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THE IMPACT OF THE AUTOMATIC TERMINAL INFORMATION SERVICE ON AIRSPACE CAPACITY AND AIR TRAFFIC CONTROLLERS WORKLOAD

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Abstract. The Automatic Terminal Information Service (ATIS) is an important part of the organization of air traffic, which automatically provides pilots with important information about the status of the airport, runways in use, meteorological and other important data. In the absence of ATIS, air traffic controllers (ATC) must repeatedly relay this information, increasing communication demands and potentially contributing to ATC workload and operational inefficiencies.

This study investigates the impact of ATIS implementation on sector capacity and controller workload. The research utilizes a year-long observational dataset from a regional airport operating without ATIS, where controller–pilot communication durations and frequencies were recorded under live operational conditions. Communication parameters, including the number of transmissions, mean message duration, and controller availability factor, were extracted and used to model sector capacity according to the Instruction of the Aeronautics Command (ICA) 100-30 methodology. The introduction of ATIS was then simulated by adjusting these parameters to reflect the automated transmission of routine information. Results show that ATIS significantly reduces the number and average duration of controller–pilot communications, leading to an increase in controller availability. Consequently, sector capacity rose by 36.03% for fixed-wing aircraft and 37.56% for rotorcraft. Statistical testing confirmed that these improvements were not attributable to random variation. The findings suggest that implementing ATIS can support more efficient communication, contribute to reducing controller workload, and may lead to a noticeable increase in sector capacity.

Keywords: workload, ATIS, capacity, sector, safety, controller.

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Notations

Variables and functions

T – flight time of the aircraft in the sector;
T_a – average flight time of the aircraft in the sector;
T_{tr} – the total time of transmissions between the controller and the pilots in the sector of responsibility during the approach or overflight;
v_m – mean speed of aircraft in the sector;
δ – average distance flown by aircraft in the sector;
η – number of communications for each aircraft in the sector;
φ – the controller availability factor;
φ_A – controller availability factor after the introduction of ATIS;
τ_{Am} – mean duration of each message after the introduction of ATIS;
τ_m – mean duration of each message.

Abbreviations

AASANA – Administration and Auxiliary Services for Air Navigation;
ATC – Air Traffic Control;
ATIS – Automatic Terminal Information Service;
ATN – Air Traffic network;
EUROCONTROL – The European Organisation for the Safety of Air Navigation;
METAR – The Meteorological Aerodrome Report.

1. Introduction

Continuous growth in air traffic worldwide and the projected growth in air traffic demand, coupled with the uncertainties arising in the Air Traffic Network (ATN) from weather, congestions, breakdowns, and other exogenous variables, brings new challenges and opens research question on safety and capacity in the ATN (Hossain et al., 2019; Netjasov, 2012). The aviation industry has increasingly prioritised improving reliability through technological innovation, rigorous maintenance practices, and advanced operational protocols (Tomaszewska, 2023).

The associated workload of air traffic controllers is one of the most important topics in the aviation industry in general (Federal Aviation Administration, 2025; EUROCONTROL, 2018). Air traffic controller profession is a highly professional and mentally demanding job (Karagkouni et al., 2025; Restuputri et al., 2022). It is characteristic by work in a complex information environment with high requirements for resistance to fatigue, stress, monotony, but also for other aspects of personal and power dimension of man, as well as above-average personal responsibility (Langr et al., 2015). The European Organisation for the Safety of Air Navigation (EUROCONTROL) is constantly striving to find new solutions to reduce air traffic controller workload to a level that ensures that air traffic is as little affected by the human factor as possible, thus striving to achieve the highest possible safety and capacity (EUROCONTROL, 2017).

Mental workload is a multidimensional construct, including the level of attentional engagement and effort that a person must expend to perform a given task (Wickens, 2008; Lahtinen, 2020; Hoškova-Mayerova et al., 2022). Prior research has shown that several factors affect the complexity and air traffic controller workload (Moreno et al., 2022; Muñoz-de-Escalona et al., 2024; Weckler et al., 2023; Mogford et al., 1995; Majumdar & Ochieng, 2002). These factors include, but are not limited to, the number of aircraft and potential conflicts, occupancy of traffic flows, vertical distribution of aircraft, number of hand-offs, headings and speed variation between two or more aircraft, aircraft proximity to each other, and weather conditions (Moreno et al., 2022; Mogford et al., 1995). Air traffic controller workload is a subjective attribute and is an effect of air traffic complexity, which can be measured objectively (Chatterji et al., 2001; Socha et al., 2020).

In recent years, various approaches have been developed to reduce air traffic controller workload, many of them based on artificial intelligence (AI) and machine learning, with direct implications for sector capacity. Nonintrusive techniques such as eye-tracking combined with machine learning provide real-time indicators of controller workload, which can help identify when sector demand approaches safe limits and thereby prevent overload (Lemetti et al., 2025). Other methods focus on neurophysiological signals, for example EEG-based workload classification (Hui et al., 2024), or on predictive deep learning models, which can anticipate high-workload periods and enable proactive capacity management (Muñoz-de-Escalona et al., 2024).

In addition, workload reduction can also be supported by intelligent automation in the form of human–AI teaming. Digital assistants are designed to handle routine tasks while leaving strategic decision-making to the ATC. This collaboration reduces the controller's workload and allows for an increase in capacity without compromising safety (Gerdes et al., 2025).

