**Workload perception of Air Traffic Control Officers and Pilots during Continuous Descent Operations approach procedures**


## Abstract

The paper examines the workload perceived by Air Traffic Control Officers (ATCOs) and pilots during Continuous Descent Operations (CDOs), applying closed and open path procedures. CDOs reduce fuel consumption and noise emissions. Therefore, they are supported by airports as well as airlines. However, their use often depends on pilots asking for CDOs and controllers giving approval and directions. An adapted NASA Total Load Index (TLX) was used to measure the workload perception of ATCOs and pilots when applying CDOs at selected European airports. The main finding is that ATCOs' workload increased when giving both closed and open path CDOs which may have a negative impact on their willingness to apply CDOs. The main problem reported by pilots was insufficient 'Distance-to-Go' information provided by ATCOs. The workload change is important when considering the use of CDOs.


*Keywords*: ATCO workload, Pilot workload, NASA TLX, Continuous Descent Operations (CDOs), closed and open path approach.

## 1 Introduction

Air Traffic Control Officers (ATCOs) and pilots are key decision makers in High Reliability Organisations. ATCOs must maintain a consistently high level of performance in order to ensure flight safety and efficiency (Edwards, Homola, Mercer and Claudatos, 2016). In particular, they aim at reducing delays as well as holding patterns and providing the most direct connection between departure and destination airport, thereby also reducing $CO_2$ emissions (Kantareva, Angelova, Iliev and Efthymiou, 2016). Pilots are responsible for safe, but also efficient aircraft operations, also trying to minimize negative effects on the environment. For both groups, workload and other factors which are influencing performance have to be monitored, analyzed and kept at suitable levels in order not to jeopardize safe and sustainable aircraft operations.

Within the different phases of a flight, approach procedures play a very important role, affecting airport capacity and environmental performance (Jin, Cao and Sun, 2013). During Continuous Descent Operations (CDOs), engines are operated at idle thrust as far as possible in order to reduce engine noise, fuel burn and exhaust gas emissions (Shresta, Neskovic and Williams, 2009). However, they are not mandatory but subject to decisions made by ATCOs and pilots, respectively. Consequently, it is important to analyze whether their workload changes when applying CDOs. If ATCOs and/or pilots perceive a too high complexity, CDOs may not be used. Furthermore, the implementation of CDOs could be obstructed by physiological or psychological barriers associated with a higher workload.

This paper aims to shed new light on the workload of ATCOs and pilots when applying CDO procedures. Different design methods of CDOs are taken into account and potential improvements on the operational level for the implementation and application of CDOs in Europe are discussed. To the authors' best knowledge this is the first paper that examines the workload related to

Continuous Descent Operations by using survey data. Moreover, few researchers have looked into pilots' and ATCOs' workload simultaneously.

The paper is divided into five sections. The first section gives an overview and links the rationale for implementing CDOs with workload considerations. The second section explains CDOs and their design, providing also an overview of pilots' and ATCOs' tasks related to CDOs. The methodological approach used in this study is described in section 3. The next section presents the results, analysing ATCOs' and pilots' perceived workload in conventional and CDO approaches. The conclusions are drawn in the final section of the paper.

# 2 Pilots' and ATCOs' tasks during Continuous Descent Operations

## 2.1 Continuous Descent Operations

### 2.1.1 General concept

Traditionally, approach procedures are combined of horizontal and descending parts of a flight movement. Rather recently, Continuous Descent Operations (CDOs), sometimes also referred to as 'Continuous Descent Approach' (CDA), have gathered airports' and airlines' attention because they lead to lower fuel consumption and less noise emissions. To facilitate this kind of aircraft operation, other framework conditions like airspace design, procedures and Air Traffic Control (ATC) clearances have to be adapted, limiting the number of airports where CDOs are currently used. Since the aim of CDOs is to apply no thrust during the descent, the aircraft's potential energy (i.e. altitude) and kinetic energy (i.e. speed) have to be well managed (Shresta et al., 2009). To ensure a proper energy management and a suitable flight path, the aircraft has to pass a certain altitude (window) at a certain distance from the runway to provide a constant descent angle. To facilitate the calculation of the optimum flight path for a particular descent, pilots can use the on-board Flight Management System (FMS) to plan their trajectory. According to the International Civil Aviation Organization (ICAO, 2010) continuous descents can be flown with or without the vertical guidance function of the FMS, but the use of such systems improves the performance of a CDO due to the better calculation of the vertical flight path. Figure 1 shows the difference between a conventional and a CDO approach.

