Identifying Human Performance Metrics in Air Traffic Control

Lisa Aldridge[1,2], Jediah Clark[1] & Mark S. Young[2]

[1]NATS UK Ltd, [2]University of Southampton

SUMMARY

Whilst maintaining safety remains the top priority, the UK needs to increase the number of aircraft that can fly through its airspace. This study uses task analysis to identify a set of performance metrics that will support air traffic controller training, inform airspace and technology design, and support operational decisions that balance the number of aircraft that can fly through UK airspace. A literature review, a review of existing task analyses and a set of workshops with controllers were conducted. The study concludes that measuring the performance of air traffic controllers holistically and continuously, using objective measures of task performance, is relatively unexplored.

KEYWORDS

Air Traffic Control, Task Analysis, Workload, Airspace Complexity, Human Performance Metrics.

Introduction

Summer 2019 saw record levels of aircraft flying through UK airspace, with its air traffic control (ATC) system approaching full capacity (CAA 2023). The following year, records were broken yet again, but this time a record low, as the world shut down due to Covid. Many believed this was a pivotal moment for aviation, as businesses turned to virtual conferencing (Sun et al., 2021), and the reduction in travel was hailed as a new era for the environment (Suau-Sanchez et al., 2020). The future of air travel and for ATC was uncertain and so training for new operational personnel, in many Air Navigation Service Providers[1] (ANSPs), was paused. Four years later, air traffic is quickly growing towards 2019 levels (Eurocontrol, 2024).

Whilst maintaining safety remains the top priority for ANSPs, there is a need to train air traffic controllers faster, modernise tools, airspace and procedures, to increase the number of aircraft that can fly through UK airspace. This study is the first in a programme of work aiming to identify better ways to measure the performance of air traffic controllers. The expectation is that the new measures will support training, inform airspace and technology design decisions, and enable operational personnel to balance the number of aircraft that can fly through UK airspace, within the workload capacity of air traffic controllers (hereafter referred to as 'controllers').

Method

Task analysis was considered the most appropriate method from which to derive a structured set of task performance measures. Task analysis supports many of the activities carried out by the human factors team at NATS, the largest ANSP in the UK. These existing task analyses were reviewed to identify common themes and goals. A literature review of published ATC task analyses provided additional insights. Facilitated workshops were carried out with 12 controllers to explore what 'good controlling' meant to them, which indicated potential measures of performance.

[1] Air Navigation Service Provider is an organisation that provides air traffic control services.

Task analysis can be used for a wide range of activities and needs to be tailored to focus on the attributes that are most relevant to the purpose (Kirwan and Ainsworth 1992). In this study, since the purpose was to identify holistic and, if possible, tangible measures of human performance the focus was on what is done, and how performance could be assessed.

The task analysis was scoped to focus on the activities of controllers responsible for London Terminal Manoeuvring Area (TMA). This is one of the busiest and most complex volumes of airspace in the world, due in part to the number of airports in and around London, with arrival and departure routes that intersect one another. The safe and efficient management of this airspace is therefore highly dependent on the skill and expertise of the air traffic controllers. The task analysis does not cover supervisors, assistants, operational engineers, network managers, or meteorologists, although they all play an important role in providing controllers with the tools and information they need, as well as managing the number of aircraft that are allowed into the London TMA.

The most comprehensive task analysis of ATM identified through the literature review are industry reports by EATCHIP (1998) and EATMP (1999), which aimed to review skills, training, and tool support to enable controllers to cope with the growing traffic. Seamster et al. (1993) compared novices and experts to generate a high-level framework of the tasks carried out, the information that controllers must maintain awareness of, the "expert mental model", and the strategies they use to manage traffic.

Results

The top-level goal-oriented tasks resulting from this study are presented hierarchically in Figure 1. Lower levels of decomposition have been omitted from this publication for brevity. No plan or numbering is provided because the tasks are not carried out sequentially, other than their session beginning with 'build situation awareness' and ending in 'handover traffic picture' to the next controller. Controllers must continually carry out all other tasks in parallel, switching between tasks and switching between aircraft as necessary (see also EATCHIP 1998). It could be likened to spinning plates, in that controllers need to keep checking the status of each plate (plane), and give each plate just enough input, to keep them spinning (flying in the right direction), but not spend too long on any one plate at the expense of the others. The precise timing of this task switching is an aspect that can be studied more closely with large-precise data sets.

