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Determination of Way Points Position on Sequencing Leg for Point Merge System

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***Abstract**: This paper aims to propose a novel approach to determination of way points position on sequencing leg for point merge system. This research uses the Base of Aircraft Data to analyze the flight efficiency. Although it is not a general rule, it can be said that there is a tendency in practice to design the waypoints in the sequencing leg at equal distances from each other. In general, essentially equidistant waypoints are designed to facilitate the adaptation of airspace users (both pilots and air traffic controllers). However, it does not seem possible to say that this tendency always gives the most appropriate and optimal results in terms of flight efficiency. A scenario that includes four different cases was ideated and was resolved to discover the potential benefits and/or drawbacks of equidistant and non-equidistant interspace of waypoints. The comparison results of equidistant and non-equidistant interspace show that the average reduction of 9,5 percent of total flight time; 12,5 percent of total flight distance in favor one of a non-equidistant interspace, which is Case-4. Moreover, the Case-4 could be a promising solution for sequencing aircraft conveniently in terms of a first come first service (FCFS) rule.*

***Keywords**: Aircraft Scheduling/Sequencing, Air Traffic Management, Flight Efficiency, Point Merge System.*

I. INTRODUCTION

The aviation industry includes the main sub-activity areas such as the aviation industry, airline companies, airport management, air navigation service providers. All of these activities play an essential role in supporting the global-scale sustainable development goals [1] within the framework of the "2030 Agenda for Sustainable Development" [2] adopted by the United Nations (UN) General Assembly in 2015 [3].

Reliable forecasts for the aviation sector play a critical role for all areas of activity associated with aviation and all its stakeholders [4].

In this context, detailed analysis and statistical studies on aviation-related activities have shown that aerospace activities have increased by about twice as much every 15 years since the mid-1970 [5]. When RPK and ASK data of the International Civil Aviation Organization (ICAO) for the seven years covering the 2013-2019 years were reviewed, the Revenue Passenger-Kilometres (RPK) increase was 5.97 percent annually. The Available Seat-Kilometres (ASK) increase was an average of 5.40 percent yearly [6]. However, it should be noted that in addition to the rapid increase it has shown, the aviation sector is the most affected sector of regional or global crises around the world, such as the 9/11 attacks (2001), SARS virus outbreak (2003), global financial crisis (2008) and Eyjafjallajökull volcanic eruption (2010) [7]. The coronavirus epidemic (COVID-19 pandemic), which began in Wuhan, China, in the last quarter of 2019 and has taken the world under its influence, has quickly brought life to a halt worldwide.

Travel restrictions and quarantine measures following a series of steps to reduce and control the spread rate of the pandemic have profoundly affected the aerospace industry [8]. In this context, the positive increase in the RPK and ASK values over the years has quickly dropped with rapid negative acceleration. Although air traffic activities have come to a standstill against the spread rate of the COVID-19 pandemic, they have regained an increasing momentum within the scope of the measures taken. It is estimated that it will take years to reach the desired level with positive acceleration. However, the aerospace authorities have taken several measures quickly to bring the industry back to its old days after the initial impact of the pandemic [9-10]. The analysis based on statistical data and forecast for the future is revealed that it is expected to reach air traffic density to levels in 2019 by 2024 and grow there as previously predicted [11]. In this context, the importance of continuous innovation and projects in air traffic management (ATM) is emphasized during the recovery process of the aerospace sector [12].

The "Air Traffic Management" strategy aims to provide appropriate air traffic services and ensure its sustainability, depending on the air traffic that has increased in the past and is expected to increase in the future [13]. In this context, air traffic management not only responds to current needs but also explores and reacts to different scenarios for the future [10-12].

The approaches and solution proposals for this purpose focus on increasing the air traffic safety level, expanding the airspace capacity, reducing air traffic delays, increasing the cost-effectiveness of the air traffic management system, and reducing the adverse effects of air traffic on the environment. In this study, the effect of the position of the way-points along the sequencing leg on the scheduling of the arrival traffic is investigated. The remainder of this paper is organized as follows. Section 2 provides the details of the literature. Section 3 provides a general idea about the Point Merge System (PMS). Section 4 contains the results and discussion, and in the final part, the conclusions and future research possibilities are explained.

II. LITERATURE REVIEW

The intrinsic growth of the number of air traffic requires the effective use of airspace; therefore, it is essential to stress the necessity of the optimum usage of accessible and available airspace.

