Data-driven Airspace Efficiency Study

Case Study: EU-Asia Interface

Executive Summary

Airspace operational efficiency is a critical indicator of effective airspace utilization and the overall health of civil aviation development. Enhancing airspace efficiency is essential for driving high-quality growth in the aviation sector. Within the Eurasian air corridor, the Lanzhou–Urumqi (Lan–U) route in China serves as a vital air bridge connecting East Asia with Europe and Central Asia and handles a growing volume of flight traffic. The closure of Russian airspace due to geopolitical factors has necessitated rerouting a significant portion of Eurasian traffic through this corridor, resulting in a sustained surge in traffic volume. This increase, coupled with frequent local airspace restrictions and delays in NOTAM issuance, has created significant operational pressure, causing serious flight delays, reduced operational efficiency, and increased costs, thereby posing substantial challenges for airlines and air navigation service providers (ANSPs).

In response, the International Air Transport Association (IATA) has proposed the development of new air routes within the Ulaanbaatar Flight Information Region (FIR) as a strategic alternative to the Lan–U corridor. This initiative aims to provide flexible and reliable routing options for Eurasian flights, thereby enhancing the resilience and operational performance of the regional airspace network. To support informed decision-making by stakeholders, IATA also proposed a data-driven study of airspace efficiency to evaluate the potential benefits of the new routes. This study defines specific route proposals based on an analysis of current operational conditions, a survey of airline requirements, and an evaluation of air navigation service capabilities in Mongolia. Flight plan data was collected from the 22 airlines with the highest frequency of operations along the Lan–U corridor. Simulations were then performed to obtain key operational parameters for these flights operating on both the existing routes and the proposed alternatives, covering the period from 30 March 2024 to 29 March 2025. These parameters encompass flight distance, time, fuel consumption, route charges, and delays caused by airspace restrictions. The study's findings are structured around a framework of 13 key performance indicators (KPIs) spanning efficiency, predictability, economic impact, environmental impact, and workload, enabling a quantitative assessment of the potential benefits and implications associated with the proposed routes.

Based on simulated data and the KPI framework, the study systematically evaluates the potential outcomes of the proposed route network from several perspectives, including overall performance, specific route pairs, stakeholder impacts, and traffic distribution. The analysis indicates that the new routes are expected to deliver significant operational improvements, including reduced flight distances and times, lower fuel consumption and CO2 emissions, optimized route-related costs, and enhanced routing flexibility. For air traffic management, these routes would provide more effective tools for traffic distribution, alleviating congestion on the Lan–U corridor and reducing both controller and pilot workload. The proposal demonstrates significant strategic value in mitigating pressure on the existing corridor and enhancing the overall resilience of the regional airspace.

Consequently, this white paper recommends that all stakeholders collaboratively advance the planning, validation, and phased implementation of the new routes. Such collaboration is essential for improving the overall efficiency, safety, and sustainability of the Eurasian air corridor. It also calls for the establishment of a cross-border ANSP coordination mechanism to optimize route utilization and ensure safe and stable operations in this complex environment.

Contents

1. Background and Introduction

Airspace operational efficiency is a key indicator of the effectiveness of airspace resource utilization and the quality of civil aviation development. Assessing airspace efficiency and optimizing resource allocation are essential for promoting high-quality growth in the aviation sector. The Lanzhou and Urumqi FIRs (Lan–U FIRs) of China, as key segments of the Eurasian air route, have operational efficiency that is directly linked to the performance of the Eurasian air transport network.

Prior to 2022, flights between East Asia and Europe predominantly used Russian airspace. Following its closure due to geopolitical factors, numerous flights between these regions were forced to reroute through the Lan–U FIRs. Consequently, the air routes within the Lan–U FIRs have become a primary corridor connecting Asia and Europe, leading to increased flight traffic volume and significant operational pressure. At the same time, the Lan–U FIRs have experienced frequent airspace restrictions due to military activities and special operations. This situation, together with delays in NOTAM issuance, has further reduced airspace availability. As a result, airlines and ANSPs face substantial challenges, including reduced capacity, frequent delays, decreased efficiency, higher costs, limited routing flexibility, and increased controller workload.

In response to the operational challenges confronting the Lanzhou–Urumqi (Lan–U) corridor, the International Air Transport Association (IATA) has proposed the development of alternative air routes within Mongolian airspace. This initiative aims to alleviate pressure on the core Lan–U route and enhance operational efficiency. Establishing new international air routes is complex and involves multiple stakeholders, airspace optimization, infrastructure development, and cross-border coordination. Ensuring the feasibility and effectiveness of such a proposal requires a comprehensive performance-based assessment prior to implementation to provide a scientific basis for informed decision-making by all parties involved.

Consequently, IATA launched the “Data-Driven Airspace Efficiency Study” project. This project assesses airspace efficiency by collecting flight data from airlines operating along the Lan–U corridor and applying the performance-based approach recommended by the International Civil Aviation Organization (ICAO) to design a framework of key performance indicators (KPIs) for airspace operational efficiency and establish an evaluation model. By quantifying the potential benefits and impacts of the proposed new routes, the study aims to support informed decision-making by all stakeholders involved in the route development process.

To systematically evaluate the potential impacts and benefits of the new routes, this white paper focuses on the Lanzhou–Urumqi (Lan–U) FIRs and is structured as follows. First, it examines the airspace structure and operational status of the Lan–U FIRs, analyses route restriction characteristics, and summarizes current systemic pressures. Second, it reviews the challenges encountered by airlines and air navigation service providers (ANSPs), along with their proposed improvements, to identify a shared vision for airspace optimization. Third, it presents the proposed new route plan, supported by field investigations in Mongolia and other relevant areas to assess air navigation service capabilities and enabling conditions. Fourth, it introduces the data-driven KPI framework and analytical methodology. Based on simulation data, the evaluation results are synthesized from multiple perspectives, including overall performance, route pairs, stakeholder impacts, and traffic flow characteristics, to quantify the benefits and impacts of the new routes. Finally, it summarizes the key conclusions and proposes actionable recommendations for each stakeholder group. Through this structured analysis, the white paper seeks to establish a scientific basis for advancing the proposed new routes over Mongolia, thereby contributing to improved efficiency, safety, and sustainability of the Eurasian air corridor.

2. Current Operational Situation in Lan–U FIRs

2.1. Airspace Structure

The Lanzhou FIR and Urumqi FIR serve as core management centres of northwestern airspace in China and key hubs along the "Silk Road in the Sky." The Lanzhou FIR connects the eastern, western, southern, and northern parts of China, while the Urumqi FIR acts as the western gateway to Europe and Central Asia. Together, they form the Lanzhou–Urumqi (Lan–U) corridor, a critical juncture linking East Asia with Europe and Central Asia. If Russian airspace closes or imposes restrictions, this corridor becomes the core route for flights between East Asia (e.g., Japan, Korea, eastern and southern China) and Europe.

The primary air route structure within the Lan–U FIRs is illustrated in Figure 2.1. Lanzhou FIR is crucial for east-west traffic across China, adjacent to Beijing FIR, Kunming FIR, and Urumqi FIR, and bordering Ulaanbaatar FIR to the north. It features the MORIT entry/exit point for routes to Mongolia. Positioned at the geometric centre of China's land area, it provides air navigation services across eight provinces or regions, including Gansu, Qinghai, and Ningxia. Lanzhou FIR’s extensive airspace supports numerous international routes connecting East Asia, Southeast Asia, the Middle East, and Europe, serving as an essential route along the Lanzhou–Urumqi corridor.

Within Lanzhou FIR, the primary east-west trunk routes are W66/W270 and B215/W191. These routes traverse relatively flat terrain, supported by established infrastructure, positioning them as core arteries of the Eurasian air corridor and resulting in substantial traffic demand. By contrast, the Y1 and L888 routes are area navigation (RNAV) routes crossing the Qinghai-Tibet Plateau. Y1 connects Chengdu and Urumqi, offering shorter flight distances and extended periods at fuel-efficient cruising altitudes. Initially, it faced limitations, including sparse communication, navigation, and surveillance (CNS) coverage, complex route application processes, and demanding aircraft performance requirements. Following infrastructure upgrades, Y1's operational capabilities have improved significantly, and Y1 now serves as a key link between southern Xinjiang and southwest China, south-central China, and Hong Kong. That said, its location on the high plateau, where emergency diversion aerodromes remain insufficient, continues to cap its growth potential. The L888 route (specifically the SANLI-XKC segment) is one of the few in China utilizing Performance-Based Communication and Surveillance (PBCS) technology. Due to its alignment across the Qinghai-Tibet Plateau, operations on this route demand exceptionally high safety standards. Minimum safe altitudes for most segments approach 7,000 meters, with actual operating levels typically around 9,200 meters or above. Specialized oxygen procedures are mandated to ensure flight safety. Currently, L888 is predominantly used by cargo operators. In summary, east-west traffic pressure within Lanzhou FIR remains concentrated primarily on the W66/W270 and B215/W191 trunk routes.

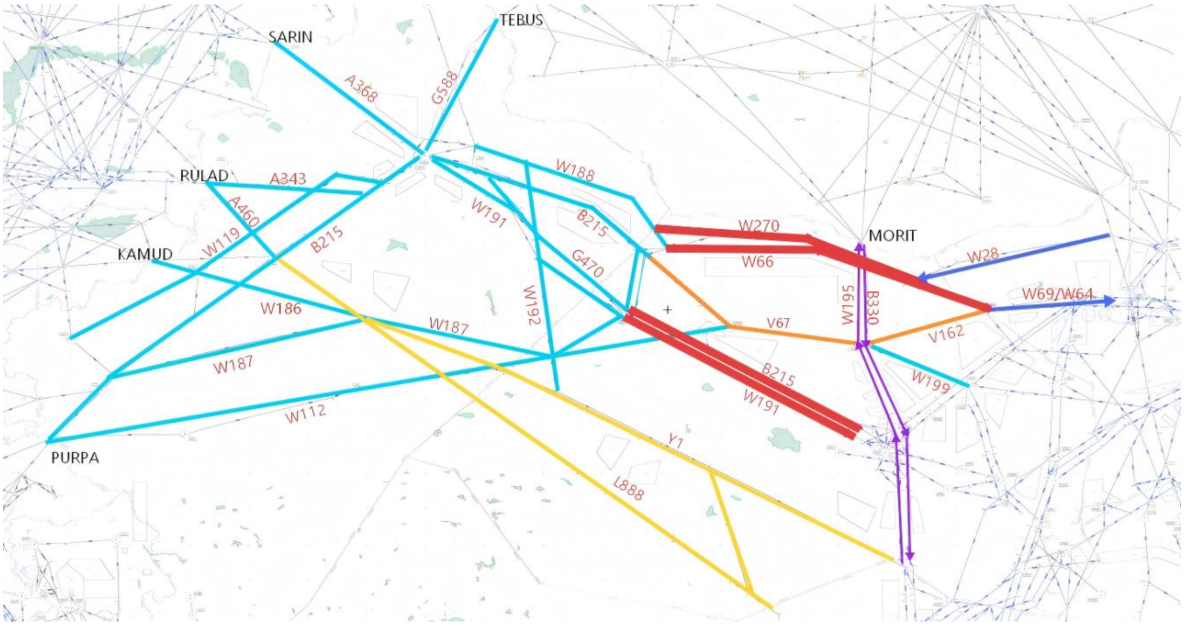

Figure 2.1 Schematic Diagram of the Main Eurasian Corridor Air Route Structure within the Lan–U FIRs

Urumqi FIR is China's primary gateway to the West and a strategic international hub connecting Europe and Asia. Located at the heart of the Eurasian continent, the FIR covers approximately 2 million square kilometers. Domestically, it neighbors Lanzhou FIR and Kunming FIR, while internationally, it shares borders with nine countries: India, Nepal, Pakistan, Afghanistan, Kyrgyzstan, Tajikistan, Kazakhstan, Russia, and Mongolia. The FIR has established Letters of Agreement (LOA) for control transfers with six area control centers across five neighboring countries and maintains eight transfer-of-control points with two domestic ACCs. This positions Urumqi FIR as an essential passage for flights between China, Europe, and Central Asia. Major air routes within Urumqi FIR include B215, W188, W112, A368, A343, Y1, and L888. Eastbound departures from Urumqi Tianshan International Airport experience significant operational pressure due to the airport's status as the busiest in Xinjiang and its substantial domestic traffic volume. Each route serves as a critical artery for international air traffic, functioning as a primary connector to multiple international boundary crossing points.

2.2. Regional Environment

The complex geographical environment significantly influences airspace utilization, route planning, and operational support. The topographical characteristics of Lanzhou FIR and Urumqi FIR are illustrated in Figure 2.2. Lanzhou FIR lies at the convergence of the Qinghai-Tibet Plateau, the Loess Plateau, and the Inner Mongolia Plateau. The terrain descends from west to east with dramatic undulations, characterized by crisscrossing mountain ranges and an average elevation exceeding 1,500 meters. Constrained by the Qinghai-Tibet Plateau, conventional communication, navigation, and surveillance (CNS) infrastructure cannot achieve full coverage across the area, leaving only a narrow corridor extending from the plateau to the China-Mongolia border. This geographical configuration creates a natural bottleneck for airway traffic.

Urumqi FIR extends across both the northern and southern sides of the Tianshan Mountains, featuring a "three mountains flanking two basins" topography: the Altai Mountains to the north, the Tianshan Mountains in the center, and the Kunlun Mountains to the south. The Junggar Basin lies between the northern and central mountain ranges, while the Tarim Basin is situated between the central and southern ranges. The southern Tarim Basin is predominantly desert, presenting significant challenges for civil aviation infrastructure development and resulting in limited surveillance and communication coverage.

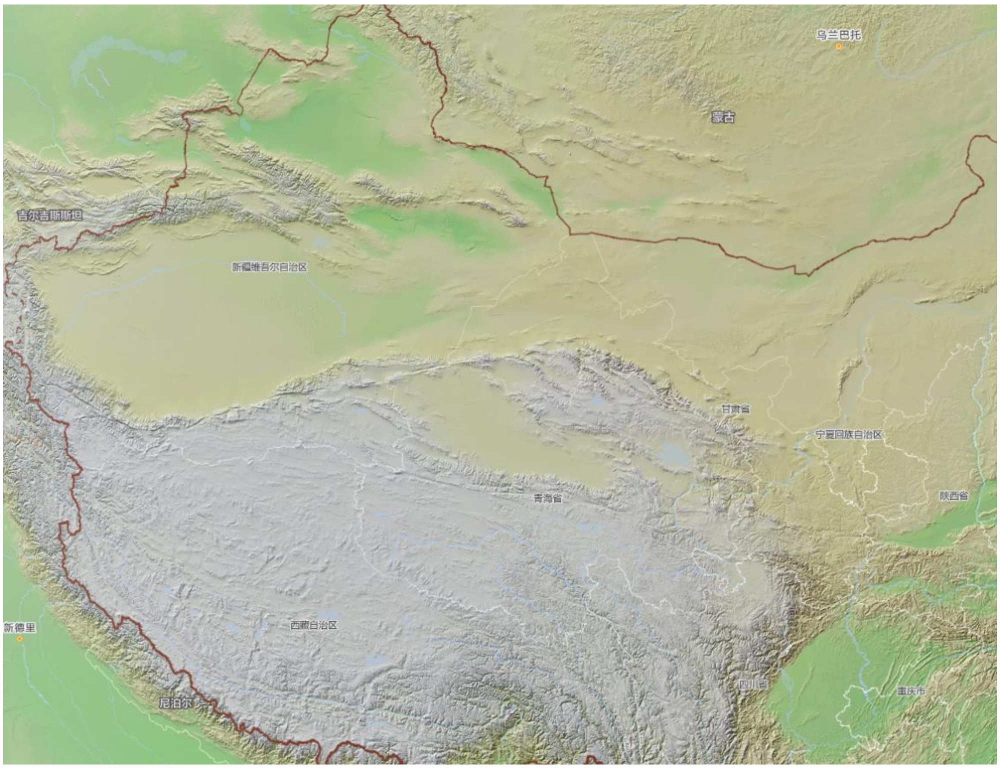

Figure 2.2 Topography of the Lanzhou–Urumqi Region

The Lan–U region generally exhibits stable climatic conditions. However, areas with complex terrain frequently experience severe weather phenomena such as strong convection, low cloud cover, high winds, and sandstorms, along with intense upper-level jet stream activity. During winter and spring, strong upper-level winds significantly impact east-west flight operations. The prevalence of plateaus and mountainous terrain contributes to common seasonal turbulence. The arid climate exacerbates sandstorms and low visibility, which significantly affect flight operations. In the Lanzhou Control Area, for example, the B215 and W191 routes manage dense traffic flows over complex terrain, where frequent turbulence poses higher operational risks. In July and August, the Lan–U region is prone to thunderstorms, often necessitating flight deviations from planned routes. This period coincides with peak traffic season, and the combination of thunderstorm activity and high traffic volumes leads to frequent flight delays and flow control measures. Thus, summer thunderstorms represent one of the most significant meteorological factors affecting flight operations in this region.

2.3. Area Control Service Profile

2.3.1 Lanzhou FIR

Lanzhou FIR contains two area control centers (ACCs) located in Lanzhou and Xi'an. Air traffic services along the Lan–U corridor are provided by Lanzhou ACC, which is the primary focus of this section.

Lanzhou ACC comprises up to 18 sectors (as illustrated in Figure 2.3), encompassing approximately 1.5 million square kilometers of airspace. Most of this area is sparsely populated owing to topographical constraints, resulting in less route density and infrastructure development compared to more developed plain regions. Significant portions of Lanzhou FIR consist of high-elevation, mountainous terrain, particularly in the Qinghai-Tibet Plateau areas served by the Y1 and L888 routes, as well as the non-route area south of W191. In these regions, the deployment of communication and surveillance facilities is constrained, leading to gaps in radar coverage and communication connectivity at lower altitudes. The remaining airspace benefits from comprehensive radar surveillance and VHF communication coverage, extending north from the W191 route to the W66 route. For navigation, the Y1 and L888 routes operate under area navigation (RNAV) procedures. In radar-controlled airspace, the minimum horizontal separation is 5 nautical miles. In airspace with either radar or ADS-B surveillance, separation is maintained at or above 5 nautical miles. Procedural separation applies in areas lacking surveillance coverage.

The distribution of airports within Lanzhou FIR (Figure 2.4.) includes major international airports such as Lanzhou Zhongchuan, Xining Caojiabao, Yinchuan Hedong, and Dunhuang Mogao. Additionally, a network of regional airports, including Jiayuguan Jiuquan, Zhangye Ganzhou, Jinchang Jinchuan, Golmud, and Haixi Mangya, constitutes the primary alternate aerodrome system for the region.

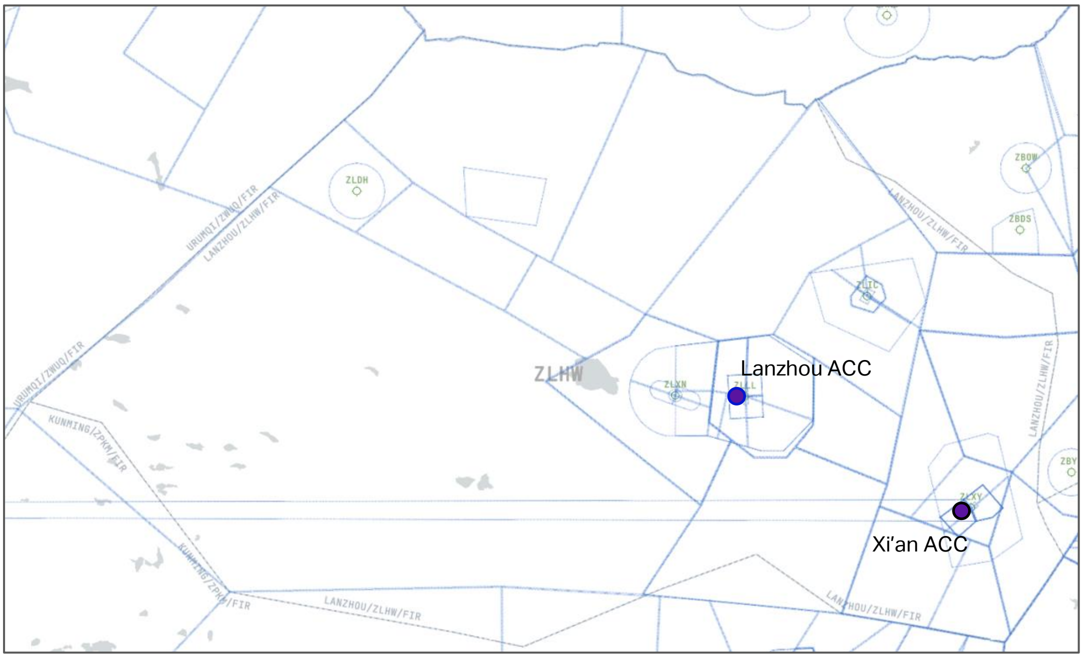

Figure 2.3 Sector Configuration of Lanzhou ACC[1]

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[1] Source: https://aips.siniswift.com/#/nav-map

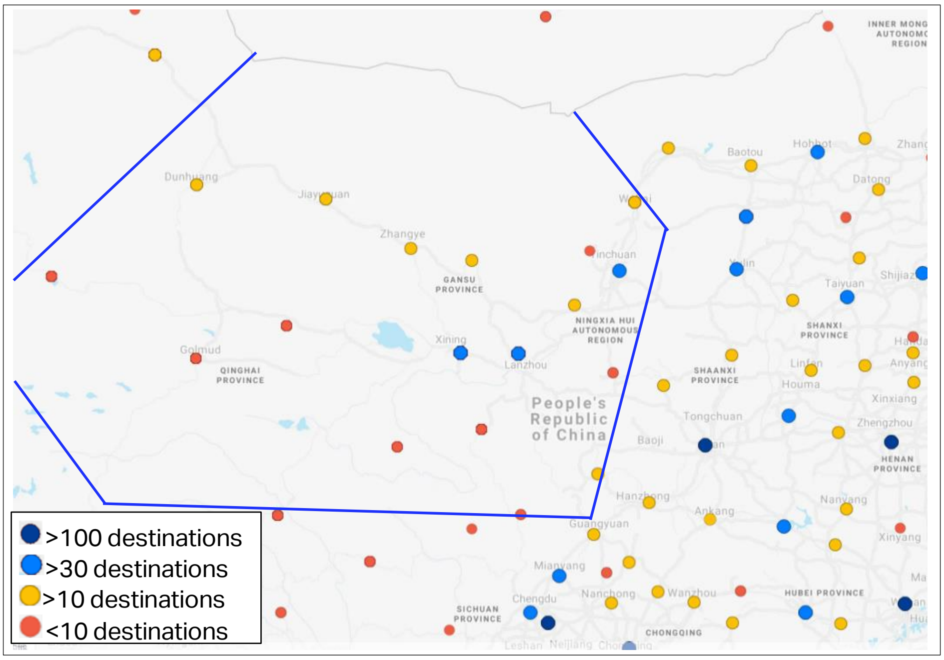

Figure 2.4 Distribution of airports in Lanzhou ACC area[2]

2.3.2 Urumqi FIR

Urumqi FIR is served by a single area control center in Urumqi City, with its airspace organized into a maximum of 12 sectors (see Figure 2.5). The communications infrastructure provides VHF and HF coverage throughout the FIR, with VHF air-ground communication as the primary method. Multiple ground-based NAVAIDs are installed along major routes to support en-route navigation. The secondary surveillance radar (SSR) infrastructure within Urumqi FIR is undergoing enhancement, with SSR coverage extending to approximately 80% of major air route areas at and above 7,800 meters. ADS-B has been deployed as the primary surveillance source across most of the FIR, except south of the W112 route and in certain low-altitude sectors below 6,300 meters. Existing radar facilities are located in northern Xinjiang, including Hami, Shanshan, Qitai, and Urumqi, providing coverage for major air routes and terminal areas in that region. Plans are underway to deploy approximately seven additional SSR units in southern Xinjiang to further enhance surveillance capabilities in conjunction with the existing ADS-B infrastructure. The minimum horizontal separation under radar surveillance is 5 nautical miles, while under ADS-B surveillance, it is 10 kilometers.

The distribution of airports within Urumqi FIR is shown in Figure 2.6. Major international airports include Urumqi Tianshan Airport, Kashgar Laining Airport, and Yining Airport. More than 20 regional airports, including Hotan Kungang, Korla Licheng, Ruoqiang Loulan, Turpan Jiaohe, Hami Yizhou, and Bole Alashankou, form a comprehensive network of alternate aerodromes within the FIR.

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[2] Source: https://www.flightconnections.com/cn

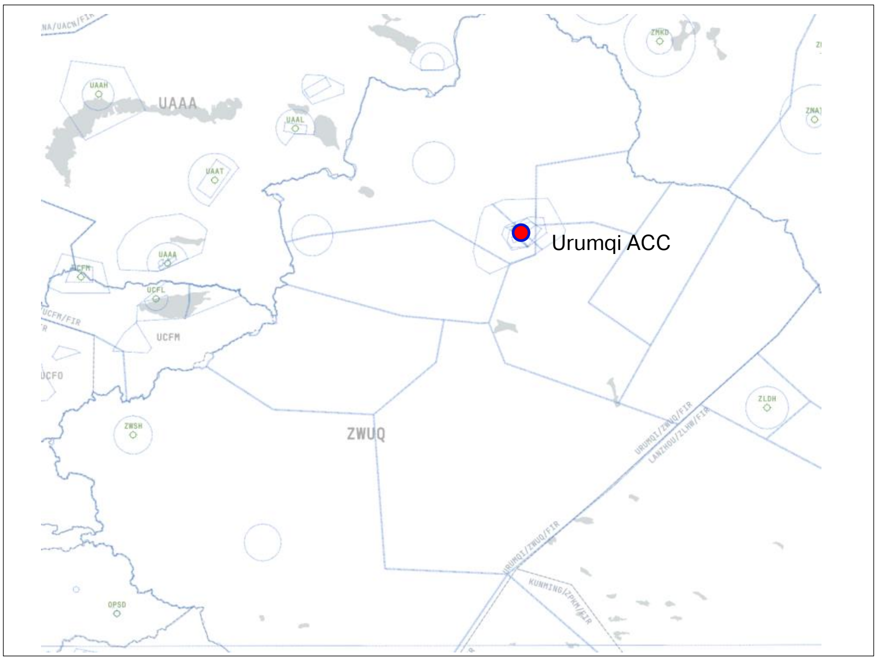

Figure 2.5 Sector Configuration of Urumqi ACC[3]

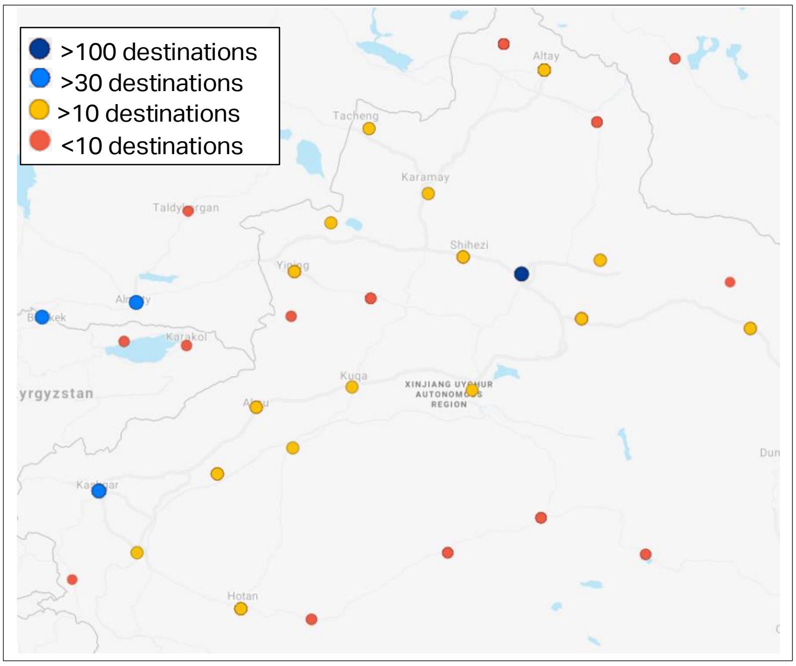

Figure 2.6 Distribution of airports in Urumqi ACC area[4]

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[3] Source: https://aips.siniswift.com/#/nav-map

[4] Source: https://www.flightconnections.com/cn

2.4. Air Traffic Flow

2.4.1 Lanzhou FIR

Flight statistics from both Lanzhou and Urumqi ACCs covering 2019 to 2025 were collected from publicly available sources to assess the scale and development trends of traffic along the Lan–U corridor. Figure 2.7 presents the total annual flights handled by Lanzhou ACC, while Figure 2.8 shows the corresponding peak daily flights for each year. The data indicates a clear upward trend in traffic volumes at Lanzhou ACC, with fluctuations observed between 2020 and 2022 attributed to the pandemic. Recovery has been pronounced since 2023, with peak daily flights continuously setting new records as traffic volumes have grown. In 2025, peak daily flights surpassed 2,400 movements, an increase of more than 40% compared to 2019. This trend reflects intensifying operational pressure on the ACC, increasing demands on airspace resource allocation and ATC efficiency, and a marked rise in controller workload.

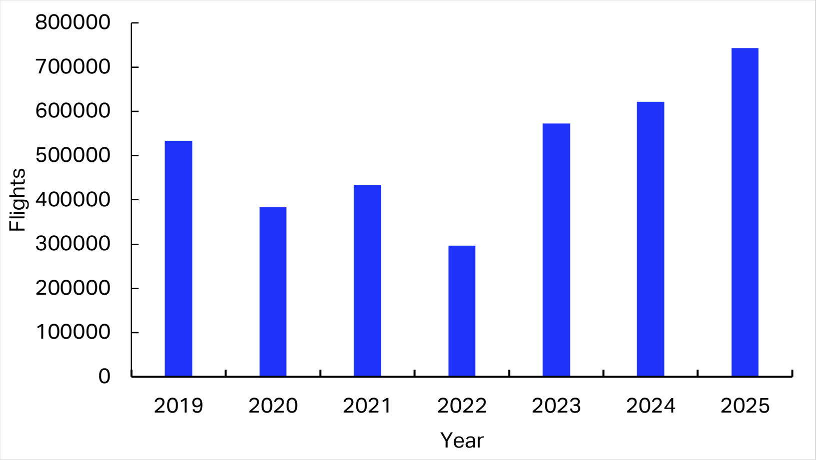

Figure 2.7 Annual Flights Handled by Lanzhou ACC[5]

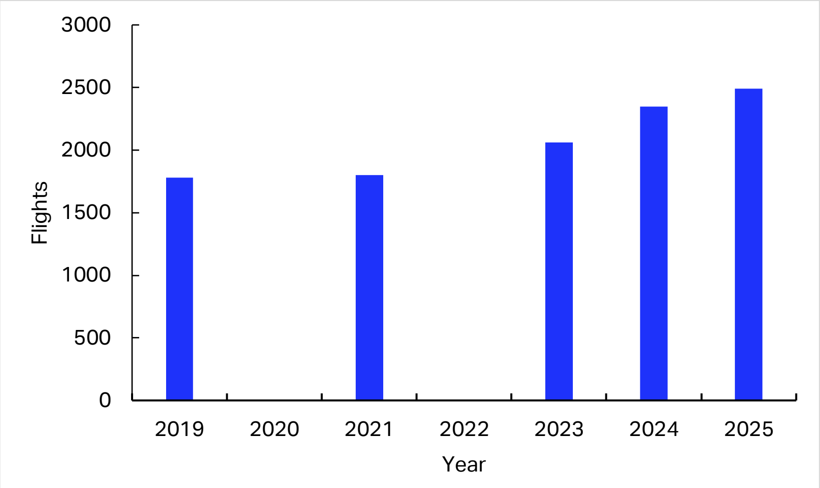

Figure 2.8 Peak Daily Flights in Lanzhou ACC[6]

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[5] Data Source: WeChat Official Account "守航丝路"

[6] Data Source: WeChat Official Account "守航丝路"

2.4.2 Urumqi FIR

Figures 2.9 and 2.10 show the total annual flights handled by Urumqi ACC and the corresponding peak daily figures from 2019 to 2025. The data indicates a sustained upward trajectory in traffic volumes at Urumqi ACC, with consistent growth evident since 2023. In 2025, annual traffic surpassed 500,000 movements, while peak daily flights exceeded 1,600, reflecting an increase of over 57% compared to 2019. Given that no structural changes have been made to the route network or airspace resources during this period, this continued traffic growth presents unprecedented operational pressures for the air navigation service provider.

