A Human-In-The-Loop Simulation Study on the Requirements of Air Traffic Control Operations for Expanding Continuous Descent Operations

H. Hirabayashi, N. K. Wickramasinghe, and D. Toratani

Abstract Continuous descent operations (CDO) is an efficient aircraft descent procedure that results in minimal fuel consumption because aircraft descend from their optimal top of descent (TOD) at idle engine thrust. To expand the implementation of CDO, we focus on enhancing the decision-making abilities of air traffic controllers (ATCOs). We conducted a series of human-in-the-loop (HITL) simulations to understand the issues involved in CDO approval decision making by ATCOs and to provide effective inputs to support the decision making. From our initial simulation results, we identified several issues that can affect ATCO CDO-specific decisions. As a proposal to solve these issues, we then created support information displays and evaluated them in follow-on simulations. Our support displays were found to be increasingly effective if their information was sufficiently accurate to avoid premature judgment. It was also found necessary to provide support information to ATCOs to enable more proactive air traffic control (ATC) measures for CDO execution.

Keywords Air traffic control · Continuous descent operations · Human-in-the-loop simulation

1 Introduction

Continuous descent operations (CDO), in which aircraft descend at idle engine thrust from their top of descent (TOD), is an efficient aircraft descent procedure [1]. Performing CDO affords minimum fuel consumption and also prevents early

---

H. Hirabayashi (✉) · N. K. Wickramasinghe · D. Toratani
Air Traffic Management Department, Electronic Navigation Research Institute (ENRI), National Institute of Maritime, Port and Aviation Technology (MPAT), Tokyo, Japan
e-mail: h-hirabayashi@mpat.go.jp

N. K. Wickramasinghe
e-mail: navinda@mpat.go.jp

D. Toratani
e-mail: toratani-d@mpat.go.jp

Air Traffic Management and Systems IV, Lecture Notes in Electrical Engineering 731,
https://doi.org/10.1007/978-981-33-4669-7_12

descent, leading to noise reduction at localities situated around airports, so it is desirable for all descending aircraft to follow CDO from the viewpoints of efficient aircraft operations and reduced environmental impact. Thus, CDO has been specified by the International Civil Aviation Organization (ICAO) as one of the modules to be implemented in its Global Air Navigation Plan (GANP) modernization program [2].

Efforts to enable more flights to conduct CDO are being made around the world. In the USA, the introduction of Optimized Profile Descents (OPD) is being actively promoted. OPD procedure design and post-implementation evaluation methods have been studied [3], and OPDs are being introduced at many major airports [4]. An OPD is specified as an RNAV (Area Navigation) standard terminal arrival (STAR) procedure. OPD STARs contain upper / lower altitude limits and speed constraints at several waypoints, so the descent is not completely free, but it is possible to descend from cruise with fewer level flight segments than a conventional procedure. In Europe, the Continuous Climb and Descent Operations (CCO/CDO) task force was launched in 2015, and conducted a detailed analysis of actual traffic data. The results showed that continuous descent from TOD had only been achieved by 24% of flights in nominal CDO procedures, and task force activities to expand the use of CDO are still ongoing [5].

In Japan CDO routes, which approve the entire flight trajectory from the TOD to the end of the STAR, are currently designed and published for three airports [6–8], but their operation time window is restricted to late-night when the air traffic volume is low because of difficulties in maintaining the required separations between aircraft in higher traffic situations. However, simple comparisons between radar track trajectories and simulated CDO trajectories have demonstrated that there are sometimes traffic gaps (intervals) in the airspace during which CDO can be implemented even during day light hours when the traffic volume is heavy [9]. Enabling such potentially CDO-capable flights to execute CDO can extend current CDO operations from light traffic to regular air traffic scenarios.

The aim of our study is to expand CDO in Japan and more widely beyond its current usage and limitations. Since CDO is initiated with air traffic control (ATC) approval, we focus on assisting and enhancing the air traffic controller's (ATCO's) CDO approval decision-making abilities. Therefore, to expand CDO beyond its current usage and limitations, in this study, we conducted a series of human-in-the-loop (HITL) simulations with the assistance of experienced former ATCOs to determine the relevant issues and identify the requirements for ATC operation involving CDO approval specific decision making. HITL simulation is very important for evaluating the feasibility of a proposed operational procedure. HITL simulation has been used to evaluate the support information required by pilots during CDO operations [10], but prior to our study, there have been no published HITL studies focusing on ATC procedures and ATCO performance during CDO operations.

2 Cdo Procedures

2.1 CDO at Kansai International Airport

In our HITL simulations, we utilized certain target scenarios relevant to Kansai International Airport (ICAO code "RJBB"), one of the three airports where CDO routes are established. RJBB is a 24-h international airport located offshore on an artificial island close to the highly populated Kansai region. There are two parallel runways (RWY06R/L and RWY24R/L), which are mainly used as dedicated runways for departure and arrival, respectively. The airport operator Kansai Airports reported 189,658 aircraft movements in fiscal year 2018 [11], an increase of 1.8 since fiscal year 1995, the year after the airport was opened, mainly due to traffic connecting the Asia region.