Figure 1: General CDO concept (EUROCONTROL, 2011: 2)

To maximize the benefits of CDOs in terms of fuel savings and noise reduction, the descent should be flown from the Top-of-Descent (TOD) to the Final Approach Fix (FAF) close to the airport (ICAO, 2010). However, CDOs create measurable reductions in fuel burn and noise emissions even if they are not applied to the full extent and during all stages of the approach. Amongst others, additional advantages of CDOs could be a more efficient use of airspace, more consistent flight paths, and a reduction in the incidence of controlled flight into terrain (ICAO, 2010, p. A-1-2).

Without further substantiation, ICAO (2010, p. A-1-2) states that CDOs reduce the workload for ATCOs and pilots as well as the number of necessary radio transmissions. However, ICAO (2010, p. A-2-6) concedes that 'controller workload may increase in some areas and may decrease in others (e.g. level-off management)'. The human performance related aspects of CDOs will be discussed in the forthcoming sections in more detail.

In practice, the uninterrupted descent from the TOD is rarely possible, usually due to external constraints. Therefore, doubts evolved whether 'continuous' is the right term to describe the approach operation (EUROCONTROL, 2015). In the US, the term Optimised Profile Descent (OPD) is often used to indicate that an improvement in terms of fuel consumption and emissions is achieved but there are still unavoidable interruptions of the descent, also known as level offs (Shresta et al., 2009). According to ICAO (2010, p. xvi) an Optimised Profile Descent is 'a descent profile normally associated with a published arrival (Standard Instrument Arrival, STAR) and designed to allow maximum practical use of a CDO. It starts from top of descent, taking into consideration the limitations of the local airport, airspace, environment, traffic and aircraft capabilities, and ATC.'

The development of CDO procedures can have an influence or can be influenced by the following factors (EUROCONTROL, 2011, p. 5): a) airspace design (i.e. the way in which a given airspace block is used e.g. solely of departing and arriving commercial aircraft in the vicinity of international airports instead of utilisation by aircraft used in general aviation), b) Aeronautical Information Publication (AIP) (i.e. the way in which information are presented to pilots e.g. approach procedures on approach charts), c) traffic planning and coordination (i.e. general handling of traffic flows), d) Tactical ATC (i.e. guidance of aircraft and application of prescribed separation minima between aircraft) and e) flight crews and human factors (i.e. handling of the aircraft).

In general, CDOs should be designed and implemented in such a way that neither the optimum Airport Arrival Rate (AAR) nor other traffic (non-CDO, departing, or crossing en-route flights) are adversely affected (ICAO, 2010).

### 2.1.2 CDO procedures design

During a standard flight, the aircraft follows the prescribed routes and procedures with the help of its navigation equipment. But the adherence of such procedures may result in an inefficient utilisation of a limited airspace. Furthermore, the flexibility to react to a large variety of traffic especially in the terminal airspace around an airport is reduced. To allow a more efficient traffic flow, ATC has the possibility to advise the aircraft to leave the prescribed procedures by assigning explicit directions / headings and altitudes which the aircraft has to fly. Due to the use of radar technology, this method is called radar vectoring. If such a radar vectoring is a part of a published Instrument Approach Procedure (IAP), this procedure is called “open path” because one part of the published approach procedure is not fully predictable. In contrast, closed path is a published and predefined approach procedure or routing where the information about the aircraft’s distance from the touchdown point (hereinafter referred to as ‘distance to go’ (DTG)) can be calculated by the flight crew.