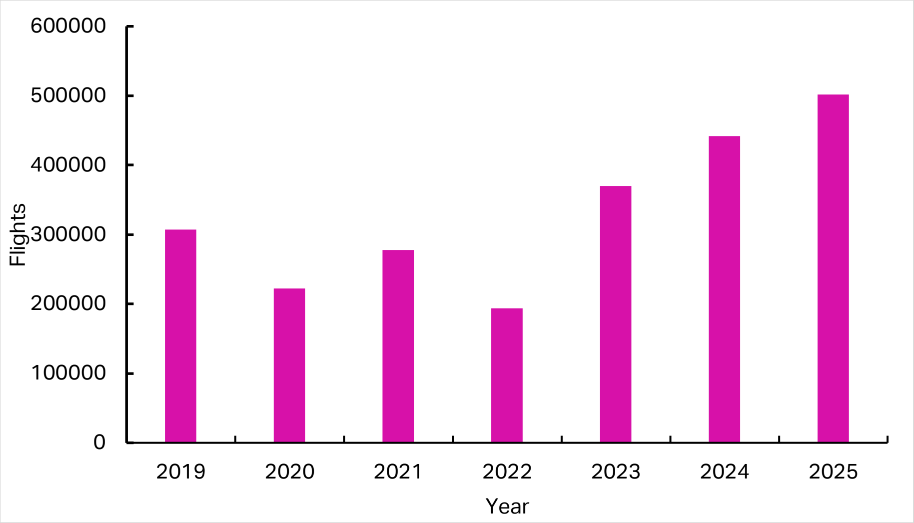

Figure 2.9 Annual Flights Handled by Urumqi ACC[7]

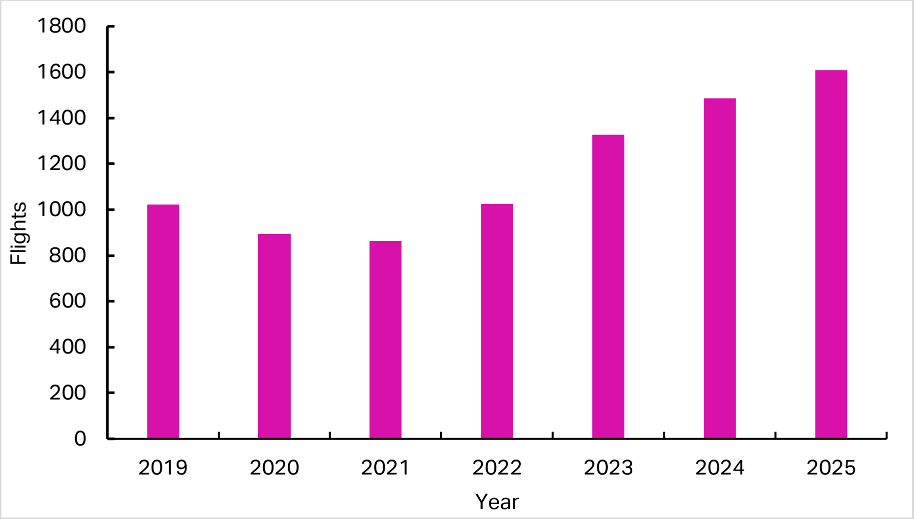

Figure 2.10 Peak Daily Flights in Urumqi ACC[8]

2.4.3 International Flights via Entry/Exit Points of Urumqi FIR

All flights between Europe and Asia mainly enter and exit Chinese airspace via the Urumqi FIR through key points to Central Asian States, including SARIN, RULAD, KAMUD, and PURPA. Figure 2.11 illustrates the total

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[7] Data Source: WeChat Official Account "新疆空管"

[8] Data Source: WeChat Official Account "新疆空管"

annual flight volumes at these points from 2022 to 2024. The data show a sharp increase in international flight movements. In 2024, flights at these entry/exit points exceeded 130,000, a 64% increase compared to 2023 and accounting for 30% of Urumqi ACC's total annual traffic. This data reflects strong demand and sustained growth along the Eurasian corridor, highlighting its vital role in connecting air traffic between Asia and Europe.

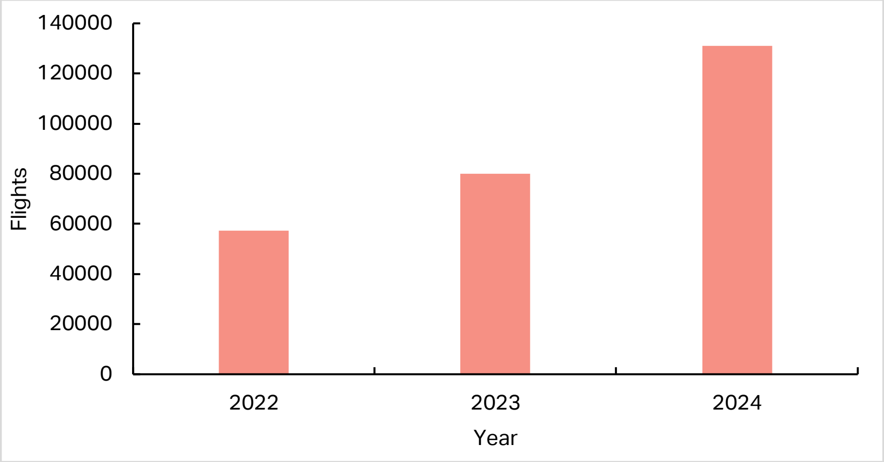

Figure 2.11 Annual flights via Urumqi FIR Entry/Exit Points[9]

2.5. Airspace Restriction Profile

Airspace restrictions frequently occur within the Lan–U FIRs owing to various factors, posing challenges to airline operations and air traffic control. NOTAM data were collected and analyzed for the one-year period from 30 March 2024 to 29 March 2025 to characterize the nature and extent of airspace restrictions within the Lan–U FIRs, with separate analyses for each major route segment. To provide a detailed understanding of the impact of NOTAMs on route availability, notices related to route closures were filtered out and the following metrics were examined:

- Monthly closure-related NOTAM frequency: Distribution of closure-related NOTAM issuances by month throughout the year.
- Restriction start time: Time of day when each airspace restriction becomes effective, indicating temporal patterns of route unavailability.
- Restriction duration: Length of time each restriction remains in effect, reflecting the temporal severity of the impact.
- NOTAM lead time: Interval between NOTAM issuance and restriction effective time, indicating the planning horizon available to operators.
- Restricted flight levels: Altitude ranges affected by each restriction, defining the vertical scope of airspace limitations.

Furthermore, the following parameters were calculated for each critical route segment over the one-year period: frequency of restrictions (FoR), average restriction duration (ARD), and average NOTAM lead time. These metrics provide a detailed characterization of the impact on route segments.

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[9] Data Source: Investigation on ANSP

2.5.1 Airspace Restrictions in Lanzhou FIR

Of the 1,965 NOTAMs collected for Lanzhou FIR, 1,907 were closure related. Key metric distribution characteristics are presented in Figures 2.12 through 2.17. Figures 2.12 and 2.13 illustrate monthly NOTAM frequency and total restriction duration, respectively. Data indicate NOTAM issuances were more frequent from April to November 2024, with September recording the highest number. Monthly restriction duration exhibited a similar pattern.

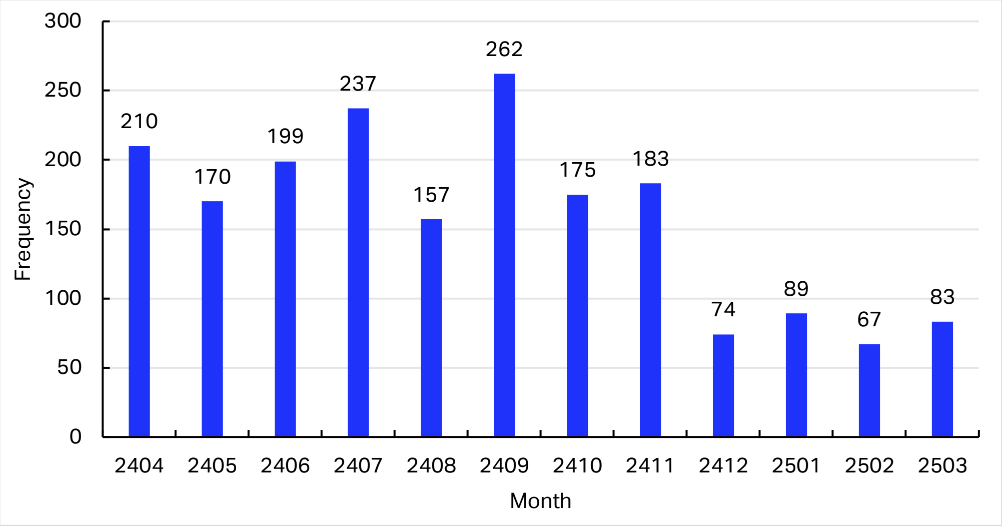

Figure 2.12 Monthly closure-related NOTAM frequency of Lanzhou FIR

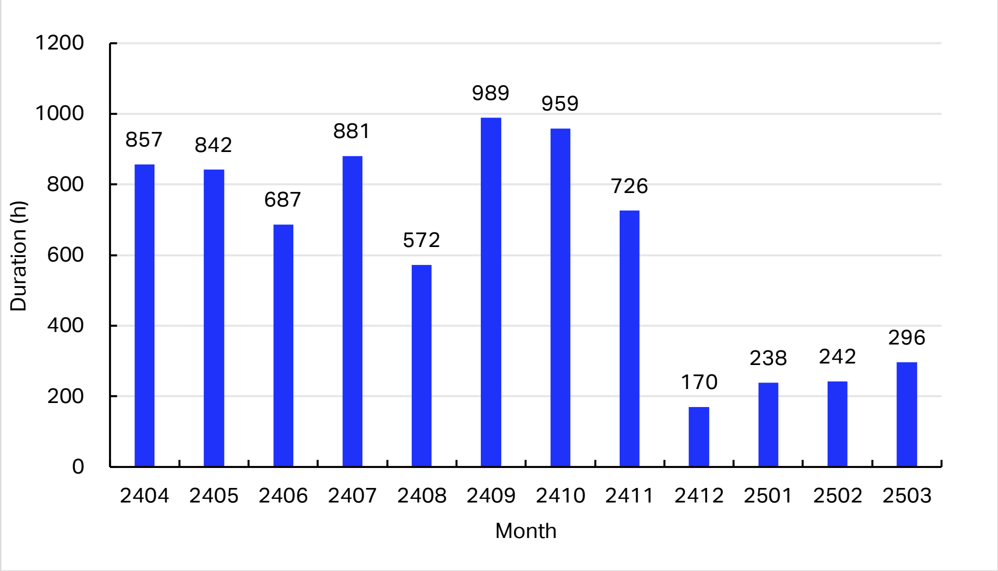

Figure 2.13 Monthly restriction duration of Lanzhou FIR

Figure 2.14 shows that airspace restrictions in Lanzhou FIR typically commence from 07:00 local time, with the peak start times occurring between 07:00 and 11:00. Route unavailability predominantly happens during daytime hours, with significantly fewer restrictions at night. Figure 2.15 indicates that restriction durations generally range from 0.5 to 4.5 hours, with the most frequent durations between 1.0 and 2.5 hours.

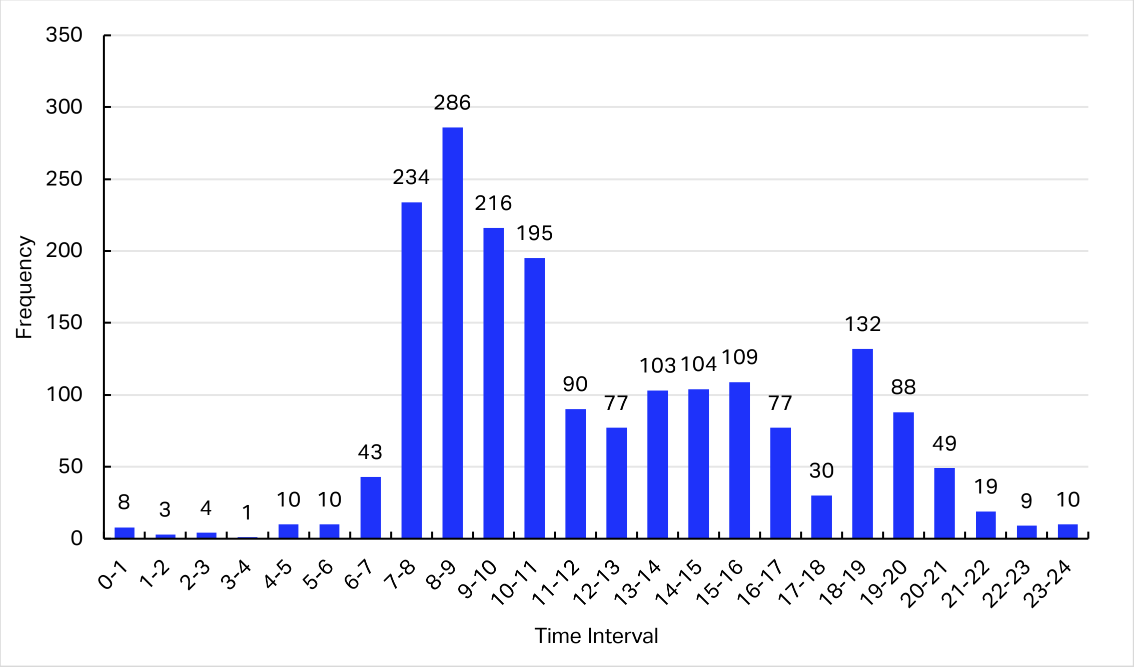

Figure 2.14 Restriction start time distribution of Lanzhou FIR (UTC+8)

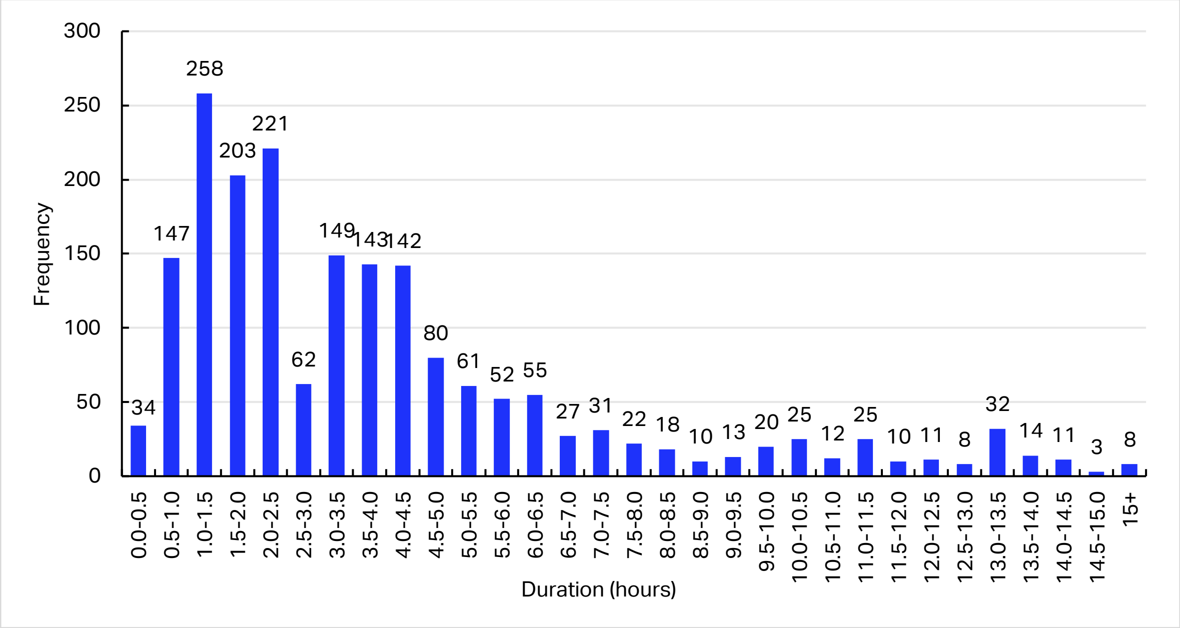

Figure 2.15 Restriction duration distribution of Lanzhou FIR

Figure 2.16 presents the closure-related NOTAM lead time in Lanzhou FIR. Longer lead times for airspace restriction information are strongly preferred by airlines, as they provide dispatchers with adequate time to plan flight routes. Feedback from dispatchers indicates a minimum lead time of 15 hours is desirable. As shown in Figure 2.16, most NOTAMs were issued with a lead time exceeding 15 hours; however, 144 closure-related NOTAMs (7.7%) had a lead time of less than 15 hours, with the shortest being 7–8 hours. These late-issued NOTAMs pose challenges for airlines in flight planning and may be received after departure, potentially impacting operational safety.

Figure 2.17 illustrates the distribution of restricted flight levels in Lanzhou FIR. A total of 398 closure-related NOTAMs (20.9%) imposed restrictions on all flight levels, while the remainder primarily restricted specific altitude bands, allowing operations at certain levels.

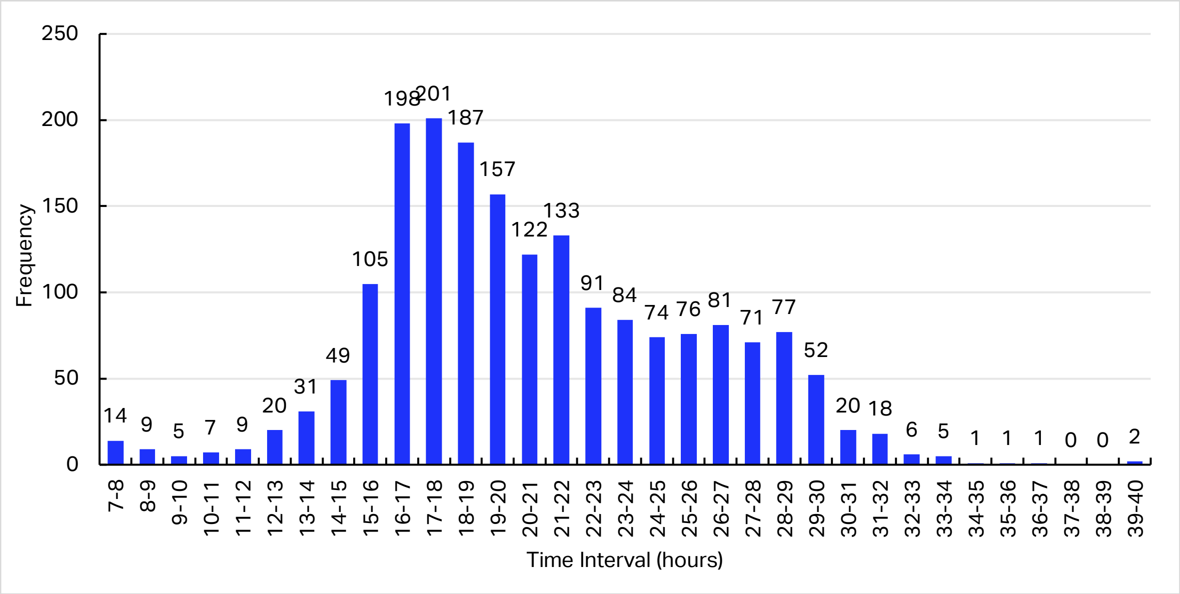

Figure 2.16 Distribution of the NOTAM lead time in Lanzhou FIR

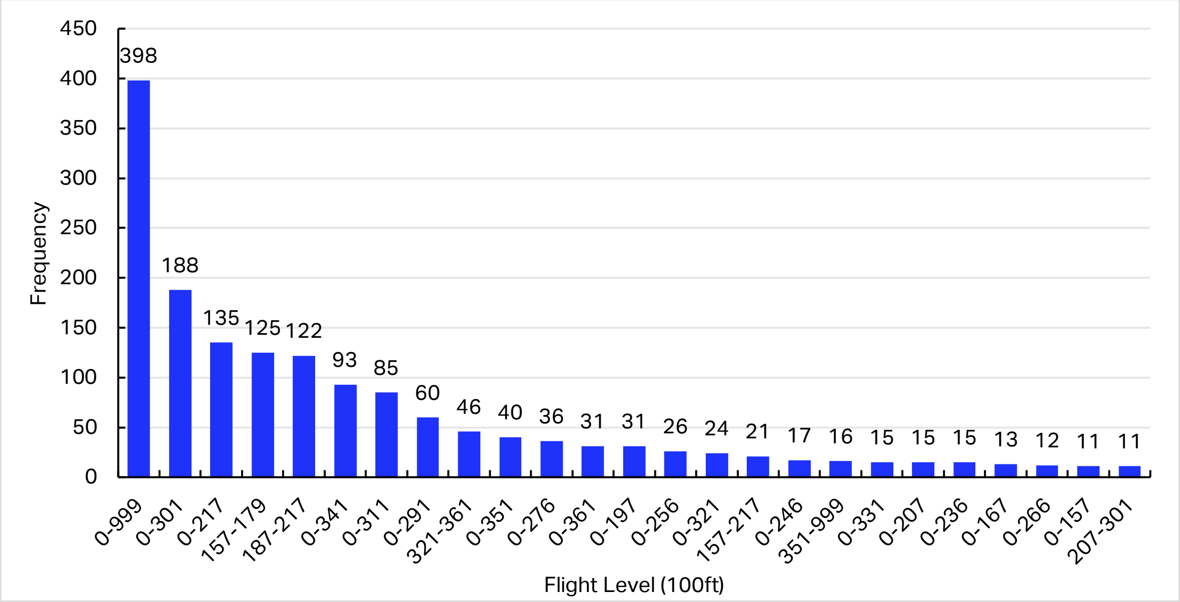

Figure 2.17 Distribution of the restricted flight levels in Lanzhou FIR

Figure 2.18 provides a schematic overview of restrictions affecting major route segments within the Lanzhou FIR, differentiating frequency of restriction (FoR) and average duration of restriction (ADR) by category for each segment. The most significantly affected routes are W66, B215, B330, A596, W199, W112, and W187. Among these, W66, B215, A596, and W187 each recorded elevated restriction frequencies exceeding 150 occurrences, while W199 combines high frequency with longer average restriction durations, exceeding 300 minutes. The RNAV routes Y1 and L888 are also subject to notable restrictions, with Y1 having a relatively high frequency of restrictions and L888 having a longer average restriction duration. Detailed restriction data for each route segment are provided in Appendix 1.

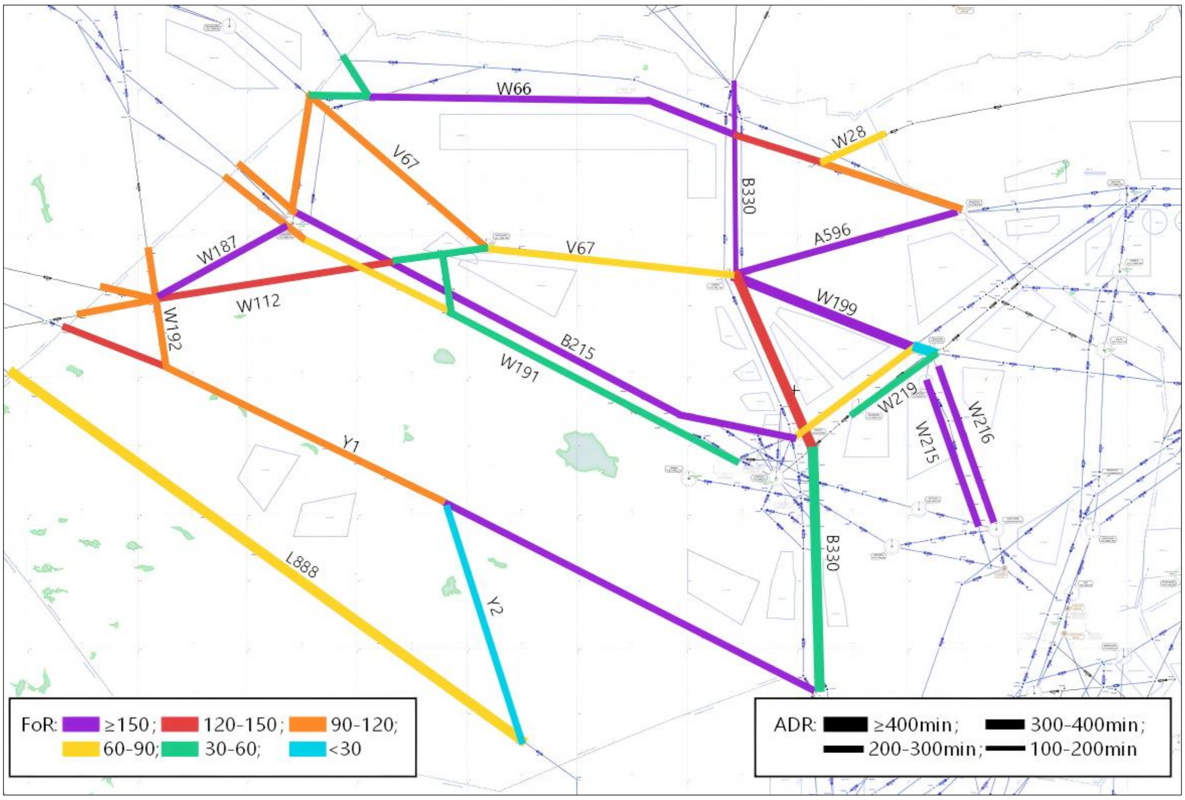

Figure 2.18 Distribution of Airspace Restrictions by Major Route Segments in Lanzhou FIR

2.5.2 Airspace Restrictions in Urumqi FIR

Of the 1,582 NOTAMs issued for Urumqi FIR between 30 March 2024 and 29 March 2025, 984 were closure related. Statistical results are presented in Figures 2.19–2.24.

Figures 2.19 and 2.20 illustrate the monthly distribution of closure-related NOTAM frequency and total restriction duration for Urumqi FIR. The data indicates a trend of higher frequency and longer durations from July to November 2024.

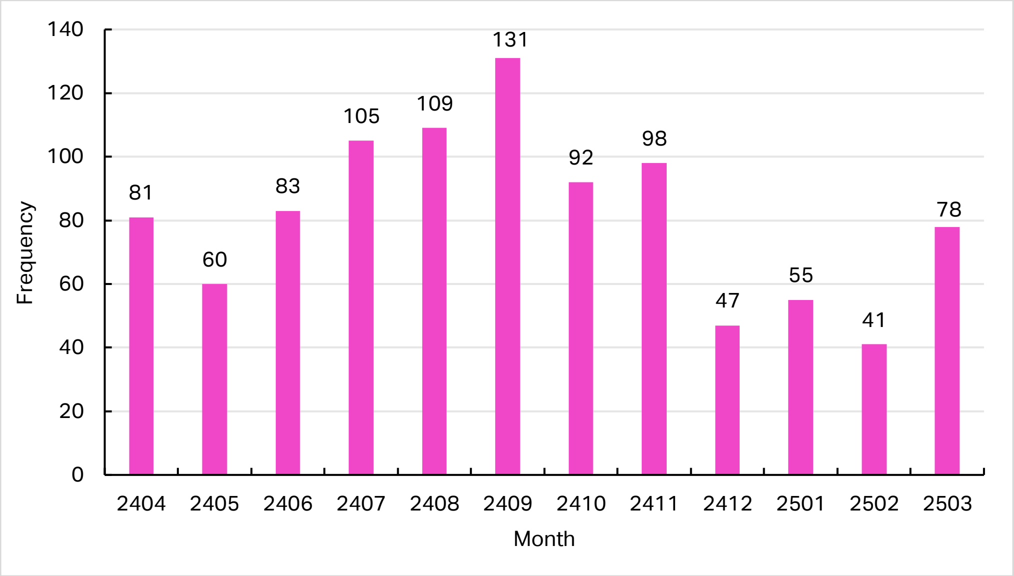

Figure 2.19 Monthly closure-related NOTAM frequency of Urumqi FIR

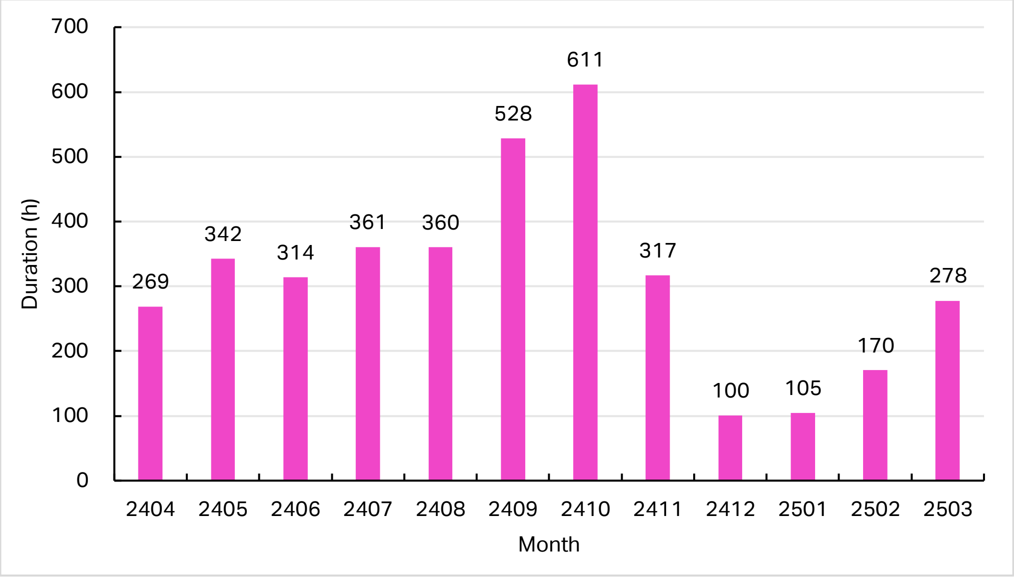

Figure 2.20 Monthly restriction duration of Urumqi FIR

Figure 2.21 shows that airspace restrictions in Urumqi FIR typically commence from 06:00 local time, with the period between 09:00 and 11:00 representing the peak for restriction start times. Daytime hours account for most of the route unavailability, with significantly fewer restrictions occurring at night. Figure 2.22 indicates that restricted durations range from 0.5 to 6.5 hours, with durations of 0.5 to 3 hours being most common.

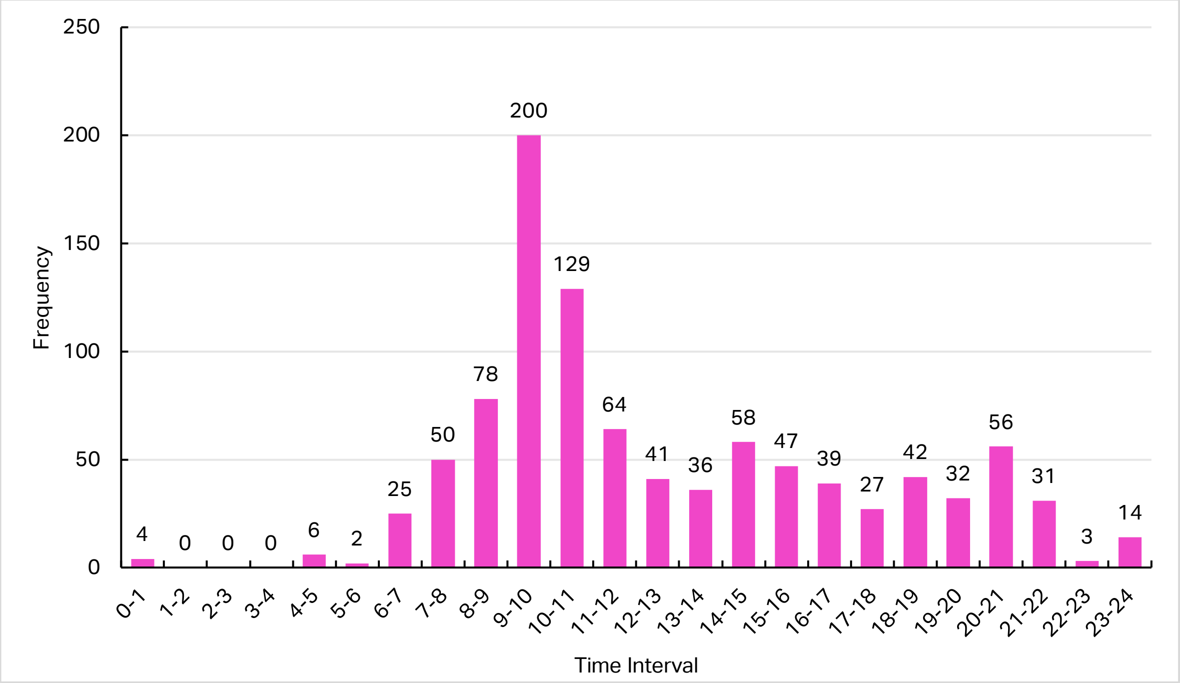

Figure 2.21 Restriction start time distribution of Urumqi FIR (UTC+8)

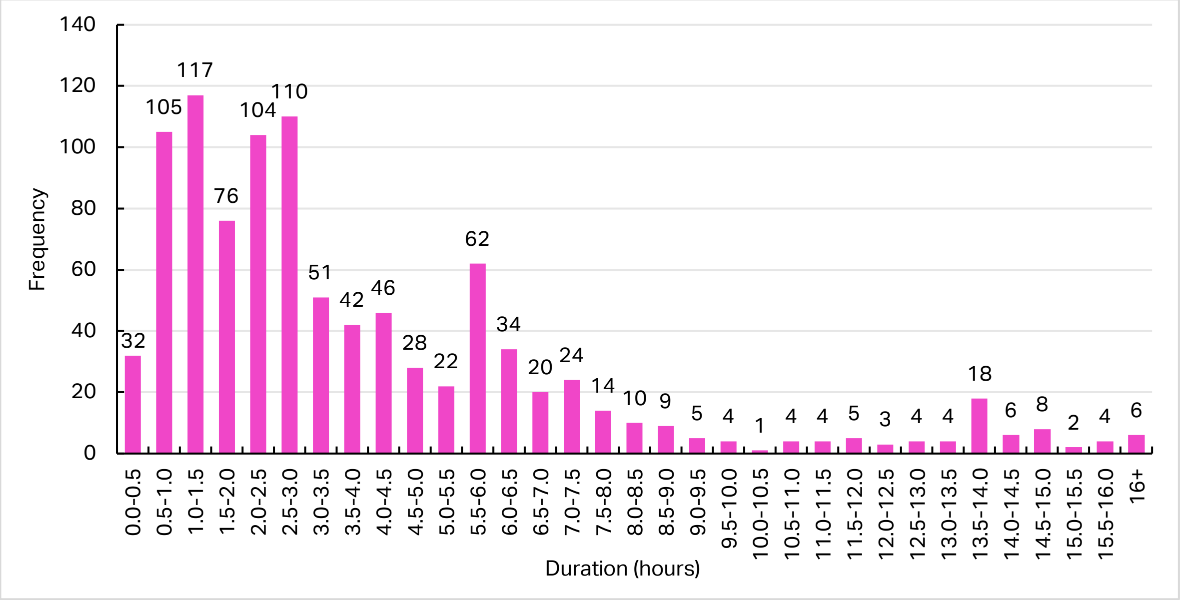

Figure 2.22 Restriction duration distribution of Urumqi FIR

Figure 2.23 illustrates the closure-related NOTAM lead time in the Urumqi FIR. The data indicate that while most NOTAMs were issued with a lead time exceeding 15 hours, 242 closure-related NOTAMs (24.6%) were issued with a lead time of less than 15 hours, with the shortest lead time being 7–8 hours. These late-issued NOTAMs present significant challenges for airline dispatchers in flight route planning and have implications for operational safety.

