Workload and the En Route Controller – An Overblown Issue?

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Abstract. This is the first in a series of papers on the mental process of the En Route Air Traffic Controller. These papers will explore Situational Awareness, Mental Models, Workload, and a variety of related issues in an attempt to both improve the research community's understanding of the En Route Controller and to enable more productive and applicable future research activities. This paper will describe the learning process and experiences for a typical Developmental trainee.

Keywords: Air traffic control · Mental Models · Human factors · Situation awareness · Training

1 Introduction

Workload is one of the most studied and debated topics in the domain of En Route Air Traffic Control. Countless papers introduce themselves with nearly identical paragraphs about the forecast of large increases in the amount of air traffic in the coming decades, followed by the authors' ideas of technology or other methods of coping with it, usually supported by the results of a Human in the Loop (HITL) simulation they have designed.

The implication is that ever-increasing traffic will result in taskloads that will overwhelm controllers without improved technology, resulting in sector overload, reduced efficiency, increased likelihood of Loss-of-Separation events, or the non-spoken worst case scenario of a mid-air incident.

Employing an extensive literature review combined with the author's in-depth Air Traffic Control knowledge and experience, this paper will examine those implications and the overall topic of workload in the En Route environment.

Please keep in mind that what follows applies only to the En Route environment. Terminal/TRACON operations share many similarities with En Route, but not enough to include them. Tower operations are completely different and a subject for someone with more expertise in that area.

2 Definitions

As several different papers have pointed out (Murphy 2004, etc.), there isn't complete agreement on what is meant by the term 'workload'. Coming up with a conclusive

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definition is beyond the scope of this paper, but for the purposes of this paper a few working descriptions will be defined.

Taskload – Taskload is the major component of workload, and is defined as the demands being put on the controller to safely and efficiently manage traffic situations while complying with all directives such as LOAs, SOPs, and ATC rules (the 7110.65 in the US). Histon and Hansman [1] call this **Situation Complexity.** Kopardekar and Magyarits [2] refers to this as **Dynamic Density**.

Taskload is more than just the situation at the sector. Air Traffic Control is a cooperative endeavor, especially at the En Route level. “Controllers are team players who must coordinate their actions and plans with pilots and many other controllers.” [3]

Workload – Is defined as the individual controller’s perception of the complexity of the Taskload. This will vary due to the controller’s overall skill level and mental and physical state at that moment. Histon and Hansman refer to this as **Cognitive Complexity.**

Situational Awareness (SA) – Situational Awareness (SA) is the 3-dimensional picture of the sector and traffic that the controllers have in their heads. The controller uses radar and other information sources to update Situational Awareness, and then uses this mental picture to make decisions. Controllers refer to SA as ‘The Flick’ or ‘The Picture’.

3 Why Does Workload Matter?

As noted earlier, the primary concern about excessive workload is that it could lead to overload, resulting in a loss of SA and potentially leading to a serious LOS event.[1]

However, several studies such as Hilburn’s *Cognitive Complexity in Air Traffic Control* [4] show no significant correlation has yet been shown between workload and errors.

Redding et al. [5] posited that “…errors tend to occur most frequently during periods of relatively light workload…committed by good controllers who…fail to monitor an aircraft plainly on their scope. These results suggest that lack of vigilance in performing the key cognitive task Maintaining Situational Awareness is a frequent source of error.” [It must be noted here that there is serious concern that many of the proposed initiatives to decrease controller workload will result in an overreliance on automation increasing instances of lost vigilance].

A second concern is the loss of efficiency. After safety, the main mission of most ANSPs is to increase efficiency through programs such as free-flight, TBFM, Optimized Profile Descents, etc. As Hilburn put it, “excessive complexity drives taskload, which indirectly drives workload, which raises the risk of overload, which ultimately sets an upper limit on sector capacity.” [4] As the sector gets busier, the controller will be able to offer fewer additional “services” such as shortcuts, discretionary descents, and advisories.

[1] The fact that as of this writing there has never been a major accident in the En Route environment in the US attributable to controller error somewhat belies this concern, though one could argue that this a “Black Swan” statistic.