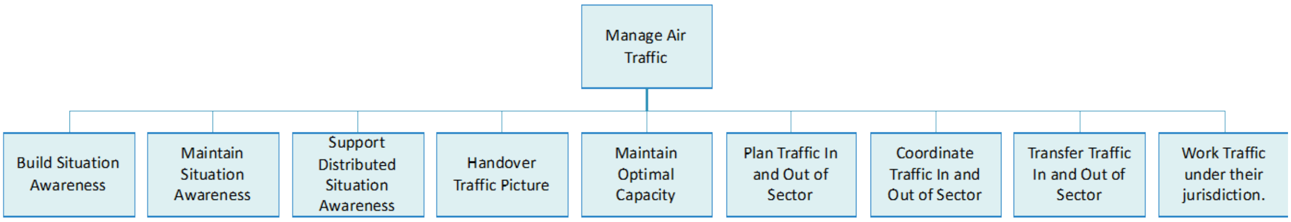

Figure 1. High-level Hierarchical Task Analysis (HTA) of Air Traffic Control

The HTA represents top-down goal-oriented cognition. EATCHIP (1998) reported that en-route controllers in their study believe this to drive most of their behaviour. However, there must also be some bottom-up processing, particularly where controllers must respond to unplanned events such as system alerts and aircraft emergencies.

Build Situation Awareness

At the start of each eight-hour shift, and to a lesser extent before each session, controllers must 'build situation awareness'. This begins to some extent subconsciously even before controllers arrive on site. They might notice they are feeling lethargic, they might hear something in the news that could affect air traffic for the day, or they will notice extreme weather conditions as they travel to work. Controllers are required to check the electronic notice board for any procedural changes or special notices. When they enter the control room they will check the traffic predictions and weather forecasts before going to their workstation to take a handover from the incumbent controller. As experts, controllers learn to do this efficiently by selecting where they will find the most important and relevant information. The procedures provide a mnemonic for handovers covering air pressure, roles, runways in use, weather, anything non-standard, and the current situation. However, in the workshops, controllers suggested that this is not as rigidly adhered to now, because so much of the information can be gleaned directly from the information systems. EATCHIP (1998) suggested that incoming controller needs to understand the plans and conflict solutions of the incumbent controller. Once the incoming controller feels they have the 'traffic picture', they will give a verbal acknowledgement that they are ready to take over.

Maintain Situation Awareness

The wide range of information that controllers have to maintain awareness of has been summarised well by Seamster et al. (1993) and presented in detail by Endsley and Rodgers (1994). Although these accounts appear comprehensive, they do not portray the subtleties and nuances assimilated by controllers that are important to good performance, or perhaps a sign of exceptional expert performance. For example, controllers report judging pilot capacity from verbal and non-verbal cues from radio transmissions (R/T). For example, a pilot who hesitates could be distracted or unfamiliar with the local procedures and may therefore be given an additional mile of separation as a safety buffer. EATMP (1999) found that controllers spoke about their situation awareness in terms of their visual scan, believing they have a consistent visual scan when workload is optimal. They also found that controllers felt like they were losing their situation awareness if they were unable to spend enough time planning in between reacting to pilots.

Support Distributed Situation Awareness

Controllers can work traffic in their sector single handed, as the radar controller. However, they can have a coordinator, a second controller who focuses on the task of coordination. In this case, they should work closely as a team and have a shared plan. Due to the complexity and intensity of the London TMA it is normally the radar controller who dictates how traffic will be worked, and they need to try to communicate their plan to the coordinator. Due to the very high rate of verbal communication between radar controller and pilots, it is very difficult for the radar controller and coordinator to communicate, and so the coordinator must interpret the traffic situation and use their intuition to determine what the radar controller needs. Conformance to standard procedures, knowing one another's preferred way of working, and the ability to adapt to different ways of working, are therefore considered 'good controlling'.

Handover Traffic Picture

Each controller typically works for 25-45 minutes before taking a rest break, before which they must handover their traffic picture to the next controller, whilst continuing to issue instructions to aircraft. Controllers refer to short, concise handovers, that present only the pertinent facts, in a consistent order, to be a measure of good controlling, as was simply seeming engaged and giving feedback that assures the outgoing controller that they have understood the picture.

The traffic picture also needs to be handed over if the sector is being split, a process of dividing the airspace and therefore the number of aircraft between two controllers, to reduce workload. Controllers say that when splitting a sector the incoming controller should not rely on a verbal handover from the incumbent controller since they will be too busy. In this case, inference and intuition are required.

Maintain Optimal Capacity

Controllers have a number of mechanisms available to them to reduce or increase the number of aircraft on frequency and therefore reduce or increase their workload. For example, they can reduce the number of aircraft getting airborne or split the sector. However, none of these mechanisms take immediate effect, meaning that if peaks or troughs in workload are not anticipated far enough in advance, workload can escalate or decline to uncomfortable levels. Providing information that helps to anticipate changes in workload is a key objective of this research programme.