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Furthermore, the growth of the aviation industry refers to a wide range of infrastructure, human resources, training, and related capacity-building activities. The ultimate aim of these efforts is to realize safe and efficient airspace management. Therefore, enhanced operational efficiency derived from the implementation of emerging techniques has prompted the development of navigation applications for all phases of flight. Today, the Performance-Based Navigation (PBN) concept comprise area navigation (RNAV) and required navigation performance (RNP), and these aim to shift sensor-based navigation to performance based navigation. The system performance requirements of PBN are defined in terms of accuracy, integrity, continuity, and functionality for the proposed operations [14]. The PBN procedure called the PMS builds upon precision navigation technology (P-RNAV) for merging traffic at a single merge point, which allows efficient integration, scheduling, and sequencing of arrival traffic, and also enables Continuous Descent Approaches (CDA). The PMS merges arrival flows with closed-loop instructions while consolidating the predictability of P-RNAV routes, allowing controllers a degree of flexibility with the way aircraft are handled compared to conventional procedures. Therefore, PMS procedures also incorporate aspects of P-RNAV route structures for aircraft operations to achieve entirely practical airspace usage [15].

The PMS procedures have been studied in generic environments. They have been conducted for real environments in a terminal control area (TMA), notably with two, three, or four entry/exit points, one or two runways, and different TMA sizes. Research has been carried out under this generic validation thread, including ground prototyping sessions using real-time human-in-the-loop simulations, flight deck simulations, and model-based simulations. Although PMS implementation started in the 2010s, the conception and theoretical studies related to merging date back to the late 1990s. Bolender and Slater [16] discussed the technical challenges of merging departure aircraft onto their filled routes in congested airspace. Boursier et al. [17] worked to sequence aircraft on predefined legs at isodistance to merge point by applying path shortening or stretching. Also, open-loop radar vectors were no longer used, and aircraft remained on lateral navigation mode. Another study by Favennec et al. [18] presented a series of simulations on the PMS for merging arrival flowed with existing technology and studied how the PMS could be adapted to typical terminal area configurations with benefits in terms of staffing predictability and environmental damage, even under high traffic load.

A study conducted by Man et al. [19] recommended a novel multi-point merge route system for multi-parallel runway operations in complex terminal areas. They focused on reducing delays and increasing capacity in metroplex airports based on the classic PMS route structure. Sahin and Usanmaz [20] compared vectoring to point merge system in real simulation environment. They studied a PMS model on converging runways and proposed a model Istanbul Ataturk Airport. The results have indicated that proposed model has significant advantages in terms of vectoring and frequency occupancy. Another study by Sahin et al. is related to an air route model based on the PMS for metroplex airports in the Istanbul TMA. The flight time, flight distance, fuel consumption, and CO$_2$ emissions were evaluated at metroplex airports. Aircraft scheduling and sequencing problem have been studied by numerous academicians such as Hong et al. [21], Lee et al. [22], Christien et al. [23], Toratani and Itoh [24]. Oren and Sahin [25] proposed a novel approach for Point Merge System which is called Multi-Arrival Route Point Merge System (MAR-PMS). This novelty enables the additional arrival routes to sequencing leg and gives flexibility to air traffic controllers. The comparison results of PMS and MAR-PMS show that the average reduction of 19% of total flight time, 23% of total flight distance, and 19% in total fuel burned and reduction in CO2 emissions in favor of a proposed model.

As seen in the literature, most PMS studies are related to the advantages of the PMS, such as fuel and emission reduction, flight efficiency, runway throughput, sequencing, scheduling, etc. The PMS-based scheduling studies noted that it enables aircraft scheduling standardization; however, sometimes it may not be possible, and traffic could not be instructed in order. In order to provide the scheduling in the PMS, traffic had to be ordered before entering the procedure. If this was not the case, traffic could not join the sequencing legs in order and fairly.

Besides the literature, it should be mentioned that PMS method is actively used in approximately 25 airports around the world, including Paris-CDG, Kuala Lumpur, Incheon and Istanbul International Airports [26]

III. METHODOLOGY

The PMS is designed to extend lateral guidance usage by the flight management system (FMS) in airspace management of high-density arrival traffic and to continue previous work on “sequencing and merging” as part of the execution of continuous descent operations. [27].

