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INVESTIGATION OF THE APPLICATION OF CPDLC TO AERODROME AIR TRAFFIC CONTROL PROCEDURES

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Abstract. This paper analyzes the application of Controller Pilot Data Link Communication (CPDLC) technology to different air traffic control sectors. It also presents the analysis of the performed research and tests. A CPDLC program is being developed that is adapted for aerodrome flight control. The program takes into account the advantages and disadvantages of other software, as well as the recommendations of other authors. The program is developed using JAVASCRIPT and HTML programming languages. The tests of the developed CPDLC program are performed in the Expert NITA flight control simulator. The CAPAN method is used for data analysis. Analysis of changes in workload, language errors, and time saved using different communication methods during simulations is also performed.

Keywords: CPDLC technology, aerodrome flight control, flight control simulator, workload, CAPAN method, CPDLC software.

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Introduction

The COVID-19 pandemic has halted the growth of flights around the world. With the advent of vaccines and the situation improvement, the number of flights began to rise again and will soon exceed pre-pandemic levels. According to updated Eurocontrol forecasts, the number of flights in 2024 is expected to exceed the number in 2019 slightly and will double by 2030 (Eurocontrol, 2021).

As the number of flights increases, voice radio channels are often overloaded. This increases the workload of air traffic controllers and often reduces the sector's capacity. In the case of aerodromes, their radio communication is loaded with long voice messages, including such messages as: air traffic control (ATC) clearances, start-up and push-back clearances and instructions, and taxiing instructions. All of these messages must be accurately repeated by the pilot, and their repetitions must be carefully listened to by air traffic controllers to avoid any errors. The more aircraft, the more air traffic controllers have to say and, consequently, hear repetitions. This increases the workload of air traffic controllers, the load on the radio, the load on the entire aerodrome and deprives air traffic controllers of time that can be used, for example, for runway and aerodrome monitoring. CPDLC technology can be used to address this issue. The aim of this work is to adapt the CPDLC to aerodrome traffic control and to investigate how this adaptation reduces the workload of air traffic controllers, reduces language errors and the time that air traffic controllers can spend on other duties.

1. Adaptation of CPDLC to different sectors

CPDLC technology has been in use for many years. It was first introduced in the Flight Information Region (FIR). Most of Europe currently uses CPDLC in its FIR.

As it can be seen from Figure 1, all European Union (EU) countries use one of the CPDLC systems, such as the Aeronautical Telecommunication Network (ATN) and air traffic controllers in the UK, Ireland, and Benelux already use the newer and more advanced Future Air Navigation System (FANS 1 / A). A recent study on the application of the CPDLC to regional air traffic controllers has been conducted. It was performed using an Itec simulator and a CPDLC in it. The study found that the change in air traffic controller workload loss with and without CPDLC functionality ranged from 15.21% to 17.34%.

As for the use of CPDLC for approach control, this may be slightly complicated by the specifics of the work itself and the structure of the airspace.

As may be observed in Figure 2, the TMA airspace of any Lithuanian airport is significantly smaller than that of the entire Lithuanian FIR. Regional air traffic controllers have a flight level range of 095 to 660. In comparison, all aerodrome approach air traffic controllers only have a

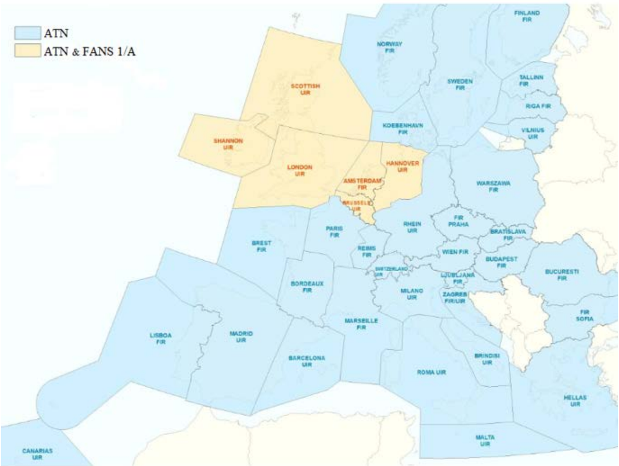

Figure 1. European countries using CPDLC according to 2020 data (Rockwell Collins, 2017)

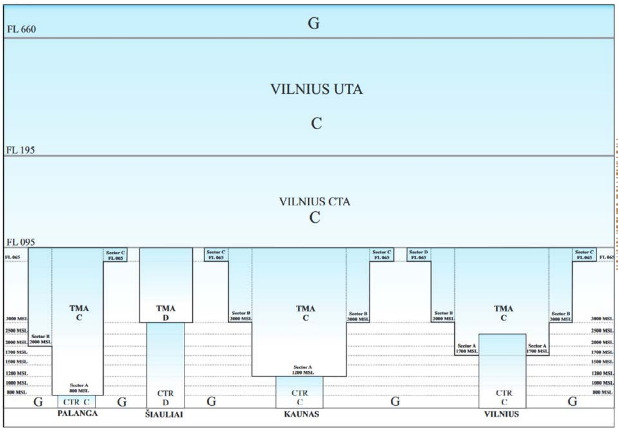

Figure 2. Section of Lithuanian airspace

flight level range of up to 095, and the access airspace is highly staggered, reducing the usable area. As a result, aircraft stay in the airspace for a much shorter time. Also, for the same reasons, decisions have to be made very quickly and sometimes there is no room for a delayed reaction, which can be done with CPDLC.