In this study the impact of the introduction of the Automatic Terminal Information Service (ATIS) as a way to increase capacity is examined. This paper aims to emphasize on effectiveness of using Automatic Terminal Information Service (ATIS) for reducing the controllers' workload and the associated airspace capacity. The paper is organized as follows. Section 2 presents the preliminaries, including a discussion of air traffic controller workload and capacity. Section 3 states the objectives and hypotheses of the study. Section 4 describes the applied methodology and data collection procedures. Section 5 provides the analysis of the collected data, while Section 6 discusses the obtained results in the context of existing literature and practical implications. Finally, Section 7 concludes the paper by summarizing the main findings.

2. Preliminaries

2.1. Air traffic controller workload

The workload, as used in this paper, is a comprehensive summary of all inputs affecting the work of air traffic controllers (Hoskova-Mayerova et al., 2022). This includes all routine and non-routine activities of air traffic controllers and human factors. Human factors as a set of human characteristics and abilities, assessed primarily through psychological and physiological conditions, have an influence on human performance, efficiency and reliability, and account for approximately 70% to 94% of aviation accidents across different years, with a consistent trend of around 80 % being reported in multiple analyses (Lyssakov & Lyssakova, 2019; Shappell et al., 1999). Not only pilots, but also air traffic controllers are exposed to a large number of factors during their work, which can affect their concentration, performance, and also the possible occurrence of errors that could lead to safety hazards (Chang & Yeh, 2010). These factors include stress, fatigue, or current health and mental condition (Putri et al., 2019; Socha et al., 2020).

The workload, despite it's ubiquity, is very hard to pinpoint. It is generally considered to be a multifaceted construct that cannot be seen directly but must be inferred from what can be seen or measured (Athenes et al., 2002). Measures of Air Traffic Controll (ATC) workload are typically based on subjective ratings made by controllers either while controlling air traffic or just afterwards. Because subjective ratings interfere with controller activities (thus affecting their perceived workload) and are prone to rater errors, objective workload estimates are being developed that may be used in place of subjective ratings activities (Athenes et al., 2002). These estimates are computed from routinely recorded ATC data that describe both aircraft and controller activities (Athenes et al., 2002).

2.2. Sector capacity

The ATC sector mostly has the shape of a polyhedron with defined vertical and horizontal borders where aircraft flight operations are realized while being supervised by air traffic controllers (ATC) (Dmochowski & Skorupski, 2017). According Majumdar and Ochieng (2002) "*the capacity of an ATC sector can be defined as the maximum number of aircraft that are controlled in a particular ATC sector in a specified period, while still permitting an acceptable level of controller workload*".

Note that air traffic controllers manage their workload based on the number of aircraft they are actively controlling, rather than simply the number of aircraft entering, exiting, or passing through their sector within a specified timeframe (Loft et al., 2007; Histon & Hantsman, 2008a; Majumdar & Ochieng, 2002). This implies that air traffic controllers may spend significantly more of their capacity on managing a specific aircraft rather than others.

In today's airspace operations, each sector has a capacity threshold in the form of the maximum number of aircraft. This threshold, called the Monitor Alert Parameter, serves as a controller workload limit indicator for each sector (EUROCONTROL, 2000).

The method for determining capacity based on workload is based on assessing how much time the controller needs to perform all necessary tasks. The threshold is typically set to 40–45 minutes per hour. Free time (15–20 minutes) is used as a buffer for abnormal situations and prediction inaccuracies. For example, the CAPAN methodology calculates sector capacities based on the evaluation of air traffic controllers' workload using fast-time simulation (EUROCONTROL, 2024). The workload threshold is set at 70%. This means that the theoretical sector capacity is reached when the controller's workload reaches 70% of the total working time, i.e., 42 minutes per hour (EUROCONTROL, 2024). There are five levels of workload (see Table 1).

Table 1. Workload and recorded working time of air traffic controllers (EUROCONTROL, 2003)

Threshold	Interpretation	Recorded Working Time during 1 hour
70% or above	Overload	42 minutes +
54%–69%	Heavy load	32–41 minutes
30%–53%	Medium Load	18–31 minutes
18%–29%	Light Load	11–17 minutes
0%–17%	Very Light Load	0–10 minutes

Part of the CAPAN method is the identification of factors contributing to workload. The next step is to assign points or weights to each factor based on relative comparison among them, and then all assigned points are summed up for each minute of exercise.

Sector capacity can also be expressed as the number of aircraft that can be controlled simultaneously by a single controller N in a given sector and it is estimated using the following formula (ICA 100-30) with factors directly and inversely proportional to ATC capacity (Jaurena, 2009):

$$N = \frac{\varphi \cdot \delta}{\eta \cdot \tau_m \cdot v_m}\left[-\right]. \tag{1}$$

Factors directly proportional to ATC capacity:

φ – the controller availability factor, defined as the percentage of time available for planning aircraft separation procedures;

δ – average distance flown by aircraft in the sector, which is a function of the paths and en route or terminal procedures established for each sector;

Factors inversely proportional to ATC capacity:

η – number of communications for each aircraft in the sector, which must be limited to the least possible number required for an understanding between the pilot and the controller. This number can be minimized by issuing a complete clearance in advance for flight planning;

τ_m – mean duration of each message. This factor can be minimized by issuing messages objectively, without long explanations that are detrimental for an understanding between the pilot and the controller; and

v_m – mean speed of aircraft in the sector.