RJBB offers several CDO routes in the late-night to early-morning time window [6]. During the most recent two years (1 Jan. 2017 to 31 Dec. 2018), the daily average number of CDO requests was 2.6, and the approval rate of CDO requests was 78% [12].

Each CDO route is set via a "transfer point" to the end point of the STAR. Here, transfer point refers to a waypoints at which ATC responsibility for arriving flights is transferred from en-route radar control to terminal radar control, indicated by the star in Fig. 1 which shows the location of the transfer point in an airspace vertical view.

The RJBB CDO routes are indicated by blue lines in Fig. 2. There are five transfer pints (indicated by stars), and CDO routes are available from three of these. For each of these transfer points, three CDO routes are defined depending on the landing runway. In the RJBB procedure designs, the end point of the STAR is collocated with either the Initial Approach Fix (IAF) or an Intermediate Approach Fix (IF) at 4000 ft.

The CDO procedure, triggered by pilot request, is as follows:

(1) A flight requests CDO from ATC at least 10 min before reaching TOD, giving the TOD position and estimated time at the transfer point.

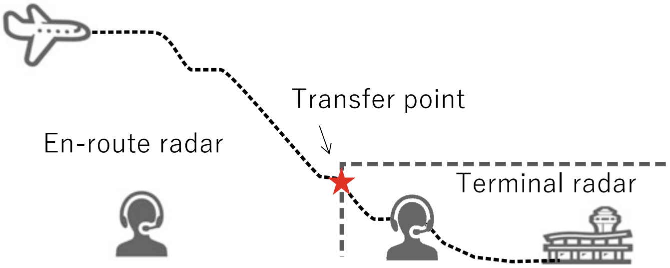


Fig. 1 ATC transfer from en-route radar to terminal radar

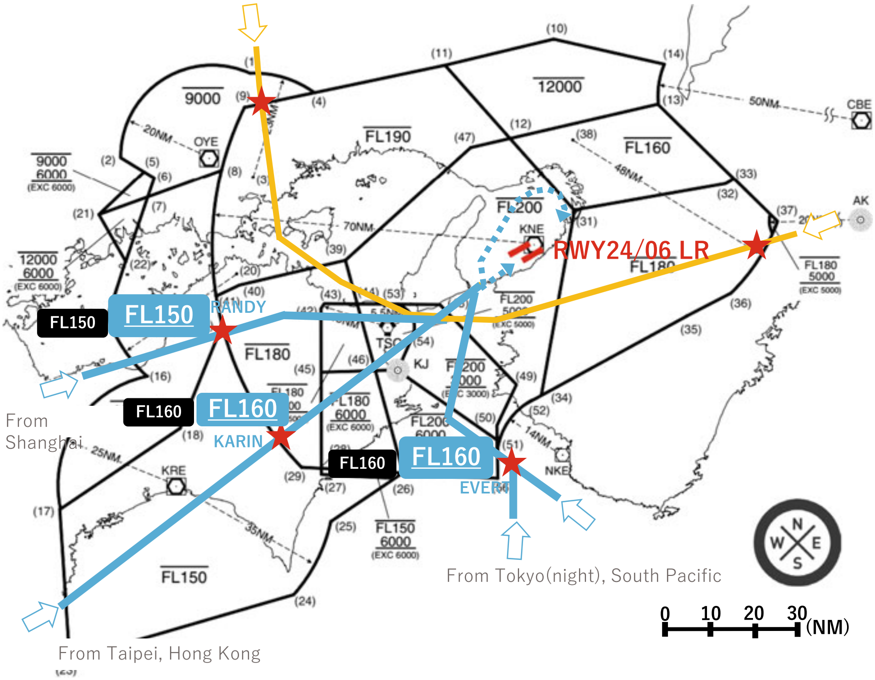


Fig. 2. Outline of CDO routes at RJBB

(2) ATC issues CDO approval clearance if it is determined that the requesting aircraft can fly the CDO route and that there will be no conflicting aircraft during the CDO descent. This procedure is almost the same at the other two airports.

Maintaining safe separation between aircraft is an essential part of an ATCO's role. When approving a CDO, ATCOs must ensure adequate separation from other traffic during the CDO descent, which we call "competing" traffic in this paper. Aircraft flying along airways or departure routes that cross the CDO route and aircraft landing at the same airport from different directions, may be candidates for competing aircraft (Fig. 3). ATCOs must issue instructions to aircraft, including the CDO aircraft, in a timely manner to ensure safe separation from the other traffic. However, as the traffic volume increases, the number of competing aircraft and ATCO workload increases correspondingly. To ensure a reasonable workload to maintain airspace capacity as traffic volume increases, it becomes necessary to impose descent constraints that deviate from the ideal, such as descending aircraft prior to their ideal TOD (early descent).

