linear latent and mixed model or gllamm analysis is an alternative analytical technique that can be called a statistical multitasker. In this scenario, it does more than explore the impact of censoring events. It also evaluates the key performance areas that govern the development of these hybrid airspaces and predicts the effect on their performance. Gllamm analysis is one example of a data analysis used in aviation. Yet it has the drawbacks of being novel as well as being a long and tedious methodology. However, it is useful as a comparative, post estimation technique. Based on the indomitable presence of heterogeneous factors that weigh upon the performances of air navigation service providers, there is scope for other exploratory techniques with data in Air Traffic Management.

Keywords: Air Navigation Services Providers, air traffic management, efficiency, functional airspace blocks, generalized linear latent and mixed model, hybridization

I INTRODUCTION

Icebergs play an important role in the proliferation of marine ecosystems.[1] Just off the island of Malta, oceanographers have found a higher concentration of phytoplankton, krill[2] and seabirds within 1 to 4 kilometers off a nearby iceberg than in the open sea. But icebergs also pose a serious threat to the structure of ships. Recall the movie based on the account of the Titanic who had struck an iceberg that tore her side which weakened her structure and inevitably caused her to sink.[3]

Similarly, the concepts of functional airspace blocks (FABs) have been described as holding important positive roles in the optimization of the performance of Air Navigation Services Providers (ANSPs). These airspace blocks are hybridized upper enroute air spaces of the European Union (EU). But with economic hybridization comes the side effect of censoring factors which detract from the efficiency of the process. In addition, Air Traffic Management (ATM) is already highly subjective to a preponderance of latent events which impinge upon ANSP performance and in turn will affect FAB efficiency even more. Thus, in measuring the progress and prosperity of FABs, the evaluation will not be complete without the inclusion of the negative impacts upon them.

A general, latent, linear and mixed model or gllamm analysis is an alternative method that evaluates the performance of FABs by including the censoring factors in the analytical process. It is a useful technique that can predict, explore and validate relationships between efficiency concepts and the factors that influence them. This method operates on the principle that the efficiency of a FAB is affected by the productivity of an ANSP. In order to derive the test variables for this data analysis, we review the conceptual framework of the FAB initiatives and the latent factors that will impinge upon the process.

[1] National Geographic News, Thursday 28th October, 2010; news.nationalgeographic.com
[2] Shrimplike plankton
[3] Bassett, 1998 Engineering Department, University of Wisconsin

TABLE 1 – Summary of Europe's FABs[4]

FAB	STATES and ICAO Regions
UK-Ireland	United Kingdom, Ireland and NOTA/SOTA region, excluding Shanwick Oceanic FIR
DK-SE	Denmark except Greenland area (Sønderstrøm FIR) and Sweden
NEFAB	Estonia, Latvia, Finland and Norway including Norwegian Bodo Oceanic FIR
FABEC	Belgium, France, Germany, Netherlands, Luxembourg and Switzerland
Baltic FAB	Lithuania and Poland
FAB CE	Austria, Bosnia & Herzegovina, Croatia, Hungary, Czech Republic, Slovak Republic and Slovenia
Danube FAB	Bulgaria and Romania
South West FAB	Portugal including Madeira (and Santa Maria Oceanic FIR) excluding the Azores and Spain (including the Canaries FIR)[5]
BLUE MED FAB	Cyprus, Greece, Italy and Malta, Albania and Tunisia as associate partners, Jordan and Lebanon as observers

II HYBRID AIRSPACES

A preliminary report by the European-directorate of Transport stated that the airspace and its routes had been structured around national borders. Even though the modus of aircraft separation had been based on global ICAO standards, the level and quality of air navigation services (ANS) were based on differential equipment and domestic operational procedures for 63 ACCs of the ECAC area.[6] This resulted in an inefficient, fragmented air transport service that contributed to congestion, increased delays and exaggerated operational costs to provide a unit of air traffic control (ATC) and ancillary services[7] to 1 aircraft.

In 2004, a model of bottom-up regional cooperation[8] had been proposed to ANSPs of the EU to establish the regulatory framework for FABs of their upper air spaces. These FABs would be designed on the bases of uniform operational requirements and be free from the constraints of national borders. A more integrated airspace will mean less fragmentation, less delays, and lower costs of providing essential services to aircraft. According to Figure 1, these jointures would also fulfill the expectations laid out in ICAO's Global Air Navigation Plan for optimal efficiency which encompassed features of seamless interoperability, increased capacity, safety performance and environmental friendliness.