With respect to CDO, the open path method implies that the remaining flight path distance is unknown to the flight crew and the calculation of the optimised vertical profile is hardly possible. To solve this problem and to increase the efficiency of CDO approach procedures in an unpredictable radar vectored environment, the ATCO shall provide progressive DTG information to the pilot to the greatest extent (ICAO, 2010).

According to ICAO (2010) there are two types of open path procedures, the partly open path and the complete open path. The first type provides an initial guidance of the aircraft based on a predefined and published routing which is comparable to the closed path method. The difference is that this routing is terminated on a predetermined point on the downwind, the so called Downwind Termination Waypoint (DTW). After the aircraft has passed the DTW, the ATCO is supposed to guide the aircraft with the help of radar vector headings to the final approach of the landing runway. During the plannable and published part of the approach, CDOs can be flown in an efficient manner. But the possibility that the aircraft has to apply thrust during the unplanned radar vectored part of the approach on lower altitudes, remains.

The second type of open path procedures, i.e. the complete open path, is the radar vectoring of the airplane by the ATCO for the entire approach, starting at the TOD. During this type of open path, the flight crew is solely dependent on the progressive DTG information given by the ATCO to arrange the vertical profile and to establish a stable continuous descent without the application of thrust (ICAO, 2010).

## 2.2 ATCOs' and pilots' workload during CDOs

### 2.2.1 Workload concept and workload measurement

Although the term 'workload' is widely used, a large number of different definitions exist (Cain, 2007). For the purpose of this study, mental workload can be defined as 'the mental "cost" of performing the information processing required by task performance' (Vidulich, Wickens, Tsang and Flach, 2010, p. 202). Mental workload is in any case subjective, because different operators may perceive the same task in a different way (Hopkin, 1995, p. 332).

Analysing mental workload is crucial because it helps to understand the relationship between task demands and human performance (Bommer and Fendley, 2018). Too much as well as too little workload might lead to an increasing number of errors (Kantowitz and Campbell, 1996, p.119). According to Rubio, Díaz, Martin and Puente (2004) safety, health, comfort and long-range productivity can be improved when the task demands are at a 'suitable' level.

A direct measurement of workload is deemed non feasible given the fact that workload is intangible. The measurement of workload as a relative index (i.e. based on subjective ratings, objective performance evaluation or physiological indices of an operator) is more realistic (Hitchcock, Bourgeois-Bougrine and Cabon, 20016; Kantowitz and Campbell, 1996). For instance, pilot subjective workload can be measured using the Rating Scale of Mental Effort (RSME), the semi-objective workload by means of Instantaneous Self-Assessment (ISA) or the objective workload by Visual scanning randomness (Ruigrok and Hoekstra, 2007).

The most common scientific workload measurement procedures according to EUROCONTROL (2015) are: a) Air Traffic Workload Input Technique (ATWIT), b) Assessing the Impact on Mental Workload (AIM), c) Bedford Workload Scale, d) Calibrated approach of NASA Task Load Index

(TLX) regarding scenarios, e) Instantaneous Self-Assessment of workload (ISA), f) Malvern Capacity Estimate (MACE), g) NASA TLX and h) Subjective Workload Assessment Technique (SWAT). The methods b, f and g do not require any technical equipment. The AIM method (b) does not cover the workload assessment of pilots since it was developed for a specific ATC environment. The comparison of NASA TLX and MACE shows that the NASA TLX method is widely used in aviation related research (Hart, 2006, p. 4). Thus, NASA TLX was selected as the basis for this study (for more information see section 3). It assumes that the workload is a hypothetical construct which represents the costs of a human operator to achieve a certain level of performance (EUROCONTROL, 2004; Hart and Staveland, 1988; Majumdar, Ochieng, Bentham and Richards, 2005; Tobaruela et al., 2014).2.2.2 ATCOs' workload during CDOs.