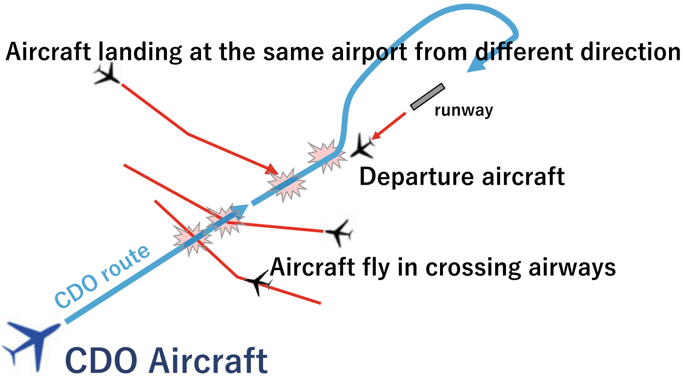


Fig. 3 Competing aircraft

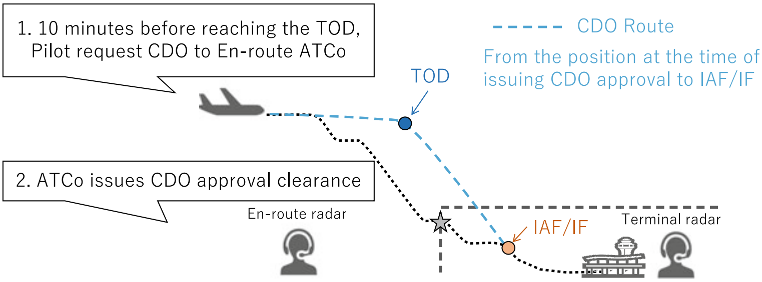
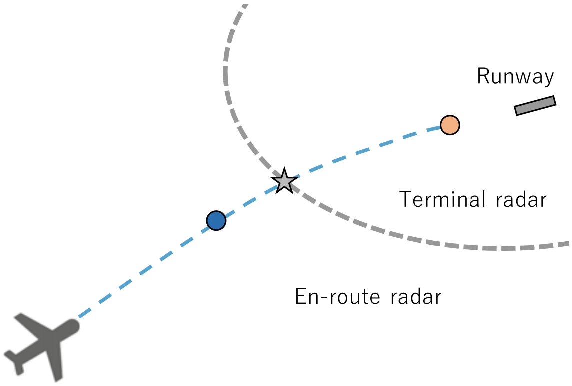


Fig. 4 Vertical view of CDO procedure

Fig. 5 Horizontal view of CDO procedure



2.2 ATC Operation for CDO

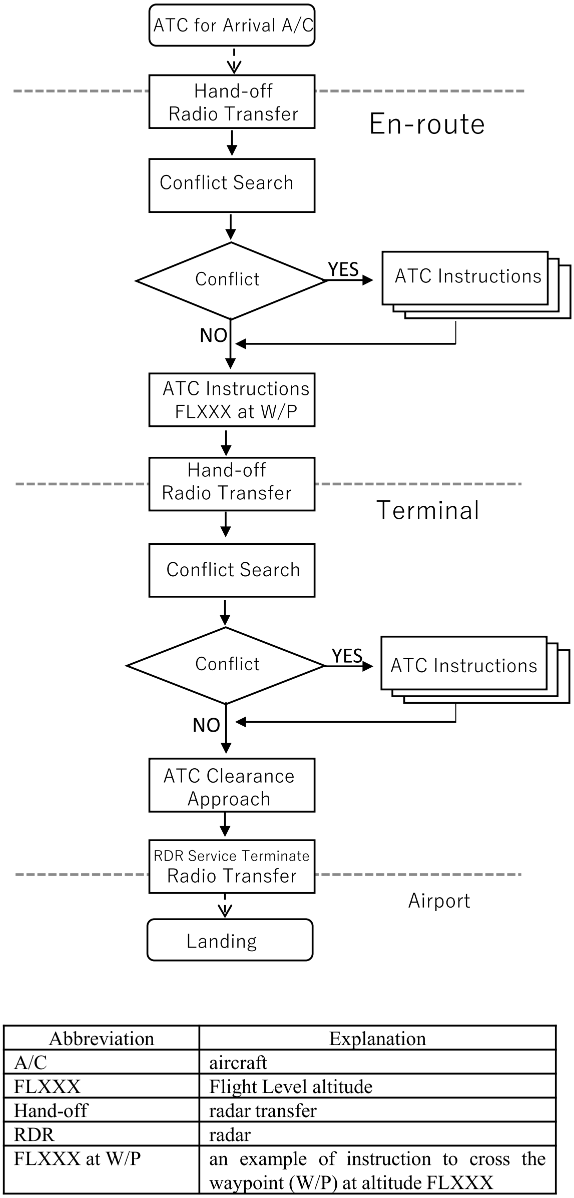
Figures 4 and 5, respectively, show the schematics of a CDO route in vertical and horizontal views. Since the TOD is located before the transfer point, CDO must be requested within en-route radar control airspace. The gray dotted line in Fig. 4 indicates a conventional descent for comparison, which has a different vertical profile.

