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Research Article

Air Traffic Flow Impact Analysis of RECAT for Istanbul New Airport using Discrete-Event Simulation

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ABSTRACT

The rapid annual increase in air traffic volume leads to serious capacity problems especially at major airports. Airport runway capacities are significantly limited by wake turbulence phenomena between arriving and departing aircraft pairs. RECAT, an international joint effort, aims to redefine wake turbulence categories and their associated minima to increase runway capacities. This study analyses the impacts of possible RECAT implementation on arriving and departing flight sequences for independent parallel runway configurations with saturated demand. Istanbul New Airport is modelled as a test case using Simmod Pro, a discrete-event simulation tool. A baseline and an alternative scenario has been created to compare the current and RECAT separation minima. The implementation of RECAT improved the total throughput and reduced airborne delays for arriving flights while it increased departure queue delays and lengths. Further operational strategies are required to increase the benefits of RECAT for departing flight sequences.

Keywords: *Air Traffic Control, Airport Capacity and Delay Analysis, Discrete-Event Simulation, RECAT*

RECAT Uygulamasının İstanbul Yeni Havalimanı Hava Trafik Akış Yönetimine Olan Etkisinin Kesikli Olay Benzetimi ile Analizi

ÖZET

Hava trafik hacmindeki hızlı yıllık artış, özellikle büyük havaalanlarında ciddi kapasite sorunlarına yol açmaktadır. Havaalanı pist kapasitesinde geliş ve kalkış uçakları arasındaki kuyruk türbülansı farklılıkları önemli ölçüde sınırlayıcıdır. Bu konuya odaklanmış uluslararası bir ortak çaba olan RECAT, pist kapasitesini artırmak için kuyruk türbülans kategorilerini ve bunlarla ilişkili ayırma minimalarını yeniden tanımlamayı amaçlamaktadır. Bu çalışmanın amacı, yüksek talebe sahip bağımsız paralel pist konfigürasyonları için olası RECAT uygulamasının geliş ve kalış uçuşları üzerindeki etkisini analiz etmektedir. İstanbul Yeni Havalimanı için bir kesikli olay benzetim aracı olan Simmod Pro ile bu konuya örnek olabilecek bir model geliştirilmiştir. Mevcut ve RECAT ayırma minimini karşılaştırmak için bir mevcut durum ve alternatif olmak üzere iki senaryo oluşturulmuştur. RECAT'ın uygulanması, kalkış uçuşlarındaki gecikmeleri ve uzunlukları artırırken, gelen

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uçuşların toplam verimini ve havadaki gecikmelerini azaltmıştır. Kalkış uçuşlarında RECAT'in faydalarını arttırmak için ilave operasyonel stratejiler gereklidir.

Anahtar Kelimeler: *Hava Trafik Kontrol, Havaalanı Kapasitesi ve Gecikme Analizi, Kesikli Olay Simülasyonu, RECAT*

I. INTRODUCTION

The air traffic volume has been increasing annually by 4.4% in European Network Manager Area [1]. This rapid increase leads to serious capacity problems in airspace and airports. Most of the major airports, especially in Europe, have been largely suffering from congestion problems [2]. These problems force civil aviation authorities and air navigation service providers to search new operational methods to increase the current capacities of airports. Recategorization of aircraft wake turbulence (RECAT) is one of this method for the capacity enhancement.

The wake turbulence is produced as the side-effect of lift generated on aircraft and constrains the separation minima between leading and trailing aircraft during approach and departure phases. The trailing aircraft must be separated with the pre-defined distance or time from the leading aircraft to avoid potential hazards of wake turbulence effect. The separation minima are currently defined based upon the aircraft weight categorization. ICAO divides aircraft into three categories as heavy, medium and light. If the maximum take of weight (MTOW) of the aircraft is higher than 136 tons, it is referred to as heavy. If MTOW of the aircraft is more than 7 tons but less 136 tons, it is referred to as medium. The aircraft under 7 tons of MTOW are referred to as light. After the introduction of Airbus 380-800 having a MTOW of 560 tons into the service, ICAO recommended an increase for its wake turbulence separation minima. Therefore, such aircraft are referred to as super or super heavy category aircraft [3]. This revision clearly indicates that the conventional categorization is not sufficient to represent wake turbulence characteristics and associated separation minima of more than 350 different aircraft types with different weight, size and performance characteristics operating in European Network Manager Area [4]. RECAT aims to develop a more refined aircraft wake turbulence categorization based on not only MTOW but also geometric and performance characteristics of aircraft. This new categorization is expected to increase the runway throughput using the more accurately described distance or time separation minima without comprising from the safety of operations. This study aims to analyze the effects of RECAT on throughput, airborne and ground delays during arrival and departure sequences for an airport with independent parallel runway configuration. The first phase of Istanbul New Airport has been selected and modelled using Simmod Pro, a discrete-event simulation tool for the analyses. A baseline and alternative scenario have been generated to compare ICAO’s current and Eurocontrol’s new RECAT wake turbulence separation minima.