### 2.2.2 ATCOs' workload during CDOs

Air Traffic Control (ATC) was one of the earliest application fields of workload research. Almost every study regarding ATCOs shows a consistent high workload (Hopkin, 1995). Their actual workload depends on a wide range of external factors and tasks. One of these external factors is the working position of the ATCO, i.e. working as a tower, approach, or en-route ATCO. ATCOs tend to adapt in different ways on the same amount of workload. These adaption processes are influenced by the skill level, the task management strategies, but also by other individual characteristics (National Research Council, 1997).

According to the National Research Council (1997) the workload of ATCOs employed in different working positions can be influenced by a large number of factors including airspace setting, airspace load, general control tasks, procedures, other controllers, supervisors, display, Controller-Pilot communication (i.e. complexity of required phraseology) and Controller-Controller communication (i.e. coordination and transfer of control between different ATC units).

As already mentioned above, the ICAO CDO manual (2010) states that as a consequence of applying open path CDOs, a change in ATCOs' workload is possible, with different elements suggesting either a higher or a lower workload. The (additional) task of providing progressive DTG information most likely results in an increase of the ATCO's workload. A decrease of the workload can be expected for example due to the overall reduction of the number of altitude or flight level changes (ICAO, 2010). In an ideal scenario, i.e. without airspace congestion or adverse weather conditions, the controller only considers the upper starting level and the lower final level of the overall descent. On the other hand, the use of CDOs might prevent vertical aircraft separation techniques, imposing a higher workload to the ATCO due to the additional required planning, surveillance and communication (ICAO, 2010). The optimum descent point can vary between different aircraft types but also between aircraft of the same type. Potential reasons are differences in meteorological conditions, aircraft weights or airline specific Standard Operating Procedures (SOPs). Therefore, predicting the descent point and the corresponding descent profile becomes more complex for the ATCOs (ICAO, 2010).

Closed path CDO procedures may reduce the ATCO's workload because of the higher predictability of the flight path, but also due to less controller-pilot communication (ICAO, 2010). On the other hand, the workload can be increased due to the additional work to guide the non-CDO traffic around the CDO traffic.

### 2.2.3 Pilots' workload during CDOs

The workload of a pilot depends on mental and perceptual demands in combination with time pressure in a flight environment (Hitchcock et al., 2016). Thereby, the Task Demand Load (TDL) for pilots consists of trajectory demands, meteorological demands and other tasks (Heiligers, Van

Holten and Mulder, 2011). Take-off and landing usually are the parts of the flight with the highest workload for pilots.

According to Heiligers et al. (2011), management, training and maintenance of the aircraft have an indirect influence on the execution of an approach, whereas meteorological conditions, the aircraft, airport infrastructure, ATC, navigation, communication and ATC systems, rules, regulations, procedures (e.g. SOPs) and approach trajectories are factors with a direct influence on the execution of an approach.

While analysing the design of approach procedures, Heiligers (2011, p. 29) identified the following features to be relevant for the pilots' workload:

- Number of heading changes during an approach
- Number of incorporated altitude steeps (compared to a continuous descent)
- Applying a horizontal approach instead of a CDO
- Distance available on the localizer intercept heading
- Heading change when turning towards localizer intercept heading
- Localizer intercept speed
- Distance in a more or less straight and level flight to configure the aircraft (i.e. lowering the flaps and landing) safely
- Aircraft mass
- Energy management of the aircraft

Whereas the first six points of the list reflect direct design issues of the instrument approach procedures, the last two points represent aircraft related factors which - in combination with the instrument procedure design – have an effect on the workload of pilots. Especially the energy management seems to be an important part of the pilot's workload during the approach because of speed or altitude restrictions. Also a non-adherence of these constraints can affect adversely the critical phase of the final approach (Heiligers, 2011).

Heiligers (2011) states that a larger number of level-offs can also create a higher workload to pilots. The reason for this increased workload can be that the thrust and the resulting energy of the aircraft have to be changed. Initially, it can be also assumed that too steep descent path angles create difficulties in regard to the energy management during the approach. The correct energy management of aircraft requires permanent calculations of the vertical flight path. Many of these calculations can be done by the help of automation which can lead to reduction of tasks and consequently workload (Kantowitz and Campbell, 1996).