Figures 6 and 7 clarify the differences in the ATC processes between conventional and CDO descents. For a conventional arrival, the en-route ATCO first provides a descent instruction to the aircraft to cross the transfer point at the prescribed altitude, and ATC responsibility is transferred to the terminal radar ATCO at the transfer point. The terminal radar ATCO then assumes responsibility for the flight until giving a runway approach clearance. Both ATCOs proactively issue ATC instructions to the aircraft to ensure adequate separation from other traffic by repeatedly searching for potential “conflicts” with competing aircraft from a few minutes to tens of minutes ahead. For en-route ATCOs, the major competing aircraft is aircraft on crossing airways and other arrivals with the same transfer point. For terminal ATCOs, the primary competing aircraft arrivals to the same airport and departure / arrival traffic at nearby airports. For a CDO arrival, a pilot CDO request triggers a CDO-specific conflict search by both the en-route radar ATCO and terminal radar ATCO (as indicated by the red rectangles in Fig. 7) before the CDO can be approved. Since the CDO clearance includes approval up to the STAR end point, a conflict search up to about 30 min ahead is required. At first, conflict searches are conducted separately by the en-route and terminal radar ATCOs to ensure that there are no conflicts along the CDO route within their areas of responsibility, then coordination between the ATCOs is required, as indicated by the area highlighted in yellow color in Fig. 7. The crossing altitude at the transfer point varies for each CDO operations, which forms another element of the coordination.

Although the ATC process for a CDO arrival is more complex than for a conventional arrival with regards to conflict search and coordination, the CDO process requires fewer communications between the CDO flight and ATCOs. With a conventional arrival, ATCOs have to issue multiple instructions at the proper instances, but a CDO arrival requires only a single CDO approval clearance to descend from the TOD to the STAR end point.

Upon comparing the two ATC processes, it could be argued that the CDO-specific ATC operation is a reactive task while conventional ATC operation is proactive. For a conventional arrival, ATC instructions are issued actively according to minute-by-minute predictions of the traffic situation. On the other hand, for a CDO arrival, it is necessary to continually monitor whether the aircraft can fly as per long-term predictions, and if a competing aircraft appears, the CDO is canceled and the procedure reverts to the conventional descent.

Fig. 6 ATC task flow (conventional descent)

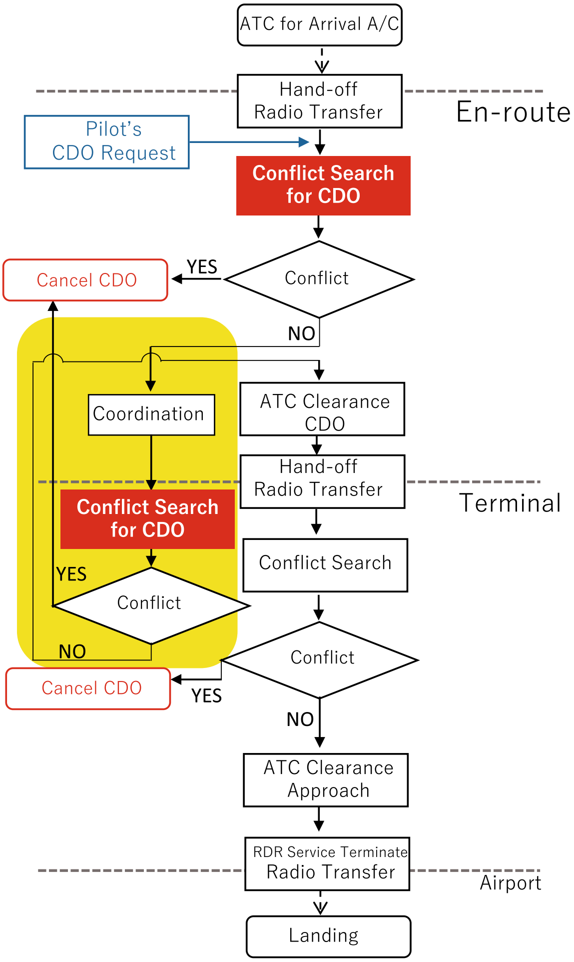


Abbreviation	Explanation
A/C	aircraft
FLXXX	Flight Level altitude
Hand-off	radar transfer
RDR	radar
FLXXX at W/P	an example of instruction to cross the waypoint (W/P) at altitude FLXXX

3 Human-in-The-Loop Simulation

In the CDO procedure, the en-route and terminal radar ATCOs have to judge whether or not a requesting aircraft can execute the CDO; that is, whether or not CDO is applicable to the aircraft. If the determination is made as “CDO-applicable”,

Fig. 7 ATC task flow (CDO descent)



CDO approval clearance is issued after coordination between the en-route radar and terminal radar ATCOs. Since the CDO approval clearance is made through the end point of the STAR, the ATCOs have to consider the entire aircraft trajectory from the point at which the request was made to the IAF/IF point (corresponding to approximately 30 min of flight time in the case of an RJBB arrival), and conduct corresponding conflict searches within their airspaces of responsibility.

HITL simulations were conducted with experienced former ATCOs to determine the relevant factors and necessary information pertaining to the "CDO-applicable" decision making. That is, the main questions addressed through the simulations were as follows: What are the relevant issues to consider, and what is the information required for deciding on whether CDO can be applied when CDO is requested?

Fig. 8 HITL simulation examination

3.1 Decision Support Tool for Simulation Experiments

In the HITL simulations, we utilized a decision support tool customized for CDO. The tool was developed at ENRI, and has two functions: a fast-time simulation function for CDO flight trajectory calculation, and a real-time air traffic simulation function that reflects input ATC instructions. The tool presents the traffic situation on simulated radar screens and has several support information displays. The real-time simulation function was used for our experiments.