Figure 2.24 presents the distribution of restricted flight levels in the Urumqi FIR. A total of 738 closure-related NOTAMs (75.0%) imposed restrictions on all flight levels, indicating that altitude restrictions are prevalent in the Urumqi FIR, with most restrictions effectively closing the routes to traffic.

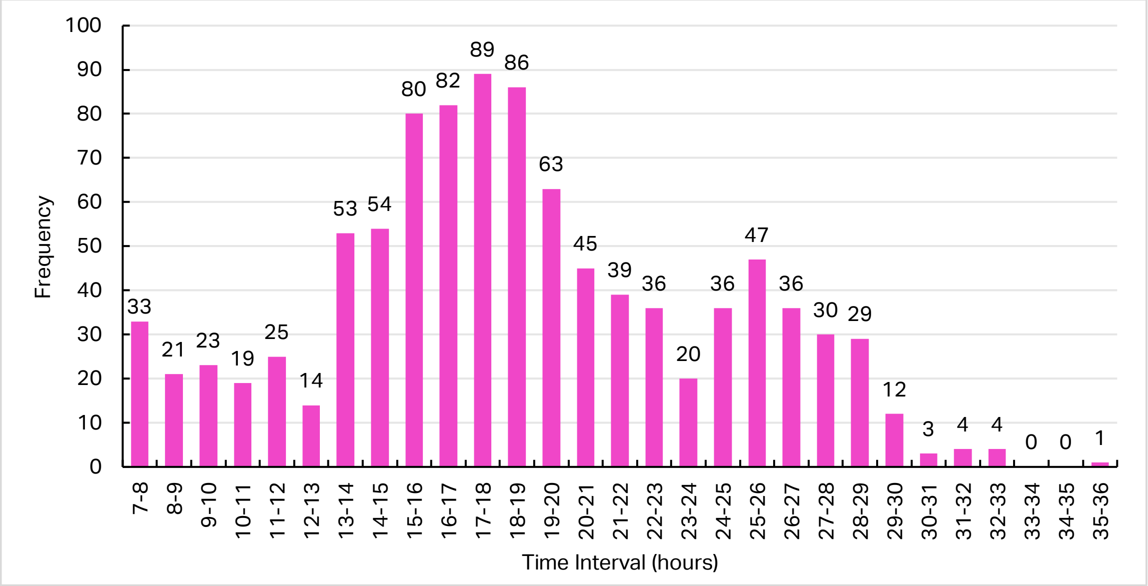

Figure 2.23 Distribution of the closure-related NOTAM lead time in Urumqi FIR

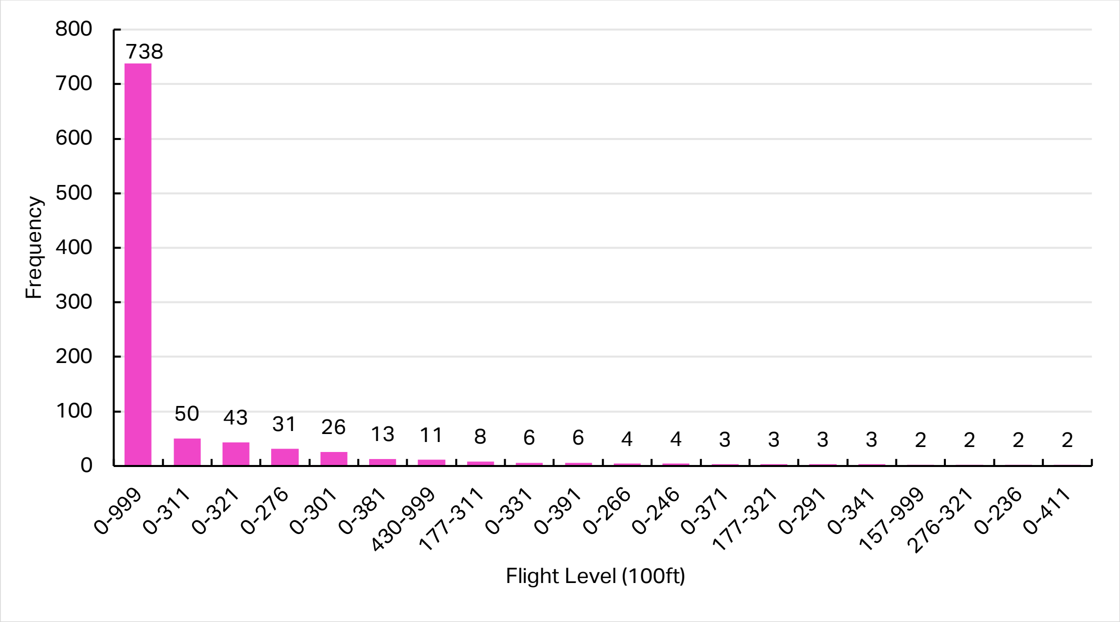

Figure 2.24 Distribution of the restricted flight levels in Urumqi FIR

Figure 2.25 shows the distribution of restrictions affecting major route segments within the Urumqi FIR. The data indicates that the most significantly affected segments are Y1, W187, W112, W192, and L888, each recording restriction frequencies above 90 occurrences with average restriction durations below 300 minutes. Routes W188, W119, and W189, by contrast, show relatively lower restriction frequencies but longer average durations, each exceeding 400 minutes. Detailed restriction data for each route segment are provided in Appendix 1.

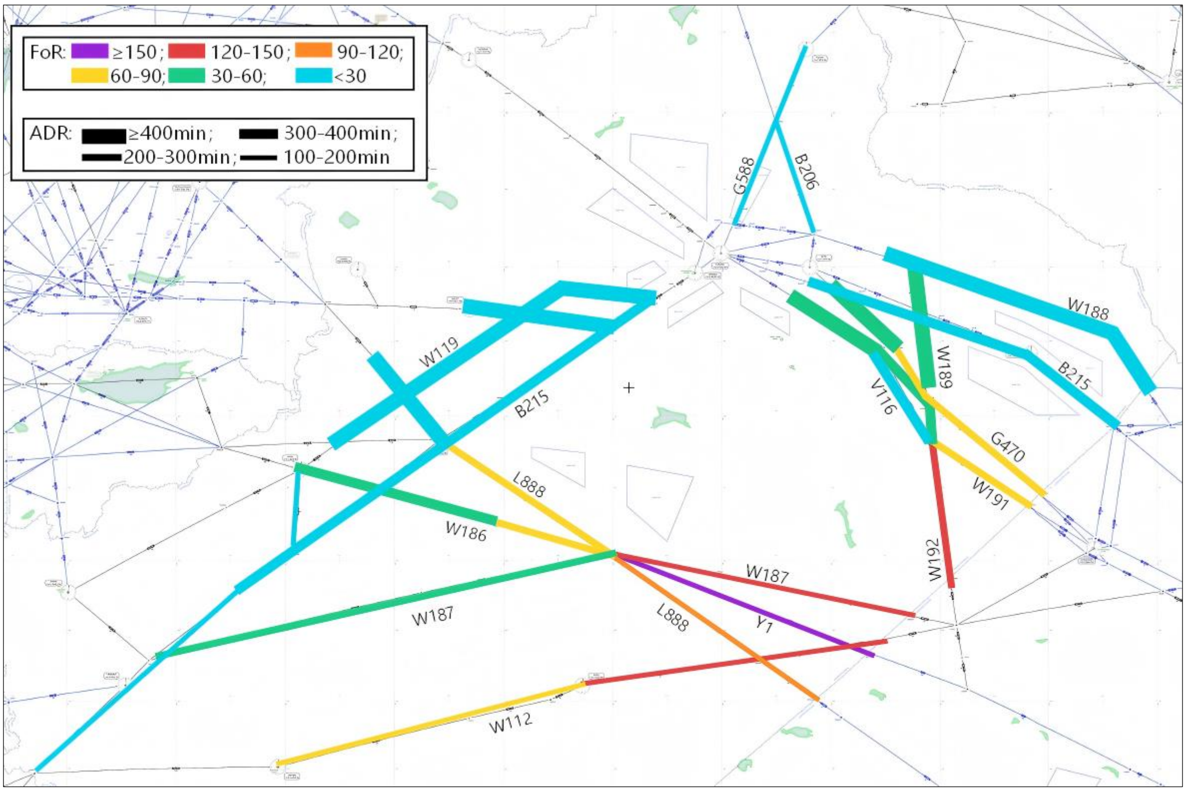

Figure 2.25 Distribution of Airspace Restrictions by Major Route Segments in Urumqi FIR

2.6. Summary of the Operational Situation in Lan–U FIRs

Based on the analysis, the current operational situation of air routes within Lan–U FIRs can be characterized by four core features:

First, a critical strategic position. The Lan–U corridor is a key artery connecting East Asia with Central Asia and Europe. The Lanzhou FIR, constrained by the Qinghai-Tibet Plateau's topography, offers only a narrow east-west passage. This geographical limitation creates a natural bottleneck, underscoring the strategic scarcity of this corridor.

Second, gaps in surveillance coverage. Certain areas within the Lanzhou and Urumqi FIRs experience communication and surveillance blind spots owing to complex terrain, particularly at lower altitudes and in remote airspace. These gaps constrain the capacity and operational flexibility of affected routes.

Third, sustained growth in traffic volume. Flight traffic in the Lan–U region has rapidly increased in recent years, placing greater demands on airline operations, ATC capabilities, and airspace resource allocation. All stakeholders face mounting operational pressure as a result.

Fourth, the high frequency of airspace restrictions. The number of NOTAMs issued in the Lan–U region remains high, and frequent airspace closures severely limit route availability. This significantly impacts flight planning, route selection flexibility, and the predictability of flight operations.

These characteristics indicate that while the Lan–U corridor is essential for Eurasian air traffic, it faces increasing structural pressures. The tension between its strategic importance and limited airspace resources, compounded by the conflict between sustained traffic growth and frequent route restrictions, has created a core bottleneck constraining regional airspace efficiency. These macro-level operational challenges translate into concrete difficulties for airlines and ANSPs in their daily operations.

To understand the underlying operational issues in the Lan–U region and lay the groundwork for proposing solutions, Chapter 3 will examine these challenges from the operators' perspective, systematically reviewing the specific difficulties encountered by airlines and ANSPs, as well as proposed improvements to address them.

3. Operational Challenges and Requirements

3.1. Challenges and Requirements of Airlines

The project team conducted interviews with flight dispatchers and operations managers from multiple airlines to understand operational issues along the Lan–U corridor. These interviews aimed to identify daily operational challenges and capture proposed improvements and concerns from the airline perspective, with findings intended to inform airspace resource allocation and operational efficiency enhancements.

3.1.1 Operational Challenges Faced by Airlines

In flight operations planning, airlines typically consider a range of factors when selecting routes, including flight time, operational costs (fuel and route charges), operational predictability, wind direction and speed, temperature conditions, route availability, available flight levels, and the availability of alternate aerodromes. Any of these factors can critically affect the regularity of operations. Based on these considerations and a review of historical operations along the Lan–U corridor, the specific issues and challenges reported by airlines can be summarized as follows:

1. Impact of Airspace Route Closures on Operational Regularity

The Lan–U corridor has become a mandatory passage for certain airlines operating flights between East Asia and Europe, with a notable lack of viable alternative routings. Flights between Europe and Seoul or Tokyo typically operate via the W66 route in Lanzhou FIR, entering or exiting Chinese airspace through the SARIN or RULAD points in Urumqi FIR. Similarly, flights between Hong Kong and Europe primarily utilize the Y1 and B215/W191 routes, along with the relevant entry/exit points in Urumqi FIR. The high volume of traffic along these routes places significant demands on route stability. However, frequent airspace closures within the Lanzhou–Urumqi FIRs often necessitate last-minute rerouting or ground delays, increasing flight delays, reducing operational predictability, and increasing fuel consumption and carbon emissions. These issues pose considerable challenges for airline operations, including flight planning, dispatcher route selection, and the efficient scheduling of flight crews.

2. Delayed Issuance of NOTAMs Affecting Route Selection

In some cases, NOTAMs announcing airspace closures within the Lanzhou–Urumqi FIRs are issued with very short notice, sometimes as little as eight hours before the restriction takes effect. This limited lead time leaves airline dispatchers insufficient opportunity to adjust flight plans, resulting in disruptions to scheduled operations. More critically, there have been instances where airspace closure information was received only after a flight had already departed, forcing airlines to identify alternative routings in real time. In extreme cases, this may compromise flight safety owing to insufficient fuel reserves. Accordingly, the delayed issuance of NOTAMs has become a key constraint affecting the quality of airline operational planning.

3. Absence of Alternative Route Information in NOTAMs Affecting Route Selection

Most NOTAMs announce route closures without providing alternative routing information. This absence of guidance makes it difficult for airlines to identify suitable alternatives during flight planning, affecting the regularity of flight operations and the continuity of planned schedules.

4. Insufficient Route Flexibility Constraining Routing Options

The route network within the Lanzhou–Urumqi FIRs, along with the configuration of entry/exit points with neighboring States, is relatively fixed, offering limited routing choices. The scarcity of viable alternative routes and entry/exit points necessitates rerouting some traffic via significantly longer paths. This rigidity restricts route selection and operational flexibility, ultimately constraining improvements in flight efficiency.

5. Additional En-Route Holding Impacting Operational Efficiency

In the Lan–U region, flights may require additional en-route holding due to insufficient ATC sector capacity or flow management initiatives. This holding increases flight time, reduces operational efficiency, and adversely affects airlines' scheduling precision.

Additionally, Table 3.1 provides an overview of the core issues impacting airline operations along the Lan–U corridor and their corresponding operational effects.

Table 3.1 Key Issues and Operational Impacts for Airlines Operating in the Lan–U Region

No.	Issue	Operational Impact
1	Inefficient airspace and route structure	ATFM delays, reduced operational efficiency
2	Insufficient airspace capacity	Increased delays, reduced predictability
3	Operational disruptions and route closures due to geopolitical factors	Extended flight time, increased flight distance, higher fuel consumption, and increased emissions
4	Limited route flexibility and lack of viable alternatives	Reduced operational flexibility, decreased efficiency, increased costs
5	Limited and inflexible entry/exit points	Reduced operational flexibility and efficiency, fewer routing options
6	Limited availability of diversion or emergency alternate aerodromes	Increased fuel carriage requirements, higher operating costs, and reduced efficiency
7	Flight crew duty time limitations	Increased operating costs
8	Frequent route restrictions	Higher operating costs, increased delays, and reduced efficiency
9	Insufficient NOTAM lead time	Compressed flight planning, reduced plan quality; potential for post-departure NOTAM receipt requiring contingency handling, risk of delays, and fuel shortage
10	ANS charges for additional flight distance	Increased operating costs

3.1.2 Proposed Solutions from Airlines

Building on the identified challenges, the airlines proposed targeted solutions that provide insights for optimizing airspace operations in the Lan–U region and enhancing the resilience of the route network. These recommendations can be summarized into five areas.

1. Optimization of Airspace Resource Allocation and Expansion of the Route Network

In response to frequent route restrictions in the Lanzhou–Urumqi FIRs, airlines have recommended pursuing alternative airspace resources. The Ulaanbaatar FIR, adjacent to the Lan–U region, presents strong potential for new route development. Airlines propose establishing routes within Mongolian airspace to utilize its resources and alleviate traffic pressure in the Lan–U region. Specific route proposals are as follows:

(1) Development of a backbone route traversing Mongolia from east to west

The flights operating between East Asia (e.g., Tokyo, Seoul, Beijing) and destinations in Central Asia and Europe predominantly utilize the Lan–U corridor, exiting via the SARIN boundary point. To address frequent closures of the Lan–U corridor and mitigate traffic congestion, it is proposed to establish new routes within Mongolian airspace connecting the eastern China-Mongolia boundary points (POLHO, INTIK, NIXAL) with the western boundary point (TEBUS), thereby creating an alternative corridor to the Lan–U route. Additionally, establishing connecting routes between TEBUS and SARIN within Urumqi FIR will reduce flight distance between these points. The proposed routes are illustrated in green in Figure 3.1. Compared to existing routings, the proposed routes offer shorter flight distances and are expected to be less susceptible to airspace closures in Mongolian airspace. If successfully implemented, these routes would provide airline dispatchers with greater routing flexibility, resulting in reduced fuel consumption, improved on-time performance, decreased pilot workload, enhanced operational flexibility within the Lanzhou–Urumqi FIRs, and increased airspace capacity.

(2) Alternative routings for flights from southern China

For flights to the SARIN point from Hong Kong, Guangzhou, and Chengdu, some airlines have proposed a route connecting the MORIT China-Mongolia boundary point to TEBUS within Mongolian airspace (illustrated by the brown route in Figure 3.1). This alternative routing option aims to mitigate the impact of potential route closures within the Lanzhou–Urumqi FIRs, thereby enhancing route flexibility.

(3) New China-Mongolia boundary point and associated routes

Numerous flights from East Asia utilize the RULAD, KAMUD, and PURPA boundary points for entry and exit via Urumqi FIR. Considering the operational requirements for arrivals and departures at Urumqi Airport, some airlines have proposed establishing a new boundary point at the China-Mongolia border (coordinates 4433N09419E), provisionally designated TSEEL. It is further proposed to develop routes within Mongolian airspace connecting this point to POLHO, INTIK, NIXAL, and MORIT, as well as a route within Chinese airspace connecting this point to the ADPET navigation aid (as illustrated by the blue routes in Figure 3.1). These enhancements would expand available routing options and strengthen the regional route network structure.

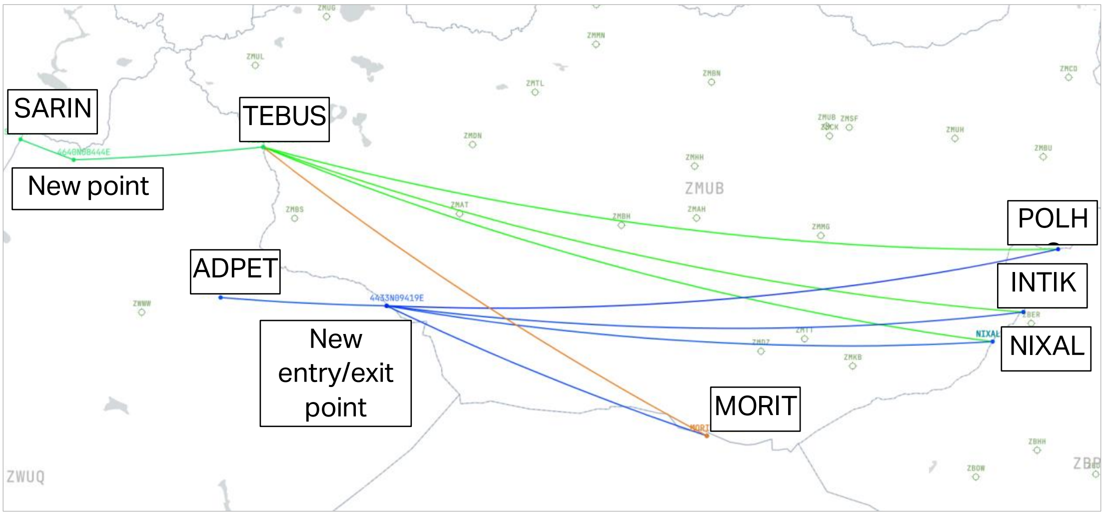

Figure 3.1 Proposed New Routes by Airlines

2. Enhanced Infrastructure Support Along the Newly Developed Routes

Airlines recommend conducting a concurrent assessment of supporting infrastructure when planning new routes, particularly the availability of adequate alternate aerodromes for emergencies. For proposed new routes within Mongolian airspace, Chinggis Khaan International Airport (ZMCK/ZMUB) in Ulaanbaatar is suggested as the primary alternate, with ZMAT and ZMKD considered as additional emergency alternates. This approach enhances safety margins and contingency response capabilities for operations on the new routes.

3. Earlier Issuance of NOTAMs

In response to challenges posed by late-issued NOTAMs that compress flight planning timelines, airlines recommend issuing NOTAMs at least 24 hours in advance. In exceptional circumstances where this is not feasible, a minimum lead time of 15 hours should be observed. This allows dispatchers sufficient time to adjust flight plans, improving the predictability and regularity of flight operations.

4. Simultaneous Provision of Alternative Route Information with Route Closure Notices

The airlines recommend that NOTAMs announcing route closures include information on available alternative routings to assist airline dispatchers in identifying suitable alternatives when specific route segments are closed. This would support airlines in making informed route selection decisions.

5. Simplify airline procedures for rerouting requests.

When flights must be rerouted due to airspace closures, airlines are typically required to submit individual rerouting applications to air traffic control authorities and await approval. This process not only increases the workload for operations teams but also reduces response efficiency. Airlines recommend strengthening information-sharing between airspace management and flight planning approval departments, and streamlining rerouting application procedures. This would shorten decision-making and execution time for rerouting, thereby improving the predictability and flexibility of flight operations. Specific measures proposed include:

(1) Where a NOTAM already specifies a clear alternative route, flight planning approval authorities should grant default approval for affected flights to use that route, without requiring airlines to submit separate applications or await further clearance.

(2) The simplified rerouting model used by Chinese civil aviation during typhoon conditions should be adopted as a reference. Under this model, when a specific airspace is closed, the ANSP coordinates with airspace users to pre-identify available backup routes, enabling airlines to autonomously select and use those routes based on their operational needs without reapplying to ATC authorities.

6. Strengthened China-Mongolia Coordination Mechanisms and Enhanced Contingency Response Capabilities

For Chinese airlines operating domestic services, flights transiting Mongolian airspace and diverted to Mongolia due to emergencies face a challenge: passengers do not possess exit visas and encounter immigration issues upon entry. Some airlines recommend strengthening bilateral coordination mechanisms between China and Mongolia, in conjunction with the development of new routes, to establish protocols for handling such exceptional situations and thereby address operational challenges.

In summary, proposed solutions can be categorized into three areas: optimizing the route network structure, enhancing airspace operational flexibility, and improving information notification and approval mechanisms. Establishing new routes within Mongolian airspace would shorten flight distances, reduce fuel consumption, and circumvent the risk of airspace restrictions in the Lan–U region, thereby improving on-time performance and operational efficiency. Adding new China-Mongolia boundary points and associated routes would enrich the regional route network and enhance operational resilience. Improvements in NOTAM management would provide dispatchers with adequate decision-making time, thereby enhancing the safety and smoothness of flight operations.

3.1.3 Key Considerations for Implementing Airline Proposals

From the airlines' perspective, their shared objectives center on securing shorter flight distances, a broader selection of routing options, a stable operating environment, fewer airspace restrictions, and enhanced coordination and communication mechanisms. In advancing the implementation of these proposals, airlines have identified several key matters requiring clarification:

- **Feasibility assessment of the new routes and entry/exit point:** A systematic analysis should evaluate the operational benefits and potential impacts of the proposed new routes and additional entry/exit points relative to the existing route structure. This assessment should clarify the specific benefits or challenges these enhancements present to each stakeholder group, including airlines, ANSPs, and States.
- **Fundamental operational conditions for the new routes:** A comprehensive evaluation of terrain characteristics, meteorological conditions, and CNS coverage along proposed routes is necessary to ensure that safety margins meet operational requirements.
- **Available flight levels and dynamic allocation rules:** The range of flight levels available on each route segment should be clearly defined, along with mechanisms for dynamic allocation. This would help prevent route congestion or deviations caused by flight level restrictions and ensure adequate longitudinal separation and operational efficiency.
- **Alignment of new route capacity with ANSP capabilities:** A rigorous assessment should determine whether the capacity of proposed new routes will accommodate growing traffic demand, considering ANSP capabilities and the precision of navigation aids.
- **Alternate aerodrome capabilities:** The capabilities of alternate aerodromes along new routes should be established, including runway conditions, navigation aids, rescue services, and fuel supply capacity to address emergency situations.
- **Cross-border coordination and information-sharing mechanisms:** An evaluation should examine whether coordination and information exchange between ANSPs, airports, and airlines across different States function effectively and whether airspace status and operational restriction information can be shared promptly to facilitate seamless cross-border operations.

- **Mechanisms for addressing special operational scenarios involving Chinese airlines:** For Chinese airlines operating domestic services that transit Mongolian airspace, a key concern arises during emergency diversions to Mongolia, where passengers may face entry barriers owing to the lack of exit visas. It is recommended that bilateral coordination mechanisms between China and Mongolia be strengthened to establish contingency protocols for such exceptional situations, thus alleviating airlines' operational concerns.

3.2. Challenges and Requirements of ANSPs

3.2.1 Operational Challenges Faced by ANSPs

The project team conducted surveys with ATC units within the Lan–U FIRs to identify the challenges and requirements faced by ANSPs. The main challenges can be summarized under five areas.

1. Reduced operational capacity due to Airspace restrictions

Civil aviation routes in western China often experience partial or full closures of specific flight levels due to competing airspace demands, significantly diminishing airspace availability and constraining capacity enhancement. Air traffic flow management (ATFM) measures are typically implemented following pre-tactical assessments of traffic demand and available capacity, with flow restrictions imposed when capacity is insufficient. Given the frequency of airspace restrictions, the available airspace increasingly struggles to accommodate sustained traffic growth.

2. Increased controller workload due to airspace restrictions

Restricted airspace often necessitates rerouting, adjusting flight levels, or concentrating within a limited range of altitudes, increasing potential conflicts. The dynamic nature of available airspace further compounds this challenge, as controllers must continuously monitor usable airspace while managing traffic sequencing and separation. This complexity elevates controller's workload and psychological demands.

3. Greater complexity in handling contingency situations

In exceptional circumstances, such as technical malfunctions or emergency descents, aircraft may need to deviate from planned routes or occupy additional flight levels. The spatial resources for handling contingencies are constrained by airspace limitations. Controllers frequently coordinate with other airspace users before implementing necessary actions, significantly increasing the difficulty of managing such situations.

4. Increased coordination workload

ATC units must frequently coordinate with other airspace management authorities, adjacent control centers, and various airspace users. This increase in coordination efforts consumes significant time and energy, adding to the controller workload and diminishing overall ATC operational efficiency.

5. Constraints on overall ATC performance improvement imposed by restricted airspace

Fragmented airspace utilization leads to insufficient route flexibility. Constrained by degraded route structures and limited flight-level availability, controllers often prioritize safety assurance, making it difficult to achieve multidimensional performance targets related to efficiency, economics, and environmental protection. This structural contradiction hampers overall improvement in ATC system performance.

In summary, frequent airspace restrictions exacerbate the tension between limited airspace availability and growing operational demand. Operating within constrained airspace resources, ATC units face mounting operational pressure and safety challenges, requiring a balance between maintaining safety margins and improving efficiency. This structural dilemma hampers flight regularity and poses severe challenges to the resilience and flexibility of the ATC system.

3.2.2 Proposed Improvements and Requirements from ANSPs

In response to the challenges outlined above, ANSPs have put forward the following requirements and recommendations for improvement:

1. Optimization of airspace structure to enhance route flexibility

Airspace structures should be optimized by adjusting route orientations and flight-level allocations, and by positioning civil aviation routes away from areas with frequent airspace activity. This will improve airspace utilization efficiency and reduce route restrictions. An optimized airspace structure should provide ANSPs with more usable routes and enhance operational flexibility, ensuring the smooth flow of civil aircraft.

2. Enhancement of multi-party coordination mechanisms to improve coordination efficiency

Coordination among various airspace management authorities and users should be strengthened to enable refined management of airspace restrictions. This will facilitate the acquisition of additional temporal and spatial resources for route availability and enhance collaborative flow management, minimizing the impact of airspace restrictions. Establishing effective coordination mechanisms is encouraged to promote a better understanding among stakeholders of civil aviation operational pressures and to improve situational awareness during coordination processes.

3. Development of standardized control procedures for typical airspace closure scenarios

Standardized control procedures for typical airspace closure situations should be established. Given the frequent changes in airspace resource availability, controllers often improvise control measures based on real-time conditions, compromising their effectiveness and operational performance. By developing clear control procedures in advance, controllers can achieve proficiency through prior familiarization, enabling rapid response and efficient handling during closures, thereby enhancing overall control effectiveness.

4. Release of additional usable airspace to provide maneuvering room during restrictions

During airspace restrictions with high traffic volumes, controllers frequently vector aircraft to take deviation measures. It is recommended that, considering the characteristics of route operating areas, additional usable airspace be released during restriction periods. This will provide controllers with the necessary maneuvering space, ensure buffer zones during exceptional situations, enhance operational flexibility, and alleviate controller workload.

In summary, ANSPs require systematic interventions at multiple levels to address the fundamental contradiction between limited airspace resources and the demand for efficient flight operations: releasing additional airspace resources, improving airspace utilization efficiency, and optimizing operational performance. The recommendations outlined above—encompassing airspace structure optimization, advancement of coordination mechanisms, refinement of standardized control procedures, and unlocking the potential of the route network—aim to enhance airspace operational resilience and ATC service capabilities, laying the foundation for sustained improvements in airspace efficiency.

3.3. Summary of Operational Challenges and Requirements

From the perspective of primary operators, the challenges confronting airlines center on three key areas: operational disruptions, information delays, and a lack of routing alternatives. Frequent airspace closures impact flight regularity, delayed NOTAM issuance provides insufficient time for flight plan adjustments. A critical shortage of viable alternative routes severely constrains operational flexibility. Collectively, these factors contribute to increased flight delays, higher fuel consumption, and elevated operating costs, placing significant pressure on airline operations and economic performance. For ANSPs, challenges include capacity saturation, workload intensification, and coordination complexity. Frequent airspace restrictions reduce available capacity, requiring controllers to maintain continuous monitoring and frequent adjustments within a dynamically changing airspace environment, leading to increased workloads. The compressed maneuvering space during contingency situations, along with a surge in coordination activities, further exacerbate operational pressure. ANSPs confront a difficult systemic trade-off between maintaining safety margins and enhancing operational efficiency.

From a systemic perspective, these challenges indicate a fundamental contradiction: the supply and reliability of available route resources fall short of meeting operational demand. The Lan–U route, a critical node along the Eurasian air corridor, continues to grow in strategic importance, with rising traffic demand. However, constrained by terrain, airspace structure, and civil-military coordination requirements, available route resources remain concentrated, leading to a critical shortage of viable alternatives. This structural weakness has eroded the resilience and flexibility of the airspace system and is identified as the underlying cause of the current operational predicament.

Despite differing operational perspectives, airlines and ANSPs align in their core requirements: the need to expand route resources, enhance airspace flexibility, and improve operational predictability. Airlines call for greater route selection and more adequate planning time, while ANSPs seek optimized airspace structures and more efficient coordination mechanisms. Developing new and reliable alternative route resources has thus emerged as a fundamental solution sought by both parties.

4. Solutions

4.1. Potential Solutions

Based on the analysis of the operational situation and challenges along the Lan–U corridor, and considering recommendations from airlines and ANSPs, this section systematically examines and evaluates potential solutions. These measures aim to mitigate airspace efficiency issues stemming from route resource constraints and frequent airspace closures. Each option is assessed in terms of its underlying logic, expected benefits, feasibility, and limitations, to identify the optimal strategic path forward through comprehensive comparison.

4.1.1 Development of New Routes Within Lan–U FIRs

The most direct approach to increasing the diversity of route options is to develop new diversionary or temporary routes within the existing Lan–U FIRs, to serve as alternatives in the event of main route closures. By combining newly developed alternative routes with simplified approval procedures for using those routes and well-established flight diversion mechanisms, flights can be systematically transferred to alternatives during primary route closures. This would enrich the route network and enhance the supply of available routes, thus improving system redundancy. Consequently, when a particular route is closed, flights would still have access to efficient routing options, strengthening the operational resilience of the overall airspace system. This approach could, in theory, alleviate congestion. In conjunction with improved service strategies, it could effectively ease traffic pressure.

However, an assessment of its feasibility reveals meaningful geographical and airspace structural constraints. As shown in Figure 4.1, the east-west route corridor in Lanzhou FIR is severely constrained by the terrain of the Qinghai-Tibet Plateau and various existing restricted areas, leaving very limited usable airspace resources. The southern part of Urumqi FIR is similarly constrained by features such as the Taklamakan Desert. Developing new routes that meet safety standards in these regions presents significant technical challenges. The northern part of Urumqi FIR appears to offer the only realistic potential for new route development.

Consequently, this approach is further limited by terrain, existing airspace structures, and China's airspace utilization requirements. The room available for new route planning is inherently restricted, and implementation barriers are high. Moreover, airspace closures in the Lan–U region frequently affect entire zones simultaneously, manifesting as "area-based" rather than "single-route" closures. New routes developed within the same geographical and airspace management environment would likely fall under the same NOTAMs, rendering them unavailable precisely when alternatives are most needed. These factors make full implementation of this solution considerably challenging.