In general, the workload of pilots should be considered while designing CDO procedures and the workload shall be kept within the limits common during normal flight operations. The autopilot and/or the FMS are used to modify the horizontal and vertical flight path of an aircraft. The on-board computer use requires several additional pieces of information (e.g. actual atmospheric pressure, temperature, etc.), especially during CDO approaches. This system management might lead to a higher workload for pilots in certain flight phases (e.g. during radar vectoring) (ICAO, 2010). On the other hand, training of pilots on radio communication phraseology, the effect of meteorological conditions, handling of the available automation and on managing speed restrictions, altitude constraints or crossing restrictions, can increase the pilot's understanding of CDO and CDO related problems and therefore reduce the workload during CDO (ICAO, 2010).

### 2.2.4 Intermediate summary

During an approach, the workload of ATCOs as well as of pilots is influenced by a large number of determinants. As shown above, moving from ‘traditional’ approach procedures to Continuous Descent Operations might affect the workload of both groups in different ways. An empirical analysis of changes in the perceived workload might help to understand the overall effect of CDOs on workload of ATCOs as well as pilots.

# 3 Methodology

### 3.1 Participants

For the survey, airports were selected which - according to EUROCONTROL's Public Airport Corner - have published CDO arrival routes via the Aeronautical Information Publications (AIP). However, most of these airports have only published a general description of CDO in the text part of the AIP and a detailed description of CDO in approach charts was not available. Therefore, it is assumed that most of the closed-path CDOs are flown along the published normal non-CDO approach procedures. The ATCOs and pilots that participated in the survey are based at the airports of Brussels, Cologne Bonn, Dublin, Lisbon, London Heathrow, Oslo Gardermoen and Warsaw.

In total 32 approach ATCOs from BelgoControl (Brussels Airport), Deutsche Flugsicherung/DFS (Cologne Bonn Airport), NAV Portugal (Lisbon Portela Airport), Avinor (Oslo Gardermoen) and Polish Air Navigation Service Authority (Warsaw Chopin Airport) participated in the survey with 21 ATCOs replying to all questions. With respect to pilots, the sample is bigger since the population of pilots is larger than the ATCO population. In total 91 pilots answered the questionnaire and they were operating nine different aircraft types. However, more than 90% of the pilots in the survey flew Airbus A320 series, Boeing 737 series and BAe 146 aircraft. The pilots were flying for Brussels Airlines (Brussels Airport), Ryanair (Brussels Airport and Dublin Airport) and British Airways (London Heathrow). The survey was conducted via an EUROCONTROL survey platform in May 2015.

### 3.2 Questionnaire, surveyed tasks and rating scale

The questionnaire first asked for selected personal information (age, gender, years of working experience (ATCOs only), flight hours, and aircraft type (pilots only)). Moreover, participants were asked how often they conduct CDOs.

In order to measure workload, the first version of the respective parts of the questionnaire to a large degree was based on the NASA TLX (see subsection 2.2.1) which is used in different working environments ranging from aviation to surgeries or website designs The workload is described with the help of six scales of attributes which may have a different importance to individuals: mental demand, physical demand, temporal demand, own performance, effort, and frustration level (Trujillo, 2011, p. 7).

In order to confirm the suitability of the questionnaire a preliminary test was conducted. In the preliminary test ATCOs as well as pilots had difficulties in distinguishing between the mental demand and the effort scales. Therefore, the NASA TLX questionnaire was amended and the mental demand and the effort scales were combined to a new scale, the “challenge” scale. Finally, the physical demand scale was removed, since it has a low influence on the workload in conducting CDOs, but also to reduce the size of the questionnaire. Consequently, the scales of attributes adopted for the CDO related workload were challenge, frustration level, performance and temporal demand. The workload measurement procedure inspired by NASA TLX will be referred to as CDO TLX in the following sections of the paper.