Figure 8 shows the setup for the simulation experiments. There were three simulated controller-working positions (CWP) corresponding to en-route radar control, terminal radar control, and traffic flow coordination. ATC instructions to aircraft were input directly at the CWP user interface rather than by voice. The traffic flow coordinator was also responsible for inputting system commands. Figure 9 shows the radar simulation screen used in the experiments.

3.2 Participants and Scenarios

Three former ATCOs who were familiar with ATC operation in the target area participated in our experiments. Two participants were utilized as the ATCOs directly involved in the CDO procedure outlined in Sect. 2, that is in the roles of en-route radar ATCO and terminal radar ATCO, while a third participant acted as the traffic flow coordinator.

The simulation airspace range was approximately 200 NM from the target airport (RJBB). The ATCOs input instruction commands to the tool to ensure adequate separations between aircraft according to the following prerequisites:

- All aircraft arriving at RJBB request CDO.
- ATCOs can apply speed adjustment to the CDO aircraft. If an change to vertical profile or flight course is required, CDO is cancelled.

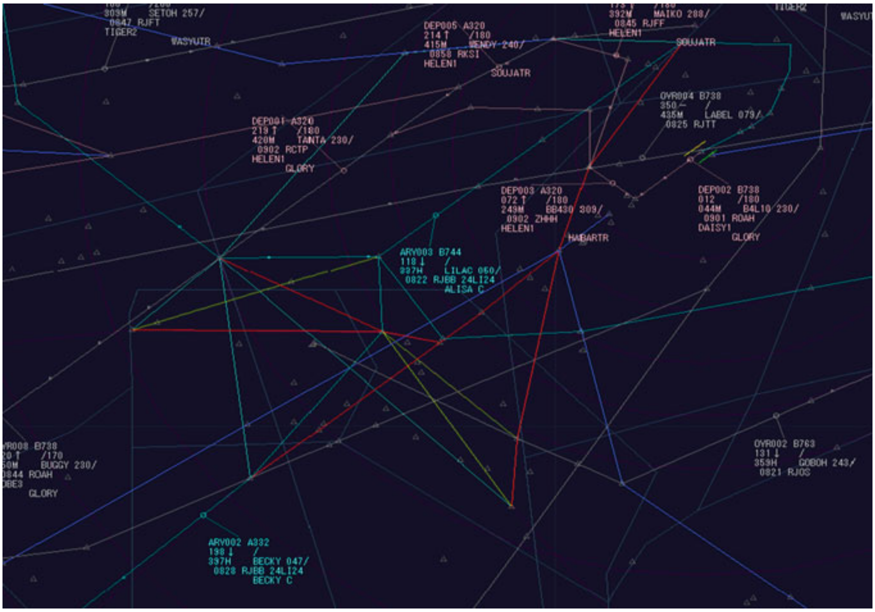


Fig. 9 Radar simulation screen

- The longitudinal separation between aircraft crossing the same transfer point must be 10 NM or more.
- All actual operational restrictions (no-fly zone, STAR restrictions, etc.) are applicable.

Ten simulation experiments were performed over a period of 7 days, including familiarization with the tool.

Scenarios were created based on historical flight plan data. Two days in 2016 and 2017 were selected for the scenarios: One day was focused on RWY06 arrivals while the other day was dedicated to RWY24 arrivals. On each day, traffic scenarios for three time periods were created from corresponding flight plan data: (a) 0000–0800 JST (Japan Standard Time), (b) 1000–1300, and (c) 2100–2400. Scenarios (a) and (c) include several hours after and before the current CDO operation time period at RJBB, respectively. The arrival rate during the CDO operation period was 0–1 flights every 10 min, but increased to 1–3 flights/10 min. During the one-hour time periods immediately before and after CDO operation period. These scenarios were prepared to examine the CDO operability during time periods spanning several hours earlier and/or later than current CDO operations. Scenario (b) includes the peak traffic time period during each day, and was prepared to extract issues and to study the feasibility of HITL simulation of CDO in heavy traffic environments. A total of six scenarios was, therefore, prepared for two runway operation configurations and three time periods. The simulations were conducted reflecting the wind conditions during the selected days.

To create realistic traffic flows, the time and altitude of entry of flights into the simulation were set based on historical radar track data, and the subsequent flight trajectories were calculated using an aircraft type-dependent performance model and the wind conditions. In addition to RJBB arrival traffic flows from multiple transfer points (refer Fig. 2), the RJBB departure traffic flows, crossing airway traffic flows, and traffic flows at nearby airports were also simulated.

The scenarios were not arranged to be conflict-free; that is, loss of separation could occur if all RJBB arrivals executed CDO, so participants had to give ATC instructions to ensure separation. For example, eight arrivals in 30 min were set in a time period during which traffic volume gradually increased. If all aircraft executed CDO without speed restrictions or route stretching, two pairs of aircraft executing CDO would lose longitudinal separation prior to reaching the IAF/IF, and there were other competing aircraft such as RJBB departures and crossing airway traffic.