By the autumn of 2012, 9 Functional Airspace Blocks were declared by the European Commission as shown in Table 1. Data analytics determined that the hybridization of Europe's upper airspace would counteract the growing problem of inefficient ANS.

[4] As at December 2012
[5] Under review
[6] For further reading, see the following link : http://www.skybrary.aero/bookshelf/books/1351.pdf
[7] Examples of this service include Aeronautical information and ATIS reports of localized weather and field conditions
[8] Model originally introduced by Wilmer, Cutler and Pickering, 2001

FIGURE 1 – The FAB Approach – a common framework

If common strategic objectives are met that yield increases in safety performance, the ANSP's inefficiency decreases and in turn, the FAB efficiency increases. But FABs, like icebergs, exhibit a two-fold significance. If left unchecked, the inherent latent factors could undermine the optimal management of air traffic. As noted in the 2011 benchmarking report for ANSP performance, the ATM is a service industry that is highly characterized by unobserved heterogeneity.[9] Thus, an evaluation of FAB performance will not be complete without an estimation of the negative repercussions associated with economic hybridization.

III INHERENT LATENT FACTORS

A major challenge facing hybrid organizations[10] is the evolution of the organizational structure.[11] Organizational disorder (OD)[12] becomes magnified after a hybridization process. In this context, it is the merging of groups of enroute ACCs; each having an idiosyncratic organizational style; to follow innovative processes in ANS.[13] Organizationally deficient factors such as off-the-wall management policies, discord within the management hierarchy and a lack of clearly established organizational policy detract from the good intentions of hybridization. ANSPs are not exempt in this regard. One controller from the Middle East lamented that focus is usually placed on technical advancement but not much is done to promote the wellbeing of the controller.

Even small deficiencies in organizational structure (OS) negatively impacts upon ANSP performance. And the proverbial saying about one bad apple holds true in this case. One ANSP with a weak OS will affect the efficiency of a FAB for a group of ANSPs. OD is a latent effect in the FAB scenario. Very little documentation exists on the OS of ANSPs.

In addition to the role of OS, the second latent effect of economic hybridization is the operation of the unfortunate economic principle of marginal substitution.[14] As Figure 2 shows, there will always be a tradeoff between lowering the costs of ATM services and the quality of these services.[15] Let us assume that the strategic objectives of safety and efficiency for the FAB scenario are a set of goods that are available for each consumer – the ANSP. Efficiency is a composite good. It can be further subdivided into the goods of technical, operational, cost and environmental efficiency.

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[9] ACE Benchmarking Report 2011, PRC EUROCONTROL
[10] For further reading, follow this link: http://rachelp0504.blogspot.com/2013/02/hybridized-to-be-or-not-to-be.html
[11] Prof. Claude Ménard, 2004 Centre d'Economie de Sorbonne, Université de Paris 1 Panthéon Sorbonne
[12] Godkin and Allcorn, 2009 College of Business, Lamar University
[13] The hybridization of enroute upper airspace is a double process of merging and innovation which will not only increase the latent effect but the situation will also be more overwhelming for the stakeholders (internal and external)
[14] Jehle and Reny, 2001 explored the issue of marginal rate of technical substitution (Publishers: Prentice Hall)
[15] ACE Benchmarking Report 2011, PRC EUROCONTROL

According to the principle of marginal substitution, each consumer or ANSP will substitute at least one unit of a good so as to gain 1 additional unit of another good in order to keep maximized utility constant. Neither will 2 ANSPs have the same utility nor the same combinations of figurative goods. ANSPs are of comparable ages; unequal sizes; manage air traffic differently and accomplish organizational aims at varying operational speeds. It is therefore not economically viable for FABs to achieve maximum safety and efficiency simultaneously, or even to achieve constant indications of optimal performance. One of the goods will always trump the other. Optimal efficiency will exist in a state of flux.[16]

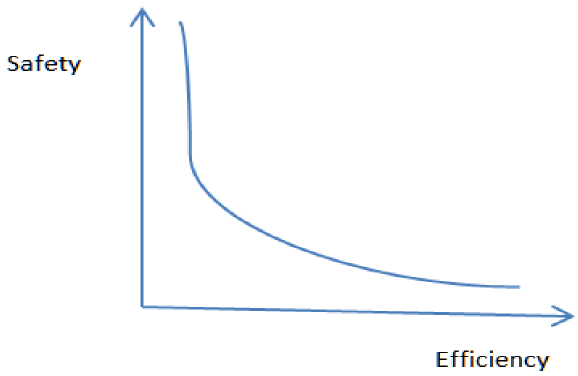

Figure 2 – Marginal rate of substitution between 2 ANSP goods

The same reasoning can be applied to the composite good of efficiency. One of the 4 aspects will always remain outstanding.