The PMS is a technique that allows continuous descent into arrival traffic and allows arrival traffic to be sorted in route structures called sequencing legs, directing to the merge point.

A pre-determined distance from “Merge Point” which allows arrival traffic topologically to be collected at a pre-determined point The PMS, which consists of the “Sequencing legs” components which provide the order of inbound traffic by shortening or extending the path of arrival, is based on the precise P-RNAV road structure [27-28].

The merge point, which is usually a single point, is used for traffic harmonization and integration. Predefined sequencing legs from the merge point, aim to collect arrival flows from different directions and provide path stretching and shortening. The number and shape of legs can be varied according to traffic density. In addition, range markers are utilized in order to increase the situation awareness of controllers. The primary illustration of the PMS is indicated in Figure 1.

A PMS structure with two arrival routes consists mainly of two sequencing legs, which are the sequencing of each route as shown in Figure 1. The point where the arrival route ends is considered the beginning of the sequencing leg. The sequencing legs are perpendicular, parallel, but opposite, as the arrival route is continuous and the basis for safe separation between traffic.

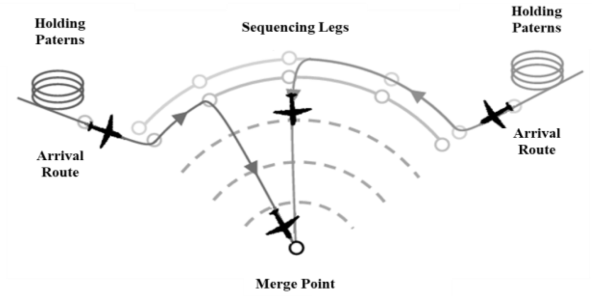


Figure 1: Illustration of PMS

The PMS operational strategy is used to integrate inbound flows from different directions. The aircraft flies on sequencing legs until taking an instruction directing it to the merge point. In case of no intervention, the aircraft should fly to the end of the sequencing legs and starts turning to the merge point by descending. After leaving the legs, speed control strategies should achieve the separation between successive aircraft.

The PMS aims to sequence arrival traffic on sequencing legs by path stretching or path shortening. The aircraft are prepared to land on sequencing legs by enabling separation in the order of traffic. Moreover, all aircraft are joined to sequencing legs so as to provide enough separation from others.

IV. RESULTS AND DISCUSSION

The waypoints contribute to ensuring adequate and safe separation between inbound traffic and determine the distance that inbound traffic must fly along the sequencing leg. At this point, the importance of the position of the waypoints comes to the fore.

Although it is not a general rule, it can be said that there is a tendency in practice to design the waypoints in the sequencing leg at equal distances from each other.

In general, essentially equidistant waypoints are designed to facilitate the adaptation of airspace users (both pilots and air traffic controllers). However, it does not seem possible to say that this tendency always gives the most appropriate and optimal results in terms of flight efficiency.

In this study, a scenario of 10 aircraft was created to examine the effect of the variation of the interspace between the waypoints along the same sequencing leg on the arrival traffic.

The first waypoint on the sequencing leg (WP1) was also considered the entry waypoint for the scheduling. In this paper, the angle of turning between the arrival route and the sequencing leg was assumed to be 90 degrees.

In the design phase, 10 NM intervals were assigned for the route structure. From that perspective, from EP to EP’, the course length was 20 NM, and from EP’ to WP1, the course length was 10 NM. Two intermediaries' waypoints were determined considering the route structure, Turn Initiation Point (TIP) and Turn Completion Point (TCP), respectively, as illustrated in Figure-2. The airspeed of the arrivals traffic was assumed as 220 kts TAS up to the EP, followed by 180 kts TAS for the remainder of the procedure, including the sequencing leg. The flight distance and flight time values per aircraft between EP-TIP, TIP-TCP, and TCP-WP1 were calculated on BADA version 3.14 [29]. The flight distance from EP to WP1 was measured 31.5 NM, and the flight duration from EP to WP1 was found 7 minutes 42 seconds.