The quotient of the average distance flown by aircraft in a sector δ and mean speed of aircraft in a sector v_m is an expression of the average *a* flight time of the aircraft in a sector T_a:

$$T_a = \frac{\delta}{v_m}\left[s\right]. \tag{2}$$

If δ and v_m are replaced with the average flight time of the aircraft in a sector T_a, Equation (1) can be replaced with a simpler version (Jaurena, 2009):

$$N = \frac{\varphi \cdot T_a}{\eta \cdot \tau_m}\left[-\right]. \tag{3}$$

2.3. Automatic terminal information system

Automatic Terminal Information System, or ATIS, is a continuous broadcast of recorded uncontrolled information in busier terminal (i.e. airport) areas. ATIS broadcasts contain essential information, such as weather information, which runways are active, available approaches, and any other information required by the pilots. Pilots usually listen to an available ATIS broadcast and can simultaneously read the same information displayed at cockpit if necessary, before contacting the local control tower or approach, in order to reduce the controllers' workload and relieve frequency congestion (Dandegaokar et al., 2016).

The pilot listens to the ATIS just prior to the initial contact and notes the code letter; on check-in, the pilot reports the code letter of the ATIS copied. This enables the controller to confirm that the pilot has copied the current ATIS. The usual practice is for the controller to inform the pilot if the ATIS or any element of it subsequently changes (SKYbrary, 2024).

Voice-ATIS broadcasts usually contain the following information in the order listed (SKYbrary, 2024):

- aerodrome name;
- arrival and/or departure indicator;
- contract type for communication via D-ATIS;
- designator;

- time of observation, if appropriate;
- type of approach(es) to be expected;
- runway(s) in use; status of arresting system constituting a potential hazard, if any;
- significant runway surface conditions and, if appropriate, braking action;
- holding delay, if appropriate;
- transition level, if applicable;
- other essential operational information.

Smaller regional airports and some military airports do not have ATIS even though there may be a significant amount of traffic with high requirements for air traffic controller. The air traffic controller shall thus transmit meteorological information from the The Meteorological Aerodrome Report (METAR) in the form specified in International Civil Aviation Organization Doc. 4444 (International Civil Aviation Organization [ICAO], 2016).

At aerodromes with a high air traffic level, dictating the METAR to each pilot has become a problem, according to data gathered from the Airports Administration and Auxiliary Services for Air Navigation (AASANA) (Vargas-Cuentas et al., 2015). For example, if there are several aircraft wishing to leave at the same time, the air traffic controller would have to transmit the same weather report for each of the aircraft, which creates unnecessary congestion to the frequency in the airport, causing aeronautical incidents due to a wrong instruction that could be given to the pilot; otherwise the operations are delayed and are not as smooth and efficient on the aerodrome (Vargas-Cuentas et al., 2015).

If the standard speech rate is assumed, i.e. 100 words per minute (ICAO, 2001), the transmission of information by the controller to the pilot and weather conditions should take around 18 s. A length of 30 words and therefore a time of 18 s is assumed only if there is no significant weather in the vicinity of the airport and no special runway conditions. A standard transmission example would be:

Runway in use 24, wind 250 degrees, 5 knots, cavok, temperature 15, dew point 5, QNH 1005.

This message should be spoken in 16 seconds.

3. Objectives and hypotheses

Smaller international or regional airports typically do not have ATIS. Therefore, pilots only receive the basic meteorological information necessary for flight operations after establishing contact with air traffic control. The aim of the paper is to determine how the introduction of ATIS at the airport impacts the air traffic control load and the capacity of the area.

The following hypotheses were established:

H1: The introduction of ATIS at the airport reduces the workload of air traffic controllers, thereby increasing the controller availability factor φ.

H2: The introduction of ATIS at the airport reduces the mean duration of each message τ_m and number of communications for each aircraft in the sector η.

H3: The introduction of ATIS at the airport increases the capacity of the sector.

4. Methodology

To verify the established hypotheses, a series of measurements was carried out under live operational conditions at the airport. The measurement of the length of communication between the air traffic controller and the pilot took place over the course of the whole year, exactly 365 days. Maintaining the anonymity of the airport was a condition for obtaining permission to conduct research at this airport.

An unnamed airport with continuous operations providing radar services to mixed Instrument Flight Rules (IFR) and Visual Flight Rules (VFR) traffic was selected for the case study, where 20 air traffic controllers were on duty during the data collection. These controllers participated in shifts controlling traffic in the Terminal Maneuvering Area (TMA) of the airport, during which the values from Equation (3) were obtained from timestamped voice transmission events using the built-in clock function of the voice communication system used by the air traffic controller at the station. Raw data were extracted and anonymized, then processed to identify individual controller–pilot communication exchanges. Over the study period, a total of 12 415 flights were analyzed, of these, 61% corresponded to VFR traffic and 39% to IFR traffic. The communication samples were further categorized by aircraft type (fixed-wing vs. rotorcraft) and message content. Depending on the traffic density, the shift was occupied by 2 to 5 air traffic controllers, however, only one controller was actively managing the traffic at any given time, while the others were either on break or assigned to other operational duties.

All shifts were conducted without the Airport Terminal Information Service (ATIS) present, requiring air traffic controllers to relay meteorological information from METAR reports.