But as Howell et al. [6] showed in their research, once Center traffic levels reach 30%, the average inefficiency remains mostly constant, with only a slight increase after 70%. Further, Myers et al. [7] showed that En Route delays are an insignificant issue with their 2005 study which found that the average flight was delayed an average of less than 2 min above 12,000 ft. This figure includes unavoidable weather delays.

At this point one might wonder if things have changed since these studies were done over 10 years ago.

They have. Domestic Air Carrier Traffic Operations have actually decreased in the US by 20% in the period from 2005 – 2016[2]. Eurocontrol reports a slight decline in overall air traffic operations for the same period[3]. Traffic will inevitably increase again, especially as UAS's start to become IFR qualified, but the projections of increasing traffic and congestion have been significantly delayed at the very least.

For the sake of argument, let's assume that traffic will grow again sometime in the near future at such a rate that efficiency will be significantly affected and safety somewhat compromised. What is the best way to measure workload and test initiatives designed to mitigate it?

4 Current Methods for Mitigating Workload

In the cockpit, workload is a very serious issue, especially during takeoff and landing. Taskload is highest at the beginning and ending of the flight which, according to separate studies by Boeing [8] and Airbus [9], is also when almost 90% of all accidents occur. The departure and arrival phases of flight is where fuel is most likely to be a concern - too much to land again quickly after takeoff, not enough on arrival to explore other options. This is also the phase of flight where there is little room to recover from an altitude mistake. And if the flight crew does become overloaded and consequently makes an error that leads to an accident, they will personally suffer the physical effects.

The En Route controller, on the other hand, has many resources to call upon when taskload begins to exceed capacity. And if an LOS occurs, it may be as minor as two aircraft passing within 4.9 miles of each other. In most cases, the most serious repercussion would be a temporary decertification followed by a short period of remedial OJT. But there are several barriers in place to prevent excess taskload from arising.

The first line of defense for sector overload is the Traffic Management Unit (TMU). Well before the sector reaches at saturation point, Traffic Management Coordinators (TMCs) monitor projected traffic levels throughout the center using tools such as Traffic Situation Displays (TSDs). When a sector's traffic levels are projected to rise near capacity, the TMC will alert the Front Line Manager (FLM) for the affected sector. Together they will work out a strategy to mitigate the sector overload, most likely involving restricting the rate of traffic coming into the sector or rerouting aircraft around the sector, laterally or vertically.

[2] https://www.transtats.bts.gov/Data_Elements.aspx?Data=2.

[3] http://www.eurocontrol.int/articles/statistics.

If the TMC doesn't notice the pending saturation alert in time, the second line of defense is the FLM. The FLM also has access to a TSD, and has the additional advantage of being physically located near the affected radar teams. FLMs are more aware of basic traffic patterns for sectors in the area and know what times of day different sectors generally become busy. They are also aware of the capabilities of the controller(s) staffing the affected sector. The FLM can mitigate sector overload by alerting TMU, using proactive tactical maneuvers, increasing sector staffing, and monitoring the sector themselves either directly or remotely.

Sector staffing is a shared responsibility. Unlike a flight crew, the controller can get help[4]. The controller often is first one to recognize that weather, such as turbulence or storm cells, is disrupting the traffic flow. Both the controller and the FLM can see the URET screen or strip bay and notice if it is becoming full of aircraft. A good FLM will also be attuned to clues that an individual controller is getting busy such as louder or faster transmissions, swinging a leg, moving around in her seat, etc.

At a one-person sector a data (planning) controller can be added to assist the radar controller. If still more help is needed a third person in the form of a coordinator (L-side) can also be inserted to add an extra set of eyes and handle interphone calls. If it is a combined sector, it can be split. As a last resort, traffic coming into the sector can be shut off until the workload has returned to a safe and manageable level.

"Air traffic control is so intrinsically the product of a team that part of the work of each controller can often be done by his or her colleagues if the controller is inexperienced, overloaded, or for any reason less efficient than normal." – Hopkin [10]

[The one shift where both strategic and tactical assistance are not readily available is the midnight shift. Typically, TMU is not staffed overnight and there is one supervisor responsible for all the controllers on duty. Two certified controllers are on duty for each area, but once traffic slows on or the other is usually on an extended break. While there were a great number of factors that led to the mid-air over Uberlingen, these were a couple of the major ones cited in the official report [11].]