II. RECAT CONCEPT

Wake turbulence recategorization (RECAT) is a collaborated effort of International Civil Aviation Organization (ICAO), Federal Aviation Administration (FAA) of the United States and European

Organization for Safety of Air Navigation (Eurocontrol) to redefine wake turbulence categories and their associated separation minima to increase capacity of airports [5]. Runway capacity of airports primarily depend on radar surveillance capabilities and wake turbulence circulation generated in-trail of aircraft. To prevent any accident or incident induced by the wake turbulence during the approach and departure phases, successive arrivals and departures should be separated according to some pre-defined distance and/or time minima (Figure 1 and 2). The magnitude of these minima depends on wake turbulence category of the leading aircraft and it may affect throughput (number of aircraft served per a defined period) as well as delays in the air or in the departure queues on the ground.

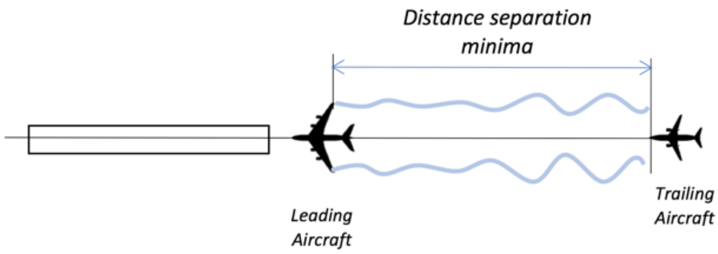

Figure 1. *Wake turbulence separation between two arriving aircraft on approach phase*

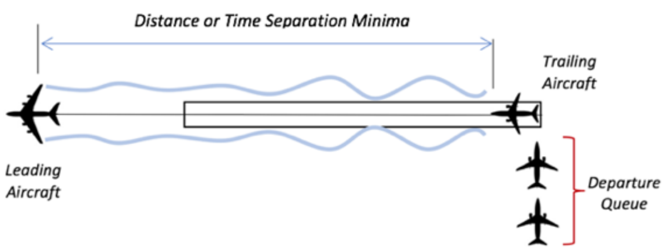

Figure 2. *Wake turbulence separation between two departing aircraft on approach phase*

ICAO uses a three plus one-category wake turbulence separation based on maximum take-off weight of aircraft (i.e. heavy, medium, light and super heavy). These wake turbulence categories and their associated separation minima are presented in Table 1 for distance-based separation during approach and departure, and in Table 2 for time-based separation during departure. When a wake-turbulence separation is not required between leading and trailing aircraft, a minimum radar separation (MRS) can be used (Table 1). MRS can be 3 NM or 2.5 NM under the given conditions according to ICAO [6]. Similarly, when no wake turbulence time separation is required (Table 2), time-equivalent of MRS can be used to separate aircraft pairs during the departure.

Table 1. *ICAO wake turbulence categories and distance-based separation minima on approach and departure [6].*

Leading / Trailing	Super Heavy	Heavy	Medium	Light
Super Heavy	MRS	6 NM	7 NM	8 NM
Heavy	MRS	4 NM	5 NM	6 NM
Medium	MRS	MRS	MRS	5 NM
Light	MRS	MRS	MRS	MRS

Table 2. *ICAO wake turbulence categories and time-based separation minima on departure [3].*

Leading / Trailing	Super Heavy	Heavy	Medium	Light
Super Heavy	-	120 secs	180 secs	180 secs
Heavy	-	-	120 secs	120 secs
Medium	-	-	-	120 secs
Light	-	-	-	-