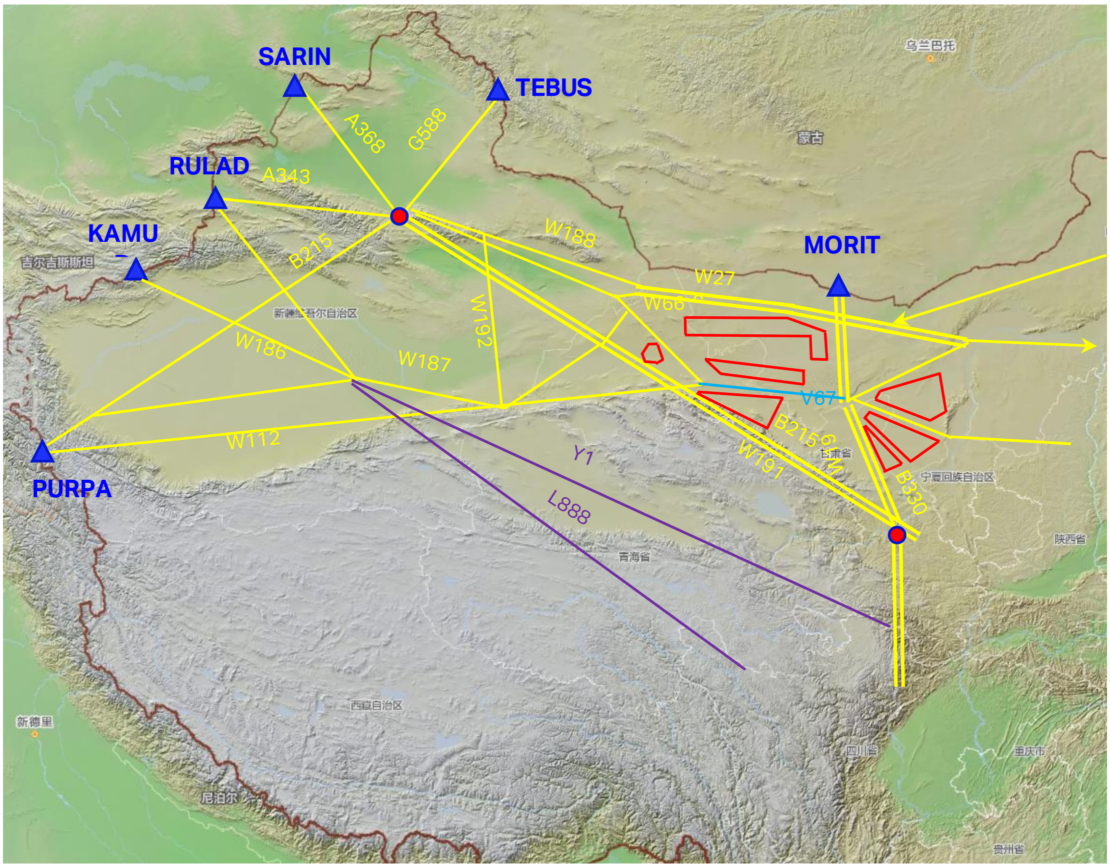

Figure 4.1 Terrain Map of the Lan–U Region

4.1.2 Optimization NOTAM Issuance and Alternative Route Information Services

One pressing concern in current operations is the delayed issuance of NOTAMs announcing airspace closures, which compresses the decision-making window for airline dispatch departments. The proposed solution advocates improving airspace management by issuing closure information earlier and, where possible, providing officially recommended alternative routings simultaneously. This approach enhances information services, securing additional time for pre-tactical decision-making and improving the quality of flight planning.

This solution does not require physical modifications to airspace structures; it focuses on optimizing administrative and information processes. It is technically straightforward to implement and aligns with industry efforts to enhance the timeliness and accuracy of aeronautical information, rendering it highly feasible.

Expected benefits include mitigating the secondary impacts of insufficient decision time and unclear route availability for dispatchers. It would provide airlines and controllers with greater response time, effectively reducing unplanned flight adjustments caused by late-issued NOTAMs. By offering clearer guidance and alternative routing options, it would minimize ad-hoc decision-making and confusion, contributing to improved flight punctuality, enhanced ATC coordination efficiency, greater operational predictability, and reduced decision-making pressure and risk.

However, this solution has inherent limitations. While it alleviates short-term decision pressure, it remains constrained by the fundamental shortage of alternative route capacity. It optimizes information flow but does not increase underlying airspace resources. When a route is closed, officially recommended alternatives are limited to the existing route network. Consequently, issues such as lengthy detours and high operating costs cannot be fundamentally resolved. The airspace structure of the Lan–U corridor illustrates that the Lan–U region—particularly the Lanzhou FIR—has limited route options. When a major route is closed, the available alternatives are extremely limited, and those that do exist may require significant detours, leading to a substantial increase in both flight distance and fuel consumption. This solution cannot address the fundamental lack of route redundancy caused by geographical and airspace structural constraints. It does not create new air passages, so its contribution to enhancing overall capacity and long-term resilience of the Lan–U corridor remains limited.

4.1.3 Strengthening Civil-Military Coordination to Enhance Airspace Flexibility

This approach aims to improve dynamic airspace management through enhanced real-time coordination between civil and military air traffic control authorities. The objective is to enable more responsive, demand-driven temporary release or sharing of airspace resources. Specific measures may include dynamic activation of temporary routes or precise reduction of the duration and scope of restricted airspace, thereby unlocking latent capacity within the existing physical network. By optimizing the use of existing infrastructure rather than constructing new facilities, this solution enhances airspace utilization efficiency and activates dormant capacity where feasible, providing flexible control options for contingency management. It alleviates short-term, localized peak traffic pressures and serves as an effective tactical tool for rapid responses to airspace constraints arising from temporary activities.

However, the timing, scope, and duration of released airspace are highly unpredictable, preventing airlines from incorporating such temporary arrangements into medium- or long-term flight planning and crew scheduling. This approach therefore cannot systematically enhance the planned reliability of the route network. Each ad-hoc, non-routine airspace release incurs substantial communication and decision-making overhead, making it unsuitable as a basis for routine, large-scale traffic diversion. Its practical application is confined to short-term, tactical traffic management scenarios.

4.1.4 Development of Alternative Routes in Mongolian Airspace

The analysis demonstrates that solutions confined to the Lan–U region face certain limitations. Addressing these challenges effectively requires looking beyond the immediate area to the broader regional airspace network. This proposal advocates planning and developing new strategic routes within Mongolian airspace (ZMUB FIR), located north of China, to serve as an alternative corridor to the Lan–U route. This approach would introduce external resources into the network by establishing a cross-border backup route system.

The proposal responds to strong demands expressed by several international airlines during stakeholder consultations and has strong industry support. It provides a geographically distinct alternative for Eurasian air traffic, creating an independent backup corridor capable of systematically alleviating constraints in the Lan–U region at a strategic level. In the event of large-scale airspace closures, flights could be systematically diverted to the Mongolian corridor, enabling planned traffic redistribution. Furthermore, routes through Mongolian airspace would shorten flight distances and times for certain city pairs, yielding meaningful fuel savings, reduced carbon emissions, and optimized operating costs for airlines.

A preliminary feasibility assessment indicates that Mongolian airspace is vast and currently experiences relatively low traffic volumes, offering the capacity to accommodate new routes. Its airspace structure faces fewer constraints, providing geographical viability for new route planning. However, infrastructure development and associated communication, navigation, and surveillance (CNS) capabilities in the region may require further investment and close coordination with Mongolian authorities. In addition, the successful implementation of this proposal depends on bilateral technical coordination between China and Mongolia, requiring a relatively lengthy development timeline. Both parties may need to undertake targeted upgrades to certain ground-air communication and surveillance facilities, involving initial capital investment. While this proposal has the potential to alleviate the challenges facing the Lan–U region, its realization will necessitate substantial coordination efforts and investment in infrastructure development.

4.1.5 Comparative Assessment of Potential Solutions

The key dimensions of the four proposed solutions are compared in Table 4.1 to highlight the fundamental differences and relative merits of each option.

Table 4.1 Comparative Assessment of Potential Solutions

Dimension	Solution 1: Development of New Routes Within Lan–U FIRs	Solution 2: Optimization NOTAM Issuance and Alternative Route Information Services	Solution 3: Strengthening Civil-Military Coordination to Enhance Airspace Flexibility	Solution 4: Development of Alternative Routes in Mongolian Airspace
Solution Type	Route structure modification (domestic)	Process optimization	Dynamic resource management	Route structure modification (cross-border)
Key Content	Planning new routes within Lan–U airspace	Earlier NOTAM issuance; provision of diversion recommendations	Enhanced real-time airspace sharing and release mechanisms	Planning new routes within Mongolian airspace
Feasibility	Low: constrained by geography and airspace structure	Moderate to high: achievable through administrative measures	Moderate: existing coordination mechanisms can be further optimized	Moderate: resources available, but require international coordination and infrastructure upgrades
Expected Benefits	Directly increases local route supply, though difficult to realize	Addresses information gaps; improves decision-making efficiency and predictability	Unlocks latent capacity; enhances instantaneous capacity; mitigates short-term congestion	Fundamentally strengthens network resilience; provides systemic backup corridor
Key Limitations	Geographical and airspace constraints insurmountable	Does not increase physical route capacity	Outcomes unpredictable; cannot be incorporated into advance planning	Dependent on international coordination; requires investment and involves longer timelines

The comparative analysis indicates that Solution 1 targets the core issue but is rendered unviable by geographical and airspace constraints. Solutions 2 and 3 are primarily operational and managerial enhancements that can improve the operational conditions at the management level and help ease operational pressure, but do not address the fundamental bottleneck of physical resource constraints. Solution 4, by introducing external, independent, and accessible airspace resources, offers a realistic and effective strategic pathway to mitigating the systemic risks of the Lan–U corridor. This solution would not only substantially relieve the operational pressures caused by route congestion and frequent closures but also help lay a solid foundation for the long-term stability and efficiency of the Eurasian air network. It does, however, require a higher level of coordination and resource investment. Overall, while Solutions 1, 2, and 3 can alleviate operational pressure on the Lan–U corridor to a certain extent and have some value for exploration and implementation, their potential to resolve the fundamental issues remains limited. Solution 4, by contrast, demonstrates significantly greater potential to address the current challenges. This study therefore considers the development of new alternative routes in Mongolian airspace as a priority option for resolving the operational difficulties of the Lan–U corridor and focuses its assessment accordingly.

4.2. Overview of the Recommended Solution

4.2.1 Objective of the Solution

The Ulaanbaatar FIR serves as a natural link between East Asia and Central Asia. The airspace offers distinct advantages for civil aviation, including limited military activity, a straightforward airspace structure, and ongoing plans for Free Route Airspace (FRA) implementation. These factors contribute to high airspace availability and operational flexibility. However, the FIR currently lacks a dedicated east-west trunk route for efficient integration with the air route network of western China.

This core objective of the proposal is to address this gap by systematically designing a new east-west route structure within Mongolian airspace that connects key waypoints in China's Urumqi FIR (ZWUQ). The proposed solution aims to enrich the Eurasian route network architecture by providing a reliable, efficient backup corridor when the Lan–U corridor is closed, thereby improving network resilience, capacity, and operational efficiency.

4.2.2 Detailed Description of the Proposed New Routes

The proposed routing scheme comprises three key components: new entry/exit points, a trunk route network within Mongolian airspace, and connecting routes within Chinese airspace, collectively forming an alternative corridor, as illustrated in Figure 4.2. The green routes in the figure represent proposed new routings, serving as alternatives to the existing red route network. The detailed components are as follows:

1. New Key Waypoints

A new entry/exit point is proposed at the China-Mongolia border (coordinates 4433N09419E), provisionally designated TSEEL.

A new navigation point is proposed within China's Urumqi FIR (coordinates 4640N08444E), provisionally designated TEST, to serve as a key domestic node connecting with the Mongolian routes.

2. Route Network Within Mongolian Airspace

Leveraging the planned Free Route Airspace (FRA) environment of Mongolia, the following direct routings are proposed to establish an east-west trunk corridor:

- Routes connecting the eastern border points (POLHO, INTIK, NIXAL) with the western border point (TEBUS) and the new point TSEEL.
- Routes connecting the China-Mongolia border point MORIT with TEBUS and TSEEL.

These routings would maximize FRA benefits by enabling direct flights, significantly reducing distances for east-west traffic traversing Mongolian airspace. The proposed direct routing between MORIT and TSEEL involves multiple crossings of the international border, creating additional coordination requirements for the air navigation service providers involved. Activation of this routing would necessitate further bilateral coordination between China and Mongolia. An alternative approach could eliminate direct route segments and route all traffic entirely within Mongolian airspace, thus avoiding frequent border crossings.

3. Connecting Routes Within Chinese Airspace

Two connecting routes are proposed simultaneously within the Urumqi FIR to ensure the continuity of the new corridor:

- A new route linking TEBUS with the border point SARIN via the proposed navigation point TEST.
- A new route linking the proposed border point TSEEL with the existing navigation point ADPET within Urumqi FIR.

As illustrated in Figure 4.2, the proposed green route network creates a parallel multi-route configuration alongside the existing red trunk routes. The proposed green routes effectively complement the existing route structure, enhancing airspace flexibility and capacity.

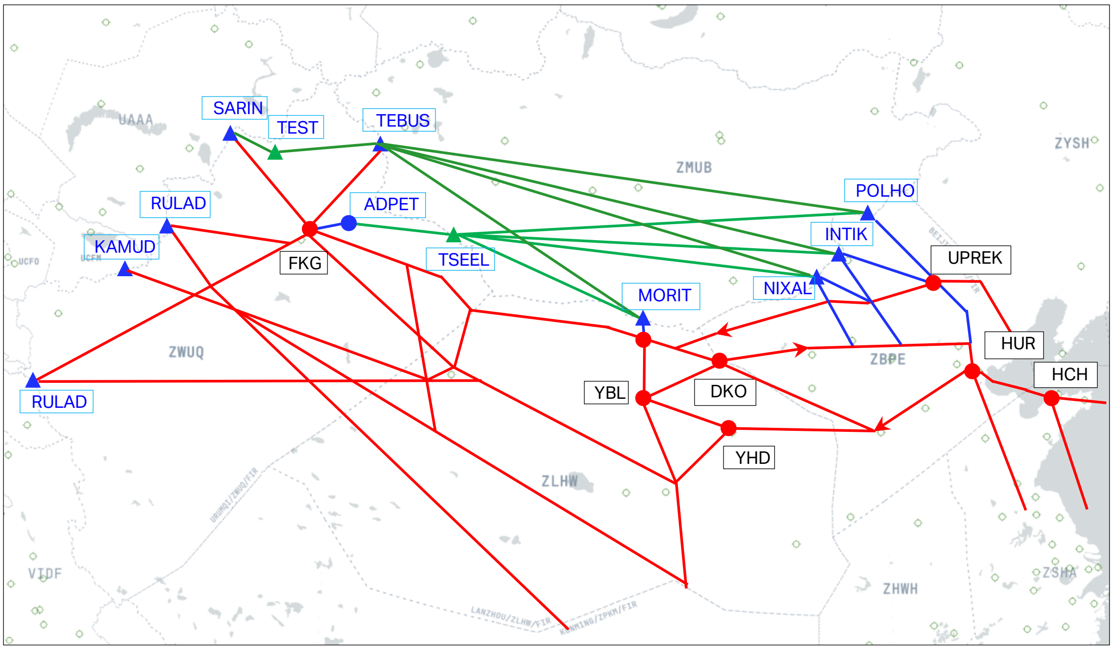

Figure 4.2 Schematic of the Proposed New Route Network Structure

4.2.3 Advantages and Value of the Proposed Solution

The value of this proposal manifests two levels: systemic enhancement of network resilience and direct operational benefits.

At the systemic level, the proposed route network establishes a strategically positioned backup corridor, independent of the complex Lan–U airspace environment. In the event of large-scale route closures within the Lan–U region, this corridor would be immediately available to absorb diverted traffic, ensuring the continued flow of Eurasian air traffic and significantly enhancing the resilience and risk mitigation capacity of the entire regional airspace system.

At the operational level, the proposed new routes will deliver tangible benefits. The distances of the proposed route segments are presented in Table 4.2. These segments offer the potential for significant reductions in flight distances, particularly for services operating via Beijing FIR and Urumqi FIR, where reductions are most pronounced. For example, flights bound for the SARIN point via UPREK can utilize the proposed routing via INTIK and TEBUS to reduce the flight distance by approximately 231 kilometers (125 nautical miles). This results in advantages such as reduced flight time, enhanced operational efficiency, lower emissions, and alleviated traffic pressure on Beijing, Lanzhou, and Urumqi FIRs. Route optimization not only shortens distances but also reconfigures airspace resources. Enriching the route network provides greater freedom for flight operations and improves overall operational reliability and connectivity. These proposed new routes are a key measure to address the operational challenges currently faced by stakeholders in the region.

Table 4.2 Distances of Proposed New Route Segments

No.	Route Segment	Distance
1	POLHO-TEBUS	1780KM (960.9NM)
2	INTIK-TEBUS	1719KM (928.2NM)
3	NIXAL-TEBUS	1663KM (897.8NM)
4	MORIT-TEBUS	1145KM (618.4NM)
5	POLHO-TSEEL	1498KM (809NM)
6	INTIK-TSEEL	1408KM (760.4NM)
7	NIXAL-TSEEL	1337KM (722.1NM)
8	MORIT-TSEEL	744KM (401.7NM)
9	TEBUS-SARIN (via TEST)	586KM (316.3NM)
10	ADPET-TSEEL	368KM (198.7NM)

4.3. Feasibility Assessment of the Proposed Mongolian Route Scheme

From a geographical and airspace structure standpoint, developing new routes within Mongolian airspace effectively reduces cross-border flight distances and addresses current operational challenges. Successful implementation depends on several factors, including Mongolia's airspace planning framework, air navigation service capabilities, progress in CNS infrastructure development, and effective coordination between China and Mongolia. To assess the feasibility of establishing new routes in Mongolian airspace, the project team conducted an on-site visit to Mongolia, engaging in discussions with the Civil Aviation Authority of Mongolia, the National Air Navigation Services Center (NCAC), and Chinggis Khaan International Airport. These discussions focused on airspace operational requirements, current air traffic control capabilities, and infrastructure development plans. This section provides a systematic overview of the findings, structured around four key themes: airspace utilization planning, infrastructure development, air navigation services, and coordination mechanisms.

4.3.1 Airspace Planning

The Civil Aviation Authority of Mongolia has expressed strong support for the IATA-proposed route, recognizing its potential to enhance the utilization of Mongolian airspace and improve flight operations' efficiency. The Mongolian authorities are favorably disposed toward developing new routes and have indicated their willingness to advance the necessary work. Mongolia follows a standard procedural sequence: project initiation, safety assessment, infrastructure development, and policy formulation. Consultations with China's civil aviation authorities will be required regarding the establishment and operational details of the proposed entry/exit points. Preliminary plans have been developed for the new routes and the additional entry/exit point at TSEEL, with implementation proceeding in stages.

Regarding airspace utilization, Mongolia has formulated a Free Route Airspace (FRA) implementation plan, approved by the Civil Aviation Authority of Mongolia in 2024 (as shown in Figure 4.3). The progressive implementation of this plan will enable more flexible route operations within Mongolian airspace, significantly enhancing flight path selection flexibility and overall operational efficiency. It also provides an important foundation for the new route proposal under consideration.

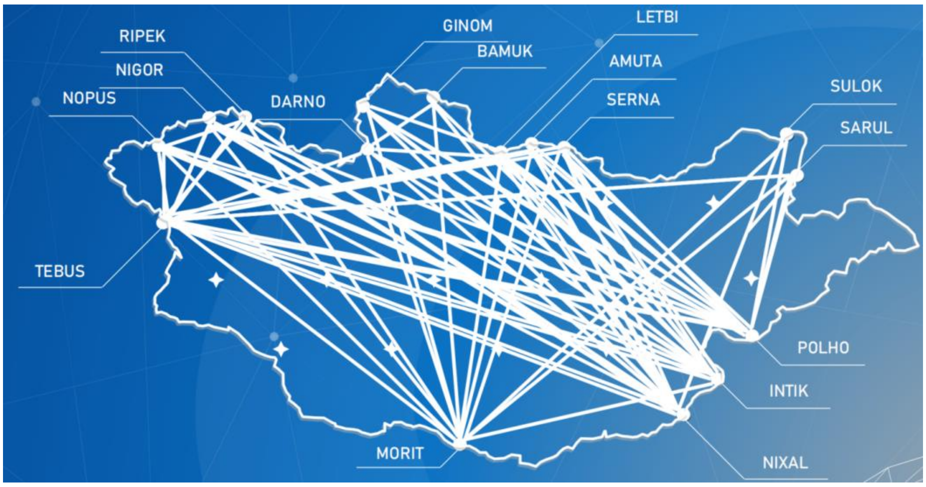

Figure 4.3 Free Route Airspace Implementation Plan of Mongolia[10]

Further Requirement: Establish a dedicated task force to coordinate and advance new route development, including feasibility studies, implementation of the FRA plan, and construction of the proposed entry/exit points.

4.3.2 Infrastructure Development in Mongolia

Mongolia has been upgrading its communication, navigation, and surveillance (CNS) and airport infrastructure. The current status of development in each area is as follows:

Communications. A total of 21 remote air-ground communication stations has been established across the Ulaanbaatar FIR, ensuring reliable air-ground communication coverage throughout the FIR.

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[10] Source: NCAC

Figure 4.4 Distribution and Coverage of Communication Infrastructure in Mongolia[11]

Navigation. Mongolia has installed 10 NDBs, 4 VOR/DME stations, and 14 DME stations, providing basic navigation coverage across the Ulaanbaatar FIR. With most flights operating using satellite-based navigation, complemented by existing ground-based NAVAIDs, Mongolia possesses adequate navigation infrastructure.

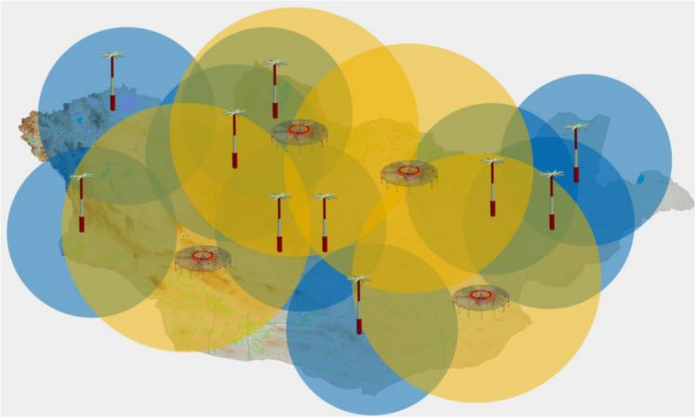

Figure 4.5 Distribution and Coverage of Navigation Infrastructure in Mongolia[12]

Surveillance. Secondary surveillance radar (SSR) coverage extends to approximately 80% of Mongolian airspace, with only the westernmost region lacking SSR coverage. However, ADS-B ground stations have been deployed throughout the FIR, ensuring comprehensive surveillance coverage, as illustrated in Figure 4.6.

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[11] Source: NCAC

[12] Source: NCAC

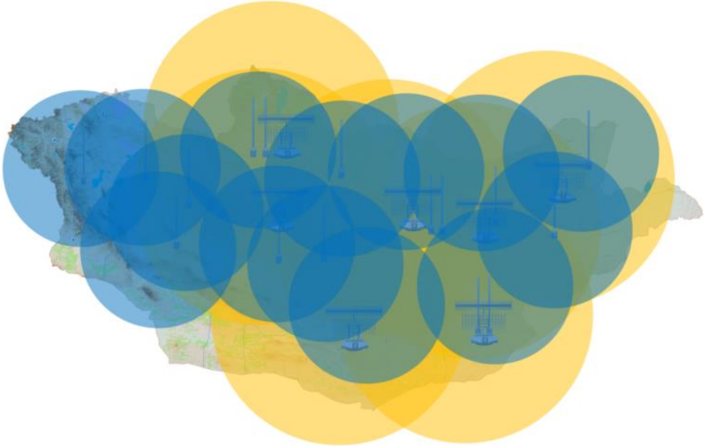
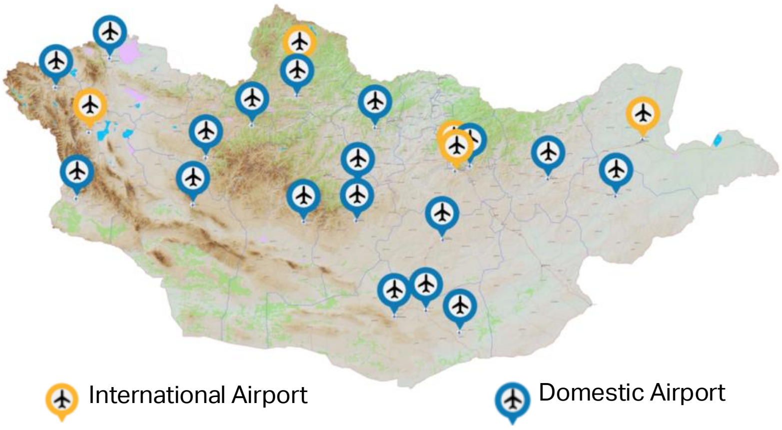


Figure 4.6 Distribution and Coverage of Surveillance Infrastructure in Mongolia[13]

Airport Infrastructure. Mongolia has five international airports and 18 domestic airports, with the distribution shown in Figure 4.7. Chinggis Khaan International Airport in Ulaanbaatar serves as the primary hub, handling most international flight operations, while the remaining airports primarily accommodate domestic traffic.

Chinggis Khaan International Airport is classified as a 4E international airport. It features a 3,600-meter-long by 45-meter-wide runway, with ILS approaches available on Runway 11 and visual approaches on Runway 29. The airport is equipped with 18 aircraft stands, including six with jet bridges, supporting wide-body aircraft operations. Its daily handling capacity is approximately 85 flights, with a peak hour capacity of 17 movements. For emergency response, the airport maintains ICAO Category 9 firefighting and rescue facilities, including three fire trucks, one ambulance, and a medical room equipped with basic first-aid supplies. Although no hotel facilities currently exist nearby, construction plans are in place. In case of delays or emergencies, passengers can be transferred to hotels in the city center, approximately 20–30 minutes away by road. The airport has established standard emergency response procedures.

The availability of suitable alternate aerodromes is critical for operations on newly developed routes. Given the current status of airport infrastructure in Mongolia, Chinggis Khaan International Airport (ZMCK) in Ulaanbaatar should serve as the primary alternate aerodrome under normal circumstances, while the remaining airports are designated for emergency contingencies.



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[13] Source: NCAC

Figure 4.7 Distribution of Airports in Mongolia[14]

Further Requirements:

(1) Continue to progressively upgrade CNS infrastructure, emphasizing enhanced surveillance coverage and reliability, particularly in the westernmost region where capabilities need strengthening.

(2) Selectively upgrade service capabilities at specific representative airports to expand the pool of available alternate aerodromes for en-route operations.

4.3.3 Air Navigation Services

Mongolia operates a single area control center (ACC) in Ulaanbaatar, responsible for six Class A airspace areas from 6,150 meters to 14,600 meters, organized into six operational sectors (see Figure 4.8). Air traffic services across the FIR are provided centrally by this ACC. The five eastern sectors currently operate under radar control, while the westernmost sector lacks secondary surveillance radar coverage and relies solely on ADS-B surveillance, thus remaining under procedural control.

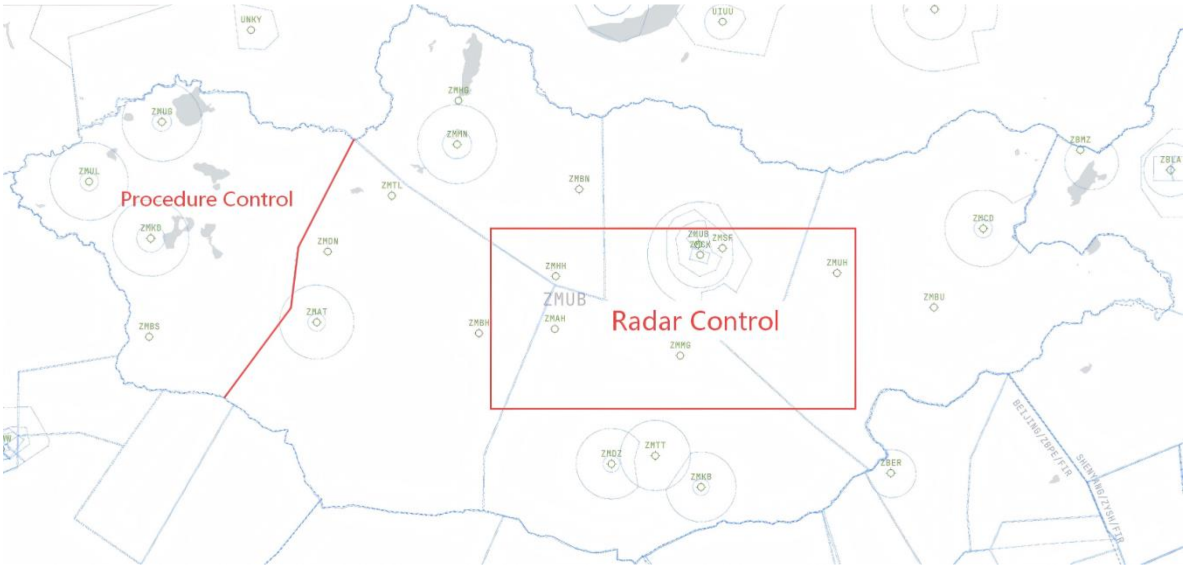

Figure 4.8 Sector Configuration of Mongolia's Area Control Center

Airspace Capacity. In radar-controlled sectors, longitudinal separation is reduced to 20–30 kilometers (equivalent to 2 minutes), vertical separation is standardized at 300 meters per flight level, and minimum horizontal separation is 10 kilometers. These reduced separation minima have significantly enhanced airspace capacity. In the procedural control sector, however, longitudinal separation is maintained at 10 minutes. The proposed TEBUS entry/exit point—a critical node in the new route scheme—sits on the boundary of this procedural sector. If this sector continues under procedural separation standards, it will constrain the capacity of the new route network.

Controller Workforce. Mongolia has approximately 120 area controllers, all qualified and holding ICAO English Language Proficiency Level 4, capable of providing air traffic services for international flights. However, the

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[14] Source: NCAC

proposed new route network will increase traffic volumes, elevating controller workloads and creating a demand for additional controllers and competencies.

Further Requirements:

(1) Prioritize infrastructure development in the westernmost sector to transition from procedural to radar control, substantially increasing airspace capacity to accommodate expected traffic demand following the opening of the new routes.

(2) Strengthen controller workforce planning through recruitment and training initiatives to ensure adequate capacity and capability to manage sustained future growth in flight operations.

4.3.4 Coordination Mechanisms

The implementation of the proposed new route scheme requires collaboration between the civil aviation authorities of Mongolia and China. Established mechanisms for bilateral cooperation are in place. The Civil Aviation Authority of Mongolia has initiated coordination with China's civil aviation authorities regarding the development of new routes and entry/exit points. Concurrently, IATA has been facilitating dialogue and cooperation to advance the operationalization of the proposed routes and entry/exit points.

Regarding control transfer procedures, the Ulaanbaatar FIR has established AIDC-based transfer mechanisms with both the Beijing ACC and the Lanzhou ACC, enhancing the efficiency of cross-border coordination. However, the continued reliance on procedural control in Mongolia's westernmost sector has prevented the establishment of a similar mechanism with Urumqi ACC. This gap may constrain the efficient handling of high traffic volumes on the proposed routes.

Further Requirements:

(1) Strengthen coordination between the civil aviation authorities of China and Mongolia, deepening consultations on operating standards for the new routes, procedures for the proposed entry/exit points, and associated interface mechanisms.

(2) Facilitate the transition to radar control in Mongolia's westernmost sector and establish an AIDC-based transfer mechanism with Urumqi ACC to enhance the overall efficiency of cross-border airspace operations.

4.4. Feasibility Assessment of the Proposed New Routes within China

In addition to the new routes proposed within Mongolian airspace, the recommended scheme includes the development of two connecting route segments within China's Urumqi FIR: one linking TEBUS to SARIN and another connecting TSEEL to ADPET. An assessment of infrastructure and service capabilities within Urumqi FIR indicates that the areas traversed by these proposed routes feature relatively flat terrain, stable airspace conditions, and robust regional development, all of which are favorable for new route development. These areas are equipped with adequate infrastructure and possess sufficient human resources and air traffic service capabilities. The development of these new route segments within China is considered highly feasible.

During the consultation process, several air traffic control experts offered optimization suggestions for the proposed routings, as illustrated in Figure 4.9. The yellow lines represent the originally recommended routes, while the green lines depict the alternative alignments proposed by the experts. Specific suggestions include:

- For the recommended TEBUS–SARIN connection, experts proposed adjusting the routing to TEBUS–OSUPO, retaining SARIN solely as an entry/exit point rather than as a route intermediate point where two routes diverge. This adjustment would facilitate more efficient transfer coordination and separation management, enhancing the operational feasibility of ATC services.

- For the proposed TSEEL-ADPET connection, experts identified a potential conflict between traffic on this new route and the high volume of eastbound departures from Urumqi Tianshan Airport near ADPET. They suggested an alternative alignment from a new point (provisionally designated New Point 4) to either ADPET or REDUB to optimize traffic distribution and mitigate potential conflicts.