Some have approached traffic complexity and workload using mathematical equations of aircraft numbers and trajectories (Ahrenhold et al., 2023; Pérez Moreno et al., 2022). Controllers commonly state though that workload is not directly linked to the number of aircraft on frequency because one aircraft can create a disproportionate amount of workload. For example, one aircraft may need to route across the main traffic streams, or a pilot may not be as quick to respond to instructions as others. Some have approached the problem from a more humanistic perspective by weighting tasks based on expected cognitive complexity using subjective measures of workload, but with limited success (Frutos et al., 2019; Ibáñez-Gijón et al., 2023; Suárez et al., 2023).

Plan, Coordinate, Transfer and Work Traffic

The second group of subtasks, centred around the aircraft, are described here in a single section because although each aircraft is planned, coordinated, transferred and worked, controllers must switch between aircraft that are at different points in relation to the sector.

Controllers normally receive prior notification that an aircraft has planned to fly through their sector, with a strip[2] arriving in their pending bay. EATMP (1999) reported that controllers conduct an initial conflict detection when the strip arrives. Controllers then plan this into the sector and start to think about how best to weave it through other aircraft trajectories. If the controller wants the aircraft to enter higher or lower, they can coordinate with the previous sector to request a different level. As the aircraft approaches the sector boundary the pilot will join the radio frequency and state their callsign and route, which is checked against the flight plan. The controller then 'works the traffic', issuing instructions to get each aircraft through the sector as quickly and as safely as possible. Controllers may have approximately five to ten aircraft on frequency at any one time. They must switch their attention between each aircraft and ensure that only one person speaks at a time. However, this simple representation of the standard sequence of tasks, associated with each flight, is rarely so simple with many variables, options and constraints to consider.

The procedures used by controllers, referred to as the Manual of Air Traffic Services, explain the rules controllers must operate within. This may provide the detail against which performance data might be structured. For example, a count of the number of aircraft transferred on standing agreements[3] versus the number of aircraft explicitly coordinated may indicate the proportion of non-standard traffic that a controller had to handle.

Controllers have many cognitive techniques and types of instruction they can issue. For example, they may anticipate which of two aircraft will call them first and so have a plan for each scenario. Although continuous climbs and descents are more fuel efficient and involve less workload, controllers may have to use stepped climbs and descents, or instructions that indicate the latitude

[2] A strip, more formally referred to as a flight progress strip, contains information from the flight plan about the aircraft and the route it wishes to take. Controllers organise the strips in groups, referred to as bays, to help them identify potential conflicts, and to record the instructions they have issued.

[3] A standing agreement is a pre-agreed coordination that can be used without the need to communicate.

and longitude that the pilot needs to achieve a level by, in order to cross inbound and outbound traffic.

Focused studies have looked into the cognitive techniques controllers use to make decisions and manage their workload. For example, Frutos et al. (2019) demonstrated that controllers chunk aircraft into groups needing similar intervention, to reduce cognitive load. Malakis and Kontogiannis (2021) demonstrated that controllers make use of leverage points to make efficient and effective controlling decisions. For example, if they have to route aircraft around weather, they might take the opportunity that the longer routeing affords, to get a faster aircraft to overtake another.

Human Performance Metrics

The task analysis provided the structure to identify an initial set of performance metrics, which was supplemented with insights from controller workshops. The measures as shown in Table 1 are not always positive or negative indicators of performance. Even deviations from the norm may indicate a significant change in task performance, particularly in combination with other performance shaping factors. Some measures vary in how quantifiable they are, and some appear against multiple tasks.

Table 1. Tasks and Initial Set of Performance Measures

Task	Performance Measures
Build Situation Awareness	Visual dwell time on key information displays Duration of handover, as a component of efficiency Number and duration of equipment setting adjustment Time after handover is complete, that behaviours normalise Clarity and relevance of questions Level of engagement and clarity of feedback to incumbent controller
Maintain Situation Awareness	Shape and frequency of visual scan, not tunnelling on a single issue Visual cross-checking between radar tracks and strips. Time spent on high priority flights Proactive searching for next action Visual scan of transponder data, such as selected flight level Quantity and clarity of auditory information Exposure to simultaneous streams of auditory information Signs of reactive controlling such as “stop climb” or sharp turns Timing of pilot error detection Timing of alert detection Timing of planning, coordination and instructions in relation to aircraft events. Pace of instructions and switching between aircraft.
Support Distributed Situation Awareness	Use of standard phraseology and full callsign in communication Quantity, conciseness, clarity, accuracy, relevance of information exchanged Timeliness and clarity of feedback Use of non-verbal communication Conformance to procedures Adaptation to others’ ways of working Alignment of actions to a common plan Workflow between controllers
Maintain Optimal Capacity	Individual workload with respect to optimal limits Time taken to respond to events such as alerts, coordinations, phone calls Workload induced error rates, such as invalid headings