For the case study, the calculation of the controller availability factor φ was defined as follows:

$$\varphi = \frac{T - T_{tr}}{T} \left[-\right], \tag{4}$$

T – flight time of the aircraft in the sector; T_{tr} – the total time of transmissions between the controller and the pilots in the sector of responsibility during the approach or overflight.

The controller availability factor is therefore the proportion of time when the controller is not transmitting or receiving on the frequency and can fully devote themselves to planning the spacing. That is, as a proportion of the time that elapses between individual transmissions and the total time of the shift, i.e. the time after the controller receives and verifies the pilot's feedback before starting the next transmission, whether it was initiated by the pilot or the controller. If the result is multiplied by hundred, then the value is the percentage of time available for planning aircraft separation procedures.

To calculate the capacity of the sector with ATIS installed at the airport, the value of the number of messages transmitted by the controller η is reduced by one, and when calculating the average duration of each message, the transmission of an ATIS message during a shift is excluded from consideration. The number of messages transmitted by the controller is thus η-1. The calculation for determining sector capacity with ATIS (N_A) is as follows:

$$N_A = \frac{\varphi_A \cdot T_a}{(\eta - 1) \cdot \tau_{Am}} [-], \tag{5}$$

where: φ_A – controller availability factor after the introduction of ATIS; T_a – average flight time of the aircraft in the sector; τ_{Am} – mean duration of each message after the introduction of ATIS.

The resulting sector capacity value is always rounded to a lower whole number. For example, for a result of 15.7, the capacity is determined to be 15 aircraft, since in the case of rounding up to a higher whole number, the capacity would be determined to be higher than the air traffic controller is able to arrange.

Data for the calculations of individual quantities were collected separately for fixed-wing aircraft and rotorcraft. The statistical processing of the data was thus less influenced by the flight characteristics of individual aircraft types.

5. Data analysis

Secod row of the Table 2 presents the calculated averages for the measured values number of communications for each aircraft in the sector η, average flight time of the aircraft in the sector T_a, mean duration of each message τ_m and calculated values of controller availability factor φ regarding fixed-wing aircraft without ATIS installed at the airport. For these values, according to Equation (3) resulting sector capacity N 9.38 aircraft. Such a value has limited practical applicability in real operation, therefore it is appropriate to round this value to a whole number, to 9, which is a closer representation of the real capacity of the sector.

Table 2. Resulting average values for fixed-wing and rotorcraft aircraft without ATIS available

Aircraft type	H	T_a	τ_m	j
Fixed-wing	11.24	549.92	4.49	0.84
Rotorcraft	10.88	882.64	4.85	0.81

Third row of the Table 2 shows the measured and calculated values for rotorcraft aircraft without installed ATIS at the airport. Sector capacity N for rotorcraft aircraft is thus 14.03 aircraft. The real number of aircraft that the air traffic controller can control in the area without ATIS is 14 aircraft.

The resulting calculated values for fixed-wing aircraft with the ATIS system introduced at the airport are presented in second row of Table 3. The sector capacity then, according to Equation (5), is N_A = 12.76. For practical reasons, the value is rounded down to 12. The sector capacity is thus 36.03% higher than without ATIS installed. At the same time, with the introduction of ATIS, the values of the controller availability factor φ_A increased by 0.02%, and the mean duration of each message τ_{Am} decreased by 0.74 s after the introduction of ATIS.

Table 3. Resulting average values for fixed-wing and rotorcraft aircraft with ATIS available

Aircraft type	$(\eta - 1)$	T_a	τ_{Am}	φ_A
Fixed-wing	10.24	549.92	3.75	0.86
Rotorcraft	9.88	882.64	4.08	0.83

The measured and calculated values for rotorcraft aircraft are shown in third row of Table 3. If ATIS were introduced at the airport, the sector capacity for rotorcraft aircraft would be N_A = 19.3. For practical reasons, the value is again rounded down to 19. The sector capacity thus increased by 37.56% thanks to the introduction of ATIS. Furthermore, the controller availability factor φ_A increased by 2.46% and the duration of each message decreased after the introduction of ATIS (τ_{Am}).

From the obtained results, the following changes can be expressed by the introduction of ATIS (which are also the above-mentioned hypotheses):

H1) $\varphi > \varphi_A$ therefore the controller availability factor has increased.

H2) $\eta\tau_m > (1-\eta)\tau_{mA}$ therefore the average duration of the entire communication with ATC decreased.

H3) $N < N_A$ therefore the sector capacity has increased.

It is now tested whether the mentioned changes H1 to H3 are statistically significant, and the introduction of the ATIS system really led to the above changes. This test is carried out against the alternative possibility that the changes mentioned in points H1 to H3 were only caused by random deviations and the next testing of the ATIS system could turn out differently.

Before proceeding to the statistical analysis of communication data before and after the introduction of the ATIS system, it is necessary to realize that the data in the first and second columns of Table 2 and 3 are interdependent. The dependency is due to the fact that part of the communication between the pilot and the approach controller takes place in the same way, regardless of whether the ATIS system is implemented or not. Then there is another part of communication, which is significantly reduced after the introduction of the ATIS system. For statistical analysis, data dependence means that it is appropriate to use one of the so-called paired tests. In a test of this type, the difference of the measured data when using and not using the ATIS system is first calculated in each row (see Table 4). The values obtained in this way are then tested with a one-sample test, whether on average they differ statistically significantly from zero.