Although wake vortex behavior is complex due to its strong dependency on weather conditions and unsteady interactions between aircraft and surrounding air flow, the recent studies significantly increased the knowledge regarding wake vortex generation and propagation. Based on this knowledge, new methodologies have been developed to identify new categories associated with acceptably safe separation minima. These methodologies have been described in detail by Lang et al. [5], Eurocontrol [3], Rooseleer et al. [7], and Cheng et al. [8]. As the first step of achieving a dynamic pairwise separation between aircraft, a new six static wake turbulence categories have been defined instead of ICAO's conventional categorization. The new categories (A-F) have been assigned to the existing aircraft types based on MTOW, wing span and other related aircraft performance data. Eurocontrol's new wake turbulence categories (RECAT-EU) and their distance and time-based separation minima on approach and departures are presented in Table 3 and 4. RECAT-EU redefines super heavy category under CAT A for aircraft types heavier than 100 tons of MTOW and having a wing span between 72 and 80 m. The current heavy category is also divided into upper heavy (CAT B) and lower heavy (CAT C) categories for aircraft heavier than 100 tons of MTOW.

Table 3. *The new RECAT-EU wake turbulence categories and distance-based separation minima on approach and departure [3].*

Leading / Trailing	CAT A	CAT B	CAT C	CAT D	CAT E	CAT F
CAT A "Super Heavy"	3 NM	4 NM	5 NM	5 NM	6 NM	8 NM
CAT B "Upper Heavy"	MRS	3 NM	4 NM	4 NM	5 NM	7 NM
CAT C "Lower Heavy"	MRS	MRS	3 NM	3 NM	4 NM	6 NM
CAT D "Upper Medium"	MRS	MRS	MRS	MRS	MRS	5 NM
CAT E "Lower Medium"	MRS	MRS	MRS	MRS	MRS	4 NM
CAT F "Light"	MRS	MRS	MRS	MRS	MRS	3 NM

Table 4. *The new RECAT-EU wake turbulence categories and time-based separation minima on departure [3].*

Leading / Trailing	CAT A	CAT B	CAT C	CAT D	CAT E	CAT F
CAT A “Super Heavy”	-	100 secs	120 secs	140 secs	160 secs	180 secs
CAT B “Upper Heavy”	-	-	-	100 secs	120 secs	140 secs
CAT C “Lower Heavy”	-	-	-	80 secs	100 secs	120 secs
CAT D “Upper Medium”	-	-	-	-	-	120 secs
CAT E “Lower Medium”	-	-	-	-	-	100 secs
CAT F “Light”	-	-	-	-	-	80 secs

While aircraft having a wingspan between 60 and 72 m are categorized under CAT B, aircraft having a wing span less than 52 m are included in CAT C. Categorization of heavy aircraft with a wingspan between 52 and 60 m are subject to the specific analysis based on a qualitative wake turbulence risk assessment. Like heavy category, the medium category is divided into upper medium (CAT D) and lower medium (CAT E) for aircraft lighter than 100 tons of MTOW. While aircraft having a wingspan more than 32 m are included in CAT D, aircraft with a wingspan larger than 32 m are classified as CAT E. RECAT-EU also classified all aircraft under 15 tons of MTOW as light category (CAT F), instead of 7 tons of MTOW upper limit in the conventional categorization.

III. MODELLING AND SIMULATION

Istanbul New Airport has been modelled for the analyses based on the first phase (P1-a) of its construction plan shown in Figure 3. The first phase is planned to be in service by the end of this year. It consists of two independent parallel runways allowing segregated parallel approaches and departures. Besides the movement area including runways, taxiways and parking stands, final approach and initial departure routes have been modelled in Simmod Pro (Figure 4). The runway 36L is used for arriving flights while 36R is used for the departing flights. Two different scenarios (i.e baseline and alternative) were run separately to compare the effects of two different wake turbulence separations, baseline and alternative were run While the baseline scenario uses conventional aircraft categorization for wake turbulence separation (Table 1 and 2), the alternative scenario uses the RECAT for the wake turbulence separation (Table 3 and 4). The minimum radar separation minima (MRS) is taken 3 NM for the baseline case and 2.5 NM for the alternative case.