4 Results and Discussions

4.1 Issues Concerning CDO-Specific ATC Operations

From the HITL simulation experiment, we identified several influences that affected ATC CDO operations and considered the underlying issues. These influences and issues are summarized in Table 1.

4.1.1 Wide Variation in CDO Trajectories

The first issue is the wide variation in CDO trajectories. Figure 10 shows the differences between conventional and CDO descent trajectories in vertical view. In a conventional descent, an aircraft crosses the transfer point at a predetermined altitude, whereas for a CDO descent, the speed and angle of descent are determined by each aircraft, so the TOD position and the position of entry into the terminal

Table 1 Issues and their influences in CDO-specific ATC operation

Issues	Influence
CDO trajectories vary widely	Transfer operation occurs outside airspace interest
Difficulty in predicting flight trajectory (Particularly altitude)	Inapplicable vertical separation Reduction in airspace capacity
Early CDO approval estimation times	Difficulty of predicting competing aircraft
Prioritization of CDO	Increase in burden of both CDO and competing aircraft

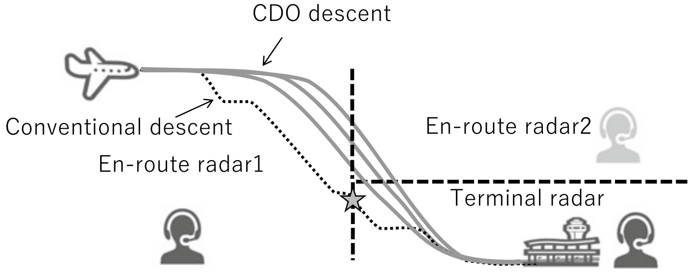


Fig. 10 Differences conventional descent and CDO descent trajectories

radar airspace vary from flight to flight. Figure 11 shows the actual TOD positions of CDO flights (the TOD positions of 56 CDO flights over 84 days in 2018 extracted from radar data provided by the Japan Civil Aviation Bureau). The TOD positions are widely spread, and the vertical profiles also vary significantly. Table 2 lists the altitude-related statistics of CDO flights at their transfer points calculated from radar data. In a conventional descent, an aircraft is instructed to descend to cross the transfer point at 16,000 feet, but on the other hand, a CDO descent profile is optimized for an idle thrust descent, and so the altitude at the transfer point varies widely. Another

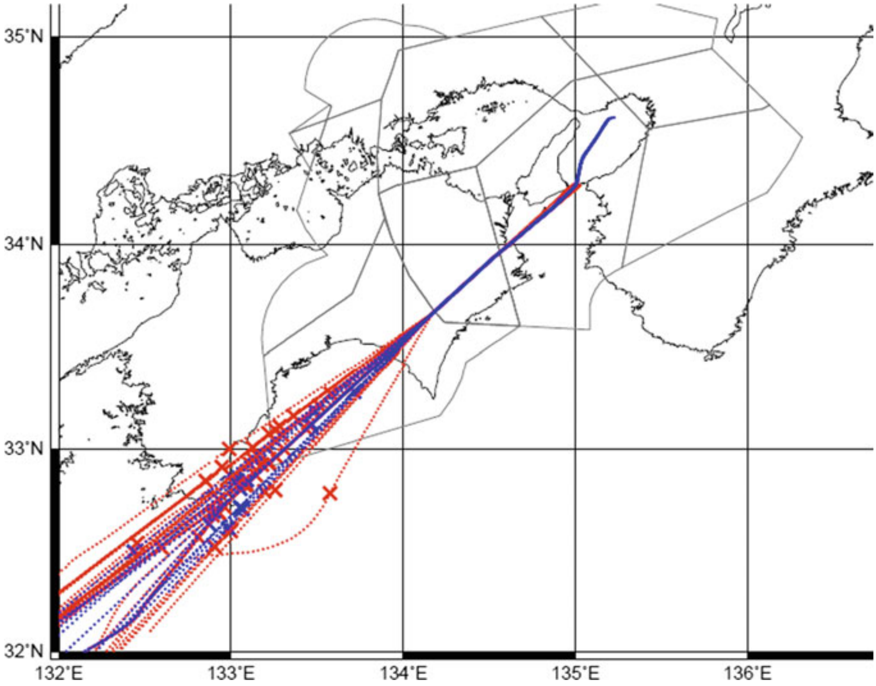


Fig. 11 TOD positions of CDO flights

Table 2 Statistics of transfer point crossing altitude of CDO flights

	Transfer point for RWY06	Transfer point for RWY24
Number	41	12
Max	24328	24072
75%	17749	21358
Median	16744	18718
25%	15741	17368
Min	15607	15809
Average	17059	19289
SD	1706	2865

Altitude is expressed in units of feet

factor in the wide scatter of CDO transfer point crossing altitudes relative to conventional descent operations is that ATC transfer occurs outside the airspace of interest. This also requires additional coordination between the ATCOs.