The following tasks of ATCOs were evaluated in the study a) Controlling aircraft, b) Communication with pilots according to the prescribed phraseology, c) Coordination with other ATC-units and d) Reaction to pilot’s special requests. The selected tasks are the most critical ones performed by ATCOs during a CDO as also indicated by the ICAO CDO manual. The pilots’ tasks analysed were a) Conducting the Approach, b) Communication with ATC according to the prescribed phraseology and c) Utilisation of approach charts.

In both surveys the classification ranged from 1-5 where 1 stands for low, 3 for moderate and 5 for high. Moreover, participants were given the opportunity to add comments and specific information. Although key terms (e.g. open and closed path) were defined in a separate page of the questionnaire, we cannot rule out that the interpretation of some of the terms used in the survey (in particular ‘open’ and ‘closed’ path CDO) differed between participants.

# 4 Results and Discussion

## 4.1 ATCOs' survey

The age of ATCOs ranged from 24 and 51 years (average age=37.5) and the corresponding working experience from two to 31 years (average years of experience=16.3). Only two ATCOs stated that they apply CDO less often than "sometimes". Two ATCOs stated that they apply them "always". Most ATCOs apply CDO "sometimes" or between "sometimes" and "always" (in total 27 of 31).

The CDO TLX values are calculated as the unweighted average of the attribute index values (i.e. challenge, performance, temporal demand and frustration level). Table 1 summarizes the results of the ATCO survey, providing information also on standard deviation (σ), confidence intervals (CI) on a 95% level, and absolute changes. Cohen's d was used to describe the standardized mean difference of the CDO TLX values for open and closed path CDOs when compared to non-CDOs. Based on benchmarks suggested by Cohen (1988) the effect sizes are small when d=0.2, medium when d=0.5, and large when d=0.8. In contrast to the ICAO CDO manual, stating that CDO reduces the workload of ATCOs, the findings revealed an increase of ATCOs' workload for every task when applying CDO based on prescribed approach procedures (i.e. closed path without radar vectoring) and an even larger workload increase when applying CDO with radar vectors (open path).

Table 1: ATCO results (CDO TLX scales)

The highest ATCO workload during the task **controlling aircraft** is experienced when radar vectoring (open path) is applied. Even if the absolute workload level for this task still is "moderate", the absolute increase is the largest in the entire survey. While controlling aircraft according to radar vectors, the challenge increases by more than one point. It can be assumed that the attempt to keep the aircraft as close as possible to the predictable flight path increases the overall workload. On the one hand, it is remarkable that closed path procedures create a lower workload compared to open path procedures. We expected that a strict adherence to the approach procedures requires a more complex preplanning of the traffic flows in regard to separation by the ATCO. On the other hand, it was expected that after the initial planning and initiation of a CDO approach along the prescribed procedure, which creates initially a higher workload, the remaining workload decreases because the ATCO is not actively responsible for the flight path guidance of the aircraft. Additionally, one ATCO mentioned the airspace design as one reason for the workload increase. In this case, a too early descent of the aircraft might cause the risk of leaving the controlled airspace. If the descent is commenced too late, the aircraft might enter a restricted airspace (e.g. military airspace).

Analysing the task of **communication with pilots** reveals an increase of the subjective workload for closed path procedures as well as for open path procedures. This may be due to the fact that the published phraseology according to the ICAO CDO manual only deals with the initiation of the CDO and especially the initiation of closed path CDOs. Intermediate situations and in particular the case of radar vectoring are not covered in detail by the guidelines. Only one ATCO indicated that the use of CDO results in a considerable change of his workload while communicating. Another ATCO stated that the complexity of communications also depends on the traffic density. During easier traffic situations, the provided communication phrases seem suitable to apply. The obligation to provide DTG information on a regular basis might be another reason for the increase of workload during open path CDOs. For instance, providing the information “Distance to go 25 nm” may seem simple and easy, but the obligation to provide this information on a progressive basis can increase the workload significantly. However, the responses of pilots (as described in the next subsection of the paper) show that there is a general dissatisfaction with the DTG information given by ATC. It seems that the obligation to deliver repeatedly DTG information is not always fulfilled. This might explain the relative small increase of workload.