In addition to the above, a third latent effect of hybrid organizations relates to the cohesion of the governance strategies that will satisfy the expectations of the stakeholders. One research paper identified the role of the stakeholders as an important measure of performance.[17] In the augmentation of optimal performance at the ANSP level and at the FAB scenario, who are the stakeholders? We may readily know about the government agencies and their subsidiaries but they are not the only stakeholders in this scheme. One online dictionary defines a stakeholder as a person or group having an investment, or an interest, or who is affected by the decisions that affect the operations of a company.[18] Can we identify the other stakeholders of the ATM industry and what is the extent of the symbiotic relationship between these stakeholders and ANSPs? Also, what criteria do ANSPs use to select compatible stakeholder aims? Instead of focusing only on their own aims or financial gains, stakeholders need to be more engaged or committed to the long-term prosperity of ANSPs.[19] It is certainly no easy feat for ANSPs to reconcile all the requests of regulatory agencies, interested parties, airline companies and air traffic controllers (ATCOs) under the umbrella of ATM hybridization.[20]

The above 3 latent effects will present as major challenges in the outworking of airspace hybridization. They will also be difficult to measure. The gllamm technique is ideally suited for these heterogeneous situations since it takes into account the latent or random effects. We now consider the methodology for our gllamm analysis.

[16] A firm is always under the threat of uncertainty or random walk effects while also subject to a life-cycle of productivity and growth; in this context the ANSP is seen as a firm and as a consumer which will weigh upon FAB efficiency

[17] Professor A. Neely and a team did research on the stakeholder's role in the performance prism, Center for Business Performance, Cranfield School of Management, UK

[18] Online Collins English Dictionary – Complete and Unabridged, 10th edition

[19] Andersson, 2012 Multifunctional Wetlands and Stakeholder Engagement: Lessons from Sweden, Working Paper Stockholm Environmental Institute (8)

[20] For further reading, follow this link : http://rachelp0504.blogspot.fr/2013/03/the-3d-view.html

IV EVALUATING FAB EFFICIENCY VIA A GLLAMM ANALYSIS

We develop a dependence structure for FAB Efficiency based on the precepts that it is a generalized linear model, the data is clustered and the outcomes are predicted by both fixed and random effects. We also make the assumption that the intercept has a normal distribution with zero mean.

$$\boldsymbol{\eta}_{ij} = \boldsymbol{x}'_{ij}\boldsymbol{\beta} + \boldsymbol{\mu}_j^{(2)}$$

FAB efficiency $\boldsymbol{\eta}_{ij}$ depends upon the fixed effect $\boldsymbol{x}'_{ij}\boldsymbol{\beta}$ which is a vector of the explanatory variables with their fixed *Beta* coefficients that impact upon an ANSP, the primary level or the elementary unit. The intercept $\boldsymbol{\mu}_j^{(2)}$ represents the random effect or any unobserved heterogeneity at the secondary level or the FAB level which is the clustering unit.[21]

The variables in the vector represent the key performance areas (KPAs) that ANSPs must strive toward in optimizing the management of air traffic in these hybrid air spaces. They are derived from 4 datasets that measured diverse indications of performance for 31 ANSPs of the European Union during the period 2006-2013.[22]

Table 2 is a synopsis of the key performance areas (KPAs).[23] It also shows the biases for the corresponding predictors or test variables. Data science is a neo-evolutionary approach to performance analysis in air traffic flow management. The collection of data is still in a nascent stage. So we expect that specific data will be difficult to obtain, inconsistent at the ANSP level and even nonexistent in some instances. In this study, we use state-specific data collected from the major ANSPs. The sample consists of 29 ANSPs. Belgium and Luxembourg is considered as a single state. To minimize the underestimation of the results, Bosnia and Herzegovina was dropped from the sample due to non-availability of data for all the fields. This bipartisan state has recently joined the FAB-CE initiative.