Another sector where CPDLC can be used is air traffic control towers. This technology would be very beneficial due to the specification of the work. First, tower air traffic controllers must issue a large number of instructions and permits before the departure of the aircraft. In addition, upon arrival at the airport, the air traffic controller must issue instructions for taxiing to the parking area assigned to the aircraft. Pilots of both departing and arriving aircraft do not always correctly understand and repeat the permits, instructions, etc., issued to them. i.e. leading to repetition or incorrect repetition of messages. However, this can happen not only due to the peculiarities of communication but also due to radio interference, interference from other channel users, misunderstanding of the message by pilots and many other reasons. A study conducted in 2016 found that CPDLC is a more appropriate technology for transmitting long, complex messages (ATC clearances, taxi instructions) than voice communication. It has also been observed that sending long messages using CPDLC reduces the load on human memory, resulting in a lower probability of error (Bone & Long, 2016).

2. CPDLC principle of operation

CPDLC is a two-way data communication technology that allows users to transmit non-urgent strategic messages to an aircraft as an alternative to voice communication. Sending a message using CPDLC consists of selecting an address, selecting the desired message from the displayed menu, and performing the transmission. CPDLC messages correspond to the phraseology used in radiotelephony. These messages include authorizations, intended authorizations, requests, reports, and related ATC information. Pilots have the skills to respond to messages, understand the information they receive, communicate it, and announce or cancel emergencies. There is also the possibility of "free text" exchanging information that does not conform to defined formats (Gomez & Ortiz, 2013).

From Figure 3, is seen that the data is sent from the air traffic control center to communication service providers' networks, from which the data reaches the aircraft via satellite earth stations or very high frequency (VHF) or high frequency (HF) earth stations. In addition, data can also be sent via satellites. However, in the case of satellites, this is in the testing phase and is not yet widely used, but it is the future because satellites can cover a larger area where data can be transmitted. When sending data to an air traffic control center from an aircraft, the data travels the opposite way to the aircraft. Although not all aircraft with a data link have access to a VHF data link, not all aircraft have access to an additional satellite or HF ground stations. Similarly, not all Service Provider networks have HF data connectivity. It should be noted that some air traffic service providers do not use or allow the use of some data transmission methods (ICAO, 2013).

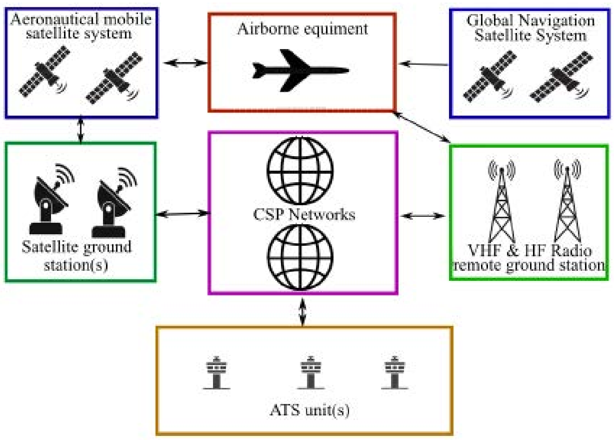

Figure 3. Data transmission scheme between aircraft and air traffic control centre (International Civil Aviation Organization [ICAO], 2013)

3. Communication errors

A study conducted in 2019 found the factors that lead to discrepancies between pilots and air traffic controllers. The study was conducted by listening to recorded conversations between pilots and air traffic controllers from various airports. The study found that communication mistakes are made by both whose native language is English and everyone else, but mistakes were more common among those who speak with an accent (Wu et al., 2019).

In Figure 4, it is seen that most errors occur when words or numbers are omitted. It is worth noting that errors usually occur when using numbers or combinations of numbers. In addition, most of the errors come from pilots who speak with a non-native English accent. There are a majority of such pilots in Lithuania, so the relevance of these mistakes is important. It should also be mentioned that the types of messages shown in Figure 4 are security-related. Therefore, any such error can lead to a serious security breach or, worse, a disaster. Thus, based on the research conducted, our study can examine the reduction in communication errors mentioned above by applying CPDLC to tower flight control.

Another study conducted in 2009 sought to find out how the application of CPDLC reduces the likelihood of language errors. The study involved 30 participants, 24 men and 6 women. The FRASCA 142/242 flight training device was used for this study. The study found that applying CPDLC to long- and medium-length messages reduced the number of errors compared to applying voice to messages of the same length (DeMik, 2009).

As seen in Figure 5, there are teams with three different loads. Low load command – when the number of elements to be repeated does not exceed 2; medium load command – from 2 to 3 repeatable elements; high load command – 3 and more repeatable elements. Regardless of the command load received, the probability of errors with CPDLC is significantly lower than with voice communication. With CPDLC, the average number of errors did not exceed one at high load, but with voice communication, the number of errors approached three (DeMik, 2009). Therefore, it proves that CPDLC is a valuable technology for avoiding errors.

