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TERMINAL HOLDING TIME MINIMIZATION BY DYNAMIC CDA ROUTING ALGORITHM

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Abstract

This article is focused on the application of 'Continuous Descent Approach' [CDA] to reduce the overall terminal traffic wastage of time and fuel consumption as well as reducing environmental emissions. This goal is achieved by introducing an online alternative CDA route under management of a heuristic optimization algorithm that minimizes the overall holding time. Performing a study on Atlanta international Hartsfield-Jackson airport, ATL, the results show considerable 60% decrease in cost function. Such achievement encourages the idea of implementing 'Dynamic CDA Routing Algorithm' [DCRA].

1 Introduction

Today's transportation is facing with two major problems, first problem is the huge increase in demand due to population growth [1]. The second difficulty is the environmental and safety limitations. Hence, due to its dynamic nature, air traffic management problems need to be solved over and over again. Planning and updating programs like 'NexGEN' in the USA and 'SESAR' in the Europe are some of these efforts [2].

Disregarding weather induced delays, statistics show that major airports in USA, suffer an average of 15 minutes general delay in departures and arrivals[3]. It is noticeable that one minute delay costs 78.17$ in average to be added to Direct Operating Costs [DOC] which results in 7.175M$ of delay costs in 2012 only in the USA [4]. In this research, a new optimization algorithm is suggested and aligned with NexGEN program concepts, to minimize holding times.

1.1 Air Traffic Management

Air traffic management [ATM] is a complex system that delivers CNS/ATM services to every flying aircraft around the world. Today, this system is under modification to be adapted for new needs of the market [5]. According to these amendments, there would be infrastructural changes with purpose of increasing the capacity of the Air Traffic Management system while maintaining its safety. One of the key adjustments is a concept which represents a shift from sensor-based operation to 'Performance-Based Operation' called PBO. Specifying aircrafts' navigational system requirements along with required navigation infrastructure and support systems (called RNAV/RNP requirements) is the main concern of this program which is also the fundamental idea of this research.

A system based on RNAV requirements, is capable of relating horizontal and vertical performance, which enables much more efficient usage of airspace in comparison with conventional route planning. (Fig. 1)

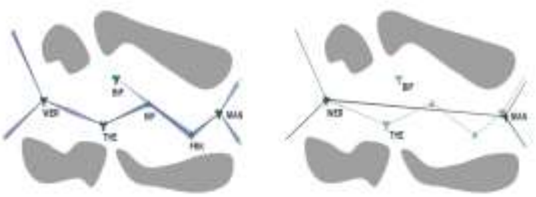

Figure 1. Navigation by Conventional Navigation (on left) Compared to RNAV (on right) [5]

Redesigning 'Standard Terminal Arrival Routes' [STAR] and introducing new and more flexible CDA paths supported by 'LASER Guided Landing System' [LGLS] [6] are presented in this article.

1.2 CDA

It has been shown that because of the idle throttle setting in 'Continuous Descent Approaches' [CDA], using CDA makes not only the benefit of saving flight time and fuel consumption, but it also reduces the amount of noise and emissions near the airport area compared to current procedural Step Descend [STD] [7]. In other words, terminal area capacity increases while remaining within environmental limits [6].

Yet, in spite of all remarkable advantages, there are difficulties in implementing CDA routes which are main concerns of this article. Experimental studies show that proceeding CDA in heavy traffics is not efficient [7]. Two main reasons are

1) Inadequate level of automation, in both aircraft and ground facilities to guarantee safe distances between arrivals,
2) Limited number of available CDA routes due to navigational constraints.

This means that one of the most important benefits of using CDAs is disregarded. This research shows that by applying DCRA, arrivals are efficiently managed through CDA routes during peak hours.

2 Dynamic CDA Routing Algorithm

The idea of dynamic routing simply comes from the dynamic nature of traffic flow. As mentioned, it is desired to perform continuous descents during peak hours. However, it's been shown in [8] that CDA routes require more separations. Besides, limited CDA route choices for an arriving aircraft, is another restriction of using CDA. Thus, DCRA suggests a solution for this dilemma. Utilizing LGLS in order to overcome navigational limitations and introduce dynamic waypoints, help defining new available CDA routes where DCRA can assign optimal path to each arriving aircraft.