The following assumption have been made to define the airport model:
(1) Arrival and departure demand is assumed continuous and near to the saturated capacity of the given runway configuration for the first two hours of the simulation.
(2) No simultaneous landings or take-offs are allowed on runway.
(3) Arrivals and departures are performed in one direction (i.e. 36) and wind effects are disregarded.
(4) All operations take place under standard atmospheric conditions at the sea level.

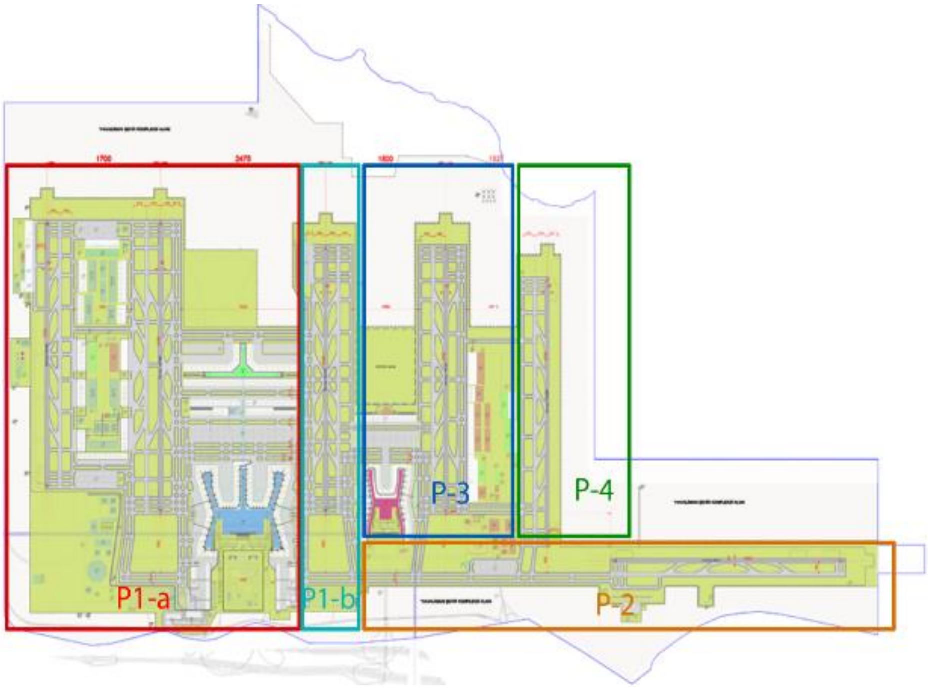

Figure 3. *The layout of Istanbul New Airport with its construction phases [9].*

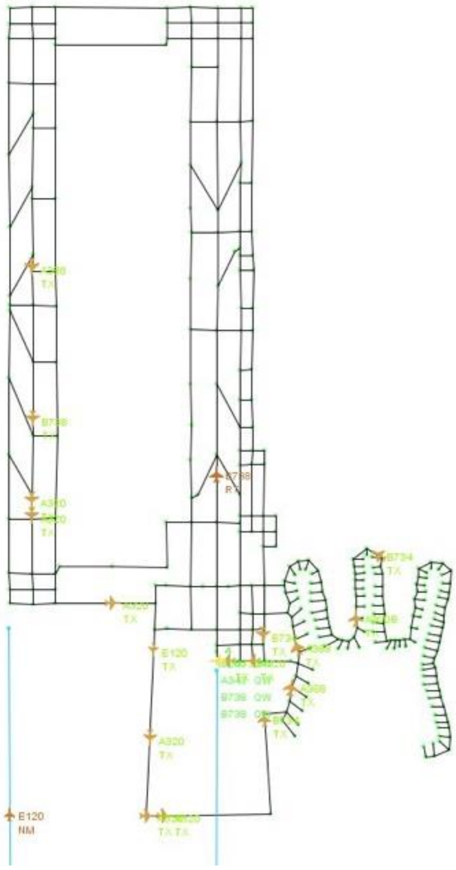

Figure 4. *The simulation model of Istanbul New Airport Phase 1-a in SIMMOD.*

To represent a near-saturation demand, a total 200 flights (i.e. 100 arrivals and 100 departures) have been generated with exponentially distributed inter-arrival times for a two-hour period (i.e. 10:0-

12:00). The arrival traffics are assigned to the runways 36L while the departure traffics are assigned to 36R. Aircraft type distribution for the baseline case is created like the current aircraft coverage for the Istanbul Ataturk Airport except A380. Unlike Istanbul Ataturk Airport, the new airport is planned to be a hub of long-range routes with high passenger demand. Therefore, A380 is included in the total air traffic demand to represent super heavy /CAT A wake turbulence category. The aircraft type distribution for the alternative case is the same with the baseline case except aircraft types are recategorized in the alternative case according to RECAT-EU classifications. The aircraft types with their wake turbulence category and relative percentage in the traffic mix are presented for baseline and alternative case in Table 4.