		Native English sounding pilot			Accented pilot		
		Category of error			Category of error		
Error type	Item type	Numeric	Word	Number of errors	Numeric	Word	Number of errors
Omissions	Altitude	-	-	0	3	-	3
	Approach type	-	-	0	-	1	1
	Callsign	-	-	0	1	-	1
	Heading	2	1	3	-	-	0
	Radio frequency	-	-	0	1	1	2
	Runway assignment	4	-	4	1	2	3
	Speed restriction	1	-	1		1	1
	Circuit pattern	-	1	1	-	-	0
	Taxi way assignment	-	-	0	1	1	2
	Hazardous report	-	-	0	-	1	1
Total omissions		7	2	9	7	7	14
		Numeric	Word		Numeric	Word	
Mistakes	Altitude	-	-	0	1	1	2
	Heading	-	-	0	2	-	2
	Radio frequency	-	-	0	2	-	2
	Runway assignment	-	-	0	-	1	1
	Taxi way assignment	-	-	0	-	-	0
	Approach type	-	-	0	-	1	1
Total mistakes		-	-	0	5	3	8

Figure 4. Types and amount of communication errors (Wu et al., 2019)

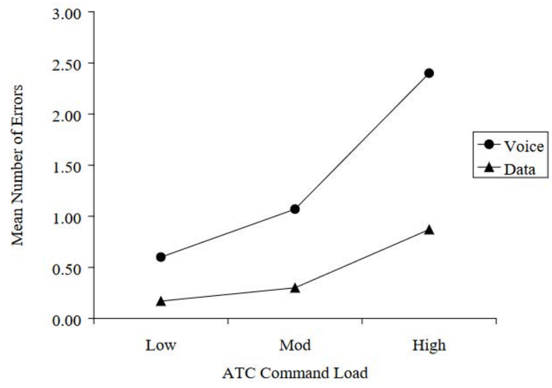

Figure 5. Comparison of the number of errors made by the pilot using voice communication and CPDLC depending on the workload of the air traffic controller team (DeMik, 2009)

A study conducted in 2016 found that CPDLC is a more appropriate technology for transmitting long, complex messages (SVT permits, rolling instructions) than voice communication. It has also been observed that sending long messages using CPDLC reduces the load on human memory, resulting in a lower probability of error (Bone & Long, 2016). A study in the simulator found that it was acceptable for all air traffic controllers to use CPDLC, sometimes in conjunction with radio, but also wanted to return to voice communication. In some cases, errors decreased from 18 to 3 (Bone & Long, 2016).

4. CPDLC application for Vilnius International Airport

Simulations with Vilnius International Airport and air traffic controllers were chosen for the research. The selection of an airport is not random. First, it is the most complex airport in Lithuania, with the most complex apron and numerous places that are poorly visible from the tower. By applying CPDLC at this airport and saving time spent monitoring critical areas, air traffic controllers are able to monitor the runway and areas with poor visibility from the tower more closely.

Another important aspect of choosing Vilnius international Airport is the traffic flow. As discussed in previous chapters, the more aircraft, the higher the aerodrome load and the higher the radio occupancy. These things increase air traffic controllers' workload and the likelihood of communication errors.

As it may be observed in Figure 6, in 2019, Vilnius international airport executed almost 5 times more flights than Kaunas Airport and almost 10 times more than Palanga international airport. As Šiauliai Airport is a military airport, the number of flights to and from it on the schedule is small. Therefore, military flights are not included in the statistics, and the number of military flights is not exactly known. This graph shows only the number of civil flights, which is 625 times lower than at Vilnius international airport. In addition, military aircraft use completely different

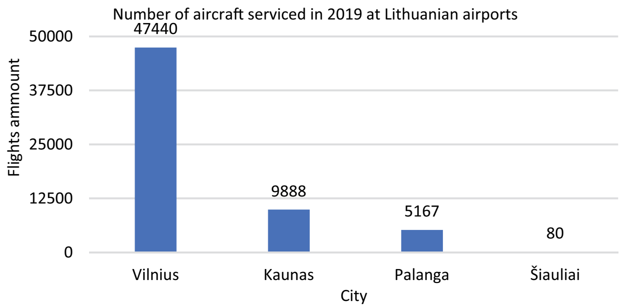

Figure 6. Number of aircraft serviced in 2019 at Lithuanian airports, created by author according to reference (VĮ Lietuvos oro uostai, 2019)

systems of the CPDLC, which is why this airport is immediately excluded from the scope of the investigation for the reasons listed. The graph includes statistics for 2019 because it was a record year before the pandemic, and the number of flights in 2024 is projected to exceed 2019 by 5 percent. As Vilnius international airport handled such a large number of aircraft compared to other airports, air traffic controllers had to face a heavy workload, radio overload and a high probability of language errors. Therefore, it is most expedient to apply CPDLC at Vilnius international Airport first, as it is the busiest airport in Lithuania.

5. Research methods

The simulations provide data on the workload of air traffic controllers and the number of language errors. The obtained data are analyzed; therefore, it is necessary to choose methods that would allow to calculate the changes in workload using CPDLC technology, as well as to find out the change in the number of language errors and changes in time saved. An analysis of the literature and other studies has shown that the ATC capacity analysis tool, commonly known as the CAPAN method, is commonly used to analyze the workload of air traffic controllers. This method is a capacity assessment method developed by EUROCONTROL. It is based on simulation modelling to calculate the workload of air traffic controllers for a given instance of air traffic flow. The current method revolves around the maximum hourly number of aircraft per air traffic controller that can be serviced while maintaining full flight safety (Flynn et al., 2003). The scenario is identical for each simulation to obtain the most accurate data.