Table 4. Pairwise test of hypotheses H1 to H3

$\varphi - \varphi_A$	Controller availability factor difference
$\eta\tau_m - (1-\eta)\tau_{mA}$	Mean duration of each message difference
$N - N_A$	Sector capacity difference

Therefore, the goal of further considerations is to decide whether the data presented in Table 4, on average, are statistically significantly different from zero. First, it is necessary to decide whether the given data has a normal distribution. Therefore, for each row of Table 4, the Kolmogor-Smirnov test is used to test the hypothesis:

Null hypothesis: the data comes from a random sample from a normal distribution, versus

Alternative hypothesis: data are not from a random sample from a normal distribution at a significance level α = 0,05.

The results of the tests for data from the rotorycraft and fixed-wing sets are shown in the following Table 5. The sample mean $\bar{x}$ and sample variance $s(x)^2$ of the data are also shown here.

For the data from the first row of the rotorcraft and fixed-wing sections of Table 5, the result was $p < \alpha$, and therefore the null hypothesis is rejected that the data comes from a random sample from a normal distribution. It is therefore further assumed that that they do not have a normal distribution.

For the data from the other rows of the rotorcraft and fixed-wing sections of Table 5, the result was $p > \alpha$. We do not reject the null hypothesis that the data come from a random sample from a normal distribution. Hence, it is further assumed that they have a normal distribution.

For the data in Table 5, which have a normal distribution, the hypothesis that says that the mean value is equal to zero was tested with a one-sample t-test at the standard significance level of α = 0.05 against the alternative hypothesis that says that the mean value is different from zero.

Null hypothesis: μ = 0 i.e. the median value of the set is equal to zero, versus, alternative hypothesis: $\mu \neq 0$ i.e. the median value of the set is different from zero at the significance level α = 0,05.

The resulting values of this test are shown in Table 6. This table also shows the interval estimates of the mean value.

For the data from Table 5, which do not have a normal distribution, the Wilcoxon signed rank test was used to test the hypothesis:

Null hypothesis: *med* = 0 i.e. the median value of the set is equal to zero,versus

Alternative hypothesis: $med \neq 0$ i.e. the median value of the set is different from zero at the significance level α = 0,05.

The resulting values of this test are shown in Table 7.

It follows from Tables 6 and 7 that the inequalities in H1) – H3) that were tested are statistically significant and that with a probability greater than 95% they did not arise due to random deviations. Hypotheses H1 to H3 were accepted.

Table 5. Normality test results

Aircraft type	x	$\bar{x}$	$s(x)^2$	*p*-value	H_0
Rotorcraft	$j - j_A$	–0.0222	0.0001	0.000002	rejected
	$\eta\tau_m - (1-\eta)\tau_{mA}$	12.1419	6.6855	0.2426	not rejected
	$N - N_A$	–5.1030	4.8012	0.3655	not rejected
Fixed-wing	$j - j_A$	–0.0222	0.0001	0.000002	rejected
	$\eta\tau_m - (1-\eta)\tau_{mA}$	11.78	5.505	0.1578	not rejected
	$N - N_A$	–3.3465	1.677	0.1124	not rejected

Table 6. Sample t-test of hypotheses H2 and H3

Aircraft type	*x*	$\mu(x)$	*p*-value	H_0
Rotorcraft	$\eta\tau_m - (1-\eta)\tau_{mA}$	11.4071; 12.8767	0	rejected
	$N - N_A$	–5.7257; –4.4803	0	rejected
Fixed-wing	$\eta\tau_m - (1-\eta)\tau_{mA}$	11.1132; 12.4468	0	rejected
	$N - N_A$	–3.7445; –3.0085	0	rejected

Table 7. Wilcoxon signed rank test of hypothesis H1

Aircraft type	Tested quantity	*p*-value	H_0
Rotorcraft	$\varphi - \varphi_A$	0	rejected
Fixed-wing	$\varphi - \varphi_A$	0	rejected

6. Discussion

The findings suggest that the introduction of ATIS has a substantial impact on sector capacity, both for fixed-wing aircraft and for rotorcraft operations. For fixed-wing aircraft, the sector capacity increased by 36.03% with ATIS, while for helicopter aircraft it increased by 37.56%. This increase in capacity is influenced by the reduction of the necessary messages transmitted by air traffic controllers to aircraft by one message, which is also related to the reduction of the mean duration of each message. The reduction of mean duration of each message after the introduction of ATIS indicates more effective communication between air traffic controllers and pilots due to more accurate and consistent information provided through ATIS. Air traffic controllers thus have more time to plan the spacing between aircraft and control the approach and landing sequence of aircraft.

The increase in sector capacity after the introduction of the Automatic Terminal Information Service may not be the primary direct consequence. It is important that the increase in the air traffic controller availability factor is also considered. This factor represents an increase in air traffic controller availability, which allows a longer window of time to plan aircraft spacing and control aircraft approach and landing sequences. This increases the safety of air traffic, as it gives air traffic controllers more time to make correct and safe decisions and react to the current situation in the airspace, i.e. it reduces their workload. These advantages of introducing ATIS are further underlined by the fact that air traffic controllers do not transmit the information normally contained in ATIS in the standard speech rate assumed at 100 words per minute. They usually convey information at a faster speech rate, which can be prone to errors and crosstalk. Otherwise, if they transmitted information more slowly and clearly, it would take time away from the air traffic controllers to focus on other activities and thus increase their workload.