The simulation entry times for the baseline and alternative case is created with the exponential distribution as it stated previously. According to this distribution the arrival and departure traffic number for the time intervals during the simulation can be seen in Figure 5.

Table 4. *The percentage of aircraft types and their corresponding wake turbulence categories for the baseline and alternative simulation scenario.*

Baseline Scenario (ICAO)			**Alternative Scenario (RECAT-EU)**		
WT Cat	**Aircraft Types**	**%**	**WT Cat**	**Aircraft Types**	**%**
Super Heavy	A388	5	**A**	A388	5
Heavy	B748, A343, A300B, B763	20	**B**	B748, A343	14
			C	A300B, B763	6
Medium	A320, B738, E170, E120	70	**D**	A320, B738	45
			E	E170	20
Light	B200	5	**F**	E120, B200	10

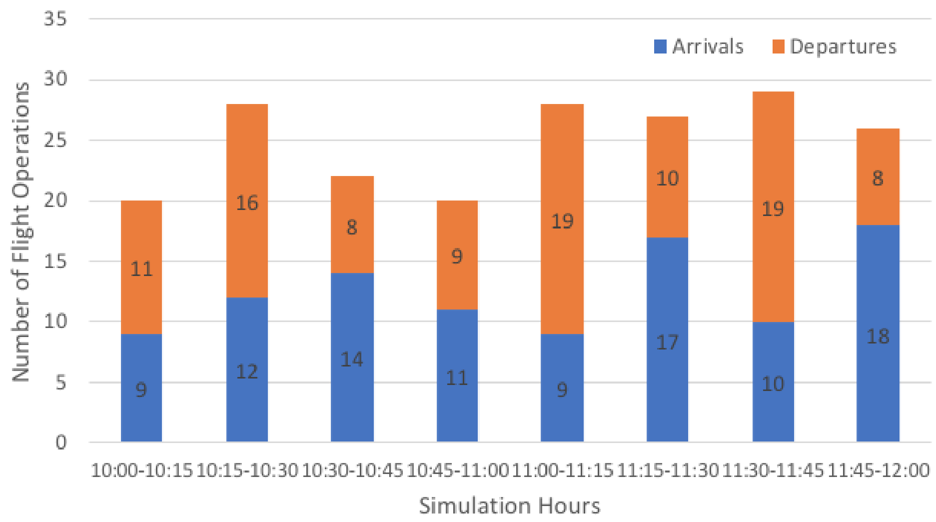

Figure 5. *Generated flight distribution of arrivals and departures aircraft at the airport.*

IV. Simulation Results

The simulation analyses were carried out between the period of 10:00-13:00 to represent a peak-hour with one-hour warm-up and cool-down periods. The total hourly runway throughputs are presented for the baseline and alternative scenarios in Table 5. In the baseline scenario, the maximum throughput is reached as 75 operations/hour with 37 arrivals and 38 departures between 11:00-12:00. Deployment of RECAT-EU separation increased the total throughput to 79 operations/hour due to four extra arrivals during the same hour while the number of departures remains the same. To make more accurate analysis, delays distributions for arriving and departing flights are provided in Table 6 and 7, respectively. The results indicate that alternative scenario decreases the number of arrivals delayed more than 15 minutes by 12 flights during the simulation time. Considering 15-minute delay per flight is accepted as a critical threshold by most airports, such a decrease provides a significant improvement in terms of airport capacity enhancement and quality of services. The results presented in Table 7, on the other hand, indicate the otherwise for departing flights. While small and moderately delayed flights decrease considerably, the number of the flights delayed over the critical threshold increases by 11 flights in the alternative scenario. These results show that RECAT-EU do not provide an improvement in the departure throughput, on the contrary adversely affects the delays in departing flights.