This method is suitable in that it can be easily applied to the workload calculations of other air traffic control centers. However, some modifications are needed to adapt the method (Di Mascio et al., 2021):

- Change and redefine the job responsibilities of the air traffic controller;
- Exclude radar tracking and flight level changes from the model;
- When using the method, command repetition must be included in the task list;
- To perform simulations in ideal conditions, when there are no emergency situations and severe meteorological conditions;
- Exclude take-off and landing clearance from the model.

As the tasks of regional air traffic controllers and aerodrome air traffic controllers are different, it is necessary to define new tasks, as one of the changes listed says. Each work task takes a certain amount of time, expressed in seconds. In addition, each work task is performed *n* times, but *n* must not be a negative and integer. The main and most time-consuming tasks are presented in the table below:

Table 1. Daily work tasks with descriptions for tower air traffic controllers

Assignment	Assignment description	Assignment performance time
ATC clearance	Long notices are issued to pilots before departure with the essential information required for departure from the airport.	t1
Start-up	Messages without which pilots cannot start engines.	t2
Push back	Allowing an aircraft to be pushed back from its parking area.	t3
Taxi	Instructions for the aircraft to reach the runway from the parking position or vice versa.	t4
Listening of pilot readbacks	Hearing whether or not each of the messages listed above is accurately repeated or not.	t5
False readback correction	Repeating a command to eliminate an error and an incorrect chance of executing a command.	t6

The data presented in Table 1 show that each task received its time stamp *t*, which is used in the workload calculation formula. Each *t* is expressed in seconds for simpler measurement options and calculations. After defining the tasks of the aerodrome air traffic controllers and making the necessary changes, the formula of the CAPAN method can be adjusted and adapted to its calculations.

$$WL = t_{FL} \cdot O_{FL} + t_{Cnf} \cdot O_{Cnf} + t_{rt} \cdot O_{rt}. \quad (1)$$

As the Eq. (1) is very abstract and not applicable to tower air traffic controllers, it is necessary to make the changes described above and modify the work tasks.

$$WL = \sum_{n=1}^{6} t_n \cdot O_n. \quad (2)$$

Thus, with the Eq. (2) and data collection during the simulations, it is possible to calculate the workload for the air traffic controller during one simulation. Three types of simulations, CPDLC alone, speech-only and mixed, allow changes in workload to be compared.

The time saved during the work used for aerodrome monitoring can be deducted from the data from the second formula. It allows for knowing the total time of the exercise and getting the workload. It is possible to deduct the time saved. The formula for calculating time savings is as follows:

$$SL = PL - WL. \quad (3)$$

In terms of time saved and workload, the change in workload is inversely proportional to the time saved: the lower the workload, the more time air traffic controllers can spend monitoring the aerodrome to ensure safety. Thus, by applying the third formula, data on the time savings from each simulation is obtained.

As the change in language errors with and without CPDLC technology is investigated in this work, it is necessary to define how this will be done. According to the scientific literature, it is necessary to write down the elements of language that will be evaluated to calculate the change in language errors. It is also indicated that elements need to be disaggregated by their type (Wu et al., 2019). In this case, the type of elements is completely irrelevant because the change in language errors using technology is under investigation. Data on how many elements were spoken correctly and incorrectly during each simulation makes it possible to calculate the percentage of incorrectly repeated elements. The following formula can be used for this purpose:

$$EL = \frac{EL_t - EL_n}{EL_t} \cdot 100. \quad (4)$$

After collecting the data, applying the Eq. (4) and performing the calculations for each simulation, it is possible to compare the data obtained and determine to what extent the application of CPDLC or the application of mixed communication reduces the number of language errors.

6. CPDLC program design

As Figure 7 shows, everything is conveniently arranged in the program. It shows where and to whom the message came from, but if the message is intended for a specific user, it is not be visible to all other users who are not destined for that message. In terms of convenience for the air traffic controller, it was decided to include the automatic entry of the pressure (QNH) and the Automatic Terminal Information (ATIS) letter in the program. When the air traffic controller starts the program and enters the verbal data, the program inserts the recorded values by providing instructions containing the verbal data. In this way, the aim is to reduce the workload of air traffic controllers further.

As for the program's functionality, since it is a program for communication, it must be connected to a certain server. It is necessary to allow the program to be used by multiple users simultaneously and thus simulate the actual use of CPDLC when used by pilots and air traffic controllers simultaneously. The JAVASCRIPT programming language was used to achieve this goal. When a server is connected, the program allows different users to connect to the application. The number of users is not limited, making the program ideal for use in flight simulators, as pseudo pilots are required to operate multiple aircraft simultaneously. This program allows users to do so. The user can choose which position to join – the air traffic controller or the pilot.

The program assigns each user a unique ID code by which they are identified. As already mentioned, the program allows choosing which user to be – an ATC or a pilot. The list of messages that can be sent also depends on the selection. In addition, when the server is connected, and users log in, the program allows to send a message to all users of the program simultaneously, and the message can be sent to a specific user (specific pilot), or the message can be sent to yourself.