TABLE 2 – Variables for a gllamm analysis of FAB efficiency

Key Performance Areas*	Variable	Significance at 95% Confidence Limit
FAB EFFICIENCY	FAB Efficiency determined from a DEA plus regression of gate-to-gate ATM costs as inputs and total IFR flights controlled by the ANSP as outputs **(FABE)**[24]	Dependent variable
***Safety Performance and Management (SPM)**	Effectiveness of Safety Management score (**ESM**) per ANSP[25]	Very significant predictor
***Economic efficiency**	Enroute Charge Index **(ECI)** based on enroute service units[26]	Non-significant predictor
	Military upper airspace Thrift Score (**MTS**) per ANSP[27]	Non-significant predictor
***Operational efficiency**	Costs of gate-to-gate delays per composite flight hour (**COD**)[28]	Very significant predictor

[21] Rabe-Hesketh et al., 2002 Graduate School of Education, University of California
[22] Data used from the e-dashboard of the Performance Review Commission, Eurocontrol
[23] The KPAs with the exception of Innovation; marked with a bold asterisk; have been established by the PRC
[24] Data Envelopment Analysis (DEA) is another statistical technique that is discussed in Section 5
[25] Data used from the e-dashboard of the Performance Review Commission, Eurocontrol
[26] *Ibid*
[27] *Ibid*
[28] The data for the rest of the variables for the KPAs in this table have been taken from the ACE Benchmarking report, 2011, PRC Eurocontrol

	Volume of Controlled Airspace size per Operational units: ACCs, TWRs and AFIS (**VAPS**) Percentage of ATCOs and assistants to Total staff (**PAT**) Organizational arrangements and scope of services (**OSS)** per ANSP	Non-significant predictors
***Technical efficiency**	Aggregated complexity score (**ACS**) per ANSP which is the interaction between flight density in the enroute region and modal states of flight configuration in close proximity	Significant predictor
***Environmental efficiency**	There is a lack of supporting variables inspite of the implementation of Continuous Descent Operations. This program is still in maturation stage. The following are used as proxies: Traffic Variability Indicators (**TVI**) for quarterly periods, 2011 and Average Transit Time in minutes (**ATT**)	First predictor not very significant, second predictor non-significant
Innovation[29]	Innovation Strategy Index (**ISI**) based on the ANSP Performance Plan Checklist[30]	Non-significant predictor

V THE ROLE OF DATA ANALYSIS IN AVIATION

Using STATA 12™ software, residual values for the FAB efficiencies were determined from an Ordinary Least Squares (OLS) regression of intermediate values derived from a non-ratio DEA. The inputs for this DEA were the total ATM/CNS costs while the total IFR flights represented the outputs. Then the gllamm used another OLS to test the significance of the above variables that represented the vector of KPAs. Only 3 variables were significant plus one other that was barely significant (see Table 2). The gllamm estimated that the safety management and the cost of delays, impacted upon the optimization process of FABs (see Table 3). It also predicted the effect upon FAB efficiency given the present conditionalities and trends (see Table 4). In addition, the gllamm confirmed that latency accompanied airspace hybridization and that unobserved heterogeneity does play an important role in the ATM industry.

The above analysis is just one example of how data is used to evaluate the impact of concepts via descriptive, exploratory and confirmatory statistical analyses. The strategies for the KPAs have been chosen through the conduction of a Cost Benefit Analysis (CBA) of the FAB initiatives. The CBA examined the costs to or the impact upon civil and military ANSPs, civil and military air space users, as well as State administrations and consumers. The focal groups for the benefits were civil ANSPs and air space users.[31]

TABLE 3 – Association between safety management, cost of delays and FAB efficiency

Significant variables	***Coefficient***	***z value***	***p value (95%CL)***
Cost of delays	-5.58e-07	-3.51	0.000
Effectiveness of safety management	-5.75e-06	-5.24	0.000

[29] Innovation is included as a distinct measure to cater for any observed but unmeasured latency in the hybridization process due to the lack of specific data
[30] PRB final report National/FAB Performance Plan Assessment Vol ii
[31] FABEC feasibility study report, 2010 (PRC, Eurocontrol)

Aggregated complexity score	5.27e-06	1.08	0.281
Constant	0.805	1.2e+04	0.000
Number of level Number of level Log likelihood Random effects at	1 units: 28 2 units: 9 167.5 FAB level: var(1) = 0.018		

The gllamm analysis upholds the aspect of a tradeoff between the effectiveness of ATM and the quality of this service. An increase in effectiveness of safety management imposes the economic principle of marginal substitution which explains the subsequent decrease in FAB efficiency.

In addition the cost of delays also impact negatively upon FAB performance. Already seen as strong detractors of the ATM optimization process, the statistical analysis clearly demonstrates that delays are intrinsic byproducts of this process and would require constant and consistent mitigative plans to counteract them.