	Workload balance across the team Workload peaks and troughs are anticipated Time taken to implement workload management techniques
Plan Traffic In and Out of Sector	Pattern and timing of visual scan How far ahead they are planning Time available between issuing clearances to carry out planning Signs of reactive controlling such as "stop climb" or sharp turns Timing of strip being brought into planning bay Spacing of aircraft arriving and leaving sector Quantity of intervention needed for each aircraft on frequency Fuel efficiency of each aircraft trajectory Overall cost-benefit of planning decisions, such as reroute, to each party
Coordinate Traffic In and out of Sector	Use of standing agreements especially when workload is high Use of coordination to optimise trajectories when appropriate Time to agree coordination and time taken to renegotiate Time that coordination is offered and accepted in relation to aircraft transfer Compromise between controllers to ensure workload balancing Controllers only accept what they can manage Context provided when phoning to coordinate Reason provided if declining a coordination.
Transfer Traffic In and Out of Sector	Detection and resolution of discrepancies between first call and flight plan Error rate in issuing next sector frequency Traffic spacing on transfer Timing of outcommed strips being removed from bay
Work Traffic under their Jurisdiction	Adaptations in controlling according to weather and time of day Use of standard phraseology Clarity and conciseness of communication Adaptation of communication in relation to pilot proficiency and familiarity Timing of information, instructions and context issued to pilots Clarity of instructions, even when workload is high Time to detect and resolve step-ons[4] Time to detect and correct errors and anomalies Fuel efficiency of each aircraft trajectory Duration that aircraft are left on standard departure routes Number of aircraft of headings Tool usage, such as datalink, vector lines, scale, conflict detection tools Judgement of scale when scanning aircraft
Handover Traffic Picture	Clarity and relevance of verbal handover Level of focus on next steps and outstanding actions in handover Consistency in how information is presented to incoming controller Adaptation of handover to the situation and expertise of the incoming controller Continuity of the plan during handover Continuity of interactions with aircraft during handover

Discussion

When reviewing the wide range of task analyses on ATC, it was evident that domain expertise as well as systems thinking are both important to developing a task analysis. This enables abstractions

[4] step-on - when two pilots try to transmit simultaneously on the radio frequency.

to be made from 'what' controllers do, including the many nuances, and identify the 'why'. For example, minimum departure intervals, suspending free flow departures, traffic regulations and sector splitting are different ways of reducing or balancing workload.

Working through potential performance measures highlighted that some measures are context-specific and that controllers have to make trade-offs. What is good controlling in one context may be poor in another. For example, sticking to standard procedures may reduce controller workload and error, but may not offer aircraft the most optimal trajectory through the sector. One controller gave the example that they might decide to delay one aircraft to climb five others, the aim being overall efficiency as well as fair service to all airspace users. Further work is needed to understand contexts and trade-offs, rather than assuming linear relationships.

This programme of research will avoid directly measuring individual or distributed situation awareness, due to the intangible nature of the constructs, the limitations of introspection (Conte et al., 2023), and limitations of probing (Black et al., 2022). Instead, the focus will be on measuring behaviours that should theoretically support good situation awareness (such as a controller's visual scan) or result from good situation awareness (such as early anticipation or detection of events).

The initial set of performance measures in Table 1 requires further work to ensure they are practical, holistic, balanced, valid, reliable, diagnostic, and sensitive to different performance shaping factors. Performance metrics must be handled sensitively so that controllers do not feel micromanaged or exposed, and can see the measures lead to them getting the support they need. Another important factor in the long term is that measures of performance do not cause unintended and undesirable behaviours to emerge.

Conclusion

Previous research into the ATC task has focused on understanding cognition to aid selection, training, user interface design and conflict detection tools. Although a significant amount of research has been carried out on measuring individual human performance constructs, such as situation awareness and workload, this research programme's aims of developing a holistic set of measures, that can be gathered continuously and automatically, appear to be relatively unexplored.