For a better illustration with the aim of determining the impact of the introduction of ATIS at the airport on the workload of air traffic control and the capacity of the airspace, it was more appropriate to divide the calculation and data collection into these types of aircraft. Using a non-segmented dataset would have introduced high variability and noise into the core metrics used in this study, such as the number of communications for each aircraft η and flight time in sector T_a. These parameters are directly tied to sector capacity and controller workload, and mixing aircraft types could have led to misleading results that obscure the actual impact of ATIS. Overall used method reflects not only the quantitative load on communication channels, but also the time constraints faced by controllers. Alternative methods such as simulation-based modeling or purely statistical regression were considered. However, those approaches would lack the granularity needed to isolate the specific impact of verbal communication load which is precisely what ATIS aims to reduce. The selected method (modified ICA 100-30) offers a transparent and replicable framework for measuring how communication-related workload metrics contribute to sector capacity.

Nonetheless, several limitations should be acknowledged. The study was conducted at a single anonymous airport with specific operational characteristics. Traffic density, weather conditions, and local procedures may differ significantly from other airports, which limits the generalisability of the results.

Another limitation is that the study did not incorporate transfer of control procedures, which usually occur at area of responsibility (AoR) borders (Bauer & Kalvoda, 2020). In some cases, controllers issue instructions before an aircraft formally enters their AoR, thereby altering communication dynamics that the ATC can thus transmit information to the aircraft even before entering the area of responsibility and plan separations earlier.

The workload was modeled solely on communication time, whereas workload is a multidimensional construct (Wickens, 2008; Lahtinen, 2020; Hoskova-Mayerova et al., 2022). The controller availability factor defined in this study reflects only time not spent transmitting or receiving, and does not fully capture mental workload. While this study shows in numbers how ATIS shortens communication time and increases sector capacity, it does not yet address the broader impact on human performance. In air traffic control, communication demands are closely linked to mental workload, stress, and the ability to stay focused under pressure. By taking over routine information delivery, ATIS helps ease frequency congestion and gives ATC more room to concentrate on complex decision-making. Earlier studies have demonstrated that reducing voice communication can lower perceived workload and improve accuracy (Loft et al., 2007; Wickens et al., 2015). In addition, the consistent and standardized messages provided through ATIS reduce ambiguity and the risk of verbal errors, which further strengthens safety (Parasuraman & Riley, 1997; Histon & Hansman, 2008b). Although these human factors were not the primary focus of our quantitative analysis, they are central to understanding the overall benefits of ATIS. Future research should therefore bring them into the picture, including systematic workload assessment, for example using NASA-TLX or other validated subjective tools, as well as objective measures such as physiological monitoring.

7. Conclusions

Every day, the aviation industry faces many risks that can potentially jeopardize the success of operations if not managed adequately. The most effective tool against accidents is prevention, and in air transport it is prevention that is given relatively extensive attention. Nowadays, there are several causes of air accidents and it is necessary to constantly look for and implement new solutions to reduce the probability of incidents. One of the possible solutions is reducing the workload of air traffic controllers.

Based on the obtained results and the performed calculations, the hypotheses H1 to H3 were proven; i.e. when introducing ATIS, the controller availability factor is increased, the mean duration of each message ε_{ti} and number of communications for each aircraft in the sector η is reduced, and the sector capacity of an area is increased. The introduction of ATIS thus significantly contributes to increasing the capacity of ATC sector.

The novelty of this work lies in its quantitative and statistically validated analysis, which suggests a significant potential impact of ATIS implementation on both ATC workload and sector capacity. Rather than comparing two different airports, the study introduces a before-and-after modeling approach by mathematically simulating the effect of ATIS through adjustments to communication parameters, such as duration of each message and number of communications. This method allows for a direct comparison of sector capacity and controller availability within the same airport context, ensuring that external variables are minimized. However, the implications of these findings extend beyond their statistical confirmation. The results provide a data-driven justification for encouraging or mandating ATIS implementation at high-density non-towered or under-equipped airports. For air navigation service providers, the evidence supports investment in ATIS infrastructure as a cost-effective way to improve airspace capacity and for airport operators, particularly in regions anticipating traffic growth, ATIS can be considered a lightweight automation solution to enhance operational efficiency without requiring additional staffing.

Author contributions

TH and SHM conceived the study and were responsible for the design and development of the data analysis. TH, JJ and ZK were responsible for data collection and analysis. SHM and ZK were responsible for data interpretation. TH wrote the first draft of the article.

Disclosure statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Athenes, S., Averty, P., Puechmorel, S., & Delahaye, D., & Collet, Ch. (2002). ATC complexity and controller workload: Trying to bridge the gap. In *Proceedings of the International Conference on HCI in Aeronautics* (pp. 55–60). AAAI.