As far as the CDO related **coordination with other ATC units** is concerned, the overall workload increases only by a small amount. Furthermore, the challenge of coordination seems to be slightly smaller during closed path CDOs. This may be attributed to the comprehensive Letters of Agreement that specify airspace sharing and delegation arrangements, hours of operation and any necessary inter-unit co-ordination arrangements signed between ATC units. Another reason might be that the approach procedures are only located in one ATC sector, therefore not requiring communication.

As expected, the flexible handling of **pilot's special requests** creates a comparable higher workload. The workload increases for closed path as well as for open path procedures. This observation appears surprising, given that radar vectoring in general allows a more flexible handling of aircraft compared to closed path procedures. It may be assumed that additional CDO considerations, such as the remaining DTG, make the flexible reaction more demanding.

The survey revealed that most participating ATCOs agree that the application of CDO has a moderate complexity. The ATCOs' comments indicate that CDO is easy to apply during low density traffic situations. If the traffic density increases, the complexity of CDO increases too. Nevertheless, ATCOs in the survey tend to deny the application of CDO only "sometimes" which shows that they are willing to provide CDO during high traffic density situations. To improve the working conditions, more than half (58%) of the ATCOs recommended the use of advanced technology and systems. According to the comments, further advancement of arrival manager system and a tool to estimate the DTG would be extremely beneficial. Interestingly, only 26% of the ATCOs state that they received some kind of feedback on their CDO performance.

### 4.2 Pilots' survey

On average, the 91 pilots (average age=36 years) in the survey have an experience of 6,500 flight hours and stated that they apply CDO "always" to "sometimes". Table 2 depicts the pilots' CDO TLX results of the survey, again providing means as well as standard deviation and confidence intervals.

Table 2: Pilot results (CDO TLX scales)

Evaluating the workload of pilots shows that they don't perceive an increase caused by CDOs. The highest workload level reached can be described as "moderate" and results from a workload increase during the task "conducting the approach" in the operation mode "open path descends". When information like DTG, speed restrictions and the aircraft approach sequence is missing or incorrect, the workload increases during the execution of CDO. The application of closed path CDO leads to a slight decrease of the subjective workload which can be explained by the advanced application of the FMS and the autopilot during this kind of approach.

The task "communication with ATC according to the prescribed phraseology" does not lead to larger changes in the workload. The cause for the slight decrease during closed path approaches can be found in the fact that after initiating the approach by using the prescribed phraseology there seems to be no reason for a CDO related communication. Comparing the open path communication with the non-CDO communication shows no difference in the workload. This result seems to be surprising due to the expected increasing communication necessity during open path CDOs. Again, pilots mentioned the problem of not receiving enough and correct DTG information from ATC. A lack of information supposedly leads to an increased number of requests for this information from pilots, resulting in a higher workload in regard to communication. But this was not the case as the findings indicate.

Another problem, that was mentioned by pilots and that influences the communication especially during open path CDOs, is the frequency saturation in high traffic density airspaces. In the approach airspace of large airports, a large number of aircraft are controlled by one ATCO at the same time. This controlling of aircraft already requires many control instructions for non-CDO purposes. Therefore, the remaining “frequency time” is very limited to allow the delivery of the required CDO approach information (e.g. DTG) to every approaching aircraft.

Regarding the task “Utilisation of approach charts” a small decrease in workload during closed path procedures and almost no change in workload during open path CDOs was revealed. The pilots’ comments indicate that they usually prepare the approach with the help of approach charts and by programming the FMS. After cross-checking the navigation information of the approach charts and the FMS navigation data, the utilisation of the approach charts is reduced. Since the approach preparation takes place during the en-route phase (with the workload being lower than during the approach), the workload in the approach phase is reduced. When being radar vectored during open path CDOs, the flight path of the aircraft usually does not follow any flight path which is indicated on the approach charts. Therefore, it can be expected that the approach charts are less often used and the workload also decreases. One possible explanation is that pilots still try to estimate the DTG based on the procedures represented on the charts.