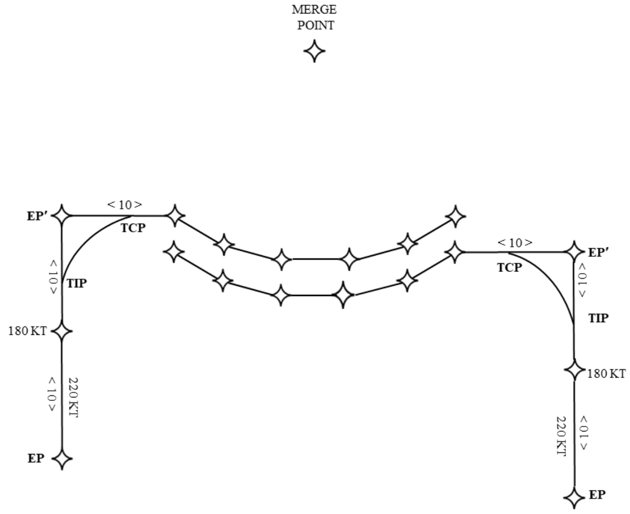


Figure 2: Route Structure of PMS (Sample of Sequencing Leg includes 6 WPs)

In this procedure, the length of the sequencing leg was determined as 30 NM. The waypoints on the 30 NM sequencing leg were distributed in two different ways: equidistant and non-equidistant. Considering the length of the sequencing leg, four different cases based on distance arrangement are shown on Table-I.

Table-I: Cases and Sequencing Legs′ Design

Case #	Way Points Intervals (NM)	Number of Waypoints
Case-1	5	7
Case-2	6	6
Case-3	4-5-6-6-5-4	7
Case-4	3-4-5-6-5-4-3	8

While Case-1 and Case-2 have equidistant interspace between waypoints alongside the sequencing leg, 5 NM and 6 NM, respectively, Case-3 and Case-4 have non-equidistant interspace. As a result of this dispersion, Case-2 has six waypoints, Case-1 and Case-3 have seven waypoints, and Case-4 has eight waypoints.

In this study, the distribution of aircraft was determined as 70% Medium and 30% Heavy by taking into account the aircraft types and the wake turbulence categories of the aircraft in the actual airspace operations [30]. Table II contains scenario times and aircraft wake turbulence categories (WTC).

Minimum separation time is a vital factor for separation. The minimum separation time between the successive aircraft concerning two typical aircraft types (heavy and medium) should be established and maintained [31]. To ensure safe and adequate separation, an aircraft should fly along the sequencing leg until the assigned waypoint or proceed with a holding pattern before the entrance point. Therefore, the distance arrangement of waypoints plays an influential role in flight distance and flight time.

Table- II: Scenario Details

AIRCRAFT ID	AC WTC	EP TIME
AC#1	M	00:00:00
AC#2	H	00:01:00
AC#3	M	00:02:00
AC#4	M	00:03:00
AC#5	M	00:04:00
AC#6	H	00:05:00
AC#7	M	00:06:00
AC#8	H	00:07:00
AC#9	M	00:08:00
AC#10	M	00:09:00

Considering the successive aircraft pairs at the scenarios and the required separation times, the optimal aircraft sequencing for each case is listed in Table III. The aircraft is to be held highlighted with (*). After waypoint allocation is obtained, the flight time and the flight distance are calculated for each aircraft and cumulatively for each case, and the flight efficiency is analyzed.

Table- III: The Aircraft Sequencing

Scenario	Sequencing
1	1-2-3-4-5-6-7-8-9-10*
2	1-2-3-4-5-6-7-8-10-9*
3	1-2-3-4-5-6-7-8-9-10*
4	1-2-3-4-5-6-7-8-9-10

The total flight time and total flight distance were found to be 172 minutes and 475 NM respectively for Case-1. Similarly, these values were found to be 182 minutes and 503 NM respectively for Case-2. Based on the comparison for equidistant distribution, from a flight time perspective 10 minutes saving in time was obtained from Case-1. Moreover, in terms of total flight distance Case-1 shortened the distance by 28 NM.

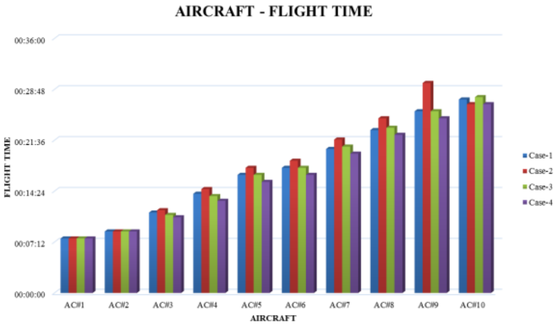
In Case-3, a total flight time of 173 minutes and a flight distance of 476 NM were obtained. For Case-4, an 166 minutes total flight time and a 447 NM flight distance were achieved. When the issue comes to non-equidistant distribution, 7 minutes was gained from total flight time and 29 NM in total distance was obtained from Case-4. Results for all cases are shown in Table IV.