As messages of pilots and air traffic controllers are different, i. e., pilots usually request permits or other requests, and air traffic controllers issue permits and various commands, so pilot and air traffic controller notification options also differ. However, as already noted in the literature review, message options should include short standard messages, free text capability, and aerodrome-specific messages.

This program cannot be installed in simulators, so it should be used on personal computers during simulations. For this reason, both pilots and air traffic controllers may not notice that they have received the message. Therefore, an audible signal was used upon receipt of the message to address this issue. When a message is received, a specific

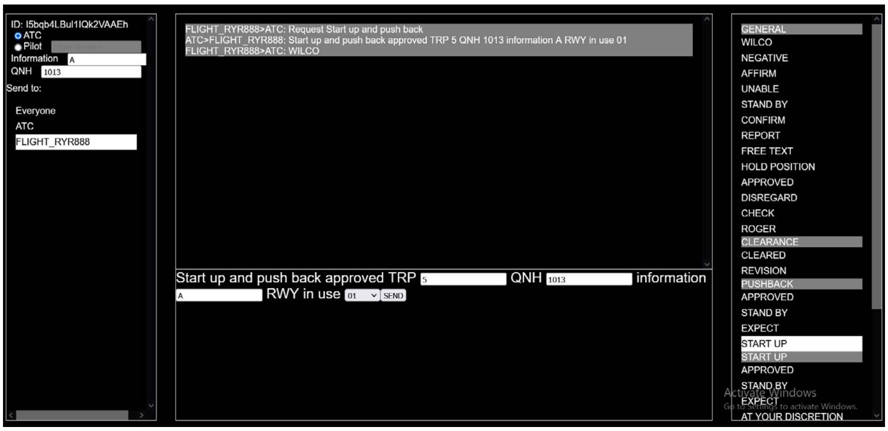

Figure 7. Created CPDLC program window

user will hears an audible signal, which can only be heard by the user to whom the message is addressed unless the message is addressed to all application users. Thus, the study can be conducted with a well-functioning, user-friendly aerodrome control program tailored to all recommendations.

7. Investigation process

The study involved five air traffic controllers, some of whom were students. The subjects were selected at random. However, all subjects had to pass at least a 75% ADI rating. The age of the subjects ranged from 24 to 30 years. The gender of the study air traffic controllers was not taken into account.

The investigated air traffic controllers performed three simulations each. The exercises were performed in the EXPERT NITA simulator. The scenario for each exercise was identical to each exercise performed for each air traffic controller. First, the investigative air traffic controller performed the simulation using voice communication alone. The aim was to find out the initial workload and the times of the work tasks. Later, in another exercise, the air traffic controller used only the developed CPDLC program to perform the work tasks. This exercise aimed to determine how the program affects the workload of air traffic controllers and the time of tasks. During the third simulation, the air traffic controller used a mixed communication method, i. e.was able to communicate by voice and using the CPDLC program. The communication method depends on the pilots, i.e., the pilot chooses the way of communication. The number of aircraft that communicated using CPDLC during the third simulation ranged from 50 to 70 percent.

The simulation method was chosen since, during the rest of the study, simulations were also performed in flight control simulators. The EXPERT NITA simulator was selected because it is the only aerodrome flight control simulator in Lithuania. Since one simulation lasted one hour, it was decided to conduct the study with 5 flight controllers only. Regarding the number of aircraft that used the CPDLC program, only 70% of the aircraft have this equipment, so this number was chosen as the maximum during mixed communication. However, it is not always possible to have such a number of aircraft for the flight controller, so it was decided to test the CPDLC functionalities in the presence of a smaller number, not less than 50%.

As for language errors, they depended on the pilots during each simulation, but there were exceptions. During the simulations, the pilot operators were asked to repeat and execute the commands and instructions as they heard or read them in the CPDLC program for the first time unless air traffic controllers corrected them. This means that when the pilot heard the instruction, they could not read it from the script sheet unless they wrote it down themselves. However, even after writing down the specific instructions, the pilots were not allowed to look at the script sheets or other simulator aids that contained instruction prompts. In this way, the aim was to obtain the most realistic results possible from the language errors.

Regarding data capture, job completion and repetition times were recorded with a stopwatch built into the Apple iPhone 12 Pro Max model. The time required to perform the air traffic controller task using voice communication was calculated from when the air traffic controller started issuing the instruction until the instruction was fully issued. The execution time of an air traffic controller task when using the CPDLC program was measured from when the air traffic controller opened the input window for a specific task until the SEND button was pressed. The time for repetitions of pilots' instructions was calculated from when they started repeating the instructions on the call until they said the entire instruction, whether correct or not. When the CPDLC program was used, the repetition time of the pilot instruction was calculated from the moment the air traffic controller pressed the SEND button when the instruction was sent. The calculation ended when the response came from the pilot.

8. Results

Figure 8 shows that the workload is reduced compared to voice communication when using different communication methods. It should be noted that the application of the CPDLC program and the resulting change in workload is an ideal case where all aircraft have and can use the CPDLC. However, for the time being, such changes in workload with CPDLC alone are only possible in simulators because not all aircraft have the necessary equipment.