Bauer, M., & Kalvoda, J. (2020). Workload features inside air traffic control electronic transfer environment. *Advances in Military Technology*, *15*(1), 191–199. https://doi.org/10.3849/aimt.01356

Chatterji, G., & Sridhar, B. (2001). Measures for air traffic controller workload prediction. In *Proceedings of the First AIAA Aircraft Technology*, *Integration*, *and Operations Forum*, Los Angeles, CA. American Institute of Aeronautics & Astronautics. https://doi.org/10.2514/6.2001-5242

Chang, Y. H., & Yeh, C. H. (2010). Human performance interfaces in air traffic control. *Applied Ergonomics 41*(1), 123–129. https://doi.org/10.1016/j.apergo.2009.06.002

Dandegaokar, D., Katre, S., & More, S. V. (2016). Automatic Terminal Information System (ATIS). *International Journal of Scientific Engineering and Research*, *4*(4), 75–78. https://doi.org/10.70729/IJSER15764

Dmochowski, P., & Skorupski, J. (2017). Air traffic smoothness. A new look at the air traffic flow management. *Transportation Research Procedia*, *28*, 127–132. https://doi.org/10.1016/j.trpro.2017.12.177

EUROCONTROL. (2018). *Challenges of growth 2018*. https://www.eurocontrol.int/publication/challenges-growth-2018

EUROCONTROL. (2017). *Twenty years of network management*. *european organisation for the safety of air navigation*. https://www.eurocontrol.int/sites/default/files/publication/files/2016-spring-skyway-magazine-full.pdf

EUROCONTROL. (2000). *Investigating the air traffic complexity*: *Potential impacts on workload and costs*. https://www.eurocontrol.int/sites/default/files/library/019_Air_Traffic_Complexity.pdf

EUROCONTROL. (2024). *CAPAN methodology – sector capacity assessment*. https://www.icao.int/ESAF/Documents/meetings/2016/Air%20Traffic%20Services%20System%20Capacity%202016/2%20 CAPAN_Sector_Capacity_A ssessment.pdf

EUROCONTROL. (2003). *Pessimistic sector capacity estimation* (Report EEC Note No.21/03, Project OCA). Brussels. https://www.eurocontrol.int/sites/default/files/library/026_Pessimistic_Sector_Capacity.pdf

Federal Aviation Administration. (2025). *Air traffic by the numbers*. FAA. https://www.faa.gov/air_traffic/by_the_numbers

Gerdes, I., Jameel, M., Materne, L. J., & Bruder, C. (2025). Synergies in the skies: Situation awareness and shared mental model in digital-human air traffic control teams. *Aerospace*, *12*, Article 472. https://doi.org/10.3390/aerospace12060472

Histon, J. M., & Hansman, R. J. (2008a). *Mitigating complexity in air traffic control*: *The role of structure-based abstractions* (Report No. ICAT-2008-05). ICAT, Cambridge. https://www.researchgate.net/publication/38002271_Mitigating_Complexity_in_Air_Traffic_Control_The_Role_of_Structure-Based_Abstractions

Histon, J. M., & Hansman, R. J. (2008b). The impact of structure on cognitive complexity in air traffic control. *Human Factors and Ergonomics Society Annual Meeting*, *52*(1), 24–28.

Hui, L., Pei, Z., Quan, S., Ke, X., & Zhe, S. (2024). Cognitive workload detection of air traffic controllers based on mRMR and fewer EEG channels. *Brain Sciences*, *14*(8), Article 811. https://doi.org/10.3390/brainsci14080811

Hoskova-Mayerova, S., Kalvoda, J., Bauer, M., & Rackova, P. (2022). Development of a methodology for assessing workload within the air traffic control environment in the Czech Republic. *Sustainability*, *14*(13), Article 7858. https://doi.org/10.3390/su14137858

Hossain, M., Alam, S., & Delahaye, D. (2019). An evolutionary computational framework for capacity-safety trade-off in an air transportation network. *Chinese Journal of Aeronautics*, *32*(4), 999–1010. https://doi.org/10.1016/j.cja.2018.12.017

International Civil Aviation Organization. (2001). *Aeronautical telecommunications* (Annex 10). ICAO.

International Civil Aviation Organization. (2016). *Procedures for air navigation services* (*PANS*) – *air traffic management* (Doc 4444). ICAO.

Jaurena, R. A. (2009). *Guide for the application of a common methodology to estimate airport and ATS sector capacity for the SAM region* (Regional Project: ICAO RLA/06/901). ICAO.

Karagkouni, A., Zantanidis, S., Moutzouri, A., Sartzetaki, M., Constantinidis, T., & Dimitriou, D. (2025). Assessment of occupational health and safety performance in air traffic control: An empirical investigation of stress and well-being. *Safety*, *11*(3), Article 88. https://doi.org/10.3390/safety11030088

Lahtinen, T. (2020). *Radio speech communication and workload in military aviation*: *A human factors perspective*. University of Oulu. http://jultika.oulu.fi/files/isbn9789526214283.pdf

Langr, D., Kalvoda, V., & Pokorný, V. (2015). Testing aptitudes as part of the selection process of air traffic controllers by the Czech Armed Forces. *Advances in Military Technology*, *10*(2), 27–67. https://www.aimt.cz/index.php/aimt/article/view/1096

Lemetti, A., Meyer, L., Peukert, M., Polishchuk, T., Schmidt, C., & Wylde, A. H. (2025). Predicting air traffic controller workload using machine learning with a reduced set of eye-tracking features. *Transportation Research Procedia*, *88*, 66–73. https://doi.org/10.1016/j.trpro.2025.05.008