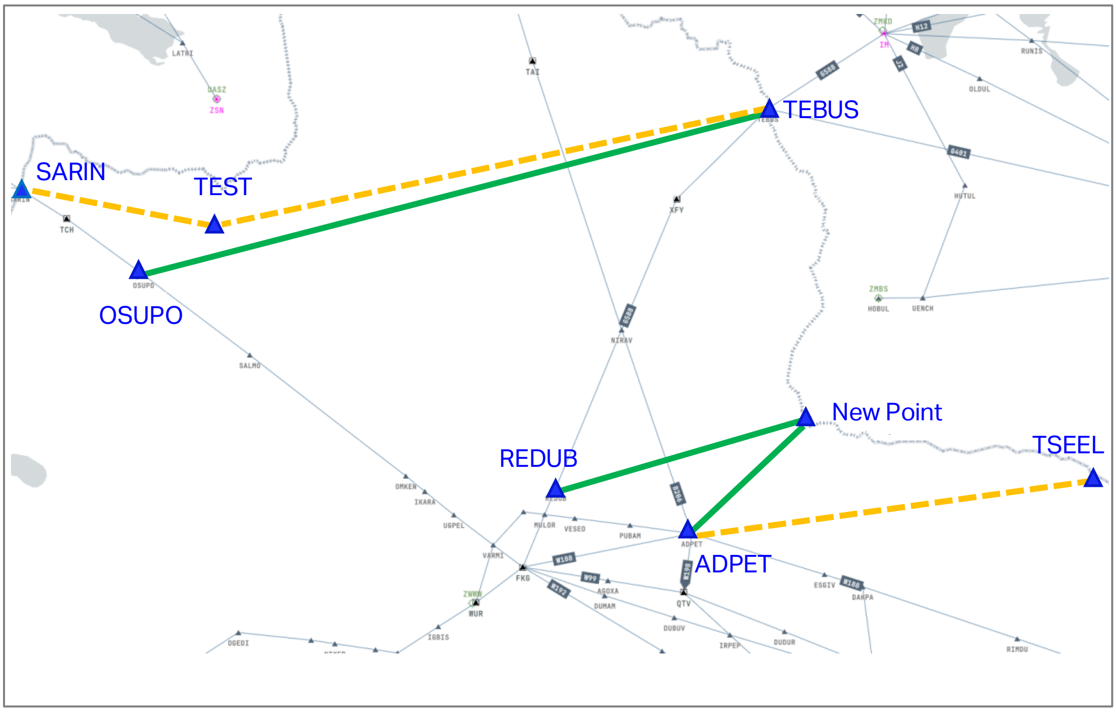


Figure 4.9 Alternative New Route Alignments Proposed by ATC Experts

The expert recommendations outlined above, primarily from an air traffic service perspective, affirm the feasibility of the proposed new routes and provide valuable input for the detailed route design needed for future implementation. This study aims to validate the overall performance trends of the proposed route scheme at a methodological level. The assessment has been conducted based on the most direct geometric alignments, and the optimization suggestions have not been incorporated into the current evaluation. These expert insights will serve as important inputs during subsequent implementation phases, informing refinements and adjustments to the detailed route design.

4.5. Summary of the Proposed New Route Development

The comparative assessment of various options for addressing operational challenges in the Lan–U region shows that the recommended new route configuration offers significant advantages in both geographical and airspace optimization. The proposed routing is expected to reduce cross-border flight distances, enhance operational efficiency, and lower fuel consumption and carbon emissions. Additionally, these new routes would enrich the regional route network structure, providing airlines with greater routing flexibility and strengthening the overall operational resilience of the Eurasian air corridor.

From an implementation standpoint, Mongolia's current airspace planning framework, infrastructure, and air navigation service capabilities support the proposed routes. The Mongolian civil aviation authorities have expressed strong support for the initiative, with the Free Route Airspace plan approved and in progress. CNS infrastructure covers most of the FIR, and the controller workforce is qualified to provide international air traffic services, providing a solid foundation for the proposed scheme.

However, the successful implementation of the new routes depends on sustained collaboration between China and Mongolia. Ongoing bilateral coordination is essential to establish new entry/exit points, harmonize operating standards, and integrate air traffic control procedures to ensure seamless cross-border operations.

The case for the new routes must not rely solely on geographical and network structure arguments. A quantitative assessment based on operational data is essential to accurately evaluate the potential benefits of the proposed scheme and to provide a scientific basis for stakeholder decision-making. Therefore, a data-driven evaluation of airspace efficiency has formed the central focus of this study.

5. Methodology for Performance Assessment

5.1. Key Performance Indicators

To evaluate airspace efficiency improvements from the proposed new routes, a multi-dimensional KPI framework has been developed. The design draws on assessment frameworks from the Global Air Navigation Plan (GANP) of the ICAO, the European Organisation for the Safety of Air Navigation (Eurocontrol), and the IATA. The framework focuses on six core dimensions: airspace operational efficiency, predictability, economic impact, environmental impact, traffic flow, and workload. Specific assessment parameters for each dimension include:

- **Airspace efficiency:** Assessed through indicators like route distance, en-route extension ratio, flight time, and delay time, measuring optimization achieved by the new routes in both physical and temporal dimensions.
- **Predictability:** Evaluated via flight time variability and restriction rate, reflecting the impact of the new routes on operational stability.
- **Economic impact:** Measured by changes in fuel consumption and route charges, assessing the effect of the new routes on airline operating costs.
- **Environmental impact:** Quantified through CO2 emissions, evaluating the contribution of the new routes to environmental sustainability.
- **Traffic flow:** Assessed through traffic volume and diversion rate, indicating the enhancement of airspace capacity enabled by the new routes.
- **Workload:** Evaluated through changes in controller and pilot workload, reflecting the impact of the new routes on operational personnel.

The complete set of KPIs is presented in Table 5.1.

Table 5.1 Key Performance Indicators

No.	Dimension	Indicator	Definition	Unit	Primary Assessment Objective
KPI1	Traffic Flow	Traffic Volume	Number of flights operating on a given route segment	Flights	To assess the level of traffic demand on a route segment
KPI2	Efficiency	Route Distance	Planned distance of the route flown	km, nm	To evaluate route efficiency in terms of distance
KPI3	Efficiency	En-route Extension Ratio	Ratio of planned route distance to the ideal great circle distance	%	To assess the efficiency of flight planning and route design
KPI4	Efficiency	Flight Time	Flight time within a given route segment	min	To evaluate time efficiency and distribution of flight times on a given route

KPI5	Predictability	Flight Time Variability	Distribution of flight times around the mean value	min/flight	To assess the stability of flight operations; greater variability indicates lower predictability
KPI6	Predictability	NOTAM-Induced Delay Rate	Proportion of flights delayed due to NOTAM restrictions	%	To evaluate the likelihood of NOTAM-related disruptions on a given route
KPI7	Efficiency	Average NOTAM-Induced Delay	Average delay per flight caused by NOTAM restrictions	min/flight	To assess the severity of NOTAM-related disruptions
KPI8	Economic/ Environmental	Fuel Consumption	Fuel consumed during flight	kg	To quantify fuel usage as an input for economic and environmental assessment
KPI9	Environmental	CO_2 Emissions	CO_2 emissions resulting from fuel consumption	kg	To evaluate environmental impact
KPI10	Economic	ANS Charges	Charges for air navigation services on a given route	USD	To assess the cost of air navigation services
KPI11	Traffic Flow	Diversion Rate	Proportion of flights diverted from original routes to new routes	%	To indicate the level of traffic redistribution achieved by new routes
KPI12	Workload	Controller Workload	Change in controller workload resulting from flight diversions, expressed as total flight hours within a sector	sector-hours	To evaluate the impact of new routes on controller workload (both China and Mongolia)
KPI13	Workload	Pilot Workload	Change in pilot workload resulting from flight diversions, expressed primarily as total flight time	flight-hours	To assess the impact of new routes on pilot workload

5.2. Data Analysis and Assessment Methodology

5.2.1 Simulated Data

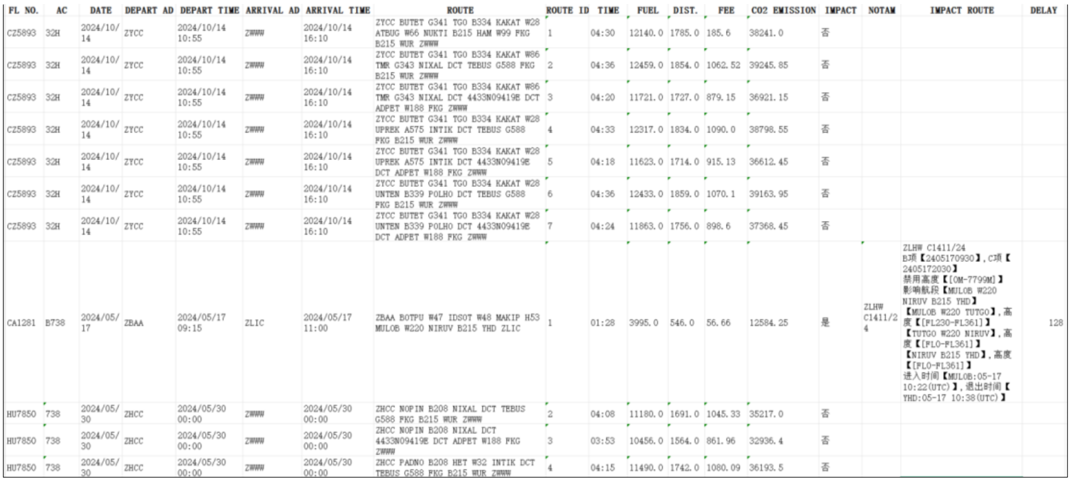
Given the difficulty of obtaining actual flight operational data and the fact that the new routes have not yet entered service, it is not possible to assess the performance of the proposed routes based on real-world data. Therefore, this study employed flight simulation techniques to generate the foundational data required for a data-driven performance assessment. The main steps were as follows:

Step 1: Baseline Data Collection. The project team identified the primary airlines operating along the Lan–U corridor, focusing on the 22 carriers with the highest operational frequency. Flight plan data from these airlines were collected for operations traversing the Lan–U FIRs over the one-year period from 30 March 2024 to 29 March 2025. A total of 6,830 flight plans were obtained, comprising 4,263 international and 1,567 domestic plans. Each flight plan included cyclical information corresponding to flights operating repeatedly across multiple days.

Step 2: Simulation of Original Route Operations. Using the simulation platform developed by NavChina, flight operations were modeled based on key parameters from the flight plans, including operational cycles, schedules, aircraft types, and planned routings. The simulations accounted for various factors, such as NOTAM information, weather conditions (wind speed, direction, and temperature), flight levels, and aircraft type. The simulations were limited to segments within Chinese airspace. Output parameters for each flight included distance, flight time, fuel consumption, route charges, CO_2 emissions, and NOTAM restrictions. Following data cleansing and filtering, a total of 68,256 flights were successfully simulated on their original planned routes.

Step 3: Simulation of Alternative Route Operations. Assuming the proposed new route network is already operational, and with the entry and exit points of flights within Chinese airspace held constant and the requirement that new routes must traverse the proposed Mongolian routes, the simulation system's automatic route search function was used to re-plan route paths for each flight, thereby generating alternative routings. For example, for a flight with an original planned route of "AGAVO A591 IKEKA W4 HCH W200 DOVIV W55 PAMRU W34 VYK B215 LEBOM W104 VEXEB W47 IDSOT W48 DKO W66 NUKTI B215 FKG A368 SARIN," where "AGAVO" and "SARIN" are the entry and exit points within Chinese airspace, all feasible alternative routings through the proposed new routes in Mongolian airspace were identified by the simulation system on the condition that these two points remain unchanged. For each flight, multiple possible alternative routings were generated. Taking into account the influence of weather factors (wind speed, wind direction, and temperature) in the relevant areas, flight operations on these alternative routings were simulated separately. This yielded a total of 797,666 simulated flights on alternative routings.

The format of the simulated output data is illustrated in Figure 5.1, and the definitions of each data field are provided in Table 5.2.



FL NO.	AC	DATE	DEPART AD	DEPART TIME	ARRIVAL AD	ARRIVAL TIME	ROUTE	ROUTE ID	TIME	FUEL	DIST.	FEE	CO2 EMISSION	IMPACT	NOTAM	IMPACT ROUTE	DELAY
CZ5893	32H	2024/10/14	ZYCC	2024/10/14 10:55	ZWWW	2024/10/14 16:10	ZYCC BUTET G341 TGO B334 KAKAT W28 ATBUG W66 NUKTI B215 HAM W99 FKG B215 WUR ZWWW	1	04:30	12140.0	1785.0	185.6	38241.0	否			
CZ5893	32H	2024/10/14	ZYCC	2024/10/14 10:55	ZWWW	2024/10/14 16:10	ZYCC BUTET G341 TGO B334 KAKAT W86 TMR G343 NIXAL DCT TEBUS G588 FKG B215 WUR ZWWW	2	04:36	12459.0	1854.0	1062.52	39245.85	否			
CZ5893	32H	2024/10/14	ZYCC	2024/10/14 10:55	ZWWW	2024/10/14 16:10	ZYCC BUTET G341 TGO B334 KAKAT W86 TMR G343 NIXAL DCT 4433N09419E DCT ADPET W188 FKG ZWWW	3	04:20	11721.0	1727.0	879.15	36921.15	否			
CZ5893	32H	2024/10/14	ZYCC	2024/10/14 10:55	ZWWW	2024/10/14 16:10	ZYCC BUTET G341 TGO B334 KAKAT W28 UPREK A575 INTIK DCT TEBUS G588 FKG B215 WUR ZWWW	4	04:33	12317.0	1834.0	1090.0	38798.55	否			
CZ5893	32H	2024/10/14	ZYCC	2024/10/14 10:55	ZWWW	2024/10/14 16:10	ZYCC BUTET G341 TGO B334 KAKAT W28 UPREK A575 INTIK DCT 4433N09419E DCT ADPET W188 FKG ZWWW	5	04:18	11623.0	1714.0	915.13	36612.45	否			
CZ5893	32H	2024/10/14	ZYCC	2024/10/14 10:55	ZWWW	2024/10/14 16:10	ZYCC BUTET G341 TGO B334 KAKAT W28 UNTEN B339 POLHO DCT TEBUS G588 FKG B215 WUR ZWWW	6	04:36	12433.0	1859.0	1070.1	39163.95	否			
CZ5893	32H	2024/10/14	ZYCC	2024/10/14 10:55	ZWWW	2024/10/14 16:10	ZYCC BUTET G341 TGO B334 KAKAT W28 UNTEN B339 POLHO DCT 4433N09419E DCT ADPET W188 FKG ZWWW	7	04:24	11863.0	1756.0	898.6	37368.45	否			
CA1281	B738	2024/05/17	ZBAA	2024/05/17 09:15	ZLIC	2024/05/17 11:00	ZBAA BOTPU W47 IDSOT W48 MAKIP H53 MULOB W220 NIRUV B215 YHD ZLIC	1	01:28	3995.0	546.0	56.66	12584.25	是	ZLHW C1411/24	ZLHW C1411/24 B项【2405170930】,C项【2405172030】 禁用高度【[0M-7799M]】 影响航段【MULOB W220 NIRUV B215 YHD】 【MULOB W220 TUTGO】,高度【[FL230-FL361]】 【TUTGO W220 NIRUV】,高度【[FL0-FL361]】 【NIRUV B215 YHD】,高度【[FL0-FL361]】 进入时间【MULOB:05-17 10:22(UTC)】,退出时间【YHD:05-17 10:38(UTC)】	128
HU7850	738	2024/05/30	ZHCC	2024/05/30 00:00	ZWWW	2024/05/30 00:00	ZHCC NOPIN B208 NIXAL DCT TEBUS G588 FKG B215 WUR ZWWW	2	04:08	11180.0	1691.0	1045.33	35217.0	否			
HU7850	738	2024/05/30	ZHCC	2024/05/30 00:00	ZWWW	2024/05/30 00:00	ZHCC NOPIN B208 NIXAL DCT 4433N09419E DCT ADPET W188 FKG ZWWW	3	03:53	10456.0	1564.0	861.96	32936.4	否			
HU7850	738	2024/05/30	ZHCC	2024/05/30 00:00	ZWWW	2024/05/30 00:00	ZHCC PADNO B208 HET W32 INTIK DCT TEBUS G588 FKG B215 WUR ZWWW	4	04:15	11490.0	1742.0	1080.09	36193.5	否			

Figure 5.1 Sample of Simulated Output Data

Table 5.2 Description of Simulated Output Data Fields

No.	Field	Description
1	FL NO.	Flight number
2	AC	Aircraft type
3	DATE	Scheduled date
4	DEPART AD	Departure airport
5	DEPART TIME	Scheduled departure time
6	ARRIVAL AD	Arrival airport
7	ARRIVAL TIME	Scheduled arrival time
8	ROUTE	Operated route (within China and Mongolia FIRs only)
9	ROUTE ID	Route identifier
10	TIME	Flight time (within China and Mongolia FIRs only)
11	FUEL	Fuel consumption (within China and Mongolia FIRs only)
12	DIST.	Flight distance (within China and Mongolia FIRs only)
13	FEE	Route charges (within China and Mongolia FIRs only)
14	CO_2 EMISSION	CO_2 emissions (within China and Mongolia FIRs only)

15	IMPACT	Whether the flight was affected by NOTAM restrictions
16	NOTAM	NOTAM reference imposing the restriction
17	IMPACT ROUTE	Route segment affected by NOTAM restrictions
18	DELAY	Delay duration attributable to NOTAM restrictions

5.2.2 Assessment Methodology

To evaluate the potential operational impacts of the proposed new route network, a multi-indicator assessment approach was adopted, utilizing simulated data to analyze changes in operational efficiency, economic performance, environmental impact, and ATC workload. The methodology involves a comparative analysis between original and alternative routings, quantifying the effects of the new route network by measuring changes in key indicators and assessing its impact on controller workload. The assessment presents a comprehensive view of performance outcomes from multiple perspectives, structured around overall performance, representative alternative routes, stakeholder-specific impacts, and traffic flow characteristics.

Prior to the assessment, a data pairing exercise matched original and alternative route operations. First, all simulated data were cleaned to exclude flights unrelated to the Lan–U corridor or lacking operational requirements for alternative routings. For each flight, the data corresponding to its originally planned route were extracted. Next, among the available alternative routings for each flight under the proposed new route network, the shortest flight distance was selected, and its simulated data were paired with the original route data. This process established a baseline dataset for subsequent comparative analysis. The specific assessment components are as follows:

1. Overall Performance

In assessing the overall performance of alternative routings relative to the original routes, the following assumptions were applied:

- For flights where the alternative route distance is shorter than the original route, all such flights were assumed to be diverted to the alternative route.
- For flights where the alternative route distance exceeds the original route, only flights affected by NOTAM restrictions were assumed to divert.

The overall performance was calculated by analyzing the impact of NOTAM restrictions on all flights operating on their original planned routes to determine the NOTAM-induced delay rate (KPI6) and average delay time (KPI7). For all paired flights, differences between original and alternative routings were computed in terms of flight time (KPI4), fuel consumption (KPI8), CO_2 emissions (KPI9), ANS charges (KPI10), controller workload (KPI12), and pilot workload (KPI13). These differences were then aggregated.

2. Performance Assessment of Representative Alternative Routes

Operational routes through the Lan–U airspace were extracted from flight plan data to form a sample set, which was categorized and organized. For each original route segment, corresponding alternative routings were identified to create route pairs. These pairs focused on portions of the original route that could be replaced by the new routes, excluding overlapping segments.

For each route pair, operational performance was evaluated according to the following rules:

- If the alternative route distance was shorter than the original, all flights were assumed to transfer to the alternative routing. The assessment included route information, route distance (KPI2), en-route extension ratio (KPI3), NOTAM-induced delay rate on the original route (KPI6), delay time for affected flights (KPI7), and changes in flight time (KPI4), fuel consumption (KPI8), and ANS charges (KPI10).
- If the alternative route distance exceeded the original, only flights affected by NOTAM restrictions were assumed to transfer to the alternative routing. For these diverted flights, changes in KPI4, KPI6, KPI7, KPI8, and KPI10 were evaluated.

This assessment calculated the changes in key indicators for each flight, illustrating the benefits of the representative alternative routes in terms of flight efficiency, predictability, economic performance, environmental impact, and workload.

3. Stakeholder-Specific Performance Assessment

Using the paired dataset and considering the distinct priorities of various stakeholders, the potential benefits and impacts of the new route network were assessed from the perspectives of Chinese airlines, non-Chinese airlines, China ANSPs, Mongolia ANSPs, and the aviation industry.

- For Chinese airlines, the assessment included overall efficiency gains, fuel savings, changes in route charges, and the net economic impact of fuel savings and route charge variations.
- For non-Chinese airlines, the evaluation focused on overall efficiency improvements, fuel savings, and route charge reductions.
- For China ANSPs and Mongolia ANSPs, the assessment examined changes in route charge revenues, traffic volumes, controller workload, and CO2 emissions.
- For the industry as a whole, the analysis highlighted the new routes' contribution to enhanced operational efficiency, reduced delays, and lower carbon emissions.

By quantifying benefits and impacts for each stakeholder group, this assessment provides data-driven insights to support informed decision-making.

4. Traffic Flow and Diversion Rate Assessment

Based on simulated data, the analysis proceeded in two stages. First, applying the same assumptions—full diversion for flights with shorter alternative routes and diversion only of affected flights for those with longer alternatives—the distribution of traffic across the new route segments was assessed. This indicated potential traffic volumes (KPI1) in Mongolian airspace. Subsequently, considering operational benefits and the route network structure, diversion rates (KPI11) were estimated for the representative routes, offering reference information for both Mongolia ANSPs and airline operational planning.

A summary of the assessment results presented from different perspectives is shown in Table 5.3.

Table 5.3 Assessment Perspectives and Content for Airspace Efficiency Evaluation

Assessment Perspective	Content	Reference KPIs
Overall Performance	NOTAM-induced delay rate and delay time, flight time, fuel consumption, CO_2 emissions, ANS charges, controller workload, pilot workload	KPI6, KPI7, KPI4, KPI8, KPI9, KPI10, KPI12, KPI13

Representative Route Performance		For each representative route: information on original and alternative routes, distance distribution within China and Mongolia airspace, route distance and en-route Extension Ratio for both original and alternative routes, NOTAM-induced delay rate on original route, delay time for affected flights, and changes in flight time, fuel consumption, and ANS charges	KPI2, KPI3, KPI6, KPI7, KPI4, KPI8, KPI10
Stakeholder-specific Performance	Chinese airlines	Operational efficiency, fuel consumption, route charges, and overall economic impact	KPI4, KPI8, KPI9, KPI10, KPI11, KPI13
	Non-Chinese airlines	Operational efficiency, fuel consumption, route charges, and overall economic impact	KPI4, KPI8, KPI9, KPI10, KPI11, KPI13
	China ANSPs	Changes in route charges, traffic volumes, controller workload, and CO_2 emissions	KPI1, KPI8, KPI9, KPI10, KPI12
	Mongolia ANSPs	Changes in route charge revenues, traffic volumes, controller workload, and CO_2 emissions	KPI1, KPI8, KPI9, KPI10, KPI12
	The aviation industry	Improvements in operational efficiency, delay reduction, and CO_2 emissions	KPI4, KPI7, KPI8, KPI9, KPI10
Traffic Flow Characteristics		Overall traffic flow changes, diversion rates, and traffic variations at different waypoints and key routes in Mongolia	KPI1, KPI11

6. Performance Assessment

6.1. Overall Performance

Simulations were conducted for a total of 68,256 flights over the one-year period from 30 March 2024 to 29 March 2025. Simulations were conducted for a total of 68,256 flights over the one-year period from 30 March 2024 to 29 March 2025. For each flight, operations on the originally planned route and diversion to the proposed alternative route were simulated. After data cleansing and filtering, removing flights with incomplete route information or those for which no suitable alternative existed, 46,161 flights were selected as the analysis sample.

Analysis of original route operations revealed that 6,664 flights (14.4%) were affected by NOTAM restrictions, resulting in an average delay of 140.3 minutes per affected flight, with a median of 114.3 minutes.

To assess the overall potential of the new routes, different assumptions based on the change in route distance following diversion were applied.

1. Flights with shorter alternative route distances

Assuming all such flights would divert to alternative routings, a total of 39,456 flights were affected, leading to the following changes in overall performance:

- **Flight time:** Annual total flight time reduced by 4,968 hours.
- **Fuel consumption:** Annual total fuel consumption reduced by 33,530.6 tonnes (approximately 91,865 kg per day).
- **Carbon emissions:** Annual total CO2 emissions reduced by 105,622.8 tonnes (approximately 289 tonnes per day).
- **ANS charges:** Annual total route charges reduced by approximately USD 2,040,908.
- **Operational delays:** Total potential delay time attributable to NOTAM restrictions reduced by 13,084 hours.
- **Controller workload:** Total controller service time reduced by 4,968 sector-hours, comprising a reduction of 72,346 sector-hours for Chinese controllers and an increase of 67,378 sector-hours for Mongolian controllers. This reduction significantly alleviates work pressure and mitigates fatigue risk for Chinese controllers. Although Mongolian controllers would see an increase in service time, the marginal impact on their workload remains relatively limited given their low baseline traffic volume.
- **Pilot workload:** Direct flight time reduced by 4,968 flight-hours. Additionally, waiting time due to NOTAM-induced delays (13,084 hours), which counts as pilot duty time, would be eliminated under the diversion scenario, further reducing pilot workload. The free route characteristics of Mongolian airspace may also simplify flight operations, contributing to further workload reduction.

2. Flights with longer alternative route distances

Assuming only those flights affected by NOTAM restrictions would divert, 6,705 flights on relevant routes were considered, with 1,044 identified as affected and subject to diversion. The resulting changes in overall performance were:

- Total delay time for diverted flights reduced by up to 2,320 hours.
- Fuel consumption for diverted flights increased by 1,630 tonnes.
- Carbon emissions for diverted flights increased by 5,134 tonnes.
- Route charges for diverted flights decreased by approximately USD 32,760.

These findings demonstrate that the proposed new route network significantly enhances operational performance across multiple dimensions, including reduced flight distances and times, lower delays, improved efficiency, reduced fuel consumption and carbon emissions, and alleviated workload for both controllers and pilots. In both absolute values and marginal benefits, the proposed new route scheme offers positive strategic value and practical significance for implementation.

6.2. Performance Analysis of Representative Routes

To illustrate the specific impacts of the proposed new routes on flight operations along the Eurasian corridor, representative flight routes traversing the Lan–U airspace were extracted from simulated flight data for analysis. The analysis focused on segments of the original routes that could be replaced by the proposed new routes, creating paired segments between original and alternative routings while excluding overlapping portions. A total of 18 representative original routes were identified through this process. This section presents a detailed breakdown of the operational performance characteristics for each representative route pair.

6.2.1 Representative Routes with Shorter Alternative Distances

All flights were assumed to divert to the alternative route for representative route pairs in which the alternative route distance is shorter than the original. The resulting changes in operational performance were assessed. For each route pair, a schematic diagram shows the configuration of the original route (in red) and the alternative route (in green), followed by a table that presents the route characteristics and corresponding changes in performance indicators. Positive values in the performance change results indicate an increase in the indicator after switching from the original to the alternative route, while negative values indicate a decrease.

1. **UPREK-SARIN**

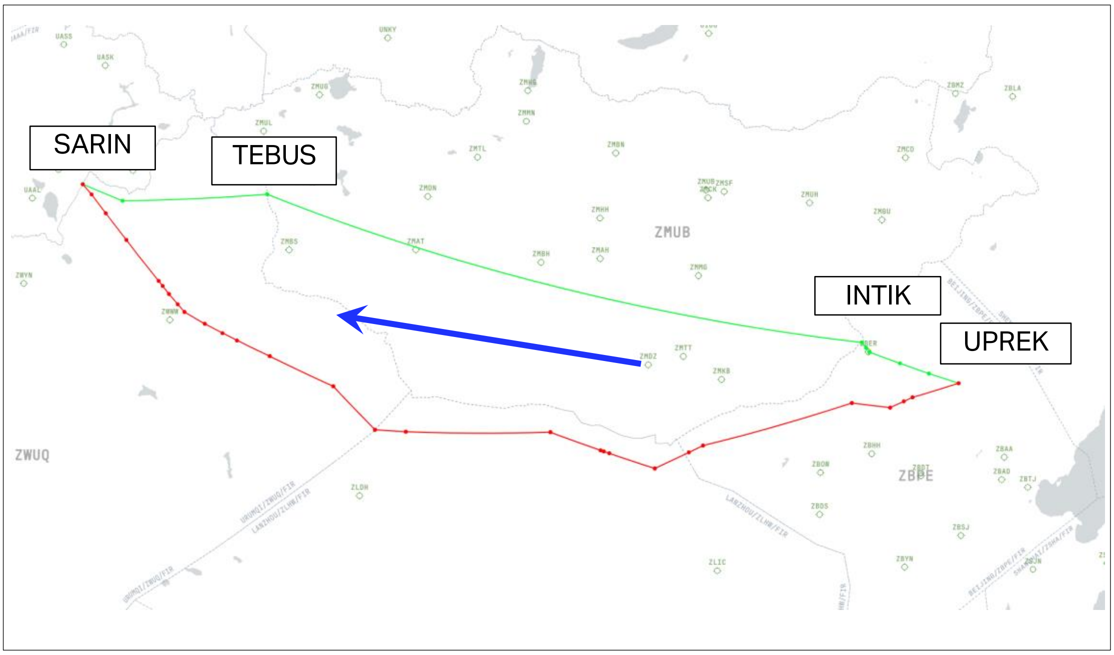


Figure 6.1 UPREK-SARIN Route Pair

Table 6.1 Performance Changes for UPREK-SARIN Route Pair Under Alternative Routing

Route Information	Simulated Performance

Origin-Destination	UPREK-SARIN	Flights Simulated	2,432
Great Circle Distance (NM)	1,406	NOTAM-Induced Delay Rate on Original Route	17.9%
Original Route	UPREK W28 KEVOB W28 ATBUG W66 NUKTI B215 FKG A368 SARIN	Average / Median Delay per Affected Flight on Original Route (min/flight)	266/282
Original Route Distance (NM)	1,543.2	Average Change in Flight Time per Flight (min/flight)	-17.1
Original Route En-route Extension Ratio	9.74%	Total Change in Flight Time (min)	-41,446
Alternative Route	UPREK A575 LHT A575 INTIK DCT TEBUS DCT 4640N08444E DCT SARIN	Average Change in Fuel Consumption per Flight (kg/flight)	-2,604
Alternative Route Distance (NM)	1,418	Total Change in Fuel Consumption (t)	-6,333
Alternative Route En-route Extension Ratio	0.85%	Total Change in CO_2 Emissions (t)	-19,947
Change in Alternative Route Distance (NM)	-125.2	Total Change in Route Charges (USD)	-1,579,604
Distance within Chinese Airspace (NM)	489.8	Change in Route Charges - China (USD)	-5,078,649
Distance within Mongolian Airspace (NM)	928.2	Change in Route Charges - Mongolia (USD)	+3,499,044

2. AGAVO-SARIN

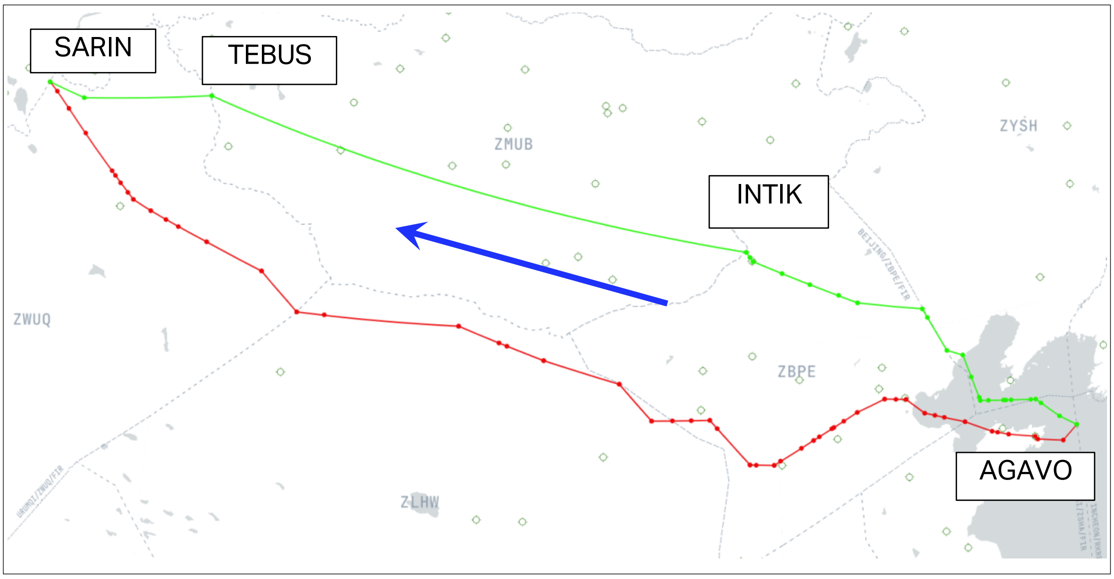


Figure 6.2 AGAVO-SARIN Route Pair

Table 6.2 Performance Changes for AGAVO-SARIN Route Pair Under Alternative Routing

Route Information		**Simulated Performance**	
Origin-Destination	AGAVO-SARIN	Flights Simulated	4810
Great Circle Distance (NM)	1904	NOTAM-Induced Delay Rate on Original Route	17.4%
Original Route	AGAVO A591 IKEKA W4 HCH W200 DOVIV W55 PAMRU W34 VYK B215 LEBOM W104 VEXEB W47 IDSOT W48 DKO W66 NUKTI B215 FKG A368 SARIN	Average / Median Delay per Affected Flight on Original Route (min/flight)	304/337
Original Route Distance (NM)	2097.2	Average Change in Flight Time per Flight (min/flight)	-16.7
Original Route En-route Extension Ratio	10.1%	Total Change in Flight Time (min)	-80210
Alternative Route	AGAVO G597 DONVO A326 UNSEK W201 UKDUM A575 INTIK DCT TEBUS DCT 4640N08444E DCT SARIN	Average Change in Fuel Consumption per Flight (kg/flight)	-2569