Table-IV: Obtained Results

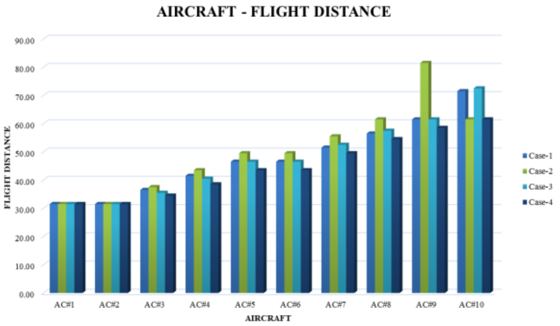
	TOTAL FLIGHT TIME (minutes)	TOTAL FLIGHT DISTANCE (NM)
Case-1	172	475.00
Case-2	182	503.00
Case-3	173	476.00
Case-4	166	447.00

Error! Not a valid link. Case studies were revealed that minimum flight time was observed in Case-4, which was 166 minutes, while the maximum was 182 minutes, which was obtained in Case-2. Similarly, minimum flight distance was obtained in Case-4, which was 447, but the maximum was 503 NM in Case-2. The flight time and the flight distance were achieved to decrease with the non-equidistant interspace. The total savings in flight time (16 min) and the total flight distance (56 NM) were found and to be 9,5 and 12,5 per cent.

In addition to the total flight time and total flight distance, the flight time and flight distance were calculated separately for each aircraft. Although the principle of first come first served (FCFS) was attempted, the distribution of aircraft in the scenario and the requirement for separation between successive aircraft did not allow the principle to be fully applied in every case. While the need for a holding pattern arose for Case1-3, only Case-4 did not require a holding pattern, and the FCFS principle could be fully applied. The average flight time per aircraft was calculated as 17 min 21 seconds, and the average flight distance was found to be 47.50 NM. Graph-1 and Graph-2 illustrate the flight time and flight distance per aircraft.



Graph 1: Flight Time of Each Aircraft



Graph 2: Flight Distance of Each Aircraft

Analysis of the different allocation of waypoints has revealed that the total flight times and flight distances increase as the distance between waypoints increases for equidistant interspace. On the other hand, flight efficiency increases based on total flight time and distance in the non-equidistant interspace. In addition, the increase in the number of waypoints contributes positively to flight efficiency.

V. CONCLUSION

PMS procedures enable flight efficiency while stepping forward to meet the requirements of the operational environment. In this paper, a novel approach to the interspace of waypoints was studied. In this regard, a scenario covering four different cases was designed and conducted to discover the potential benefits and/or drawbacks of equidistant and non-equidistant interspace of waypoints. Additionally, this paper evaluated and compared the performance of equidistant and non-equidistant interspacing in terms of flight time and flight distance.

It should be mentioned that acquisitions are expected to increase cumulatively in dense scenarios, including more than ten aircraft.

The contribution of this paper to can be summarized as follows. Firstly, this approach puts forth a novelty to the existing PMS procedures in terms of flight efficiency. On the other hand, non-equidistant interspacing reduces the utilization of back-up solutions such as holding procedures while providing flexibility. However, the author also acknowledges that holding procedures are part of PMS and are still needed. Finally, it can be said that, the architecture of proposed model can be adapted in any PMS model.