At a tactical level the controller has many tools to manage building workload, mostly in the form of "task shedding." "The competent controller generally knows the rate at which he or she can complete tasks, and this knowledge is actively managed by the ATCO to avoid overload." – Loft [12]

As taskload rises, there are several strategies controllers can use for mitigation. The controller will prioritize all potential tasks, deferring the lower priority ones if possible or "shedding" them if necessary. [1]

Both Corver et al. [13] and Knorr and Walter [14] identify "Trajectory Uncertainty" as a major contributor to controller workload. This uncertainty can be lessened by "reducing degrees of freedom" [1] through the use of "Positive Control", which usually involves vertical separation. Aircraft will be leveled off or issued crossing restrictions that ensure separation.

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[4] There are rare exceptions, the most famous being the crash-landing of UAL232 in Sioux City where an experienced fourth pilot was able to assist the three-man crew and most certainly prevented the results of the accident from being much worse.

Other task shedding strategies can be employed. They can eliminate optional advisories, revert to minimal phraseology, and employ strategies to reduce the need for coordination. In rare circumstances they may even use unconventional tactics such as asking the flight crew to coordinate a speed or heading when checking on the next frequency.

Sperandio [15] observed that "controllers used a variety of adaptive strategies, such as processing fewer aircraft variables and reducing verbal c high taskload."

"This is called *workload management*. If possible, they revert to routine actions, standard procedures and 'simple' solutions that need less attention and that gain time, for instance, by a lower load of radiotelephony. Depending on the evolving situation (routine – non-routine), they switch between low and high workload (cf. vigilance)." – Oprins [16]

This is similar to driving a car on a busy highway and encountering weather and/or unpredictable traffic. The driver will put away their cell phone and sit up and scan constantly. They can also adjust their speed, turn off audio entertainment that might be distracting, and even cease conversing with other passengers.

5 Measuring Workload

Most studies that include measurements of controller workload use subjective methods. Controllers are asked self-rate how busy they were during a simulation, most often using NASA-TLX. The self-reporting, post-event nature of the NASA-TLX may limit the applicability of findings to real world scenarios.

Different controllers will evaluate taskloads differently. Even controllers of similar abilities may define "very demanding mentally" differently – what Histon and Hansman refer to as **Perceived Complexity**. Because the rating process usually takes place after the scenario to avoid interfering with SA, the subjects may not accurately remember how "busy" they felt, nor can it provide a dynamic assessment of workload. On top of that controllers, like all professionals, are proud of their skills and less likely to admit to being "overloaded". Additionally, most studies don't use current controllers but due to financial and/or logistical reasons must rely on students or retired controllers and supervisors. Neither of these groups will have the skills to be representative of current controllers, potentially further compromising the validity of certain types of studies.

Thus, the only real use for a subjective measurement like this is to compare an individual's subjective rating in the same study under different conditions (with or without a Decision Support Tool, etc.).

Before Boeing or Airbus delivers a new model passenger jet to the major airlines, it undergoes many tests. One of the more impressive of these tests is the wing stress tests, which you can see on-line through a simple search[5]. The test is exactly what it says – increasing pressure is exerted on the wing until it snaps. This is an objective measurement of "wing overload".

[5] One of many examples is here: [https://www.youtube.com/watch?v=rak2HldVp9M].

If we truly want to a more accurate measurement on Controller workload, why don't we use a similar procedure in our HITLs? Of the innumerable studies read for this paper where attempts are made to measure "workload", none have attempted to calibrate the workload scale. How can we expect whomever is rating controller workload to give an accurate assessment if they can only see the "zero end" of the scale?

The process would be very simple. Design the first scenario of whatever simulation is being run to be open-ended with an ever-increasing workload, like a game of *Tetris*. Explain to the controller beforehand the exact goal of the scenario; for them to experience "Level 7" (or whatever the highest rating on the scale being used is) so that in the subsequent trials there will be a "yardstick" to more accurately measure workload. Then run the scenario until workload gets maxed out and overload occurs. To lessen subjectivity further, "overload" could be defined as when an LOS or some other benchmark occurs.