Figure 8 reflects the change in workload. A reduction of between 4.0% and 21.2% can be seen with the mixed communication method. These variations in workload reduction are due to several reasons: the ability of the air traffic controller to work with both voice communication and the CPDLC program simultaneously, as well as aircraft communicating with CPDLC the number varied from 50% to 70%). Regarding the change in workload with CPDLC alone, a reduction in workload from 20.8% to 32.6% is identified. This sharp decrease is due to that the CPDLC program allowing drilling times to be drastically reduced for some tasks.

From Figure 9, it is seen that task completion times are similar in all simulations. Most of the time is devoted to

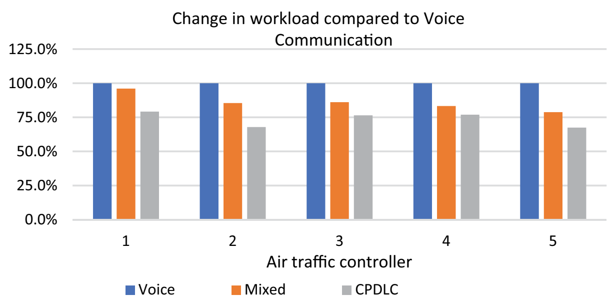

Figure 8. Diagram of the change in the workload of air traffic controllers using different communication methods

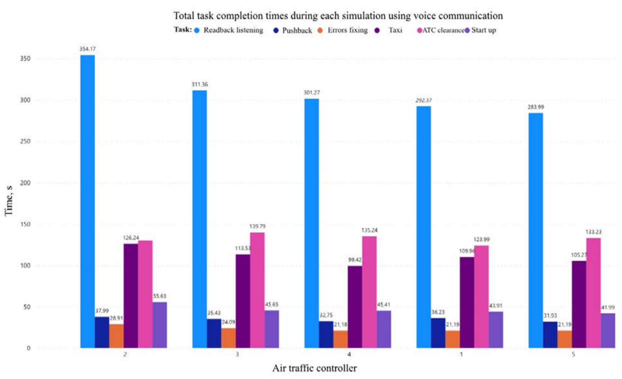

Figure 9. Total task completion times during each simulation using voice communication

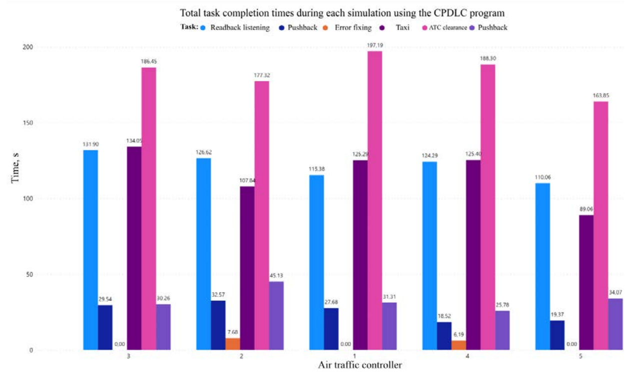

Figure 10. Total task completion times during each simulation using the CPDLC program

readback listening (from 354 to 284 s). Readback listening alone took up about 50% of the total working time in all simulations. Also, a lot of time was devoted to issuing ATC clearances and taxi instructions. Accordingly, these tasks took from 139 to 124 seconds for ATC clearances and from 126 to 105 seconds for issuing taxiing instructions. This graph shows that the least work time was spent on push-back, start-up instructions and correcting language errors. Language error correction times depended on a number of errors – the more errors the pilots made, the more time air traffic controllers allocated to them to fix them. It took between 21 and almost 29 seconds to correct speech errors. Push-back instructions took 38 to 32 seconds, and start-up instructions took 42 to 56 seconds.

As can be seen from Figure 10, ATC clearance issuing times have increased from 163 seconds to nearly 200 seconds compared to voice transmissions. This happened because when air traffic controllers issued these clearances, they often selected the destination aerodrome and standard instrument departure (SID) schemes from the lists provided. However, the time spent listening to replays was reduced by almost three times compared to voice communication. Replay listening times ranged from 110 to 131 seconds. The reduction in time for this task is that pilots using the CPDLC program only had to send a single word to show that they understood the message and would follow it while using voice communication required repeating the entire message in full. Also, the times for issuing taxiing instructions were almost unchanged or slightly increased compared to voice communication. With CPDLC, it took between 89 and 134 seconds to issue taxi instructions. As for correcting language errors, in some cases there was no time because there were no errors, and in some cases, there were. However, the errors did not occur because of the pilots. This mainly was the air traffic controllers' fault. It means that the air traffic controllers made mistakes when compiling the message and noticed them only after sending the messages, so they had to correct their mistakes themselves. In addition, during all simulations, the times for issuing pushback instructions decreased, which ranged from 19 to 32 seconds. Also, the time for issuing start-up instructions decreased – from 25 to 45 seconds. The completion times of these tasks have decreased due to the fact that almost all elements of these messages are compiled automatically by the CPDLC program itself.