Pilots stated that if CDO is flown on a regular basis, the complexity can be rated “easy” to “neutral”. Therefore, pilots appreciate the introduction of CDO at European airports. Furthermore, there are no indications that pilots tend to avoid the application of CDOs. This is also facilitated by the Standard Operating Procedures of the participating airlines. The airlines seem to support the application of CDO due to economic and ecological reasons.

With respect to the DTG information given by ATC, pilots are only sometimes satisfied with the given DTG information in terms of intensity and quality of information. If the approach takes place in a high traffic density environment, it can be less likely to receive the required DTG information.

### 4.3 Additional results and limitations

Since CDOs increase the workload of ATCOs, it might be suspected that they try to avoid this specific procedure. However, only a rather small number of ATCOs stated that they tend to avoid CDOs sometimes or even more often than sometimes. Nevertheless, a large number of participants skipped this specific question. The response of the pilots was much more positive regarding CDOs, only one pilot stated that he sometimes tries to avoid CDOs. It should be highlighted that some participants might have interpreted the terms ‘open’ and ‘closed’ path CDO differently despite having the terms defined in the questionnaire.

The interaction of the task demands, the circumstances under which they are performed, and the skills, behaviours, and perceptions of an individual affect the perceived workload (DiDomenico and Nussbaum, 2008). Therefore, the conclusion from our survey that workload increases for ATCOs during open path CDOs might be affected by traffic density, in particular, high traffic situations that require more extensive radar vectoring. Moreover, other determinants like the time of the day or weather conditions might affect the perceived workload in specific situations. In general, we are aware of the fact that any analysis based solely on rating data is subject to bias and converging data from real-time performance and/or physiological data collected during operations or simulations would be very beneficial. Given the rather small size of the sample, the survey was conducted in a way which does not allow to link demographic or work related information (e.g. experience or home airport) to workload perceptions. Therefore, analysing correlations between demographic information and workload perception is not possible within this study. Moreover, more detailed information on the specific position of the ATCOs might be desirable. Another potential extension for future research could differentiate between airports with or without mandatory CDO procedures.

# 5 Conclusions

The leading guidance material of the ICAO in regard to CDO assumes that they result in a decrease of ATCOs' and pilots' workload. The most striking finding emerging from the data gathered via the CDO TLX workload tool is that ATCOs perceive their workload as higher in CDOs in comparison to non-CDOs approaches, whereas pilots only see a rather slight increase in some areas but also workload reductions regarding other tasks.

The increase of ATCO's workload related to CDOs should not obstruct the implementation of CDOs. Pilots are interested in reducing fuel consumption and in some companies they are given performance indicators related to fuel burn; therefore they have a strong incentive to perform CDOs even though those procedures can increase pilots' workload. Additional environmental training for ATCOs might increase their environmental awareness, making them more eager to provide CDOs. The element of working conditions and situation alertness needs to be taken under consideration too.

One secondary result is related to the distance-to-go information, which is required by the pilots to calculate the optimum descent profile. To improve the performance of open path CDOs, improvement of the radar software, the available Arrival Manager Systems or the comprehensive introduction of the FAA's Tailored Approaches concept are necessary. Moreover, better training of ATCOs in regard to provide Distance-To-Go information (DTG) and accuracy of information on charts, communication, training and CDO related culture are important and required. Other areas that need to be looked at are the CDO related phraseology, airspace design, predictability of the aircraft's speed, training and awareness of ATCOs and pilots, harmonisation of flight procedures and better harmonisation of CDO and also Continuous Climb Operations.

**Acknowledgement:**

This paper was developed during a placement of one of the authors at EUROCONTROL that greatly assisted the research. However, all opinions expressed in this document are exclusively those of the authors. The authors would like to acknowledge networking support by the COST Action TU1408.

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