Loft, S., Sanderson, P., Neal, A., & Mooij, M. (2007). Modeling and predicting mental workload in en route air traffic control: Critical review and broader implications. *Human Factors*, *49*(3), 376–399. https://doi.org/10.1518/001872007X197017

Lyssakov, N. D., & Lyssakova, E. N. (2019). Human factor as a cause of aircraft accidents. In *Proceedings of the II International Scientific-Practical Conference "Psychology of Extreme Professions"* (ISPCPEP 2019) (pp. 130–132). Atlantis Press. https://doi.org/10.2991/ispcpep-19.2019.31

Majumdar, A., & Ochieng, W. (2002). Factors affecting air traffic controller workload: Multivariate analysis based on simulation modeling of controller workload. *Transportation Research Record*, *1788*(1), 58–69. https://doi.org/10.3141/1788-08

Mogford, R., Guttman, S., Morrow, S. L., & Kopardekar, P. (1995). *The complexity construct in air traffic control*: *A review and synthesis of the literature* (DOT/FAA/CT-TN-95/22). FAA Technical Center, Atlantic City.

Moreno, F. P., Comendador, F. G., Jurado, R. D., Suárez, M. Z., Janisch, D., & Valdés, R. M. A. (2022). Determination of air traffic complexity most influential parameters based on machine learning models. *Symmetry*, *14*(12), Article 2629. https://doi.org/10.3390/sym14122629

Muñoz-de-Escalona, E., Leva, M. C., & Cañas, J. J. (2024). Mental workload as a predictor of ATCO's performance: Lessons learnt from ATM task-related experiments. *Aerospace*, *11*(8), Article 691. https://doi.org/10.3390/aerospace11080691

Netjasov, F. (2012). Framework for airspace planning and design based on conflict risk assessment: Part 1: Conflict risk assessment model for airspace strategic planning. *Transportation Research Part C*: *Emerging Technologies*, *24*, 190–212. https://doi.org/10.1016/j.trc.2012.03.002

Parasuraman, R., & Riley, V. (1997). Humans and automation: Use, misuse, disuse, abuse. *Human Factors*, *39*(2), 230–253. https://doi.org/10.1518/001872097778543886

Putri, E. D., Nurmaida, H. A., Warsito, T., Sodikin, A., & Gultom, S. (2019). The effect fatigue levels of air traffic control (ATC) on work effectiveness in Soekarno-Hatta International Airport. *Advances in Transportation and Logistics Research*, *2*, 46–50.

Restuputri, D., Fatimah, S., & Mubin, A. (2022). Air traffic control work system design to improve operator performance with workload approach and safety concept. *Jurnal Sistem dan Manajemen Industri*, *6*(2). https://doi.org/10.30656/jsmi.v6i2.4582

Shappell, S., Wiegmann, D., Fraser, J., Gregory, G., Kinsey, P., & Squier, H. (1999). Beyond mishap rates: A human factors analysis of US Navy/Marine Corps TACAIR and rotary wing mishaps using HFACS. *Aviation*, *Space*, *and Environmental Medicine*, *70*, 416–417.

SKYbrary. (2023). *Methods to describe sector capacity*. https://www.skybrary.aero/articles/methods-describe-sector-capacity

SKYbrary. (2024). *Automatic Terminal Information Service* (*ATIS*). https://skybrary.aero/articles/automatic-terminal-information-service-atis

Socha, V., Hanáková, L., Valenta, V., Socha, L., Ábela, R., Kušmírek, S., Pilmannová, T., & Tecl, J. (2020). Workload assessment of air traffic controllers. *Transportation Research Procedia*, *51*, 243–251. https://doi.org/10.1016/j.trpro.2020.11.027

Tomaszewska, T. (2023). Application of Markov chains, MTBF and machine learning in air transport reliability. *Aviation and Security Issues*, *4*(2), 83–106. https://doi.org/10.55676/asi.v4i2.81

Vargas-Cuentas, N. I., & Roman-Gonzalez, A. (2015). Automatic terminal information system for El Alto airport. In *The 3rd International Conference on Technology*, *Informatics*, *Management*, *Engineering* & *Environment* (*TIME-E*) (pp. 137–142). IEEE. https://doi.org/10.1109/TIME-E.2015.7389762

Weckler, D., Matthews, B., Monadjemi, S., Wolfe, S. R., & Oza, N. C. (2023). Monitoring airspace complexity and determining contributing factors. In *AIAA SCITECH 2023 Forum* (Article 1197). Aerospace Research Central. https://doi.org/10.2514/6.2023-1197

Wickens, C. D., Hollands, J. G., Banbury, S., & Parasuraman, R. (2015). *Engineering psychology and human performance* (4th ed.). Psychology Press. https://doi.org/10.4324/9781315665177

Wickens, C. D. (2008). Multiple resources and mental workload. *Human Factors*: *The Journal of the Human Factors and Ergonomics Society*, *50*(3), 449–455. https://doi.org/10.1518/001872008X288394

Zafar, M. (2023). Safety management – human factor. In A. A. Khan, M. S. Hossain, M. Fotouhi, A. Steuwer, A. Khan, & D. F. Kurtulus (Eds), *Proceedings of the First International Conference on Aeronautical Sciences, Engineering and Technology* (pp. 386–391). ICASET. Springer. https://doi.org/10.1007/978-981-99-7775-8_42