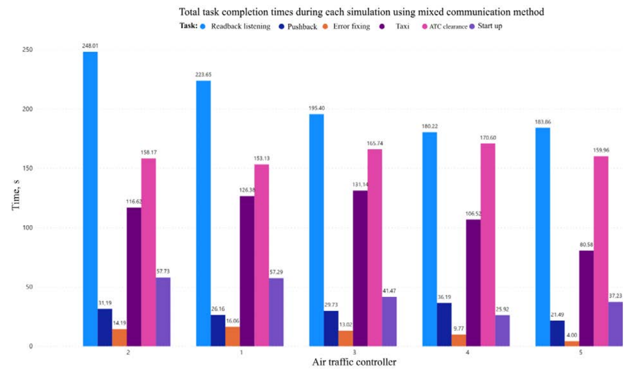

Figure 11. Total task completion times during each simulation using mixed communication method

According to the graph in Figure 11, readback listening times are reduced by a third compared to voice transmissions but almost double compared to CPDLC alone. In the mixed communication mode, the repetitions' listening time ranged from 180 to 248 seconds. ATC clearance issuing times are higher than voice transmissions but lower than CPDLC. It took between 153 and 170 seconds to issue ATC clearances. The times for issuing taxiing instructions remained almost unchanged compared to both the voice communication application and the CPDLC application. Taxi instructions took between 80 and 131 seconds. Regarding the issuance of start-up and push-back instructions, their issuance times are almost unchanged compared to the CPDLC, but slightly lower compared to voice communication. Many instruction times listed for the mixed mode are similar to the CPDLC simulations because the mixed mode also uses CPDLC, but the percentage of aircraft using the CPDLC program is lower. If the speech error correction times are compared, they are not zero during these simulations because voice communication was also applied. However, compared to voice-only simulations, speech errors took less time to correct, between 4 and 16 seconds.

The methodological part defined that the time saved that could be spent on aerodrome monitoring is inversely proportional to the workload. Therefore, as the workload decreases, the time devoted to monitoring increases. As is well known, the workload in the study is reduced by using different communication methods. As a result, the time spent on aerodrome monitoring increases accordingly.

Figure 12 shows that mixed communication saved 25 to 131 seconds. It was the same number of seconds that the workload of air traffic controllers was reduced through mixed communication. Using the CPDLC program alone saved 131 to 236 seconds. Consequently, the workload of air traffic controllers using the CPDLC alone has been reduced by the same amount of time. While the time saved seems small, remember that so much time is saved in one hour. As the shift of air traffic controllers can last up to 12 hours, it is possible to save up to one hour by using CPDLC technology to perform the tasks of aerodrome air traffic controllers.

A study in a NITA simulator yielded results of language errors. A graph in Figure 13 shows the percentage of correct language elements during each simulation. In this graph, as in others, the starting point is voice communication. When using voice communication as a means of communication, the correct elements ranged from 95.83% to 97%. Incorrect elements include errors noticed and corrected by air traffic controllers and those unnoticed. Therefore, a relatively small number of correct language elements was obtained in one simulation – 95.83%. In a mixed communication method using both voice communication and the CPDLC program, the percentage of correct speech elements was higher than compared to voice communication, but not ideal because voice communication was still used. In a mixed way, 98.2% and 98.8% of the language elements were spoken correctly. The percentage of correct items increased from 2.6% to 3% compared to voice transmissions. As for the application of the CPDLC program alone, it was expected that all language elements would be correct. However, the graph shows that this did not happen. Although the percentage of correct elements in most CPDLC simulations is 100%, in some cases, it was only 98.8%. It is worth noting that such a decrease was no longer due to pilot mistakes but due to the mistakes of air traffic controllers. It is because air traffic controllers made mistakes when composing messages, as some messages are easy to get lost in, and some elements of the message need to be entered personally. For these reasons, improvements to the additional program or the existing CPDLC program are needed to scan aircraft flight plans and automatically insert information into messages, thus completely eliminating the human factor. Nevertheless, the application of CPDLC allowed achieving the highest percentage of correct elements per simulation, from 99.4% to 100%. Compared to voice communication, the percentage of correct elements has increased from 3% to 4%, which is a large number in aviation.

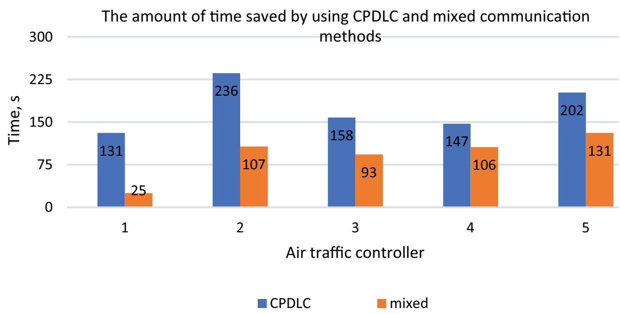

Figure 12. The amount of time saved by using different communication methods

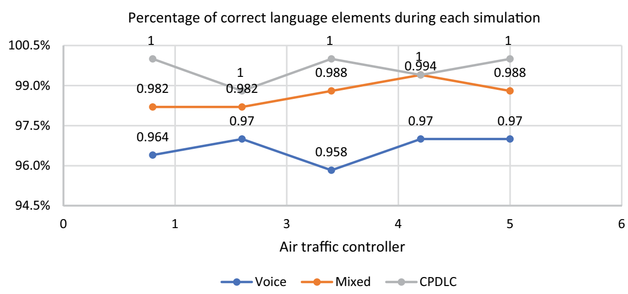

Figure 13. Graph of the percentage of correct language elements during each simulation using different communication methods

Conclusions

After the research and analysis of the obtained results, several conclusions and recommendations were formulated:

1. The application of the CPDLC program to aerodrome air traffic control reduces the workload of air traffic controllers. With the CPDLC program alone, the workload was reduced from 20.8% to 32.6% (131 to 236 s). However, such a reduction in workload is only possible in simulators, as in reality, not all aircraft have and can use CPDLC equipment. A mixed communication method using voice transmissions and CPDLC reduced workload from 4% to 21.2% (25 to 131s). The higher the number of aircraft using the CPDLC program, the more the workload of the air traffic controller is reduced.