Secondly, as Manning [17] notes, a simple solution for making subjective workload assessments more accurate and standardized is to have another person providing the assessment during the scenario. Another controller would be ideal because both for obvious reasons and because they are experienced at knowing how busy other controllers are, a necessary skill for providing OJT, which is a requirement of all controllers. This would result in more objective dynamic workload measurements throughout the scenario.

Another option is to obtain objective measurements through techniques such as secondary performance-based measurements. However, for secondary performance-based measurements to be valid, they must duplicate the primary task being measured. If visual performance is being measured, such as scanning, then the secondary task must involve additional scanning. If cognitive workload is being measured, the secondary tasks must be designed so that it is always cognitive. But this presents its own difficulties - asking the participant to answer 11 times 12 could be cognitive for one person and non-cognitive for someone else (System 1 vs. System 2 in the lexicon of Daniel Kahneman) [18].

Secondly, there must be a reason for the participants to complete the secondary task while also performing the simulation to the best of their abilities. If the subject is not motivated to complete both tasks, then the performance-based measurement will not be effective.

The Situation Presence Assessment Method (SPAM) shows some promise as noted by Zhang [19], but he also goes on to note that "no such study has been conducted (on SPAM) using high-fidelity ATC simulations with subjects who have ATC experience".

Here again it benefits all concerned if the difficulty level of the scenario could be "maxed out" to provide a defined level where overload occurs. However, to be able to truly create a scenario with a taskload that can be ratcheted up to guarantee maxing out the controller's workload abilities, the HITLs will need to be designed to be much more realistic.

6 HITL Scenario Design

The topic of HITL scenario design could fill an entire paper.

The following is a brief example of the lack of realism in most simulations:

Scenario Controller: "American Ninety-Five, descend and maintain one-one thousand."

Remote Pilot responding instantly: "American Ninety-Five roger, descending to one-one thousand."

Within a few seconds the simulated aircraft begins a relatively rapid descent at a uniform rate to 11,000 ft.

Total time elapsed, less than 15 s.

Compare that with:

Controller: "American Ninety-Five, descend and maintain one-one thousand."

"(Garbled due to blocked transmission) roger, descending to one-one thousand."

"All aircraft standby. That last transmission was for American Ninety-Five. American Ninety-Five, did you copy your descent to one-one thousand?"

"American Ninety-Five, roger, descending out of 2-3-0 for eleven thousand."

The controller must now make another broadcast to make sure another aircraft didn't answer the original clearance.

Total time elapsed, at least 30 s.

All this time he must put his "to-do list" on hold and now that 30 s have passed priorities may have changed. As he is about to key up to issue another clearance he receives a call on the interphone with a request from another controller. Meanwhile, American 95 is just starting the descent with a mode C readout of 229…

There are many ways in which HITLs do not accurately simulate actual air traffic conditions, too many to cover here. But lack of trajectory uncertainty and blocked, unanswered, or incorrect readbacks are two major ones that directly affect simulated workload.

Testing proposed new technologies under high workload situations is especially important because that is when the technology is needed. Wiener and Curry [20] pointed out that the effect of automation often is to reduce workload when the workload is low and to increase it when the workload is high. Nadine Sarter, an industrial engineer at the University of Michigan, and one of the pre-eminent researchers in the field, made the same point in a different way: "Look, as automation level goes up, the help provided goes up, workload is lowered, and all the expected benefits are achieved. But then if the automation in some way fails, there is a significant price to pay. We need to think about whether there is a level where you get considerable benefits from the automation but if something goes wrong the pilot can still handle it." [21]

7 Conclusion

While the growth of Air Traffic Operations in the US and Europe has stalled over the last 10 years, it is highly likely that this trend will be reversed and traffic will grow over the next decade. Even without this growth, if NextGen initiatives are successful in increasing acceptance rates at high capacity airports, at the very least the En Route sectors near that airport will experience a corresponding increase in traffic.

To maintain the efficiency and safety of the En Route ATC system in the US, effective ways will need to be found to manage this increased taskload. To do that, those researching potential strategies need to understand exactly what workload is for the En Route Controller, how it works, and how to effectively test and measure it. Hopefully this paper has provided a step in that direction.

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