Further, the significance of the constant or intercept in this analysis affirms that there are some situations which cannot be measured directly and some situations in which no measurement may currently exist. Examples are deviations due to inclement weather and diversions due to congestion or civil war. But heterogeneous factors in any system can be measured indirectly and the ATM system is no exception to this analytical rule.

The non-significance of the predictor variables holds different implications. It definitely means greater scope for study as the analyst will embark upon the quest for more suitable variables. It implies that data in ATM is exigent for evaluating progress of the industry. It may also be a tentative gesture that perhaps the aims of the common framework approach are either overbearing for some ANSPs or, they are not very compatible in the stakeholder arena and may require restructuring. Part of the benchmark process involves measuring efficiency and reconstructing the yardstick so that the participating organizations can comfortably fulfill the objectives. Employing data evaluation techniques such as a gllamm facilitates this process.

Another analytical technique that has been recently employed in the measurement of FAB efficiency was a Data Envelopment Analysis (DEA).[32] This estimated the cost efficiency by comparing the inputs of the costs of providing and using ANS against the outputs of flight hours and delays. Closely related to the DEA is Stochastic Frontier Analysis (SFA)[33] which was proposed for the estimation of a cost function for gate-to-gate ATM/CNS costs and also to determine the cost inefficiencies of ANSPs.[34]

Like the gllamm,[35] each statistical method comes with its own set of advantages and disadvantages or limitations. The gllamm is a long and tedious process and is not recommended if the analyst is looking for a quick method of data investigation. Other statistical methods include Markov estimations[36], SEM (structural equation modelling)[37], random coefficient analysis[38], DEA and SFA; all with their wonderful idiosyncrasies and perplexing anomalies. It is really left to the analyst’s personal choice and the prevailing budget and software to decide which method should be followed.

[32] Button and Neiva, 2013 Single European Sky and the functional airspace blocks: Will they improve economic efficiency? Journal of Air Transport Management 33 : 73-80

[33] For further reading, see Kumbhakar, Parmeter and Tsonias, 2013 a Zero Inefficiency Stochastic Frontier Model, Journal of Econometrics 172: 66–76

[34] The econometric method has been proposed to the Performance Review Body in the 2011 ATM cost-effectiveness report

[35] For further reading, see Szyszkowicz, 2006 International Journal of Occupational Medicine and Environmental Health; 19(4): 224 – 7

[36] For further reading, see Gilks, W. R. 2005. Markov Chain Monte Carlo, Encyclopedia of Biostatistics

[37] For further reading, see Bollen,1989 Structural Equations with Latent Variables, University of North Carolina

[38] For further reading, see article by Snijders, 2012 Multilevel Analysis, Department of Statistics, University of Oxford http://www.stats.ox.ac.uk/~snijders/MLB_new_S.pdf

However, irrespective of the data technique, the initial stage of collection and preparation is never an easy task, even with the best of software. The process is made more complicit in that data science in aviation is still at a nascent stage so suitable predictor variables will be difficult to find. As more data becomes available, the analyses will yield better results; a concept which is a fundamental tenet of statistics.

TABLE 4 – Predicted FAB efficiencies based on the impact of latent effects

FAB	Present efficiency	Predicted efficiency
FABEC	0.953	0.673
FABCE	1.071	0.832
BALTIC FAB	0.752	0.592
UK-IRE	0.827	0.653
DK-SE	0.778	0.923
BLUE MED	0.68	0.882
SW FAB	0.58	0.72
DANUBE	0.76	0.838
NEFAB	0.841	0.833

VI CONCLUSION

FABs are like icebergs in that they display a two-fold activity. On the one hand, these hybrid airspaces offer increased optimization of air traffic management. On the other, they also augment the latency effect of heterogeneity. As such, their evaluation will not be complete without the inclusion of the impacts of the latent effects. The gllamm analysis although novel, performs the aggregated function of determining the latency in the system, testing the suitability of the predictor variables, examining the relationship between the predictor and outcome variables and predicting the effect. This analytic technique is a long and tedious process. Yet along with other statistical methods that include SEM, SFA and random coefficient analysis, it is useful to ATM in the ongoing research and development of the optimization process.

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[6] Rabe-Hesketh and Skrondal, 2008 Multilevel and Longitudinal Modelling using STATA, 2nd edition STATA Press USA ISBN: 9781597180405
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[13] For further reading, see article by Snijders, 2012 Multilevel Analysis, Department of Statistics, University of Oxford http://www.stats.ox.ac.uk/~snijders/MLB_new_S.pdf