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REFERENCES

1. United Nations Development Programme Support to the Implementation of the 2030 Agenda for Sustainable Development, 2016.
2. A/RES/70/1, Transforming our world: the 2030 Agenda for Sustainable Development, Resolution adopted by the General Assembly on 25 September 2015.
3. Air Transport Action Group, Aviation: Benefits Beyond Borders, 2020.
4. International Civil Aviation Organization (ICAO), Doc.8991 Manual on Air Traffic Forecasting, 2006.
5. International Civil Aviation Organization (ICAO), Doc.9750, Global Air Navigation Plan, 2016.
6. https://www.icao.int/sustainability/pages/air-traffic-monitor.aspx (Last accessed 17 February 2022)
7. Air Transport Action Group, Waypoint 2050, 2020.
8. International Civil Aviation Organization (ICAO) Electronic Bulletin EB 2020/06, Novel Corona Virus Epidemic in China, 2020.
9. https://www.icao.int/covid/cart/Pages/CART-Take-off.aspx (Last accessed 17 February 2022)
10. EUROCONTROL Network Operations Plan 2020 Recovery Plan, 2020.
11. EUROCONTROL Strategic Research and Innovation Agenda (SRIA), Digital European Sky, 2020.
12. European Commission, European Partnership for Integrated Air Traffic Management, Horizon Europe Programme, 2020.
13. EUROCONTROL ATM Strategy for the Years 2000+, 2003.
14. International Civil Aviation Organization (ICAO), Doc.9613 Performance-based Navigation (PBN) Manual, 2013.
15. EUROCONTROL Point Merge Integration of Arrival Flows Enabling Extensive RNAV Application and Continuous Descent-Operational Services and Environment Definition, Edition 2.0, 2010.
16. M. A. Bolender and G. L. Slater, “Cost analysis of the departure-en route merge problem,” Journal of Aircraft, vol. 37, no. 1, pp. 23–29, 2000. 1999
17. L. Boursier, B. Favennec, E. Hoffman, A. Trzmiel, F. Vergne, and K. Zeghal, “Integrating Aircraft Flows In The Terminal Area With No Radar Vectoring,” in 6th AIAA Aviation Technology, Integration, and Operations Conference, 2006, vol. 1, no. September, pp. 418–427.
18. B. Favennec, E. Hoffman, A. Trzmiel, F. Vergne, and K. Zeghal, “The Point Merge Arrival Flow Integration Technique: Towards More Complex Environments and Advanced Continuous Descent,” 9th AIAA Aviat. Technol. Integr. Oper. Conf., no. September, pp. 1–12, 2009.
19. Man Liang, Daniel Delahaye, Xiao-Hao Xu. A Novel Approach to Automated Merge 4D Arrival Trajectories for Multi-parallel Runways. EIWAC 2015, 4th ENRI International Workshop on ATM/CNS, ENRI, Nov 2015, Tokyo, Japan.
20. Sahin O, Usanmaz O (2016) Arrival Traffic Sequence for Converging Runways. Sustainable Aviation (Springer), 291-296.
21. Hong Y, Choi B, Lee S, Lee K, Kim Y (2017) Optimal and practical aircraft sequencing and scheduling for point merge system. IFAC-PapersOnLine (50)1:14644–14649.
22. Lee, S., Hong, Y., & Kim, Y. (2020). Optimal scheduling algorithm in point merge system including holding pattern based on mixed-integer linear programming. Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, 234(10), 1638–1647. https://doi.org/10.1177/0954410019830172
23. Christien R, Hoffman E, Trzmiel A, Zeghal K (2017) Toward the characterisation of sequencing arrivals. The 12th USA/EUROPE Air Traffic Management R&D Seminar 2017 (Seattle, Washington).
24. Daichi Toratani and Eri Itoh. "Merging Optimization Method Considering Minimum Time Separation Based on Wake Turbulence Category," AIAA 2018-1596. 2018 AIAA Guidance, Navigation, and Control Conference. January 2018.
25. Oren, A., & Sahin, O. (2021). The flight efficiency analysis on the Multi-Arrival Route Point Merge System. The Aeronautical Journal, 1–13. http://doi.org/10.1017/aer.2021.105
26. EUROCONTROL Point Merge Implementation – A Quick Guide, 2020.
27. International Civil Aviation Organization (ICAO) Doc.9905 Required Navigation Performance Authorization Required (RNP AR) Procedure Design Manual, 2009.
28. Radio Technical Commission for Aeronautics RTCA DO-236 Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation, First Edition, 2014.
29. The European Organisation for the Safety of Air Navigation, EUROCONTROL User Manual for the Base of Aircraft Data (BADA) Version 3.14, 2017.
30. The European Organisation for the Safety of Air Navigation, EUROCONTROL European Route Network Improvement Plan - PART 2 European ATS Route Network - Version 2020 – 2024, 2020.
31. International Civil Aviation Organization (ICAO) Doc. 4444 Procedures for Air Navigation Services, Air Traffic Management, 2016.

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