References

Ahrenhold, N., Gerdes, I., Mühlhausen, T., & Temme, A. (2023). Validating Dynamic Sectorization for Air Traffic Control Due to Climate Sensitive Areas: Designing Effective Air Traffic Control Strategies. Aerospace, 10(5). doi.org/10.3390/aerospace10050405

Black, S. C., Bender, A. D., Whitney, S. J., Loft, S., & Visser, T. A. W. (2022). The effect of multi-tasking training on performance, situation awareness, and workload in simulated air traffic control [Article]. Applied Cognitive Psychology, 36(4), 874-890. doi.org/10.1002/acp.3977

CAA (2023) Airspace Modernisation Strategy 2023–2040 Part 1: Strategic objectives and enablers CAP1711.

Conte, S., Harris, D., & Blundell, J. (2023). Evaluating the Impact of Passive Fatigue on Pilots Using Performance and Subjective States Measures. Engineering Psychology and Cognitive Ergonomics, Cham. dx.doi.org/10.1007/978-3-031-35392-5_2

EATCHIP Human Resources Team (1998). Integrated Task and Job Analysis of Air Traffic Controllers - Phase 1: Development of Methods (HUM.ET1.ST01.1000-REP-03). Edition 1.0. Brussels: EUROCONTROL.

EATMP Human Resources Team (1999). Integrated Task and Job Analysis of Air Traffic Controllers – Phase 2: Task Analysis of En-route Controllers (HUM.ET1.ST01.1000-REP-04). Released Issue. Edition 1.0. Brussels: EUROCONTROL.

Endsley, M. R., & Rodgers, M. D. (1994). Situation Awareness Information Requirements Analysis for En Route Air Traffic Control. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 38(1), 71-75. doi.org/10.1177/154193129403800113

Eurocontrol (2024) Commercial flights by reporting country – monthly data. (accessed 01/02/2024) https://ec.europa.eu/eurostat/databrowser/view/avia_tf_cm/default/table?lang=en

Frutos, P. L. d., Rodríguez, R. R., Zhang, D. Z., Zheng, S., Cañas, J. J., & Muñoz-de-Escalona, E. (2019). COMETA: An Air Traffic Controller's Mental Workload Model for Calculating and Predicting Demand and Capacity Balancing. In Human Mental Workload: Models and Applications (pp. 85-104). doi.org/10.1007/978-3-030-32423-0_6

Ibáñez-Gijón, J., Travieso, D., Navia, J. A., Montes, A., Jacobs, D. M., & Frutos, P. L. (2023). Experimental validation of COMETA model of mental workload in air traffic control [Article]. Journal of Air Transport Management, 108, 14, Article 102378. doi.org/10.1016/j.jairtraman.2023.102378

Kirwan, B. (1994). A Guide To Practical Human Reliability Assessment (1st ed.). CRC Press. doi.org/10.1201/9781315136349

Malakis, S., & Kontogiannis, T. (2021). Leverage points: insights from a field study in the air traffic control system. Theoretical Issues in Ergonomics Science, 22(3), 360-382. doi.org/10.1080/1463922x.2020.1784307

Pérez Moreno, F., Gómez Comendador, V. F., Delgado-Aguilera Jurado, R., Zamarreño Suárez, M., Janisch, D., & Arnaldo Valdés, R. M. (2022). Determination of Air Traffic Complexity Most Influential Parameters Based on Machine Learning Models. Symmetry, 14(12). doi.org/10.3390/sym14122629

Seamster, T. L., Redding, R. E., Cannon, J. R., Ryder, J. M., & Purcell, J. A. (1993). Cognitive Task Analysis of Expertise in Air Traffic Control. The International Journal of Aviation Psychology, 3(4), 257-283. doi.org/10.1207/s15327108ijap0304_2

SESAR JU (2020) European ATM Master Plan. 2020 Edition.

Suárez, M. Z., Arnaldo Valdés, R. M., Pérez Moreno, F., Delgado-Aguilera Jurado, R., López de Frutos, P. M., & Gómez Comendador, V. F. (2023). Methodology for Determining the Event-Based Taskload of an Air Traffic Controller Using Real-Time Simulations. Aerospace, 10(2). doi.org/10.3390/aerospace10020097

Suau-Sanchez, P., Voltes-Dorta, A., & Cugueró-Escofet, N. (2020). An early assessment of the impact of COVID-19 on air transport: Just another crisis or the end of aviation as we know it? Journal of Transport Geography, 86, 102749. doi.org/10.1016/j.jtrangeo.2020.102749

Sun, X., Wandelt, S., & Zhang, A. (2021). Technological and educational challenges towards pandemic-resilient aviation. Transport Policy, 114, 104-115. doi.org/10.1016/j.tranpol.2021.09.010