4.1.2 Difficulty of CDO Trajectory Prediction

The wide variation of CDO trajectories also causes difficulty for ATCOs in accurately predicting the flight trajectory. This difficulty is captured in Table 1 along with its issues in the second row. In a conventional descent, ATCOs issue altitude instructions as they desire. However, in the CDO case, these instructions are not provided because CDO clearances involve aircraft descending as they wish. It is difficult for ATCOs to accurately predict the descent trajectory based only on human experience and judgement, and as a result, ATCOs could not apply vertical separation, which one of the separation standards. Moreover, because of uncertainty of the trajectory, ATCOs may need to set an extra buffer to maintain separation. This difficulty also leads to reduction in the airspace capacity. Assistance from automation such as a trajectory prediction function is required to enable ATCOs to estimate the crossing altitude accurately.

4.1.3 Early Judgement for CDO Approval

The third issue involves the necessity of early judgement when issuing a CDO approval. A CDO approval clearance is issued only when competing aircraft are not predicted on the estimated CDO trajectory. However, it is difficult to carry out this prediction precisely. In particular, when a departure is a competing aircraft, an estimate of its relationship with the CDO profile must be made before it has even become airborne, which is difficult even if the predicted take-off time is accurate.

4.1.4 Prioritization of CDO

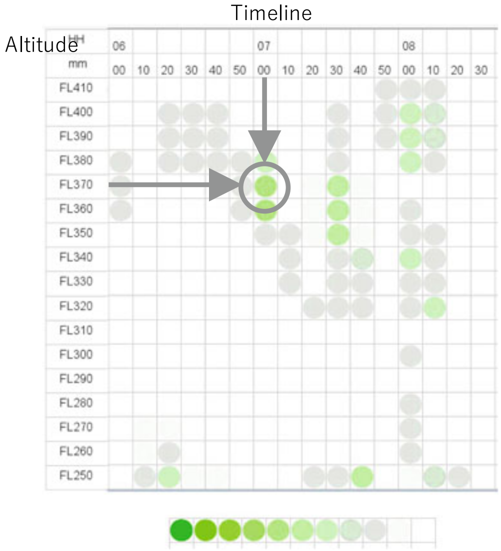
The fourth issue was whether or not to prioritize CDO flights. In the HITL simulation experiments, the ATCOs ensured ATC separations to prioritize CDO flights to the maximum extent possible. The HITL simulations were mainly of time periods slightly outside the current CDO window, wherein the traffic volume increased / decreased gradually. It was necessary to issue speed adjustment (mostly speed reduction) instructions to proceed with CDO in many of the cases considered.

4.2 Supporting ATC Operations for Expanding CDO

To enhance the ATCO judgement for CDO approvals, we integrated two decision support displays based on a ground-based trajectory prediction function into the HITL simulation tool at CWPs. One is a matrix display for the en-route radar ATCO which displays the existence of potentially competing aircraft against CDO trajectories as a time series, with altitude and time on the vertical and horizontal axes, respectively. The other display is a timeline display for the use of the terminal radar ATCO, which shows time intervals between landing aircraft on the vertical axis with the timeline at specified waypoints or runways. Figure 12 shows images of these support displays. As a result of comparing the experiment with and without supporting screens, we found that these displays could facilitate proactive ATC operations and support the CDO approval process.

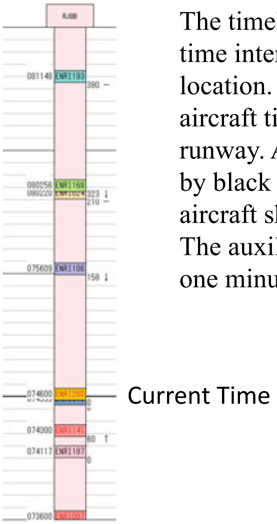
In our interviews with the ATCOs participating in the HITL simulations, they commented that our proposed displays would be feasible if the provided information were accurate. It is widely expected that improvement of highly accurate trajectory prediction will increase the effectiveness of ATCO support functions. Furthermore, the en-route ATCO commented that it would be easier for decision making if competing aircraft were clearly indicated, rather than be shown as only a probability on the matrix screen. The terminal radar ATCOs stated that the timeline display was effective for future predictions because it visualized the time intervals between aircraft, but because it did not show distance intervals it could not be used to judge whether the distance-based radar-separation criteria would be satisfied. It was remarked that both these displays would be more useful for the flow coordinator, who manages the traffic flow comprehensively, than for tactical radar ATCOs.

In this study, we attempted the following to prioritize CDO: (1) speed adjustment (of both CDO and competing aircraft), (2) delaying the take-off of departing aircraft, and (3) per-flight adjustment of the STAR before the TOD to avoid competing traffic. Regarding (1), we note that speed adjustment has been implemented in actual CDO operations, and is considered acceptable from the perspective of ATCOs because it is effective in maintaining adequate aircraft separation. However, there were several cases in the experiments when excessive speed adjustments had to be imposed to avoid radar vectors and improve the CDO success rate (i.e., the rate at which an approved CDO is successfully completed without being aborted). It is necessary to



In the example in this figure, possibility of competing aircraft existence is shown when crossing the determined point from 07:00 to 07:10 at altitude FL370. The darker the color, the longer the competitor will exist in 10 minutes.