Alternative Route Distance (NM)	1974.3	Total Change in Fuel Consumption (t)	-12356
Alternative Route En-route Extension Ratio	3.7%	Total Change in CO2 Emissions (t)	-38922
Change in Alternative Route Distance (NM)	-122.9	Total Change in Route Charges (USD)	-3054166
Distance within Chinese Airspace (NM)	1046.1	Change in Route Charges - China (USD)	-10022600
Distance within Mongolian Airspace (NM)	928.2	Change in Route Charges - Mongolia (USD)	+6968434

3. SARIN-PUKOL

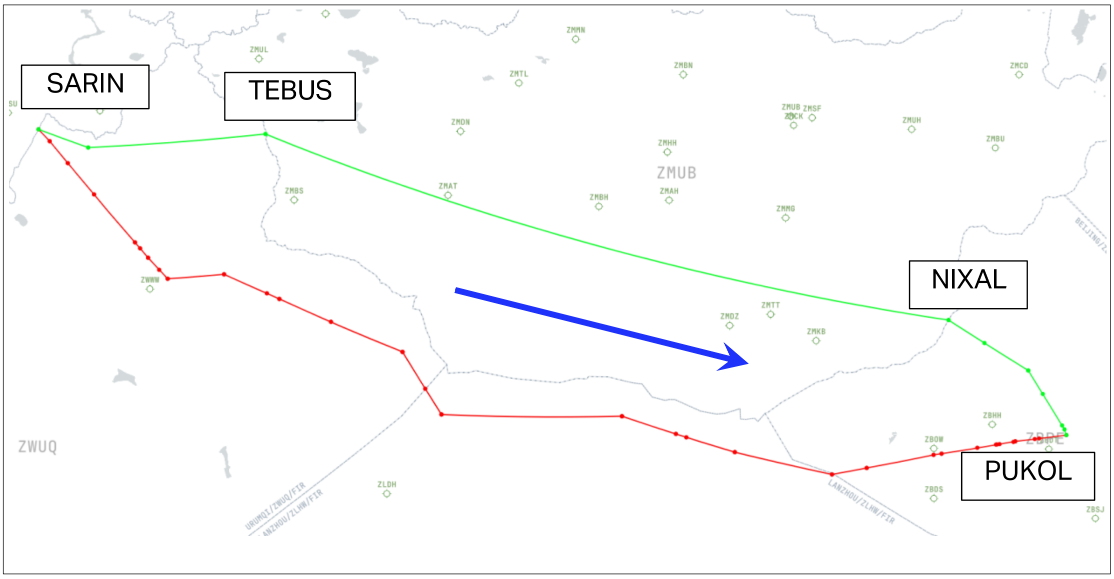


Figure 6.3 SARIN-PUKOL Route Pair

Table 6.3 Performance Changes for SARIN-PUKOL Route Pair Under Alternative Routing

Route Information	**Simulated Performance**

Origin-Destination	SARIN-PUKOL	Flights Simulated	212
Great Circle Distance (NM)	1406.6	NOTAM-Induced Delay Rate on Original Route	15.6%
Original Route	SARIN A368 FKG W188 GOVSA W66 DKO W64 PUKOL	Average / Median Delay per Affected Flight on Original Route (min/flight)	67/59
Original Route Distance (NM)	1504	Average Change in Flight Time per Flight (min/flight)	-6.7
Original Route En-route Extension Ratio	6.92%	Total Change in Flight Time (min)	-1412
Alternative Route	SARIN DCT 4640N08444E DCT TEBUS DCT NIXAL G343 TMR B458 PUKOL	Average Change in Fuel Consumption per Flight (kg/flight)	-766
Alternative Route Distance (NM)	1447.3	Total Change in Fuel Consumption (t)	-162
Alternative Route En-route Extension Ratio	2.89%	Total Change in CO2 Emissions (t)	-512
Change in Alternative Route Distance (NM)	-56.7	Total Change in Route Charges (USD)	-119148
Distance within Chinese Airspace (NM)	549.5	Change in Route Charges - China (USD)	-401147
Distance within Mongolian Airspace (NM)	897.8	Change in Route Charges - Mongolia (USD)	+281998

4. SARIN-SASAN

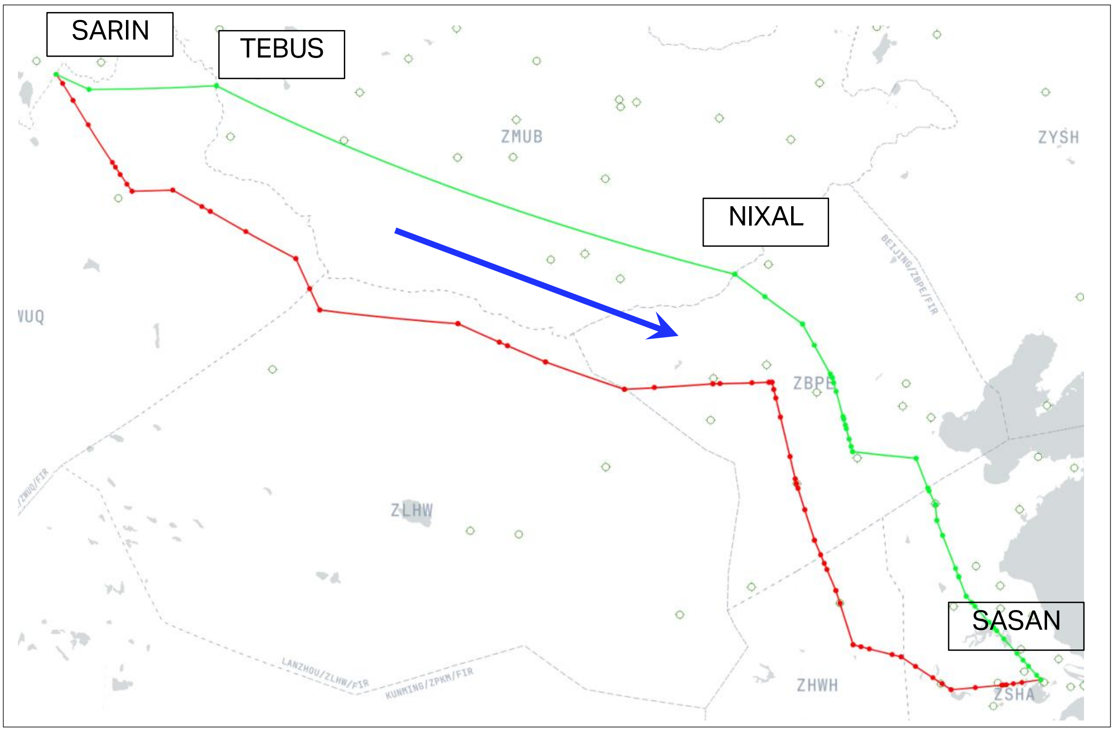


Figure 6.4 SARIN-SASAN Route Pair

Table 6.4 Performance Changes for SARIN-SASAN Route Pair Under Alternative Routing

Route Information		**Simulated Performance**	
Origin-Destination	SARIN-SASAN	Flights Simulated	1315
Great Circle Distance (NM)	1945.7	NOTAM-Induced Delay Rate on Original Route	15.2%
Original Route	SARIN A368 FKG W188 GOVSA W66 DKO W64 NUTLO B208 CGO W129 KAMDA W128 FYG B208 HFE R343 SASAN	Average / Median Delay per Affected Flight on Original Route (min/flight)	108/95
Original Route Distance (NM)	2183.7	Average Change in Flight Time per Flight (min/flight)	-9.1
Original Route En-route Extension Ratio	12.23%	Total Change in Flight Time (min)	-11948
Alternative Route	SARIN DCT 4640N08444E DCT TEBUS DCT NIXAL G343	Average Change in Fuel Consumption per Flight (kg/flight)	-1064

	TMR B458 OC H8 P149 W40 YQG W142 DALIM A593 VMB W161 SASAN		
Alternative Route Distance (NM)	2106.5	Total Change in Fuel Consumption (t)	-1399
Alternative Route En-route Extension Ratio	8.26%	Total Change in CO2 Emissions (t)	-4408
Change in Alternative Route Distance (NM)	-77.2	Total Change in Route Charges (USD)	-807512
Distance within Chinese Airspace (NM)	1208.7	Change in Route Charges - China (USD)	-2541685
Distance within Mongolian Airspace (NM)	897.8	Change in Route Charges - Mongolia (USD)	+1734173

5. SARIN-BIKUT

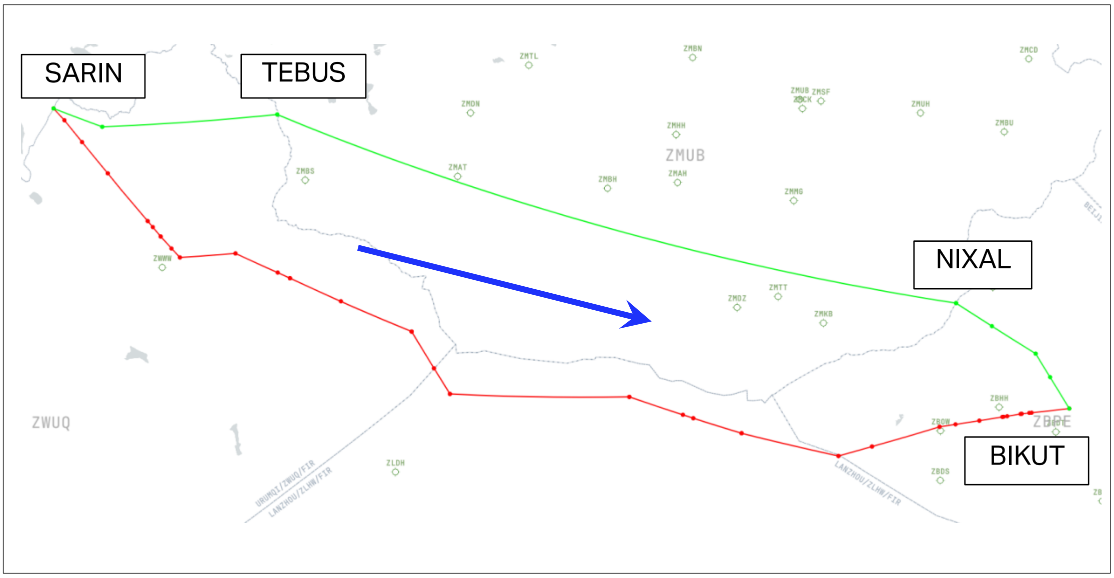


Figure 6.5 SARIN-BIKUT Route Pair

Table 6.5 Performance Changes for SARIN-BIKUT Route Pair Under Alternative Routing

Route Information		**Simulated Performance**	
Origin-Destination	SARIN-BIKUT	Flights Simulated	3893
Great Circle Distance (NM)	1396.6	NOTAM-Induced Delay Rate on Original Route	16.7%
Original Route	SARIN A368 FKG W188 GOVSA W66 DKO W69 BIKUT	Average / Median Delay per Affected Flight on Original Route (min/flight)	134/129
Original Route Distance (NM)	1500.2	Average Change in Flight Time per Flight (min/flight)	-7.8
Original Route En-route Extension Ratio	7.42%	Total Change in Flight Time (min)	-30334
Alternative Route	SARIN DCT 4640N08444E DCT TEBUS DCT NIXAL G343 TMR B458 BIKUT	Average Change in Fuel Consumption per Flight (kg/flight)	-939
Alternative Route Distance (NM)	1432.7	Total Change in Fuel Consumption (t)	-3655
Alternative Route En-route Extension Ratio	2.58%	Total Change in CO2 Emissions (t)	-11512
Change in Alternative Route Distance (NM)	-67.5	Total Change in Route Charges (USD)	-1139925
Distance within Chinese Airspace (NM)	534.9	Change in Route Charges - China (USD)	-6412727
Distance within Mongolian Airspace (NM)	897.8	Change in Route Charges - Mongolia (USD)	+5272802

6. UPREK-PURPA

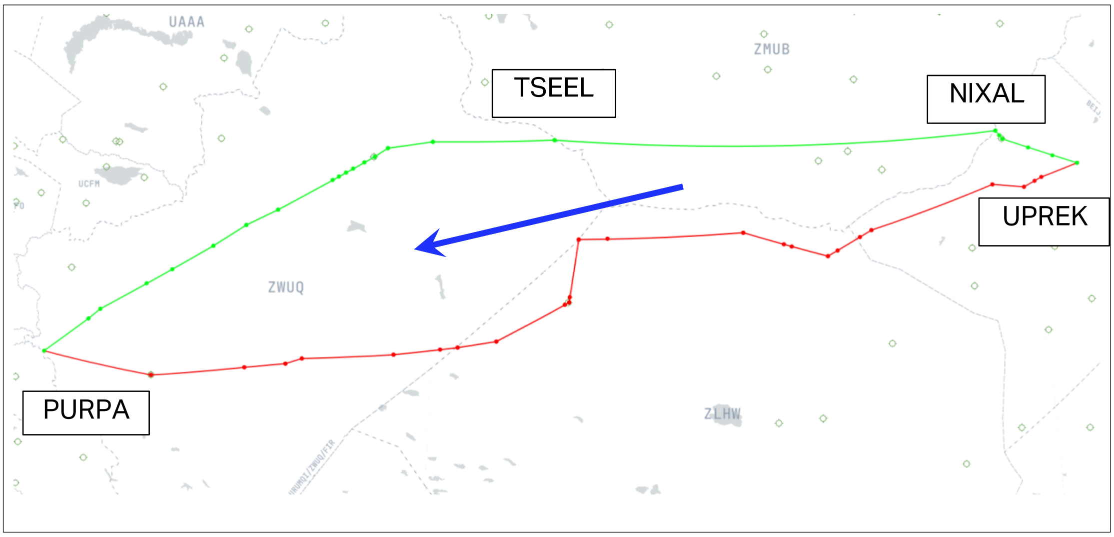


Figure 6.6 UPREK-PURPA Route Pair

Table 6.6 Performance Changes for UPREK-PURPA Route Pair Under Alternative Routing

Route Information		**Simulated Performance**	
Origin-Destination	UPREK-PURPA	Flights Simulated	1944
Great Circle Distance (NM)	1858.4	NOTAM-Induced Delay Rate on Original Route	15.4%
Original Route	UPREK W28 LAGEB W66 NUKTI B215 IBANO W187 TUSLI W112 PURPA	Average / Median Delay per Affected Flight on Original Route (min/flight)	105/64.5
Original Route Distance (NM)	1977.9	Average Change in Flight Time per Flight (min/flight)	-6.81
Original Route En-route Extension Ratio	6.43%	Total Change in Flight Time (min)	-13235
Alternative Route	UPREK A575 INTIK DCT 4433N09419E DCT ADPET W188 FKG B215 PURPA	Average Change in Fuel Consumption per Flight (kg/flight)	-990
Alternative Route Distance (NM)	1928.2	Total Change in Fuel Consumption (t)	-1925

Alternative Route En-route Extension Ratio	3.76%	Total Change in CO2 Emissions (t)	-6065
Change in Alternative Route Distance (NM)	-49.7	Total Change in Route Charges (USD)	-904025
Distance within Chinese Airspace (NM)	1167.8	Change in Route Charges - China (USD)	-3121952
Distance within Mongolian Airspace (NM)	760.4	Change in Route Charges - Mongolia (USD)	+2217926

7. UPREK-FKG

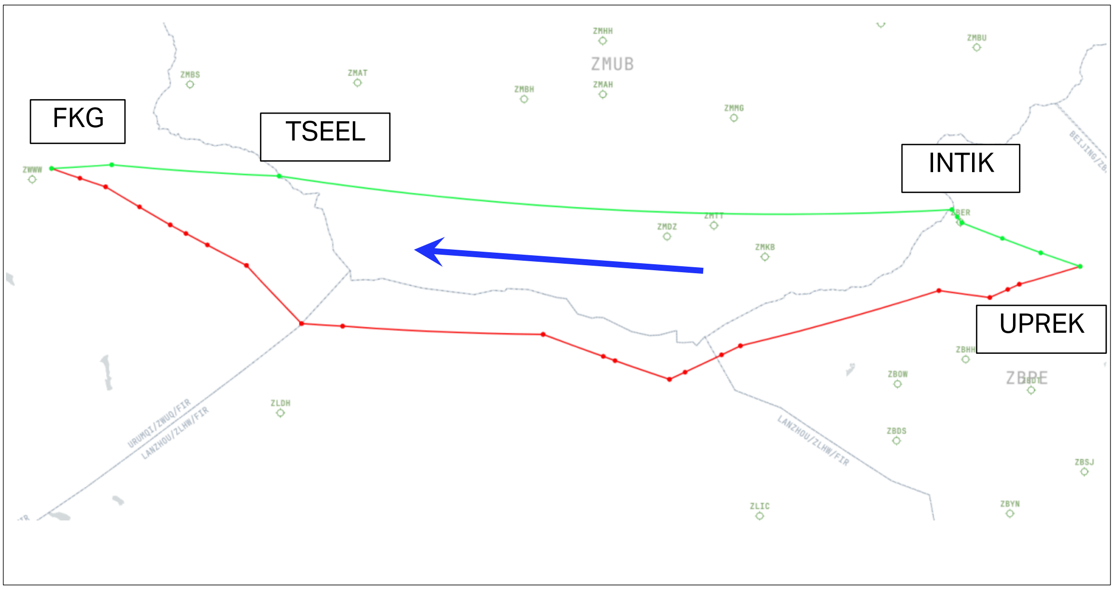


Figure 6.7 UPREK-FKG Route Pair

Table 6.7 Performance Changes for UPREK-FKG Route Pair Under Alternative Routing

Route Information		**Simulated Performance**	
Origin-Destination	UPREK-FKG	Flights Simulated	6784
Great Circle Distance (NM)	1197.2	NOTAM-Induced Delay Rate on Original Route	12.2%

Original Route	UPREK W28 LAGEB W66 NUKTI B215 HAM W99 FKG	Average / Median Delay per Affected Flight on Original Route (min/flight)	89/66
Original Route Distance (NM)	1275.2	Average Change in Flight Time per Flight (min/flight)	-10.1
Original Route En-route Extension Ratio	6.52%	Total Change in Flight Time (min)	-68537
Alternative Route	UPREK A575 INTIK DCT 4433N09419E DCT ADPET W188 FKG	Average Change in Fuel Consumption per Flight (kg/flight)	-562
Alternative Route Distance (NM)	1208.5	Total Change in Fuel Consumption (t)	-3814
Alternative Route En-route Extension Ratio	0.94%	Total Change in CO2 Emissions (t)	-12015
Change in Alternative Route Distance (NM)	-66.7	Total Change in Route Charges (USD)	+3924095
Distance within Chinese Airspace (NM)	483.5	Change in Route Charges - China (USD)	-1603427
Distance within Mongolian Airspace (NM)	760.4	Change in Route Charges - Mongolia (USD)	+5527522

8. ZBHH-FKG

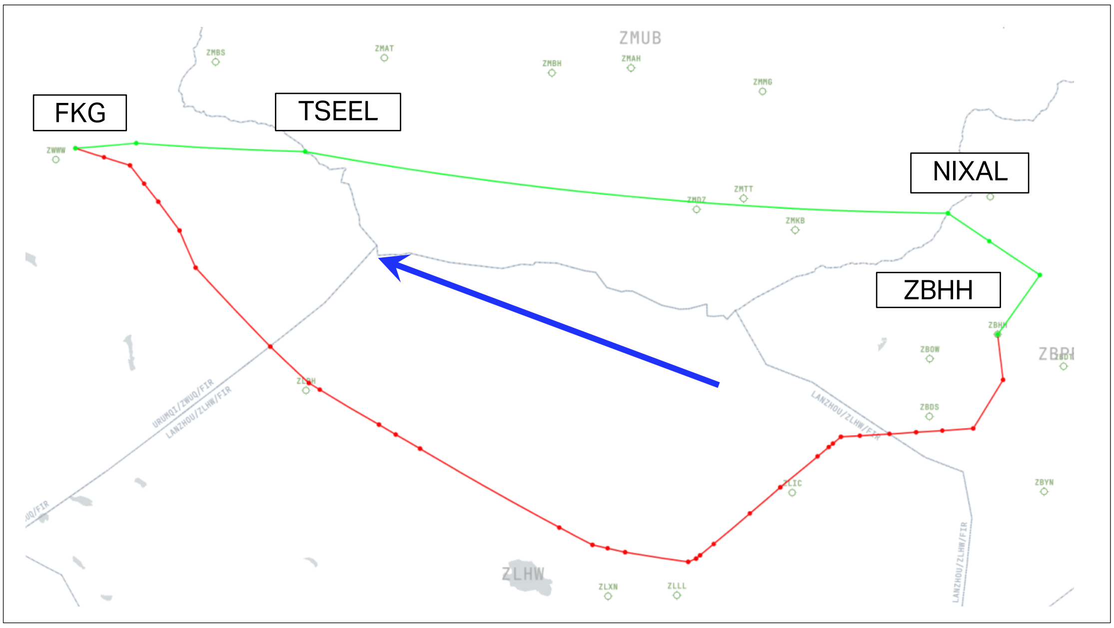


Figure 6.8 ZBHH-FKG Route Pair

Table 6.8 Performance Changes for ZBHH-FKG Route Pair Under Alternative Routing

Route Information		**Simulated Performance**	
Origin-Destination	ZBHH-FKG	Flights Simulated	364
Great Circle Distance (NM)	1072.6	NOTAM-Induced Delay Rate on Original Route	12.1%
Original Route	ZBHH IBARO W47 IDSOT W48 MAKIP MULOB W220 NIRUV B215 IBANO G470 QTV W99 FKG	Average / Median Delay per Affected Flight on Original Route (min/flight)	264/208
Original Route Distance (NM)	1354.4	Average Change in Flight Time per Flight (min/flight)	-21.9
Original Route En-route Extension Ratio	26.27%	Total Change in Flight Time (min)	-7979
Alternative Route	ZBHH TMR G343 NIXAL DCT 4433N09419E DCT ADPET W188 FKG	Average Change in Fuel Consumption per Flight (kg/flight)	-953

Alternative Route Distance (NM)	1210.6	Total Change in Fuel Consumption (t)	-347
Alternative Route En-route Extension Ratio	12.87%	Total Change in CO2 Emissions (t)	-1093
Change in Alternative Route Distance (NM)	-143.8	Total Change in Route Charges (USD)	+234218
Distance within Chinese Airspace (NM)	488.5	Change in Route Charges - China (USD)	-18911
Distance within Mongolian Airspace (NM)	722.1	Change in Route Charges - Mongolia (USD)	+253129

9. LAXAG-FKG

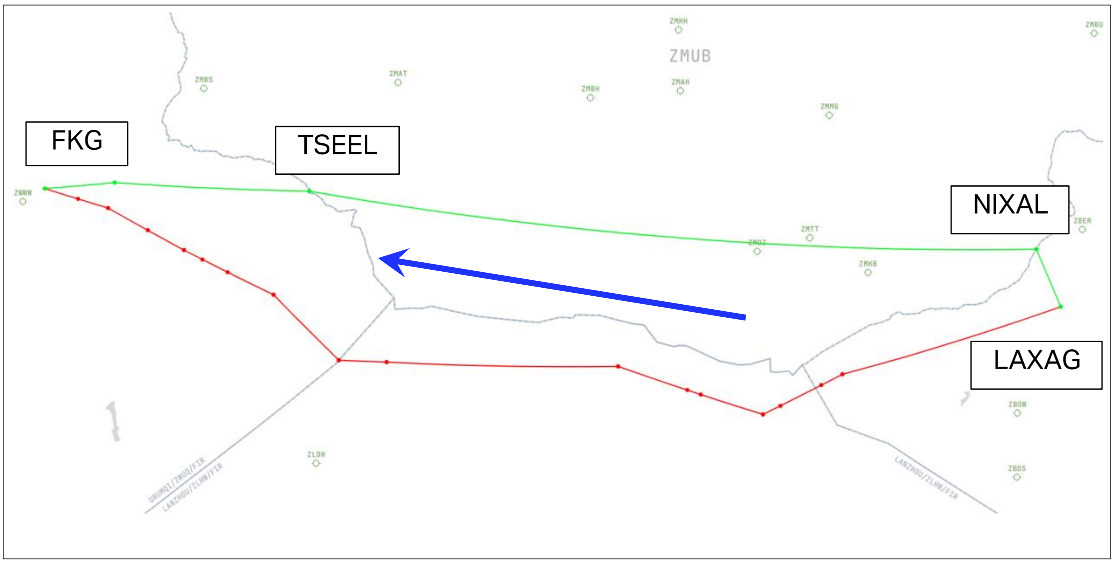


Figure 6.9 LAXAG-FKG Route Pair

Table 6.9 Performance Changes for LAXAG-FKG Route Pair Under Alternative Routing

Route Information	**Simulated Performance**

Origin-Destination	LAXAG-FKG	Flights Simulated	700
Great Circle Distance (NM)	1026.8	NOTAM-Induced Delay Rate on Original Route	11.7%
Original Route	LAXAG W28 LAGEB W66 NUKTI B215 HAM W99 FKG	Average / Median Delay per Affected Flight on Original Route (min/flight)	161/65
Original Route Distance (NM)	1094.6	Average Change in Flight Time per Flight (min/flight)	-5.4
Original Route En-route Extension Ratio	6.60%	Total Change in Flight Time (min)	-3755
Alternative Route	LAXAG B208 NIXAL DCT 4433N09419E DCT ADPET W188 FKG	Average Change in Fuel Consumption per Flight (kg/flight)	-238
Alternative Route Distance (NM)	1059.1	Total Change in Fuel Consumption (t)	-167
Alternative Route En-route Extension Ratio	3.15%	Total Change in CO2 Emissions (t)	-525
Change in Alternative Route Distance (NM)	-35.5	Total Change in Route Charges (USD)	+454968
Distance within Chinese Airspace (NM)	337	Change in Route Charges - China (USD)	-31819
Distance within Mongolian Airspace (NM)	722.1	Change in Route Charges - Mongolia (USD)	+486788

10. ZBTJ-FKG

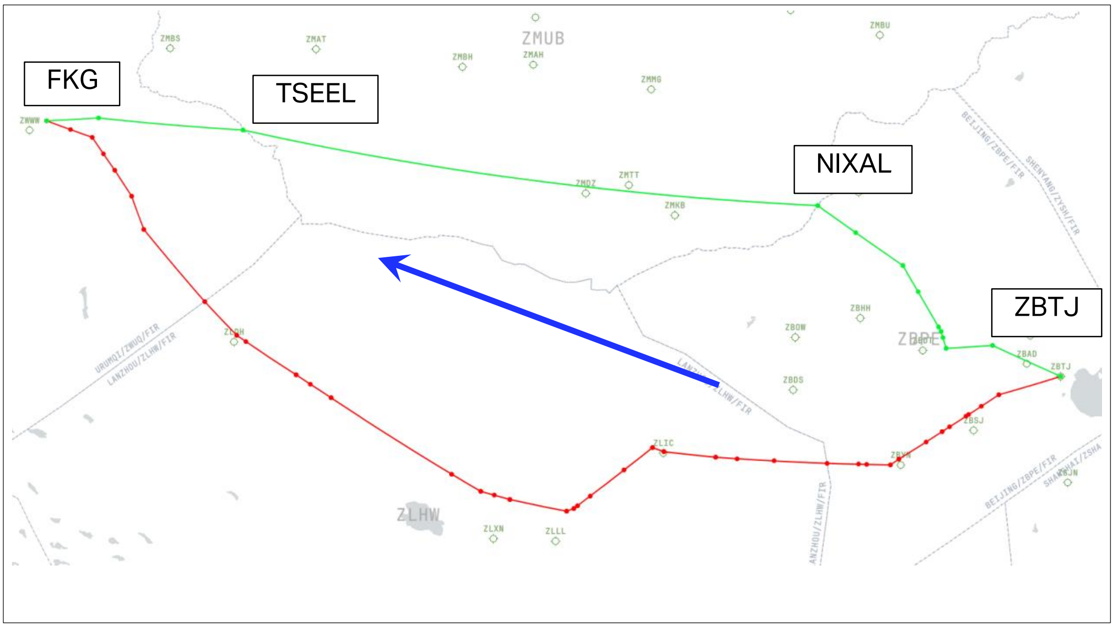


Figure 6.10 ZBTJ-FKG Route Pair

Table 6.10 Performance Changes for ZBTJ-FKG Route Pair Under Alternative Routing

Route Information		**Simulated Performance**	
Origin-Destination	ZBTJ-FKG	Flights Simulated	326
Great Circle Distance (NM)	1347.3	NOTAM-Induced Delay Rate on Original Route	10.2%
Original Route	ZBTJ PEGSO B215 IBANO G470 QTV W99 FKG	Average / Median Delay per Affected Flight on Original Route (min/flight)	199/173
Original Route Distance (NM)	1545.8	Average Change in Flight Time per Flight (min/flight)	-20.5
Original Route En-route Extension Ratio	14.73%	Total Change in Flight Time (min)	-6669
Alternative Route	ZBTJ BOTPU W47 VIGEK B458 TMR G343 NIXAL DCT 4433N09419E DCT ADPET W188 FKG	Average Change in Fuel Consumption per Flight (kg/flight)	-994

Alternative Route Distance (NM)	1405.5	Total Change in Fuel Consumption (t)	-324
Alternative Route En-route Extension Ratio	4.32%	Total Change in CO2 Emissions (t)	-1020
Change in Alternative Route Distance (NM)	-140.3	Total Change in Route Charges (USD)	+209836
Distance within Chinese Airspace (NM)	683.4	Change in Route Charges - China (USD)	-16869
Distance within Mongolian Airspace (NM)	722.1	Change in Route Charges - Mongolia (USD)	+226704

11. MAGIV-BIKUT

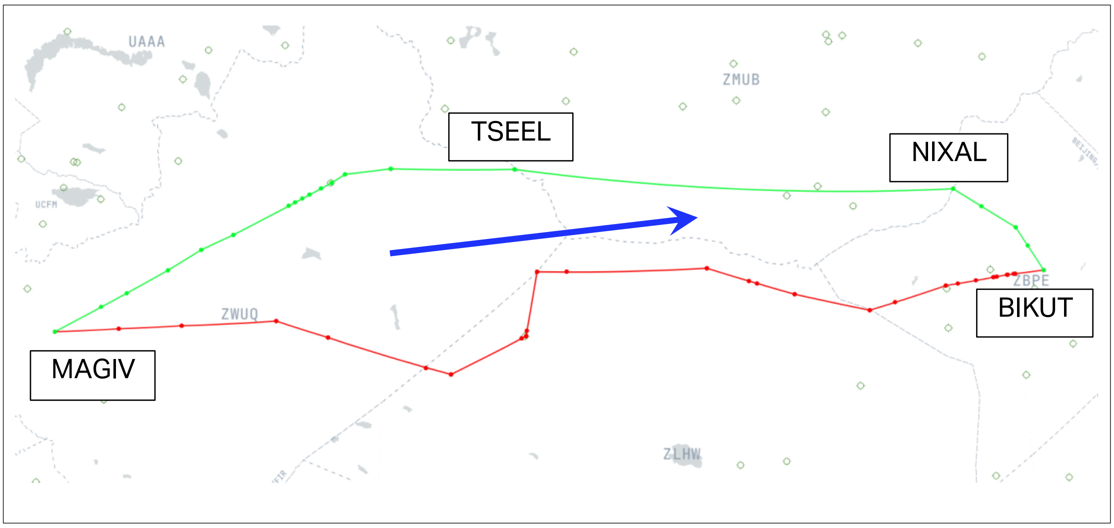


Figure 6.11 MAGIV-BIKUT Route Pair

Table 6.11 Performance Changes for MAGIV-BIKUT Route Pair Under Alternative Routing

Route Information		**Simulated Performance**	
Origin-Destination	MAGIV-BIKUT	Flights Simulated	186

Great Circle Distance (NM)	1685.7	NOTAM-Induced Delay Rate on Original Route	14.1%
Original Route	MAGIV W187 IBANO B215 NUKTI W66 DKO W69 BIKUT	Average / Median Delay per Affected Flight on Original Route (min/flight)	166/81
Original Route Distance (NM)	1806.2	Average Change in Flight Time per Flight (min/flight)	-1.4
Original Route En-route Extension Ratio	7.15%	Total Change in Flight Time (min)	-254
Alternative Route	MAGIV B215 FKG W188 ADPET DCT 4433N09419E DCT NIXAL G343 TMR B458 BIKUT	Average Change in Fuel Consumption per Flight (kg/flight)	-162
Alternative Route Distance (NM)	1794.5	Total Change in Fuel Consumption (t)	-30
Alternative Route En-route Extension Ratio	6.45%	Total Change in CO2 Emissions (t)	-95
Change in Alternative Route Distance (NM)	-11.7	Total Change in Route Charges (USD)	+168195
Distance within Chinese Airspace (NM)	1072.4	Change in Route Charges - China (USD)	-19834
Distance within Mongolian Airspace (NM)	722.1	Change in Route Charges - Mongolia (USD)	+188028