Table 5. *Arrival, departure and total runway throughput for the baseline and alternative scenarios during the simulations.*

	Throughput (flights/hour)					
Hours	**Baseline Scenario**			**Alternative Scenario**		
	Arr.	Dept.	Tot.	Arr.	Dept.	Tot.
10:00-11:00	33	37	70	33	34	67
11:00-12:00	37	38	75	41	38	79
12:00-13:00	30	25	55	26	28	54

Total	100	100	200	100	100	200

Table 6. Distribution of delays for arriving flights.

	Number of Delayed Arriving Flights		
Delays/Flight	**Baseline Scenario**	**Alternative Scenario**	**Difference**
< 5mins	12	11	-1
5-10 mins	14	10	-4
10-15 mins	15	32	+17
>15 mins	59	47	-12

Table 7. Distribution of delays for departing flights.

	Number of Delayed Arriving Flights		
Delays/Flight	**Baseline Scenario**	**Alternative Scenario**	**Difference**
< 5mins	22	13	-9
5-10 mins	27	12	-15
10-15 mins	6	19	+13
>15 mins	45	56	+11

Table 8 presents average airborne and ground delays received by arriving aircraft for the baseline and alternative scenarios. The results show that the use of RECAT-EU minima relieves the airborne delays by 2.3 minutes per flight during the peak hour and 4 minutes per flight in the succeeding hour. The results also indicate that ground delays received during the taxi-in process is insignificant for both scenarios compared to airborne delays.

Table 8. Distribution of hourly average airborne and ground delays for arriving flights.

	Average Airborne Delays (min)		**Average Ground Delays (min)**	
Hours	Base	Alt.	Base	Alt.
10:00 -11.00	6.4	7.4	0.02	0.03
11:00 -12:00	18.3	16.0	0.02	0.02
12:00 -13:00	35.0	31.0	0.0	0.02
Total	19.4	16.8	0.01	0.03

Average departure queue delays and average and maximum departure queue lengths for departing flights are shown in Table 9. The use of RECAT-EU separation minima increases the average delay by 3.4 minutes per aircraft during the peak hour of 11:00-12:00. Similarly, average queue length increases by 3.1 and maximum queue length for runway 36R reaches to 30. Evidently, newly introduced distance/time separation minima have an adverse effect on the performance metrics of departing aircraft sequence.

Table 9. *Distribution of hourly average departure queue delays, and average and maximum departure queue lengths for departing flights.*

	Average Departure Queue Delays (min)		**Average Departure Queue Length**		**Maximum Departure Queue Length**	
Hours	Base	Alt.	Base	Alt.	Base	Alt.
10:00-11.00	4.5	6.6	3.0	4.7	7	10
11:00-12:00	14.8	18.2	14.0	17.1	23	30
12:00-13:00	31.9	34.6	8.4	9.6	23	24
Total	15.2	18.8	-	-	23	30

V. CONCLUSION

In this study, impacts of possible RECAT-EU deployment have been analyzed for arrival and departure flight sequencing on the first phase of Istanbul New Airport under the construction. The independent parallel runway configuration of the airport allows segregated arrival and departure operations on runways 36L and 36R respectively. Therefore, airports maximum throughput can reach up to 75 operations even under conservative separation minima, saturated traffic demand and considerable super heavy traffic existence. Deployment of RECAT-EU further increases the maximum throughput by 5.3% which is a significant improvement during the peak-hours. Although RECAT-EU separation minima enhances the total throughput and delays for arriving flight sequences, it has an adverse impact on the departure queue delays and lengths for the predicted air traffic type mix. Especially, the maximum queue value of 30 can obstruct traffic flow in the taxiways and induce more ground delays. However, departure queues and their adverse effects can be mitigated through a set of operational procedures. Diverging flight tracks of departing aircraft in the initial climbing phase can significantly reduce the departure queue delays and lengths on the ground. Besides holding aircraft on the gates or parking positions instead of on the departure queue line. Introduction of the two parallel runways with the second part of the first phase (P1-b) will also allow operators distribute departures heavy and medium categories to different runways. Therefore, they can take the advantage of RECAT-EU in throughput and delays due to reduced separation minima differences between departing aircraft pairs.

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