Matrix Screen



The timeline shows the aircraft time interval at a determined location. The example shows the aircraft time interval on the runway. Arrival aircraft shown by black character and departure aircraft shown by red character. The auxiliary lines are shown at one minute intervals.

Timeline Screen

Fig. 12. ATCOs' decision supporting screens

consider aircraft operating efficiency to carry out speed adjustment to achieve overall effectiveness. Regarding (2), take-off delay was considered for the CDO routes that are mostly affected by departing aircraft. To ensure CDO success, competing departure aircraft required up to 7 min of delay. Regarding (3), the probability of competing aircraft existing on the CDO trajectory decreased and the CDO success rate increased. However, the STAR revisions involved path stretching to avoid competing traffic near the runway. This caused an approximately 12.6 NM stretch to original CDO route. For the issue of prioritization of CDO, both the advantages and disadvantages of CDO become very important in considering its overall effectiveness and feasibility.

In cases (2) and (3), priority given to CDO resulted in inefficiency for other and own aircraft. Further consideration is needed on acceptable departure delays, route stretch, etc.

5 Conclusions

To determine the issues involved in CDO-specific ATC operations and the necessary information pertaining to ATCO CDO-related decision making, the authors conducted a series of HITL simulations with the assistance of experienced former ATCOs. The results showed that since CDO is initiated with ATC approval, presenting information relevant to potential CDO-capable aircraft at the appropriate instant prior to TOD is effective for improving ATCO decision making. This can also expand the scope of CDO implementation, resulting in several benefits. Based on this result, we implemented controller support displays to aid the CDO-specific decision making, and evaluated them in further HITL experiments.

The experiments identified several influences faced by ATCOs pertaining to CDO, and we considered four issues underlying these influences. The issues include a wide variation in the CDO trajectories, difficulty in CDO trajectory prediction by ATCOs, the early approval required for CDO procedures, and the prioritization of CDO over conventional descents and other traffic to increase the success rate. We found that our support displays could be increasingly feasible if their information was sufficiently accurate. It is desirable to improve high accuracy trajectory prediction technology at the same time for its effective use as support information. It is also found necessary to provide such support displays to ATCOs to permit more proactive ATC measures for CDO execution, which are otherwise conventional reactive measures.

A review of the disadvantages of CDO implementation is also important to evaluate its overall effectiveness. Three trials were conducted in attempts to improve the CDO success rate. In each case, the constraints of speed adjustment, departure delay, and path stretching were imposed on the CDO aircraft and/or other competing aircraft. Among these constraints, speed adjustment appeared to be acceptable from the perspective of ATCOs. However, it is necessary to consider the aircraft operating efficiency to carry out speed adjustment to achieve overall effectiveness. The other constraints (departure delay and path stretching) need to be carefully examined, which will form the topic of our future works.

References

1. ICAO, in *Continuous Descent Operations (CDO) Manual*, ICAO Doc 9931 First edition (2010)
2. ICAO, in *Global Air Navigation Plan 2016–2030*, ICAO Doc 9750 Fifth edition (2016)
3. J.-P.B. Clarke, J. Brooks, G. Nagle, A. Scacchioli, W. White, S.R. Liu, Optimized profile descent arrivals at los angeles international airport. J. Aircraft **50**(2), 360–369 (2013)
4. FAA NextGen, in *Performance Based Navigation (PBN) Implementation and Usage*, https://www.faa.gov/nextgen/pbn/dashboard/. Referred Mar 2020
5. EUROCONTROL, in *Continuous Climb and Descent Operations*, https://www.eurocontrol.int/concept/continuous-climb-and-descent-operations. Referred Mar 2020
6. Japan Civil Aviation Bureau, in *eAIP Japan AD 2*, RJBB Kansai INTL, referred effective date 20 June 2019
7. Japan Civil Aviation Bureau, eAIP Japan "Operation Trial for Continuous Descent Operations (CDO) at Kagoshima AP/RJFK.", AIC 020/16, effective from 13 Oct 2016
8. Japan Civil Aviation Bureau, eAIP Japan "Operation Trial for Continuous Descent Operations (CDO) at Naha AP/ROAH.", AIC 010/20, effective from 26 Mar. 2020
9. H. Hirabayashi, S. Fukushima, M. Oka, N.K. Wickramasinghe, D. Toratani, in *55th Aircraft Symposium on Feasibility Study on the Expansion of Continuous Descent Operations (CDO) at Kansai International Airport with Track Data Analysis* (2017) (Japanese)
10. P.M.A. De Jong, F.J.L. Bussink, R.P.M. Verhoeven, N. De Gelder, M.M. Van Paassen, M. Mulder, Time and energy management during approach: a human-in-the-loop study. J. Aircraft **54**(1), 177–189 (2017)
11. Kansai Airports, in *Kansai airport seen by Numbers*, https://www.kansai-airports.co.jp/company-profile/about-airports/kix.html. Referred Mar 2020
12. H. Hirabayashi, N.K. Wickramasinghe, D. Toratani, Study of Requirements Necessary for CDO Operation expansion by Experienced Air Traffic Controllers, in *Proceeding of 19th Electronic Navigation Research Institute Research Workshop*, June 2019, pp. 63–69 (Japanese)