12. ADPET-PUKOL

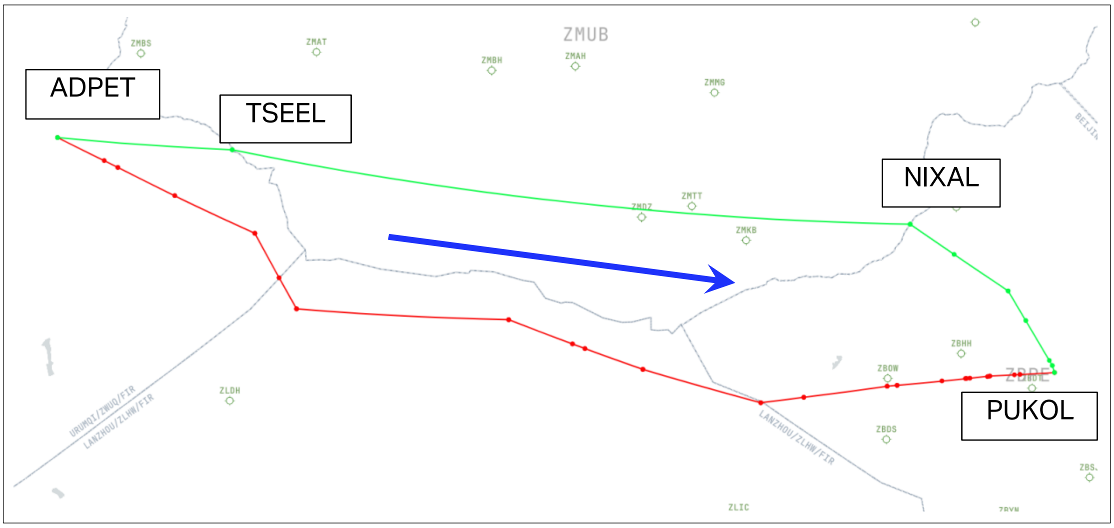


Figure 6.12 ADPET-PUKOL Route Pair

Table 6.12 Performance Changes for ADPET-PUKOL Route Pair Under Alternative Routing

Route Information		**Simulated Performance**	
Origin-Destination	ADPET-PUKOL	Flights Simulated	1693
Great Circle Distance (NM)	1108.9	NOTAM-Induced Delay Rate on Original Route	10.4%
Original Route	ADPET W188 GOVSA W66 DKO W64 PUKOL	Average / Median Delay per Affected Flight on Original Route (min/flight)	59/46
Original Route Distance (NM)	1160.1	Average Change in Flight Time per Flight (min/flight)	-0.77
Original Route En-route Extension Ratio	4.62%	Total Change in Flight Time (min)	-1286
Alternative Route	ADPET DCT 4433N09419E DCT NIXAL G343 TMR B458 PUKOL	Average Change in Fuel Consumption per Flight (kg/flight)	-33
Alternative Route Distance (NM)	1154	Total Change in Fuel Consumption (t)	-55
Alternative Route En-route	4.07%	Total Change in CO2 Emissions (t)	-173

Extension Ratio			
Change in Alternative Route Distance (NM)	-6.1	Total Change in Route Charges (USD)	+1307043
Distance within Chinese Airspace (NM)	431.9	Change in Route Charges - China (USD)	-116088
Distance within Mongolian Airspace (NM)	722.1	Change in Route Charges - Mongolia (USD)	+1423132

13. ADPET-BIKUT

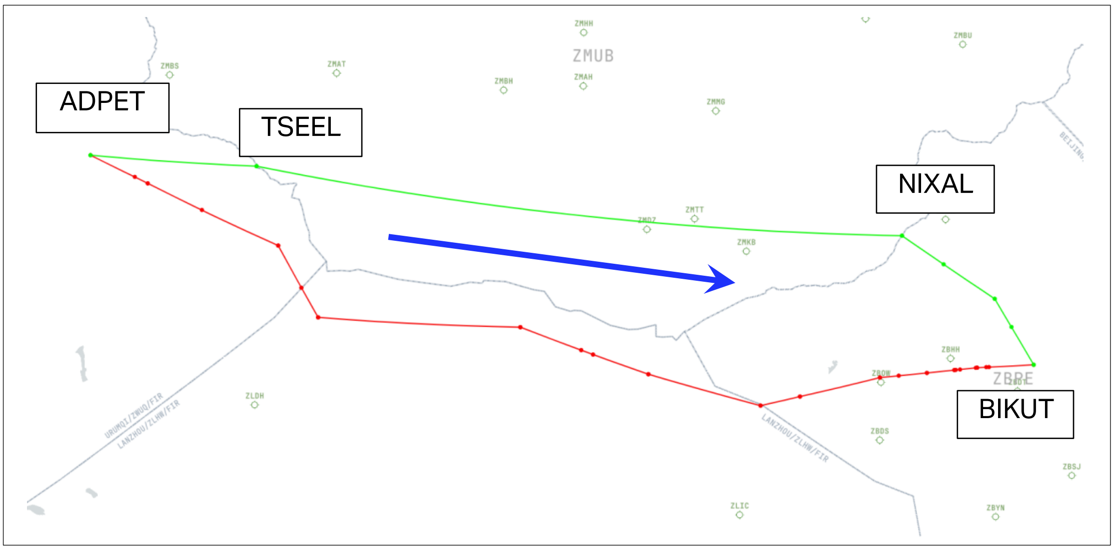


Figure 6.13 ADPET-BIKUT Route Pair

Table 6.13 Performance Changes for ADPET-BIKUT Route Pair Under Alternative Routing

Route Information		Simulated Performance	
Origin-Destination	ADPET-BIKUT	Flights Simulated	14640
Great Circle Distance (NM)	1100	NOTAM-Induced Delay Rate on Original Route	13.4%

Original Route	ADPET W188 GOVSA W66 DKO W69 BIKUT	Average / Median Delay per Affected Flight on Original Route (min/flight)	77/54
Original Route Distance (NM)	1156.2	Average Change in Flight Time per Flight (min/flight)	-1.98
Original Route En-route Extension Ratio	5.11%	Total Change in Flight Time (min)	-28961
Alternative Route	ADPET DCT 4433N09419E DCT NIXAL G343 TMR B458 BIKUT	Average Change in Fuel Consumption per Flight (kg/flight)	-196
Alternative Route Distance (NM)	1139.4	Total Change in Fuel Consumption (t)	-2869
Alternative Route En-route Extension Ratio	3.58%	Total Change in CO2 Emissions (t)	-9037
Change in Alternative Route Distance (NM)	-16.8	Total Change in Route Charges (USD)	-836273
Distance within Chinese Airspace (NM)	417.3	Change in Route Charges - China (USD)	-15256948
Distance within Mongolian Airspace (NM)	722.1	Change in Route Charges - Mongolia (USD)	+14420675

14. ADPET-TMR

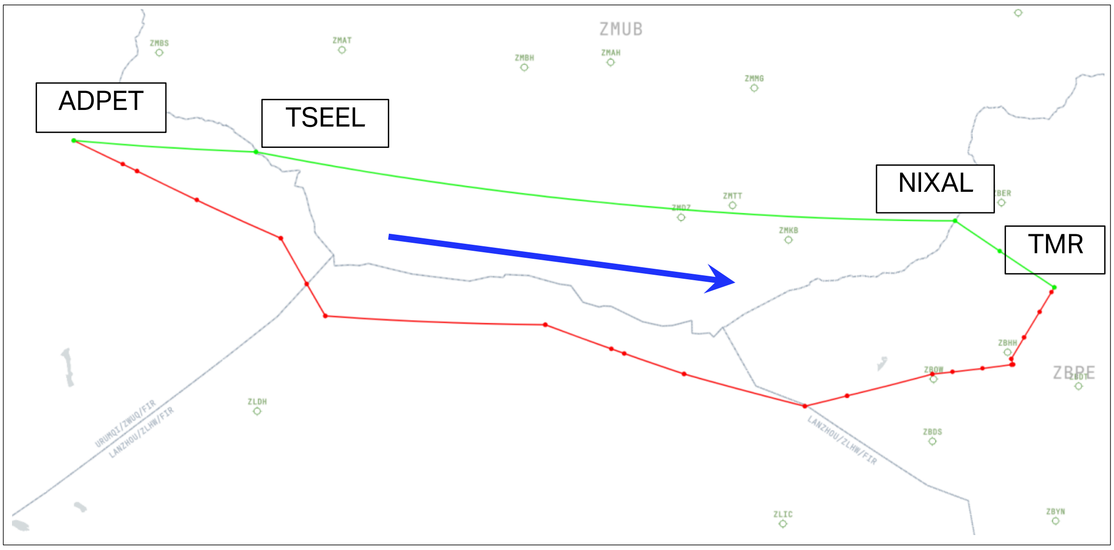


Figure 6.14 ADPET-TMR Route Pair

Table 6.14 Performance Changes for ADPET-TMR Route Pair Under Alternative Routing

Route Information		**Simulated Performance**	
Origin-Destination	ADPET-TMR	Flights Simulated	157
Great Circle Distance (NM)	1038.6	NOTAM-Induced Delay Rate on Original Route	9.6%
Original Route	ADPET W188 GOVSA W66 DKO W69 BAXOD B208 HET G218 TMR	Average / Median Delay per Affected Flight on Original Route (min/flight)	67/46
Original Route Distance (NM)	1155.6	Average Change in Flight Time per Flight (min/flight)	-13.0
Original Route En-route Extension Ratio	11.27%	Total Change in Flight Time (min)	-2047
Alternative Route	ADPET DCT 4433N09419E DCT NIXAL G343 TMR	Average Change in Fuel Consumption per Flight (kg/flight)	-603
Alternative Route Distance (NM)	1050.7	Total Change in Fuel Consumption (t)	-94.6

Alternative Route En-route Extension Ratio	1.17%	Total Change in CO2 Emissions (t)	-298
Change in Alternative Route Distance (NM)	-104.9	Total Change in Route Charges (USD)	+101389
Distance within Chinese Airspace (NM)	328.6	Change in Route Charges - China (USD)	-7790
Distance within Mongolian Airspace (NM)	722.1	Change in Route Charges - Mongolia (USD)	+109179

6.2.2 Representative Routes with Longer Alternative Distances

For representative route pairs in which the alternative route distance exceeds the original route, it was assumed that only flights affected by NOTAM restrictions would divert to the alternative route to mitigate delays. It was further assumed that these flights would not face additional airspace closures. The performance impacts of such diversions were then assessed accordingly.

1. **ADPET-NUTLO**

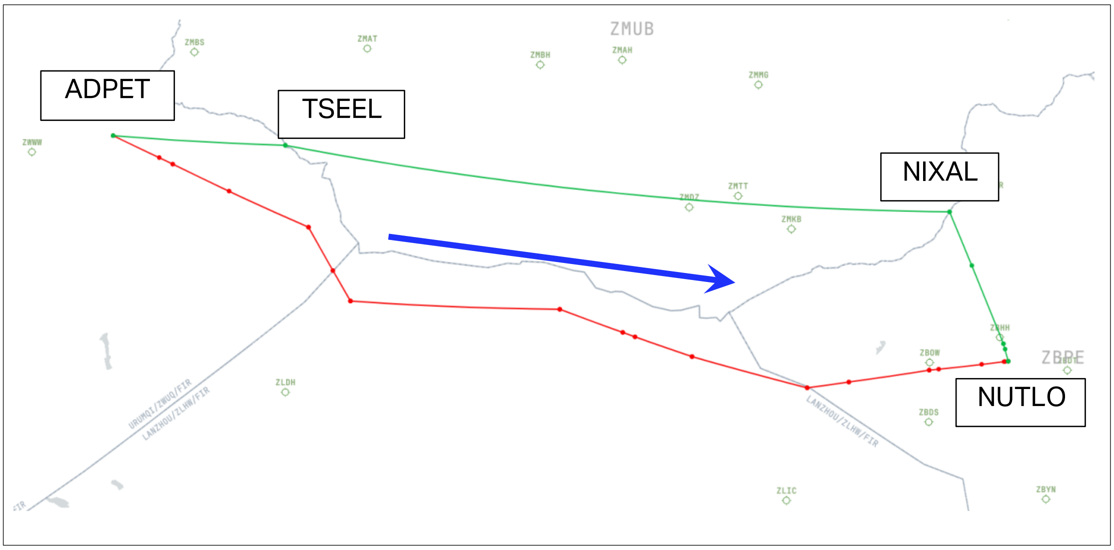


Figure 6.15 ADPET-NUTLO Route Pair

Table 6.15 Performance Changes for ADPET-NUTLO Route Pair Under Alternative Routing

Route Information		**Simulated Performance**	
Origin-Destination	ADPET-NUTLO	Number of Flights Simulated	124
Great Circle Distance (NM)	1016.1	Number / Rate of Flights Affected by NOTAM Restrictions on Original Route	12/9.7%
Original Route	ADPET W188 GOVSA W66 DKO W64 NUTLO	Average / Median Delay per Affected Flight on Original Route (min/flight)	75/58
Original Route Distance (NM)	1069.1	Change in Flight Time per Diverted Flight (min/flight)	+3.47
Original Route En-route Extension Ratio	5.22%	Total Delay Time for Diverted Flights (min)	-858.36
Alternative Route	ADPET DCT 4433N09419E DCT NIXAL B208 NUTLO	Average Change in Fuel Consumption per Diverted Flight (kg/flight)	+153
Alternative Route Distance (NM)	1096.7	Total Change in Fuel Consumption for Diverted Flights (kg)	+1836
Alternative Route En-route Extension Ratio	7.93%	Total Change in CO_2 Emissions for Diverted Flights (kg)	+5383
Change in Alternative Route Distance (NM)	+27.6	Total Change in Route Charges (USD)	+10978
Distance within Chinese Airspace (NM)	374.6	Change in Route Charges - China (USD)	-1217
Distance within Mongolian Airspace (NM)	722.1	Change in Route Charges - Mongolia (USD)	+12916

2. PURPA-PUKOL

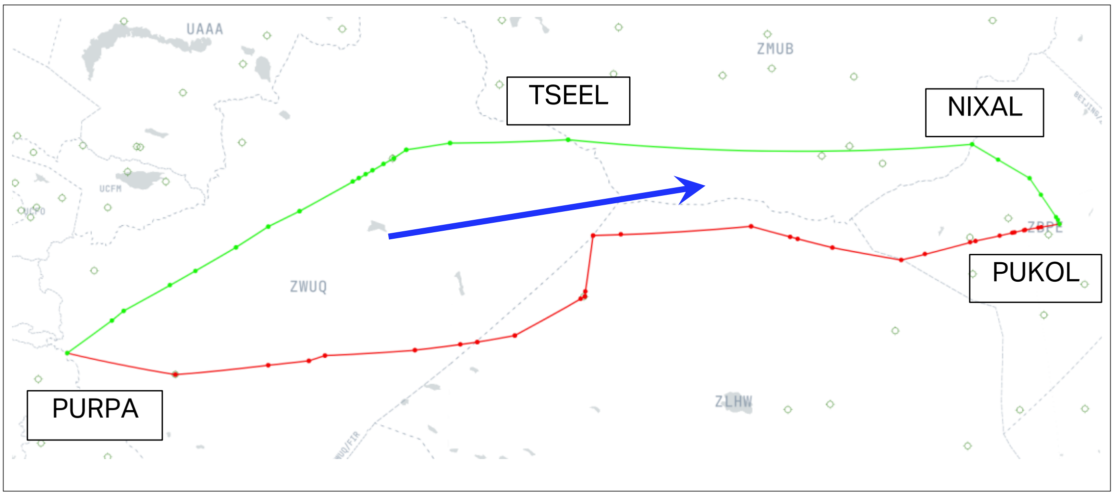


Figure 6.16 PURPA-PUKOL Route Pair

Table 6.16 Performance Changes for PURPA-PUKOL Route Pair Under Alternative Routing

Route Information		**Simulated Performance**	
Origin-Destination	PURPA-PUKOL	Number of Flights Simulated	364
Great Circle Distance (NM)	1815.5	Number / Rate of Flights Affected by NOTAM Restrictions on Original Route	57/15.7%
Original Route	PURPA W112 TUSLI W187 IBANO B215 NUKTI W66 DKO W64 PUKOL	Average / Median Delay per Affected Flight on Original Route (min/flight)	101/57
Original Route Distance (NM)	1922.7	Change in Flight Time per Diverted Flight (min/flight)	+5.95
Original Route En-route Extension Ratio	5.90%	Total Delay Time for Diverted Flights (min)	-5262
Alternative Route	PURPA B215 FKG W188 ADPET DCT 4433N09419E DCT NIXAL G343 TMR B458 PUKOL	Average Change in Fuel Consumption per Diverted Flight (kg/flight)	+762
Alternative Route Distance (NM)	1948.9	Total Change in Fuel Consumption for Diverted Flights (kg)	+43447

Alternative Route En-route Extension Ratio	7.35%	Total Change in CO2 Emissions for Diverted Flights (kg)	+136856
Change in Alternative Route Distance (NM)	+26.2	Total Change in Route Charges (USD)	-12485
Distance within Chinese Airspace (NM)	1226.8	Change in Route Charges - China (USD)	-79710
Distance within Mongolian Airspace (NM)	722.1	Change in Route Charges - Mongolia (USD)	+67224

3. PURPA-BIKUT

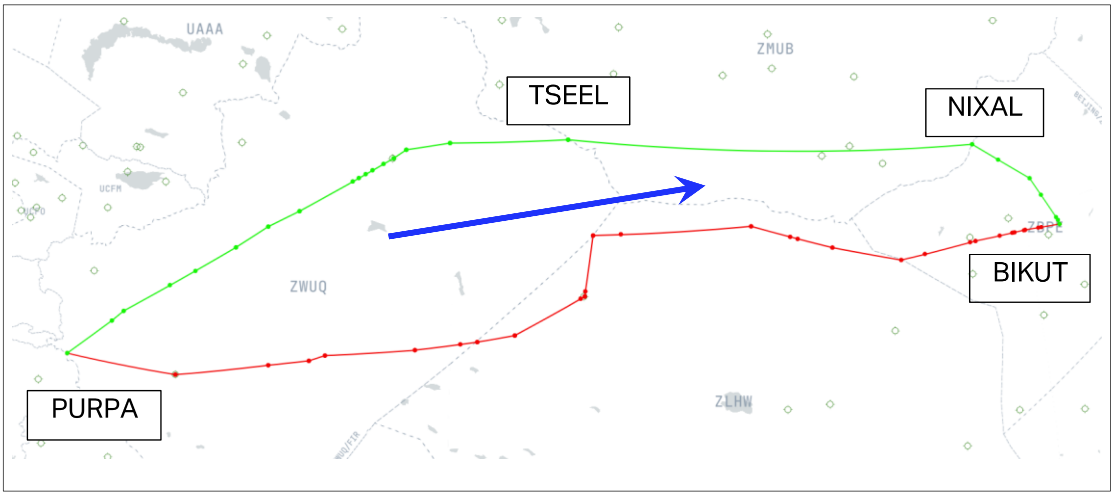


Figure 6.17 PURPA-BIKUT Route Pair

Table 6.17 Performance Changes for PURPA-BIKUT Route Pair Under Alternative Routing

Route Information		**Simulated Performance**	
Origin-Destination	PURPA-BIKUT	Number of Flights Simulated	3970
Great Circle Distance (NM)	1809.8	Number / Rate of Flights Affected by NOTAM Restrictions on Original Route	722/18.2 %
Original Route	PURPA W112 TUSLI W187 IBANO B215	Average / Median Delay per Affected Flight on Original Route (min/flight)	107/66

	NUKTI W66 DKO W69 BIKUT		
Original Route Distance (NM)	1918.9	Change in Flight Time per Diverted Flight (min/flight)	+1.75
Original Route En-route Extension Ratio	6.03%	Total Delay Time for Diverted Flights (min)	-76019
Alternative Route	PURPA B215 FKG W188 ADPET DCT 4433N09419E DCT NIXAL G343 TMR B458 BIKUT	Average Change in Fuel Consumption per Diverted Flight (kg/flight)	+228
Alternative Route Distance (NM)	1934.3	Total Change in Fuel Consumption for Diverted Flights (kg)	+164616
Alternative Route En-route Extension Ratio	6.88%	Total Change in CO2 Emissions for Diverted Flights (kg)	+518540
Change in Alternative Route Distance (NM)	+15.4	Total Change in Route Charges (USD)	-135546
Distance within Chinese Airspace (NM)	1212.2	Change in Route Charges - China (USD)	-911540
Distance within Mongolian Airspace (NM)	722.1	Change in Route Charges - Mongolia (USD)	+775994

4. OMBON-RULAD

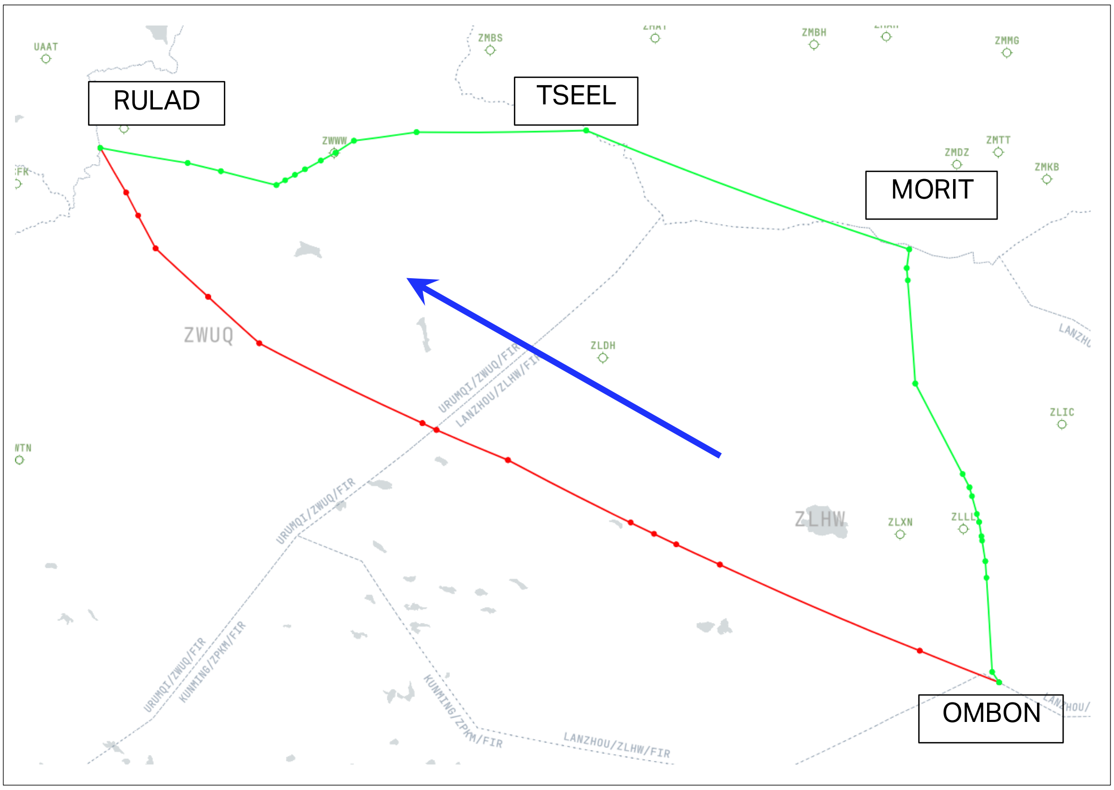


Figure 6.18 OMBON-RULAD Route Pair

Table 6.18 Performance Changes for OMBON-RULAD Route Pair Under Alternative Routing

Route Information		**Simulated Performance**	
Origin-Destination	OMBON-RULAD	Number of Flights Simulated	2447
Great Circle Distance (NM)	1259.0	Number / Rate of Flights Affected by NOTAM Restrictions on Original Route	252/11.2%
Original Route	OMBON Y1 SADAN L888 XKC A460 RULAD	Average / Median Delay per Affected Flight on Original Route (min/flight)	261/171
Original Route Distance (NM)	1283.5	Change in Flight Time per Diverted Flight (min/flight)	+34.64
Original Route En-route Extension Ratio	1.95%	Total Delay Time for Diverted Flights (min)	-57043

Alternative Route	OMBON W195 MORIT DCT 4433N09419E DCT ADPET W188 FKG B215 POSOT A343 RULAD	Average Change in Fuel Consumption per Diverted Flight (kg/flight)	+5635
Alternative Route Distance (NM)	1547.0	Total Change in Fuel Consumption for Diverted Flights (kg)	+1420020
Alternative Route En-route Extension Ratio	22.88%	Total Change in CO2 Emissions for Diverted Flights (kg)	+4473063
Change in Alternative Route Distance (NM)	+263.5	Total Change in Route Charges (USD)	+104293
Distance within Chinese Airspace (NM)	1145.3	Change in Route Charges - China (USD)	-56801
Distance within Mongolian Airspace (NM)	401.7	Change in Route Charges - Mongolia (USD)	+161094

6.3. Stakeholder-specific Benefits and Impacts

6.3.1 Chinese Airlines

A total of 14,355 flights operated by Chinese airlines were included in the simulation for routes where the alternative distance is shorter than the original. Assuming all these flights are diverted to alternative routes, the resulting changes in operational performance are detailed in Table 6.19.

Table 6.19 Performance Changes for Chinese Airlines on the Representative Routes with Shorter Alternative Distances

Representative Route	Number of Flights	Avg Change in Flight Time (min/flight)	Total Change in Flight Time (min)	Avg Change in Fuel Consumption (kg/flight)	Total Change in Fuel Consumption (t)	Total Change in CO_2 Emissions (t)	Fuel Savings Value (USD)	Change in Route Charges (USD)
UPREK-FKG	5984	-10.2	-61180	-456	-2726.2	-8587.5	2238210	4248188
ZBHH-FKG[*]	364	-21.92	-7979	-953	-346.9	-1092.7	284804	234218

LAXAG-FKG	700	-5.40	-3755	-238	-166.7	-525.0	136860	454969
ZBTJ-FKG*	326	-20.46	-6669	-994	-323.9	-1020.3	265921	209836
MAGIV-BIKUT	186	-1.40	-254	-162	-30.1	-947.0	24712	168195
SARIN-BIKUT	585	-8.00	-4675	-913	-534.4	-1683.2	438742	677446
ADPET-PUKOL	1693	-0.77	-1286	-33	-55.0	-173.0	45155	1307044
ADPET-BIKUT	4360	-2.10	-9214	-95	-415.0	-1307.1	340715	2809070
ADPET-TMR	157	-13.04	-2047	-603	-94.6	-298.0	77675	101389
Total	14355		-97059		-4692.7	-14781.6	3852706	10210354
*: Route pairs where diversion is cost-effective								

The analysis indicates that the proposed new routes through Mongolian airspace offer benefits to Chinese airlines, reducing flight time and fuel consumption; however, they also entail higher ANS charges due to the preferential charging policies Chinese airlines enjoy within Chinese airspace. These benefits do not apply once flights divert through Mongolia, where full ANS charges are levied.

From an economic perspective, based on a current aviation fuel price of USD 821 per tonne, the value of fuel savings for each route direction is presented in Table 6.19. The total value of fuel savings across all flights amounts to USD 3,852,707, significantly lower than the corresponding increase in route charges. Consequently, from a purely economic standpoint, diverting via Mongolian airspace results in higher operating costs for Chinese airlines due to the increased ANS charges.

Examination of individual route pairs reveals that only two—ZBHH-FKG and ZBTJ-FKG—yield positive economic returns. For these routes, the value of fuel savings exceeds the increase in route charges, driven by more substantial flight-time reductions and greater fuel savings. For all other route pairs, the fuel savings are insufficient to offset the increase in route charges, making diversion less attractive than remaining on the original routes. Thus, for Chinese airlines, most diversion options offer negative economic benefits. Only two route directions—ZBHH-FKG and ZBTJ-FKG—offer greater time savings and are therefore worth considering for diversion.

Nevertheless, even for route pairs with less favorable economic outcomes, the proposed alternative routes provide meaningful improvements in flight time and CO_2 emissions reduction while circumventing frequent restrictions affecting the original routes. Therefore, these alternative routes can serve as critical contingency options for Chinese airlines addressing various operational objectives, such as avoiding airspace constraints and enhancing operational reliability.

For routes where the alternative route distance exceeds the original route distance, it was assumed that only flights affected by NOTAM restrictions would divert. The resulting changes in operational performance are presented in Table 6.20. The results indicate that Chinese airlines must accept additional fuel and route charges to offset increased flight distances and mitigate delays caused by airspace restrictions. This represents the necessary cost of enhancing operational reliability and predictability.

Table 6.20 Performance Changes for Chinese Airlines on the Representative Routes with Longer Alternative Distances

Representative Route	Number of Diverted Flights	Average Change in Flight Time per Diverted Flight (min/flight)	Total Change in Delay Time for Diverted Flights (min)	Average Change in Fuel Consumption per Diverted Flight (kg/flight)	Total Change in Fuel Consumption (kg)	Total Change in CO_2 Emissions (kg)	Fuel Cost (USD)	Change in Route Charges (USD)
ADPET-NUTLO	12	+3.47	-858	+153	+1836	+5783	1507	+12916
PURPA-BIKUT	66	+1.80	-7064	+214	+14108	+44441	11583	+63797

6.3.2 Non-Chinese Airlines

For representative routes where the alternative route distance is shorter than the original, a total of 25,101 flights operated by non-Chinese airlines were included in the simulation. Assuming all these flights are diverted to alternative routes, the resulting changes in operational performance are detailed in Table 6.21.

Table 6.21 Performance Changes for Non-Chinese Airlines on the Representative Routes with Shorter Alternative Distances

Representative Route	Number of Flights	Avg Change in Flight Time (min/flight)	Total Change in Flight Time (min)	Avg Change in Fuel Consumption (kg/flight)	Total Change in Fuel Consumption (t)	Total Change in CO_2 Emissions (t)	Change in Route Charges (USD)
UPREK--SARIN	2432	-17.04	-41446	-2604	-6332.5	-19947.3	-1579605
UPREK-PURPA	1944	-6.81	-13235	-990	-1925.4	-6065.1	-904025
UPREK-FKG	800	-9.20	-7358	-1360	-1088.1	-3427.5	-324093
AGAVO-SARIN	4810	-16.68	-80210	-2569	-12356.3	-38922.5	-3054166
SARIN-PUKOL	212	-6.7	-1412	-766	-162	-512	-119148
SARIN-SASAN	1315	-9.09	-11948	-1064	-1399.3	-4407.9	-807512
SARIN-BIKUT	3308	-7.76	-25659	-943	-3120.3	-9828.9	-1817371

ADPET-BIKUT	10280	-1.9	-19747	-239	-2454.0	-7730.0	-3645342
Total	25101		-201015		-28837.9	-90841.2	-12251262

Table 6.21 indicates that diversion yields significant benefits in operational efficiency, economic performance, and environmental impact for non-Chinese airlines operating on routes where the alternative distance is shorter than the original. The newly developed routes through Mongolian airspace are expected to be the preferred routing option for non-Chinese airlines traversing the Lan–U region.

A comparison of performance outcomes between Chinese and non-Chinese airlines reveals that the difference in benefits primarily lies in ANS charges. Chinese airlines benefit from preferential route-charging policies for domestic operations, leading to higher route charges when diverting through Mongolian airspace, which partially offsets their economic gains from fuel savings. By contrast, when non-Chinese airlines divert to new routes via Mongolia, the applicable ANS charge rates are generally lower, allowing them to capture the associated cost benefits fully. Consequently, they benefit from shorter flight distances, including reduced flight time, fuel savings, and lower route charges.

Table 6.22 Performance Changes for Non-Chinese Airlines on the Representative Routes with Longer Alternative Distances

Representative Route	Number of Diverted Flights	Average Change in Flight Time per Diverted Flight (min/flight)	Total Change in Delay Time for Diverted Flights (min)	Average Change in Fuel Consumption per Diverted Flight (kg/flight)	Total Change in Fuel Consumption (kg)	Total Change in CO_2 Emissions (kg)	Fuel Cost (USD)	Change in Route Charges (USD)
PURPA-PUKOL	57	5.95	-5262	+762	+43447	+136.9	35670	-12485
PURPA-BIKUT	657	1.74	-70299	+229	+150720	+474.8	123741	-199344
OMBON-RULAD	252	34.64	-57043	+5635	+1420020	+4473.1	1165836	+104293

For representative routes where the alternative route distance exceeds the original route distance, it was assumed that only flights affected by NOTAM restrictions would divert to the alternative route. The resulting changes in operational performance are presented in Table 6.22. The results indicate that, to mitigate delays caused by airspace restrictions, airlines would need to accept additional fuel consumption and carbon emissions, along with changes in route charges. Notably, cost-benefit trade-offs vary significantly across different route pairs:

- For the PURPA-BIKUT direction, the average flight time increases by only 1.74 minutes. This modest increase effectively circumvents the risk of restrictions affecting the original route. Additionally, the

increased fuel costs are partially offset by reductions in route charges, allowing for potential operating cost optimization.
- By contrast, for the OMBON-RULAD direction, the average flight time increases significantly by 34.64 minutes, resulting in markedly higher fuel consumption and carbon emissions. While diversion would still reduce delays, the economic and environmental impacts are considerably negative.

These contrasting outcomes highlight the complexity of route selection. In balancing the need to avoid airspace restrictions with operational efficiency, economic costs, and environmental impact, the value of diversion must be assessed on a route-by-route basis, taking into account specific operational characteristics.

6.3.3 China ANSPs

Given the limited number of flights affected on routes where the alternative distance exceeds the original, this analysis focuses on those with shorter alternative distances. Assuming that all flights on these routes, totaling 39,456 movements, would divert to alternative routings, the resulting performance impacts for China ANSPs are as follows:

- **Route charge revenue:** Total route charge income for China ANSPs would decrease by USD 44,650,445.
- **Carbon emissions:** CO2 emissions within Chinese airspace would be reduced by 1,617,919 tonnes.
- **Controller workload:** Total controller service time for Chinese controllers would decrease by 72,346 sector-hours.

Additionally, diverting a portion of traffic from the Lan–U corridor into Mongolian airspace would alleviate operational pressure and mitigate congestion during peak hours.

Regarding the development of new route segments within China, specifically the TEBUS-SARIN and TSEEL-ADPET connections, the areas concerned already benefit from established infrastructure. Consequently, the additional investment required from China's ANSPs would be relatively limited. The primary efforts would focus on route planning and design, operational testing and validation, and the activation and coordination of the new China-Mongolia border point at TSEEL.