2.1 Algorithm

The DCRA, as shown in Fig. 2, uses online flight information of all arriving aircrafts to schedule aircraft to proper routes. Also three possible CDA routes (defined by two points) are given to the algorithm. These routes have slightly different throttle settings, so that the whole benefit of performing CDA is not dismissed [8]. As a result, these three routes have different flight path angles and so different TODs with the same end point (Fig. 3). It should be noticed that these routes don't have same priorities. Since R#1 in Fig. 3, has idle throttle setting, and the fact that airplanes tend to spend most of flight time in cruise level, where R#1 has the most cruise time, this route is the best possible choice. With this regard, R#2 and R#3 have second and third priorities to be selected.

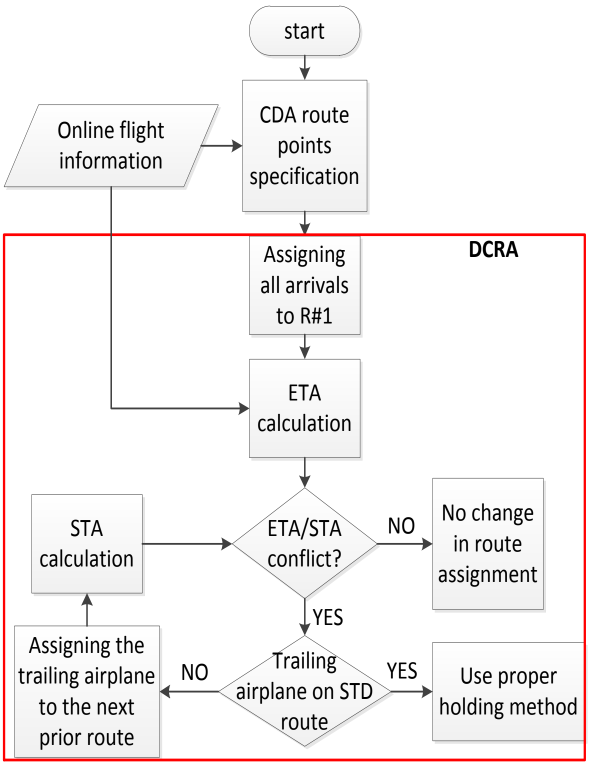

Figure 2. DCRA Flowchart

To perform DCRA process, at the first step, all arrivals are assigned to R#1. Then the algorithm calculates Estimated Time of Arrival

[ETA] for all of them. Afterwards, in case of any confliction along the path to the end point, based on First Come First Served [FCFS] logic, ETA conflicts are eliminated by reassigning the trailing aircraft to the next prior CDA route (R#2). If a conflict remains, this step is repeated with R#3 and conventional STD route. Possible remaining conflicts for two or more aircraft on the same STD route, is resolved by using holding patterns for trailing aircraft.

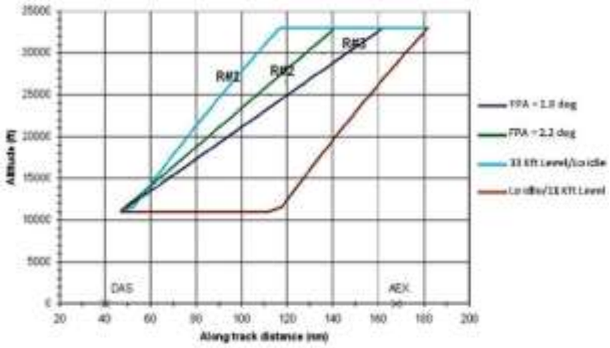

Figure 3. Vertical CDA Profiles

2.2 Modeling

2.1.1 General Assumptions

There are various number of elements that may affect route design and planning, and ATM performance assessment. Some of these factors are: climatic conditions, flight and ground crew workload, etc. In this article, normal condition for these factors are assumed.

In this research, only arriving traffic is modeled. It has been shown [9] that by defining and maintaining proper vertical separation between arrivals and departures, one can assume two separate airspaces.

Navigational requirements for this model are shown in [6] to meet RNAV1, RNAV2 and RNAV5 by using LGLS. The only constraint that this navigation aid adds, is that there cannot be two aircrafts on the same CDA path at the same time, no matter how much time separation they have (see section 2.1)

2.1.2 Air Space

Some researchers consider CDA from Top of Descent [TOD] to touch down point [7], [10], [11], [12] and [13] while some others split the path into two separate parts:

1) from TOD to 'Terminal Radar Approach Control' [TRACON] entry [14] and [15].
2) from the TRACON entry to touch down point [16]. Experiments show that traffic management constraints inside TRACON area lead to a slight deviation from CDA properties, particularly at the TRACON entry[7].

Therefore, assuming that the rest of the path is planned by the method proposed in [16], this study is focused on the path from TOD to the entry of TRACON.