2. The application of the CPDLC program to aerodrome flight control shall increase the time saved for aerodrome surveillance. As this parameter (time saved) is inversely proportional to the workload, the reduction in workload has been increased by the same amount. The application of the CPDLC program alone allowed an additional 131 to 236 seconds for aerodrome monitoring. Meanwhile, 25 to 131 seconds were allocated for aerodrome monitoring during mixed communication. Such times are available within one hour, but during the entire air traffic controller shift, these times increase further depending on the length of the shift.

3. The application of the CPDLC program in aerodrome air traffic control reduces the number of language errors but does not eliminate them. The mixed communication method reduced the error rate from 2.6% to 3% but

reached a maximum of 99.4% of the correct elements. With CPDLC alone, the number of correct items increased from 3% to 4%. In most cases, where only the CPDLC program was used, the number of correct elements was 100%, but in some cases, this was not achieved due to errors made by air traffic controllers.

4. In order to achieve more accurate results and to further reduce the number of language errors, it is necessary to improve the CPDLC program or use it with additional programs. Functionalities must be developed that scan aircraft flight plans and automatically insert information into messages, thus eliminating the human factor and thus avoiding mistakes. In addition, the program must be integrated into an air traffic control system or flight simulator for further workload reduction.

5. More tests are recommended in the aerodrome flight simulator for even more accurate results. Also, the program's functionalities and capabilities should be tested in natural working conditions.

Disclosure statement

We confirm that final work on the study "Investigation of the application of CPDLC to aerodrome air traffic control procedures" is self - written. The material presented in this work is not plagiarized. Quotes from other sources cited in the literature are used directly or indirectly. There is no other person's contribution to the completed article. We have not paid anyone any non-statutory sums of money for this work.

References

Bone, R., & Long, K. (2016). Air traffic controller utilization of voice and Data Link Communications during interval management. In *2016 Integrated Communications Navigation and Surveillance* (*ICNS*) (pp. 2D1-1-2D1-16). Herndon, VA, USA. https://doi.org/10.1109/ICNSURV.2016.7486335

DeMik, R. J. (2009). Text communications in single-pilot general aviation operations: Evaluating pilot errors and response times. *International Journal of Applied Aviation Studies*, *9*(1), 29–42.

Di Mascio, P., Carrara, R., Frasacco, L., Luciano, E., Ponziani, A., & Moretti, L. (2021). How the tower air traffic controller workload influences the capacity in a complex three-runway airport. *International Journal of Environmental Research and Public Health 18*(6), 1–14. https://doi.org/10.3390/ijerph18062807

Eurocontrol. (2021, May). *EUROCONTROL forecast update 2021–2024 European flight movements and service units*. https://www.eurocontrol.int/sites/default/files/2021-05/eurocontrol-four-year-forecast-2021-2024-full-report.pdf

Flynn, G., Benkouar, A., & Christien, R. (2003). Pessimistic sector capacity estimation. In *EEC Note 21*(03). Eurocontrol Experimental Centre.

Gomez, L., & Ortiz, J. (2013). Modeling and simulation of VDL mode 2 subnet for CPDLC in El Dorado airport. In 2013 *IEEE/AIAA 32nd Digital Avionics Systems Conference* (*DASC*) (pp. 3B4-1-3B4-15). East Syracuse, NY, USA. https://doi.org/10.1109/DASC.2013.6712560

International Civil Aviation Organization. (2013). *Global Operational Data Link Document* (*GOLD*) (2nd ed.). ICAO. http://www.skybrary.aero/bookshelf/books/2411.pdf

Rockwell Collins. (2017). NextGen overview with focus on data link. In *Rockwell Collins Operators Conference presented by Christian Renneissen*. https://www.rockwellcollins.com/-/media/files/unsecure/page-content/marketing/b/business-aviation-operators-conf/airspace-modernization.pdf?la=en&lastupdate=20180302160434

VĮ Lietuvos oro uostai. (2019). *VĮ Lietuvos oro uostai*, *Vilniaus filialas traffic report 2019*. https://www.ltou.lt/uploads/documents/files/apie-oro-uostus/Aviacininkai/Statistika/VNO%20traffic%20report%202019.pdf

Wu, Q., Molesworth, B. R. C., & Estival, D. (2019). An investigation into the factors that affect miscommunication between pilots and air traffic controllers in commercial aviation. *The International Journal of Aerospace Psychology*, *29*(1–2), 53–63. https://doi.org/10.1080/24721840.2019.1604138