In summary, the development of new routes would impact China's ANSPs across multiple dimensions:

- **Economic:** A reduction in route charge revenue.
- **Environmental:** A decrease in CO2 emissions within Chinese airspace.
- **Operational:** A reduction in controller workload and an easing of traffic pressure on the Lan–U corridor, particularly within Lanzhou FIR, would contribute to enhanced safety and overall efficiency. While China's ANSPs would face a reduction in route charge revenue, they would also benefit from lower carbon emissions, reduced controller workload, enhanced safety margins, and improved delay performance.

It is worth noting that the performance changes described above are based on an extreme scenario in which all eligible flights are assumed to divert to the new routes. In practice, whether airlines choose to divert will depend on a range of factors, including route conditions, the level of air navigation service support, traffic flow management measures, and coordination requirements. Mongolia's current air navigation infrastructure and support capabilities are relatively limited, particularly in the westernmost sector, where the continued use of procedural control restricts traffic throughput. Under these circumstances, only a portion of flights would be expected to divert in practice, meaning that actual performance benefits would be lower than those estimated under the full-diversion scenario. Furthermore, a certain proportion of flights currently operating along the Lan–U corridor was rerouted there following the closure of Russian airspace, and this portion of traffic is inherently unstable. From a long-term strategic perspective, China's ANSPs should focus on higher-level objectives such as enhancing airspace system resilience, optimizing resource allocation, and actively participating in regional airspace governance. At the same time, optimization and improvement of the regional route network would help stimulate aviation market growth in the area, offering China's ANSPs the opportunity to capture additional incremental benefits.

6.3.4 Mongolia ANSPs

Applying the same approach, this section examines representative routes where the alternative distance is shorter than the original. If all flights on these routes divert to the alternative routings, the resulting performance impacts for Mongolia ANSPs are as follows:

- **Route charge revenue:** Total route charge income for Mongolia ANSPs would increase by USD 42,609,537.
- **Carbon emissions:** CO2 emissions within Mongolian airspace would increase by 1,512,297 tonnes.
- **Traffic volume:** An additional 39,456 flights would transit Mongolian airspace.
- **Controller workload:** Total controller service time for Mongolian controllers would increase by 67,378 sector-hours.

To implement and sustain the new routes and accommodate increased traffic, Mongolia ANSP would need to strengthen capabilities in key areas: upgrading the westernmost control sector from procedural to radar control; coordinating and activating the proposed TSEEL border point; and expanding the controller workforce while enhancing operational competencies.

In summary, the development of the new route network would significantly increase ANS charge revenue for Mongolia ANSPs, but would also result in higher domestic CO_2 emissions, increased traffic volumes, and greater controller workload. Addressing these changes requires corresponding investments in infrastructure and capability development to ensure the safe and efficient operation of the new routes.

6.3.5 The Aviation Industry

From the perspective of the aviation industry, the implementation of the new route network would generate significant benefits across multiple dimensions:

Operational Efficiency and Safety. Developing the new routes would enhance the overall efficiency of Eurasian air traffic operations. Benefits include reductions in annual flight time, fuel consumption, and carbon emissions, resulting in cost savings for airlines and a more optimized allocation of airspace resources. Diverting a portion of traffic from the Lan–U corridor would alleviate pressure on this core route, reduce the risk of congestion, and enhance safety margins. This dual improvement underscores the increased resilience of the airspace system.

Environmental Protection and Sustainability. The reduction in carbon emissions enabled by the new route scheme contributes substantially to the aviation industry's green and low-carbon transition. It aligns with ICAO's CORSIA mechanism for carbon offsetting and emissions reduction, while providing a quantifiable, verifiable pathway toward the industry’s carbon neutrality goals. The data-driven performance assessment methodology used in this study offers a reference for evaluating the environmental benefits of similar airspace optimization initiatives.

International Cooperation and Regional Coordination. Close collaboration between China and Mongolia in airspace management exemplifies the effective development and sharing of cross-border airspace resources. Establishing new routes requires consensus on technical standards, operational procedures, and control transfer protocols, along with robust bilateral coordination mechanisms. This initiative reflects the potential for collaborative regional airspace governance and serves as a replicable model for other cross-border airspace optimization projects in the Asia-Pacific region and beyond.

Strategic Significance for Chinese Aviation. The development of the new routes is not only a technical response to current operational challenges; it also represents an important step for China's civil aviation in engaging in regional airspace governance and advancing green and low-carbon development. This initiative aligns with China's national strategies of promoting a green and low-carbon transition and achieving more intensive and efficient use of airspace resources. By releasing airspace capacity and optimizing the international route network, China's civil aviation can better meet national air transport demand while contributing to the sustainable development of the global aviation industry. This effort also demonstrates China's role in international civil aviation governance and may help attract more international flights to operate through Chinese airspace in the future. Looking ahead, optimization of the regional route network is expected to support aviation market growth along the Eurasian corridor and offer opportunities for ANSPs to capture incremental benefits.

Development Opportunities for Mongolian Aviation. For Mongolia, opening new routes would increase traffic through its airspace, generating higher ANS charge revenues and elevating air navigation service capabilities. This opportunity could accelerate infrastructure development, enhance controller competencies, and optimize airspace management systems, catalyzing significant progress in Mongolia's civil aviation sector.

In conclusion, implementing the new route network is not merely a technical response to the operational challenges of the Lan–U corridor. It represents a strategic investment in the overall performance of the Eurasian air corridor, delivering benefits that extend beyond individual airlines or States to the international air transport system. The initiative embodies the principles of modern civil aviation governance: data-driven decision-making, multi-stakeholder coordination, and a commitment to sustainable development.

6.4. Traffic Flow and Diversion Rates

6.4.1 Traffic Flow

To analyze the traffic flow characteristics following the implementation of the proposed new route network, the following assumptions were applied: for flights where the alternative route distance is shorter than the original route, all such flights were assumed to divert to the alternative route; for flights where the alternative route distance exceeds the original, only those flights affected by NOTAM-induced delays were assumed to divert. Based on these assumptions, the resulting changes in traffic flow on major routes over the one-year period from 30 March 2024 to 29 March 2025 are illustrated in Figure 6.19. In the figure, red routes represent segments of the original network that would be replaced, with traffic volumes decreasing accordingly; green routes represent the primary alternative routings, which would experience a corresponding increase in traffic. Taking the W66 route segment within Lanzhou FIR as an example, annual traffic could be reduced by up to 38,766 movements, demonstrating a significant redistribution effect.

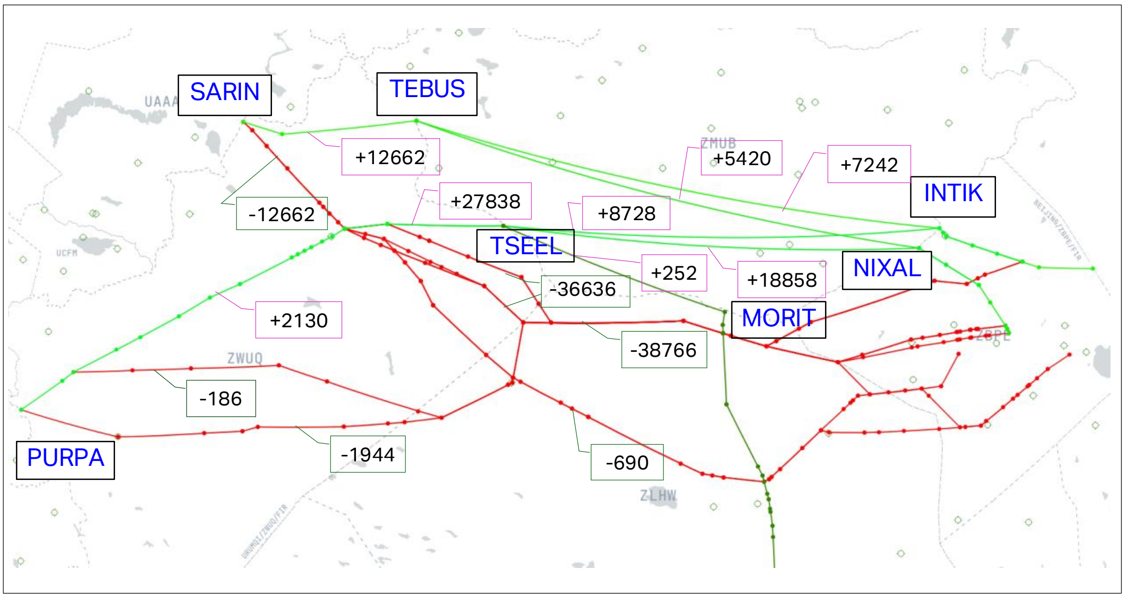


Figure 6.19 Schematic Diagram of Traffic Flow Changes on Major Routes

As the proposed routes within Mongolian airspace are still in the planning stage, and infrastructure development and capability enhancements will need to be informed by future traffic demand, this section analyzes traffic flow changes on the representative new route segments within Mongolia and at key China-Mongolia border points. The results are presented in Table 6.23. The analysis reveals the following:

- **Route traffic:** The NIXAL–TSEEL direction shows the largest traffic increase, with a maximum daily increase of 66 flights and an average daily increase of 49 flights.
- **Border point traffic:** The proposed new border point at TSEEL would face the highest demand, with a maximum daily increase of 100 flights and an average daily increase of 73 flights. The TEBUS border point would see a maximum daily increase of 42 flights and an average daily increase of 35 flights; however, it currently operates under procedural control, limiting its capacity-enhancement potential.
- **Operational characteristics:** The NIXAL-TSEEL route shows the greatest flight time variability, at approximately 7.5 minutes, reflecting a diverse mix of aircraft types and varying operational requirements along this segment.

These traffic projections place greater demands on the service capabilities of Mongolia ANSPs and provide critical input for infrastructure planning and capacity development in Mongolia. The flight volumes in this simulation represent only a partial sample. If the new routes are formally opened, actual traffic volumes are expected to be higher, and the magnitude of traffic flow changes would increase accordingly.

Table 6.23 Traffic Flow Changes on Mongolian Route Segments and at China-Mongolia Border Points

Route / Border Point	Annual Traffic	Max Daily Change	Avg Daily Change	Avg Flight Time (min)	Flight Time Variability (min)
INTIK-TEBUS	+7242	+23	+20	126	3.7
NIXAL-TEBUS	+5420	+19	+15	104	1.9
INTIK-TSEEL	+8728	+38	+24	113	6.1

NIXAL-TSEEL	+18858	+66	+49	88	7.5
TEBUS	+12662	+42	+35		
INTIK	+16334	+61	+45		
NIXAL	+23486	+85	+64		
TSEEL	+27838	+100	+73		

6.4.2 Diversion Rates

Once the new route network becomes operational, the decision by airlines to divert from original to new routings will be influenced by a combination of time costs, economic costs, operational safety, and implementation feasibility. Based on these factors, diversion rates are estimated for different route categories, without considering traffic flow restrictions on the Mongolian routes.

1. Routes with shorter alternative distances

Diversion rate estimates for this category are presented in Table 6.24, based on the following assumptions:

- **Non-Chinese airlines:** Both flight time and fuel consumption decrease after diversion, thus reducing operating costs. It is assumed that all non-Chinese airlines would divert, resulting in a 100% diversion rate.
- **Chinese airlines:** Diversion decisions involve a complex set of factors. As discussed in Section 6.3.1, except for the ZBHH-FKG and ZBTJ-FKG directions, where total expenditure decreases after diversion, all other route directions reduce flight time and fuel consumption but incur higher route charges, leading to increased overall costs. Additionally, since Chinese airlines primarily operate domestic services, routing through foreign airspace may entail extra operational requirements and policy-related coordination costs. Based on airline interviews and operational experience, for Chinese airlines, where total expenditure decreases after diversion, the diversion rate is approximately 80%; where total expenditure increases, diversion is primarily motivated by the need to avoid airspace restrictions, with an estimated diversion rate of around 10%.

Table 6.24 Estimated Diversion Rates for Routes with Shorter Alternative Distances

Representative Route	Simulated Flights	Restriction Rate	Chinese Airlines (Flights)	Net Cost Reduction for Chinese Airlines?	Net Cost Reduction for Non-Chinese Airlines?	Estimated Diversion Rate
UPREK-SARIN	2432	17.90%	\	\	Y	100%
AGAVO-SARIN	4810	17.40%	\	\	Y	100%
SARIN-PUKOL	212	15.60%	\	\	Y	100%

SARIN-SASAN	1315	15.20%	\	\	Y	100%
SARIN-BIKUT	3893	16.70%	585	N	Y	86.5%
UPREK-PURPA	1944	15.40%	\	\	Y	100%
UPREK-FKG	6784	12.20%	5984	N	Y	20.6%
ZBHH-FKG	364	12.10%	364	Y	\	80.0%
LAXAG-FKG	700	11.70%	700	N	\	10.0%
ZBTJ-FKG	326	10.20%	326	Y	\	80.0%
MAGIV-BIKUT	186	14.10%	186	N	\	10.0%
ADPET-PUKOL	1693	10.40%	1693	N	\	10.0%
ADPET-BIKUT	14640	13.40%	4360	N	Y	73.2%
ADPET-TMR	157	9.60%	157	N	\	10.0%

2. Routes with longer alternative distances

Diversion rate estimates for this category are presented in Table 6.25. Given the increased flight distance, airlines' diversion decisions are driven primarily by the severity of delays on the original route and the associated cost implications of diverting:

- **PURPA-BIKUT:** For non-Chinese airlines, the average flight time increases by only 1.75 minutes following diversion, yet overall operating costs decrease due to differences in ANS charging rates. For Chinese airlines, costs increase. Consequently, it is assumed that all non-Chinese airlines will divert, while Chinese airlines will divert primarily when affected by restrictions. The estimated overall diversion rate for this direction is approximately 70%.
- **OMBON-RULAD:** The increase in flight distance and corresponding flight time is substantial. Diversion is expected to be limited to around 5.0% of flights, primarily those severely impacted by airspace closures.
- **PURPA-PUKOL:** Diversion is assumed to occur mainly for flights affected by NOTAM-induced delays, with an estimated diversion rate of approximately 12.0%.
- **ADPET-NUTLO:** This route is predominantly used by Chinese airlines. Diversion is expected to be considered primarily when flights are affected by airspace closures, with an estimated diversion rate of approximately 3.0%.

Table 6.25 Estimated Diversion Rates for Routes with Longer Alternative Distances

Representative Route	Simulated Flights	Restriction Rate	Average Delay per Affected	Average Increase in Flight	Flights of Chinese Airlines	Net Cost Reduction for	Net Cost Reduction for Non-	Estimated Diversi

			Flight (min)	Time (min)		Chinese Airlines?	Chinese Airlines?	on Rate
ADPET-NUTLO	124	9.70%	75	3.47	124	N	\	3.0%
PURPA-PUKOL	364	15.70%	101	5.95	\	\	N	12.0%
PURPA-BIKUT	3970	18.20%	107	1.75	364	N	Y	70.0%
OMBON-RULAD	2247	11.20%	261	34.64	\	\	N	5.0%

The diversion rate estimates have been developed based on various factors, including economic factors, operational efficiency, and the risk of restriction. They may serve as a reference for Mongolian ANSP capacity planning and for developing airline operational strategies.

7. Conclusions and Recommendations

7.1. Conclusions

This white paper presents a systematic, data-driven assessment of airspace efficiency, using the Eurasian air route within the Lanzhou–Urumqi FIRs (ZLHW/ZWUQ) as a case study. The research team reviewed the operational status of the Lan–U corridor, conducted consultations with airlines and ANSPs to understand their challenges and requirements, and explored various mitigation options. Through comparative analysis, the team identified the development of alternative routes within the Ulaanbaatar FIR (ZMUB) as the optimal strategic choice. A preliminary feasibility analysis was conducted. To support informed decision-making, a data-driven assessment of airspace efficiency was conducted. This involved collecting airline flight plan data, simulating flight operations on both original and alternative routes, defining key performance indicators (KPIs), and analyzing the performance changes and impacts associated with the new route scheme.

The main conclusions are as follows:

1. Operational Situation: The Lan–U corridor, a core air bridge connecting East Asia with Europe and Central Asia, is experiencing a growing volume of flights. Traffic in the region has increased steadily in recent years; however, frequent airspace closures severely constrain the availability and operational stability of the route network.

2. Operational Challenges: Airlines encounter significant challenges, including disruptions to flight regularity due to airspace closures, insufficient time for flight plan adjustments caused by delayed NOTAM issuance, and a critical lack of viable alternative routes, limiting operational flexibility. ANSPs face pressure from saturated airspace capacity, increasing controller workload, challenges in handling contingency situations, and overall low operational efficiency. Both stakeholder groups have called for an optimized airspace network, improved coordination, and the release of more flexible airspace resources.

3. Solution Assessment and Feasibility: Developing new routes within Mongolian airspace is identified as the most promising solution to the operational challenges of the Lan–U region. By introducing independent external airspace resources, this scheme would enrich the Eurasian route network, providing an efficient and reliable backup corridor for the Lan–U route and improving flight operational performance. The proposal demonstrates sound feasibility from multiple perspectives, including geographic location, airspace structure, Mongolia's airspace planning, infrastructure development, staffing, coordination mechanisms, and existing infrastructure on the Chinese side.

4. Assessment Methodology: A KPI framework comprising 13 indicators was established to quantify the value of the proposed new routes. These indicators include peak traffic, route distance, en-route extension ratio, flight time, flight time variability, NOTAM-induced delay rate, average NOTAM-induced delay, fuel consumption, CO_2 emissions, ANS charges, flight diversion rate, controller workload, and pilot workload. By collecting airline flight plan data and conducting simulations, operational parameters for flights on both original and proposed routes were obtained, providing a robust data foundation for the comparative analysis.

5. Assessment Results: The comprehensive assessment shows that the proposed new routes through Mongolia yield significant benefits across multiple dimensions: effectively reducing flight distance and time, lowering fuel consumption and CO_2 emissions, decreasing the probability of delays caused by airspace closures, and alleviating controller and pilot workload. Analysis from the perspective of different stakeholders—Chinese airlines, non-Chinese airlines, China ANSPs, Mongolia ANSPs, and the aviation industry as a whole—indicates that the new route scheme improves performance at various levels, particularly benefiting non-Chinese airlines. The opening of the new routes is expected to significantly shift traffic patterns, notably increasing traffic within the Ulaanbaatar FIR. The successful operation of the new routes will depend on steady progress in bilateral airspace coordination mechanisms between China and Mongolia, along with continuous enhancements to Mongolia's ATC infrastructure and service capabilities.

In summary, the proposed new routes over Mongolia offer significant strategic value in alleviating operational pressure on the Lan–U corridor and enhancing regional airspace resilience. Advancing the implementation of this Eurasian corridor is an option that merits careful consideration by all stakeholders. The results of this performance assessment provide a reliable, data-driven basis for decision-making.

7.2. Recommendations for Future Research

Based on simulated data, this study assessed the airspace efficiency of the proposed new routes by comparing the performance of flights operating on the original routes within the Lanzhou–Urumqi FIRs with that of flights using the proposed alternatives through Mongolia. The findings provide insights into optimizing airspace structure and supporting stakeholder decision-making. However, several limitations of this research should be acknowledged:

1. Data Coverage: The simulation relied on flight plan data from a subset of airlines over a specific one-year period, which may not capture the full range of operational scenarios due to limited coverage across all airlines and flight plans.

2. Deviation between Simulation and Reality: While simulations can closely replicate real-world operational characteristics, they have not been validated against actual operational data. Factors such as tactical flow management, weather conditions, and pilot decision-making can lead to discrepancies between simulated results and actual performance.

3. Depth of Assessment Dimensions: Although the current KPI framework addresses multiple dimensions, there is room for refinement. Areas such as granular airspace utilization efficiency (e.g., vertical profile efficiency), predictability of operating times, and dynamic capacity impacts warrant further exploration.

Future research could be enhanced by focusing on the following areas:

1. Data Enhancement and Validation: Comprehensive and long-term operational data should be collected from airlines, ANSPs, and third-party sources. Cross-validation with simulated results would broaden data coverage and improve the accuracy of the analysis.

2. Refinement of the Indicator Framework: Incorporating more granular indicators, such as airspace capacity utilization rate, actual operating time variability, and vertical profile efficiency, would enrich the assessment, enhancing its comprehensiveness and detail.

3. Dynamic Operational Modeling: Conducting operational simulations that more closely reflect real-world conditions by integrating factors such as real-time traffic flow management, meteorological conditions, and dynamic airspace release would enable a more robust assessment of the adaptability and resilience of the new routes under complex operational scenarios.

7.3. Recommendations for Action

The findings of this study provide compelling evidence for the value of developing new air routes through Mongolian airspace. To translate these findings into tangible improvements in efficiency and resilience across the Eurasian air corridor, the following phased recommendations are proposed for stakeholder consideration.

1. Civil Aviation Administration of China (CAAC) and Civil Aviation Authority of Mongolia (CAAM)

Short Term: Initiate bilateral consultations and conduct joint feasibility studies. Establish a bilateral airspace cooperation task force to integrate the new route proposal into the existing aviation cooperation framework. Undertake collaborative safety assessments and airspace capacity analyses, and define technical parameters and approval pathways for new route designs and proposed entry/exit points. Coordinate with airspace management authorities in both countries to secure necessary endorsements for the new routes.

Medium Term: Advance infrastructure development and regulatory alignment. Guide respective ANSPs to implement the construction of new waypoints, route design, and transfer-of-control mechanisms. Establish a joint contingency coordination framework, clearly defining procedures for alternate aerodrome selection, emergency response, and information sharing for operations on the new routes.

Long Term: Organize validation trials and operations. Support and supervise validation flights and trial operations to collect operational data and assess performance. Refine operating procedures based on trial results and grant final approval for the new routes to become fully operational.

2. Air Traffic Management Bureau of China (ATMB)

Short Term: First, optimize route structures and operational services. It is recommended that China's ANSPs continue to explore approaches to improve airspace operational efficiency in the Lan–U region within the existing framework. These include developing new routes within the Lan–U FIRs, improving NOTAM issuance and alternative routing information services, and strengthening civil–military coordination to enhance airspace flexibility.

Second, assess the value of the proposed new routes through Mongolia. China ANSPs should evaluate the short-term economic impacts of the new route scheme while also considering strategic factors such as enhanced airspace resilience, reduced controller workload, environmental benefits, and improved international image. The overall value should be assessed from the perspective of enhancing the overall performance of the regional air route network. Finally, conduct internal feasibility validation and capability assessment. Deploy technical resources to perform detailed feasibility studies for new route segments within Urumqi FIR (e.g., TEST-SARIN, TSEEL-ADPET) and assess the coverage and support capabilities of existing CNS infrastructure. Coordinate with NCAC on transfer-of-control procedures for the proposed TSEEL border point, clarifying transfer points, flight levels, and coordination methods.

Medium Term: Enhance infrastructure and personnel training. Based on assessment outcomes, implement necessary upgrades or gap-filling measures for relevant CNS facilities to ensure reliability within new route coverage areas. Provide specialized training for controllers on new route operating procedures and China–Mongolia coordination processes, and conduct joint simulation exercises.

Long Term: Participate in validation trials and procedure optimization. Engage in joint China–Mongolia validation trials to gain operational experience and collect data. Continuously refine control procedures based on feedback from validation trials to improve coordination efficiency between new and existing route operations.

3. National Civil Aviation Center SOLLC (Mongolia ANSP)

Short Term: Assess capabilities and align planning. Conduct a comprehensive assessment of current controller numbers and qualifications against projected traffic growth, and develop a recruitment and training plan. Evaluate the capacity of existing CNS infrastructure to support new route operations and identify upgrade requirements. Focus on options for installing surveillance radar or upgrading ADS-B ground stations in the westernmost sector, which currently lacks radar coverage, to facilitate the transition to radar control.

Medium Term: Build capacity and optimize procedures. Implement controller recruitment and training as planned to ensure staffing levels meet the demands of new route operations. Begin construction or upgrading of surveillance facilities in the western sector to enable the transition from procedural to radar control, thereby increasing airspace capacity and enhancing operational safety. Coordinate with ATMB to progress AIDC (ATS Interfacility Data Communications) and testing, facilitating seamless cross-border transfer of control.

Long Term: Ensure stable operations and drive continuous improvement. After commissioning the new routes, continuously monitor traffic flows and controller workload to optimize sector configurations and resource allocation. Collaborate with IATA and airlines on capacity assessments and diversion forecasts for the new routes, providing a basis for future optimization of airspace resources.

4. Airlines

Short Term: Share data and provide feedback on requirements. Actively participate in IATA-led surveys and data collection initiatives, providing comprehensive operational plans, cost data, and feedback on operational challenges to support refined assessments. Submit requirements and recommendations related to dispatch, flight operations, and operational control for the proposed new routes.

Medium Term: Participate in validation and prepare for operations. Support validation flights for the new routes, providing aircraft and crew resources to gather validation data. Update flight operations manuals, dispatch procedures, and onboard navigation databases, and conduct personnel training in preparation for new route operations.

Long Term: Assess benefits and optimize selection. After commissioning the new routes, evaluate route selection strategies based on actual operational benefits to maximize value. Continuously provide feedback on operational experience and suggestions for improvement to IATA and relevant ANSPs to support ongoing optimization of new route operations.

5. International Organizations (ICAO, IATA, etc.)

Short Term: Provide coordination platforms and technical guidance. The ICAO Asia-Pacific Regional Office could include this case study in its regional route development work program, offering technical guidance and a coordination platform for the involved states. IATA should continue to organize industry workshops to share research findings, build consensus among stakeholders, and promote the inclusion of the new route proposal in the ICAO Asia-Pacific Regional Air Navigation Plan.

Medium Term: Disseminate best practices and advocate supportive policies. ICAO should promote the performance assessment methodology developed in this study as a good practice example of airspace optimization for application in other regions. It should also advocate that states incorporate such airspace optimization projects into their national carbon reduction action plans.

Long Term: Monitor performance and support the evolution of standards. IATA, in collaboration with relevant stakeholders, should conduct follow-up assessments of the actual performance of the new routes once operational to validate the research findings and accumulate experience for similar future projects.

Through the coordinated efforts of all stakeholders, the proposed new routes through Mongolia can transition from concept to implementation, strengthening the Eurasian air transport network and delivering significant benefits in operational efficiency, economic performance, and environmental sustainability.

Appendix 1: Profile of Restricted Route Segments in Lanzhou-Urumqi FIRs

Route Segment	Frequency of Restrictions	Average Restriction Duration (min)	Average NOTAM Lead Time (min)	Total Restriction Duration (min)	Restriction Time Ratio
Lanzhou FIR					
B330 MORIT-YBL	321	198	1255	63454	12.07%
W199 NIRUV-YBL	221	304	1177	67077	12.76%
W187 TUSLI-DNH	193	237	1225	45790	8.71%
A596 DKO-YBL	184	220	1266	40474	7.70%
W215 YHD-VIRIK	178	260	1262	46267	8.80%
W216 YHD-XFG	175	264	1262	46159	8.78%
Y1 OMBON-MEPEP	167	212	1238	35426	6.74%
W66 GOBIN-GOVSA	155	217	1209	33614	6.40%
B215 JTA-IBANO	151	213	1226	32095	6.11%
W66 ATBUG-GOBIN	144	213	1219	30633	5.83%
B330 YBL-MUDAP	137	301	1204	41221	7.84%
W112 TUSLI-TODOD	123	263	1199	32307	6.15%
Y1 DUMIN-MAGOD	121	267	1139	32257	6.14%
B215 IBANO-NUKTI	114	211	1225	24108	4.59%
W66 DKO-ATBUG	113	225	1218	25406	4.83%
W112 ADMUX-TUSLI	107	237	1210	25354	4.82%
Y1 MEPEP-DUMIN	104	269	1159	27959	5.32%
W192 DUMIN-TUSLI	103	243	1179	25010	4.76%
W192 TUSLI-RUSDI	101	237	1224	23931	4.55%

W191 MOVBI-TOSAP	99	214	1274	21150	4.02%
W187 OBDEG-TUSLI	94	232	1223	21838	4.15%
V67 NUKTI-CHW	92	205	1254	18886	3.59%
G470 IBANO-BIKNO	91	207	1274	18809	3.58%
L888 BEVTA-LUVAR	89	322	1158	28693	5.46%
V67 CHW-YBL	88	252	1219	22190	4.22%
W191 TOSAP-MULRU	83	242	1228	20081	3.82%
W28 KEVOB-ATBUG	82	217	1195	17806	3.39%
B215 NIRUV-JTA	61	255	1263	15536	2.96%
W112 TODOD-BILDA	58	234	1270	13578	2.58%
B330 MUDAP-OMBON	53	354	1233	18766	3.57%
W219 ZWX-YHD	53	271	1287	14386	2.74%
W619 BILDA-MULRU	48	244	1221	11727	2.23%
W66 GOVSA-NUKTI	37	257	1187	9527	1.81%
W191 MULRU-DNC	37	257	1196	9527	1.81%
W619 CHW-BILDA	35	272	1223	9519	1.81%
W188 GOVSA-LIKMI	31	245	1220	7592	1.44%
B215 NIRUV-YHD	24	326	1359	7821	1.49%
W195 MORIT ALGOT	11	190	1219	2091	0.40%
Y2 MEPEP-LUVAR	8	265	1284	2122	0.40%
Urumqi FIR					
Y1 MAGOD-SADAN	155	180	1073	27911	5.31%
W187 SADAN-OBDEG	140	173	1049	24182	4.60%
W112 DJQ-ADMUX	130	165	1075	21400	4.07%

W192 RUSDI-ESDEX	130	238	1056	30899	5.88%
L888 SADAN-BEVTA	114	186	1102	21167	4.03%
W186 ISBEB-SADAN	83	255	1032	21187	4.03%
W191 ESDEX-MOVBI	83	246	1016	20382	3.88%
L888 SADAN-XKC	80	263	1008	21003	4.00%
G470 TAMOX-BIKNO	76	251	989	19091	3.63%
W112 DJQ-HTN	74	177	1094	13109	2.49%
W187 MAGIV-SADAN	58	218	1115	12634	2.40%
W192 LUORO-ESDEX	47	355	891	16678	3.17%
G470 IRPEP-TAMOX	32	417	773	13348	2.54%
W186 AKS-ISBEB	31	314	1027	9722	1.85%
W189 DAKPA-AKLAS	31	407	792	12605	2.40%
W192 LUORO-KEXAB	30	404	789	12131	2.31%
G588 XFY-MULOR	29	133	1242	3869	0.74%
B206 ADPET-NIRAV	28	126	1253	3539	0.67%
B215 NUKTI-DUBUV	26	347	944	9009	1.71%
V116 LUPRO-ESDEX	25	386	927	9640	1.83%
B215 LEDEM-KABDO	23	321	1059	7378	1.40%
W99 HAM-QTV	16	470	846	7520	1.43%
W119 LIMOD-KABDO	14	530	862	7426	1.41%
A343 NLT POSOT	11	583	892	6416	1.22%
A460 IDMOL-XKC	10	572	920	5720	1.09%
W119 AKS-LESVI	9	140	1140	1259	0.24%
W188 ESGIV-LIKMI	9	483	1065	4345	0.83%

B215 PURPA-LEDEM	5	120	1130	600	0.11%

Appendix 2: Detailed Definitions and Calculation Methods for the KPIs

No.	Indicator	Definition	Unit	Calculation Method
KPI1	Traffic Volume	Number of flights operating on a given route, route segment, or waypoint	Flights	Count the number of flights operating on a specified route, route segment, or waypoint within a given time period. This study primarily calculated annual and daily traffic volumes.
KPI2	Route Distance	Planned distance of the route flown	km, nm	The distance of a specified route segment.
KPI3	En-route Extension Ratio	Ratio of the planned route distance to the reference great circle distance	%	1. Calculate the great circle distance between the origin and destination. 2. Determine the actual distance of the planned route. 3. Calculate the extension ratio as (actual distance – great circle distance) / great circle distance.
KPI4	Flight Time	Flight time within a given route segment	min	Record the flight time for flights operating on a specified route segment.
KPI5	Flight Time Variability	Distribution of flight times around the mean value	min/flight	For a set of flights operating on a given route segment, calculate the standard deviation of their flight times to represent flight time variability.
KPI6	NOTAM-Induced Delay Rate	Proportion of flights delayed due to NOTAM restrictions	%	1. For a specified time period, determine the total number of flights and the number of flights delayed due to NOTAM restrictions. 2. Calculate the delay rate as (number of delayed flights) / (total number of flights).
KPI7	Average NOTAM-Induced Delay	Average delay per flight caused by NOTAM restrictions	min/flight	For a specified set of flights affected by NOTAM restrictions, determine the delay time for each affected flight and calculate the average.
KPI8	Fuel Consumption	Fuel consumed during flight	kg	Estimated fuel consumption for a specified set of flights.
KPI9	CO2 Emissions	CO2 emissions resulting from fuel consumption	kg	CO2 emissions calculated based on fuel consumption for a specified set of flights.

KPI10	ANS Charges	Charges for air navigation services on a given route	USD	ANS charges calculated based on aircraft type, route, and applicable charging schemes.
KPI11	Diversion Rate	Proportion of flights diverted from original routes to new routes	%	For a specific route, the ratio of the estimated number of flights that would divert from the original route to the new route to the total number of flights on that route.
KPI12	Controller Workload	Change in controller workload resulting from flight diversions, expressed as total flight hours within a sector	sector-hours	For a set of flights within a specified control area, calculate the flight time for each flight within that area. The sum of these flight times represents the total controller service time, indicating controller workload.
KPI13	Pilot Workload	Change in pilot workload resulting from flight diversions, expressed primarily as total flight time	flight-hours	For a set of flights, calculate the flight duty time for each flight crew. The sum of these duty times represents the total flight time, indicating pilot workload.