2.1.3 CDA Routes

In this research, a CDA route is modeled by a straight line that links the TOD to an end point on the boundary of TRACON for which the coordination are calculated by DCRA. It has been shown that vertical and horizontal profiles of a CDA path are approximately straight lines that allow this assumption. (Fig. 4).

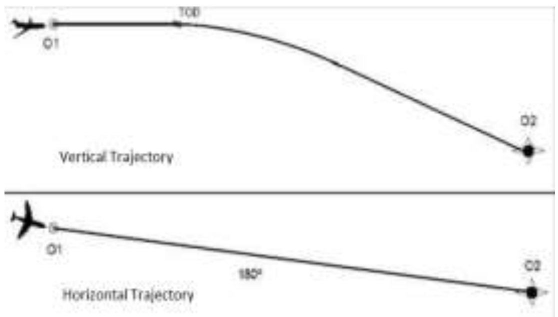

Figure 4- CDA Vertical and Horizontal Profiles, Simulated in AIDL

So, in order to specify a CDA, two points are needed:

1) As mentioned in section 2.1, for each aircraft three TOD points for three different CDA routs are proposed along airplane's cruise path after the conventional TOD which corresponds to conventional STAR route (see Fig. 3). Position of these points are calculated regarding to airplane's dynamics and performance properties.
2) The other necessary point needs to be located on TRACON entry. Here, this point is called end point. In this research, in favor of simplicity, search for optimum end point is limited to one

quadrant of TRACON boundary without losing generality. Search algorithm is described in section 2.3.

2.3 optimization

The DCRA utilizes a modified TCACS [17] optimization algorithm, while “total holding times assigned to all aircrafts (T_{total}) during one hour interval” is minimized.

$$T_{total} = \sum_{1 \le i \le n} T_i \qquad (1)$$

Where T_i is holding time assigned to i^{th} aircraft and n is total number of arrivals during one hour period.

According to Fig. 2, T_i is not zero if the i^{th} aircraft is assigned to a STD route where $(i-1)^{th}$ aircraft is on the same STD route and there is a STA conflict at any check point on the route. Two aircrafts have STA conflict if condition shown in equation (2) is not satisfied.

$$\left| STA_i^X - STA_{i-1}^X \right| < \min(T_{sep}) \qquad (2)$$

Where STA_i^X is scheduled time of arrival to point X for i^{th} aircraft, and $\min(T_{sep})$ is the minimum required time separation between two aircrafts. The latter differs based on type of leading and trailing aircraft. (see section 2.1)

As demonstrated in Fig. 5, by changing end point on TRACON boundary, while TOD points are fixed, pathway length for each aircraft varies. This changes ETA and STA of aircrafts by DCRA. The algorithm continues changing end point on TRACON boundary until optimum point is found.

3 Case Study

Traffic flow data of the north-eastern TRACON quadrant of Hartsfield-Jackson international airport (ATL) was examined as the case study in this research. This airport has been one of the busiest airports in the USA and was selected by FAA for NextGen program operational tests [18]. This study is performed in two different traffic scenarios.

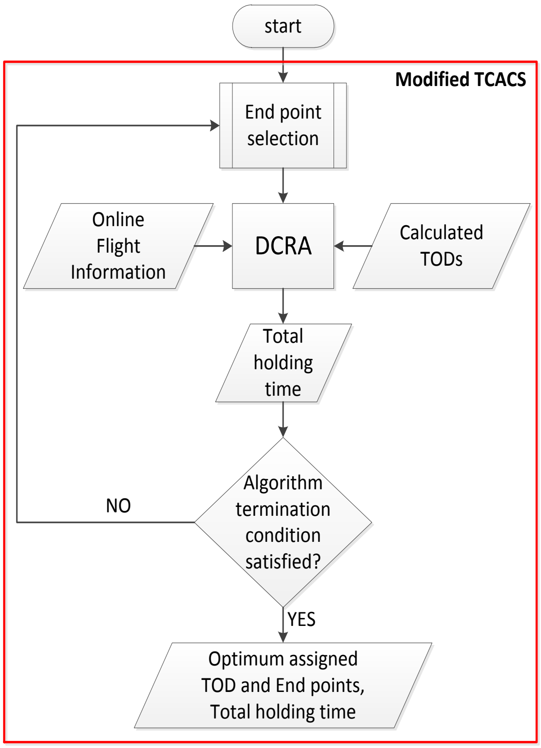

Figure 5- Optimization Algorithm

At the first scenario, current management and routing policy (i.e. through current STARs) is modeled, while the second scenario focuses the effect of using DCRA. Each scenario is considered under two traffic flow conditions:

1) Current traffic flow condition,
2) Double number of arrivals.

Traffic flow demand data for ATL airport was acquired via Email from ATL Market Research Analyst. This data is statistically analyzed during a one-month period in order to determine incoming traffic to north-eastern quadrant of ATL during one hour.

It should be noted that the number of arrivals is limited by ground operation management and airport capacity, so the condition 2 for each scenario is hypothetical and is considered to evaluate the performance of DCRA during extremely heavy traffic condition. Results of these scenarios are presented in table 1.

Table 1- Simulation Results

Scenario	Total holding time		number of CDAs per hour	
	30 AC/hr	60 AC/hr	30 AC/hr	60 AC/hr
1	15.6	48.5	-	-
2	3.3	14.4	21	38

4 Conclusion

It is shown here that by applying the DCRA to ATM system, not only the flight times decrease (3 minutes for each flight in average) due to less holding time, but also because of directing more than 50% of arrivals to CDA routes, the system benefits the advantages of less fuel consumption and environmental emissions as well as shortened paths and therefore shorter flight times.

Besides, comparing last two rows in table 1 demonstrates that the DCRA capability in traffic management increases with number of incoming aircrafts. In other words, performing CDAs would be possible and even more beneficiary during peak hours.

Despite of all mentioned advantages, safety concerns should be considered. For example, the possibility of missing R#1 TOD by a leading aircraft and its consequences which should be studied.

References

1. Gomez, P.D.R., *Next Generation Air Traffic Management, Boeing's View*, 2007, Boeing Management Company.
2. Culler, J., 2012, NASA Ames Research Center.
3. *Flight Delay Information - Air Traffic Control System Command Center*, 2013, FAA.
4. *Annual and Per-Minute Cost of Delays to U.S. Airlines*. 2013 [cited 2013; Available from: http://www.airlines.org/Pages/Annual-and-Per-Minute-Cost-of-Delays-to-U.S.-Airlines.aspx.
5. ICAO, *Performance-Based Navigation Manual-Doc 9613*, 2008.
6. Enayatollahi, F., *Terminal Area Traffic Management Using LASER Technology*, in *Aerospace Engineering*2012, Sharif University of Technology: Tehran.
7. Walton, J., *Continuous Descent Arrivals*, in *Boeing Performance and Flight Operations Engineering*2005, UPS.
8. Kwok-On Tong, E.G.S., Danial A Boyle, Julien Scharl, Aslaug Haraldsdottir, *Descent Profile Option for Continuous Descent Arrival Procedures within 3D Path Concept*. IEEE, 2007.
9. Joseph Prete Ph.D., J.K.P.D., *Flexible, Performance-Based Route Planning for Super-Dense Operations*, in *Guidance, Navigation, and Control*2008, AIAA: Honolulu, HI.
10. John-Paul Clarke, e.a., *Development, design, and flight test evaluation of a continuous descent approach procedure for nighttime operation at Louisville International Airport*, 2006.
11. Yi Cao, D.S., Daniel DeLaurentis, *A Preliminary Study on Operational Feasibility of Continuous Descent Approach*, 2005, School of Aeronautics and Astronautics, Purdue University.
12. Eric Hoffman, P.M., Thomas Pütz, *Airborne Spacing: Flight Deck View of Compatibility with Continuous Descent Approach.* AIAA, 2008.
13. Tokarev, O.I.Z.a.V.I., *Predicted Flight Procedures for Minimum Noise Impact.* ELSEVIER, 1998. **55**(Applied Acoustics): p. 129-143.
14. T. Golpar Davidson, G.H., *Preliminary Investigation of Sector Tools Descent Advisory Potential Benefits*, 1997, National Aeronautics and Space Administration Ames Research Center: Moffett Field, CA.
15. Gabriele Enea, R.V., et al., *Trajectory Prediction Uncertainty Modeling for Continuous Descent Approaches*, in *ICAS*2010.
16. S. Alam, M.H.N., H. A. Abbass and C. Lokan. *A Dynamic Continuous Descent Approach Methodology for Low Noise and Emission*. 2010. Brtigny-sur-Orge, France: EUROCONTROL.
17. Akbar Karimi, H.N., Patrick Siarry, *Continuous Ant Colony System and Tabu Search Algorithms Hybridized for Global Minimization of Continuous Multi-minima Functions.* Computational Optimization and Applications, 2010. **45**.
18. *Airport performance*. NextGen 2012; Available from: http://www.faa.gov/nextgen/snapshots/airport/?locationId=54.

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