BEYOND PREDICTION: FAST-TIME SIMULATION AS A STRATEGIC DECISION-MAKING TOOL

ALG

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THE NEED FOR AN EFFICIENT DECISION-MAKING TOOL

Airport operations comprise a network of highly interconnected systems, including passenger processing, ground handling, terminal operations, airfield management, and airspace coordination. As air traffic demand and operational complexity continue to increase, airport planning requires a careful balance among infrastructure, operational procedures, capacity, and service quality. Decision-makers must also understand how changes in one part of the system may influence overall airport performance, making a holistic and data-driven approach essential for effective planning and operational optimization.

In this context, analytical tools capable of replicating real-world operations within a controlled, risk-free, and cost-effective environment have become essential. These tools enable organizations to evaluate operational scenarios, test alternative strategies, and assess the potential impact of proposed changes before implementation. By providing reliable, data-driven insights without disrupting live operations, they support more informed decision-making while reducing uncertainty, implementation risks, and the costs associated with trial-and-error approaches.

Several complementary analytical approaches are available, including optimization tools, digital twins, discrete-event simulation, and Fast-Time Simulation. While each serves a different purpose, Fast-Time Simulation has emerged as one of the most effective methods for evaluating operational scenarios because it combines realistic system modeling with the ability to assess multiple alternatives rapidly and without disrupting ongoing operations.

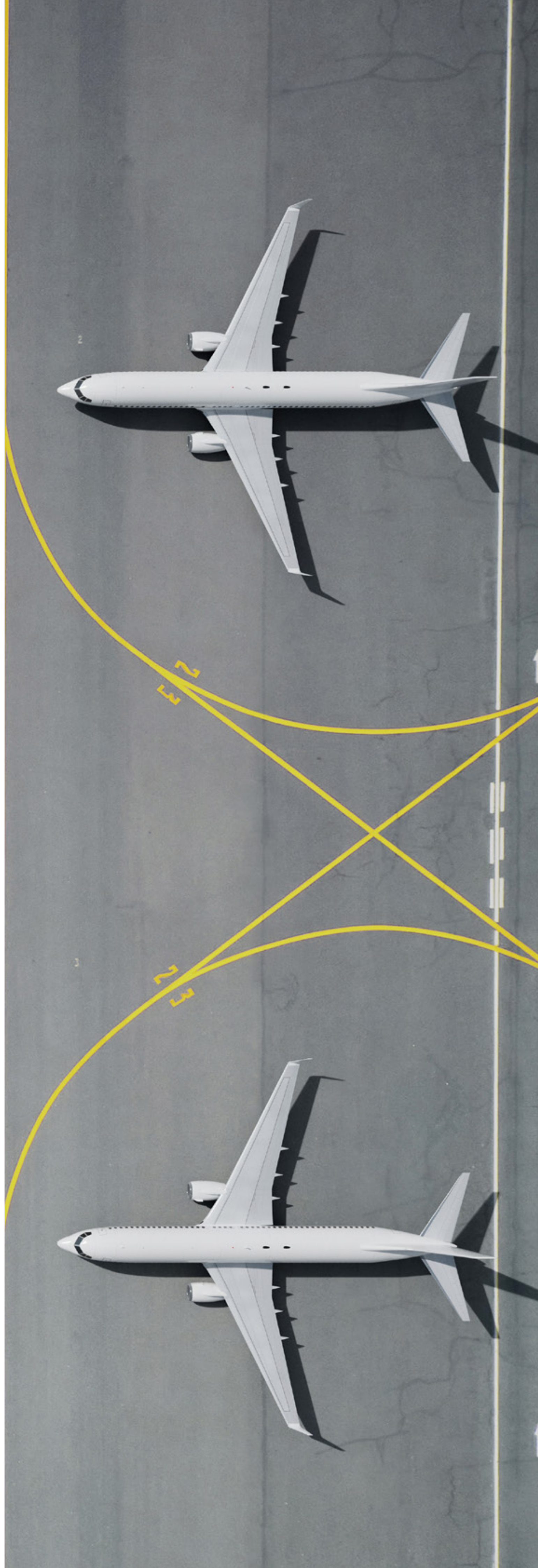
Fast-Time Simulation (FTS) is a computer-based modeling technique that replicates the behavior of complex systems by executing simulated operations much faster than they would occur in reality. Unlike real-time simulation, in which events unfold at the same pace as actual operations, FTS compresses time, allowing multiple operational scenarios to be evaluated within a relatively short period.

One of the primary strengths of FTS lies in its ability to evaluate numerous “what-if” scenarios efficiently. Decision-makers can compare different operational concepts, infrastructure layouts, resource-allocation strategies, and traffic-growth projections while measuring their effects on key performance indicators such as delays, capacity, throughput, fuel consumption, emissions, and operational resilience.

Beyond performance evaluation, FTS plays a critical role throughout the lifecycle of operational improvement initiatives. It can be used during the planning phase to validate proposed concepts, during system design to optimize operational configurations, and after implementation to assess whether the expected benefits have been achieved. As a result, simulation becomes more than a technical analysis tool; it serves as a decision-support framework that facilitates collaboration among stakeholders by providing objective, data-driven insights.

Over the years, ALG has successfully applied FTS across a wide range of airport and airspace projects, supporting strategic decision-making in areas such as capacity assessment, infrastructure planning, operational improvement, and airspace redesign. By testing future scenarios before committing significant resources, ALG’s clients have been able to reduce implementation risks, increase confidence in investment decisions, and support the development of more efficient, resilient, and sustainable operational systems.

This paper introduces the fundamental principles of Fast-Time Simulation and presents examples of its successful application across a range of projects.



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UNDERSTANDING FAST-TIME SIMULATION

The first step in developing a Fast-Time Simulation exercise is to clearly define the objectives of the study by establishing the operational questions that the simulation is expected to answer. These objectives may range from evaluating future traffic demand and assessing the impact of infrastructure modifications to validating new operational procedures or identifying potential capacity constraints. This step is critical because it determines the required level of model detail and the key performance indicators that will be used to evaluate the results.

The second step is to create a digital representation of the operational environment under assessment. This model replicates the physical characteristics of the system, including infrastructure elements such as runways, taxiways, aprons, terminals, gates, and airspace structures. However, accurately representing the physical environment alone is not sufficient. The model must also capture the operational logic governing how the system functions, including aircraft performance characteristics, air traffic control procedures, separation standards, routing rules, resource availability, and interactions among the various stakeholders involved in airport operations.

Once the model has been developed, it is populated with operational data obtained from sources such as historical records, flight schedules, traffic forecasts, infrastructure databases, and operational procedures. These inputs define the demand profile and system characteristics under which the simulation will operate.

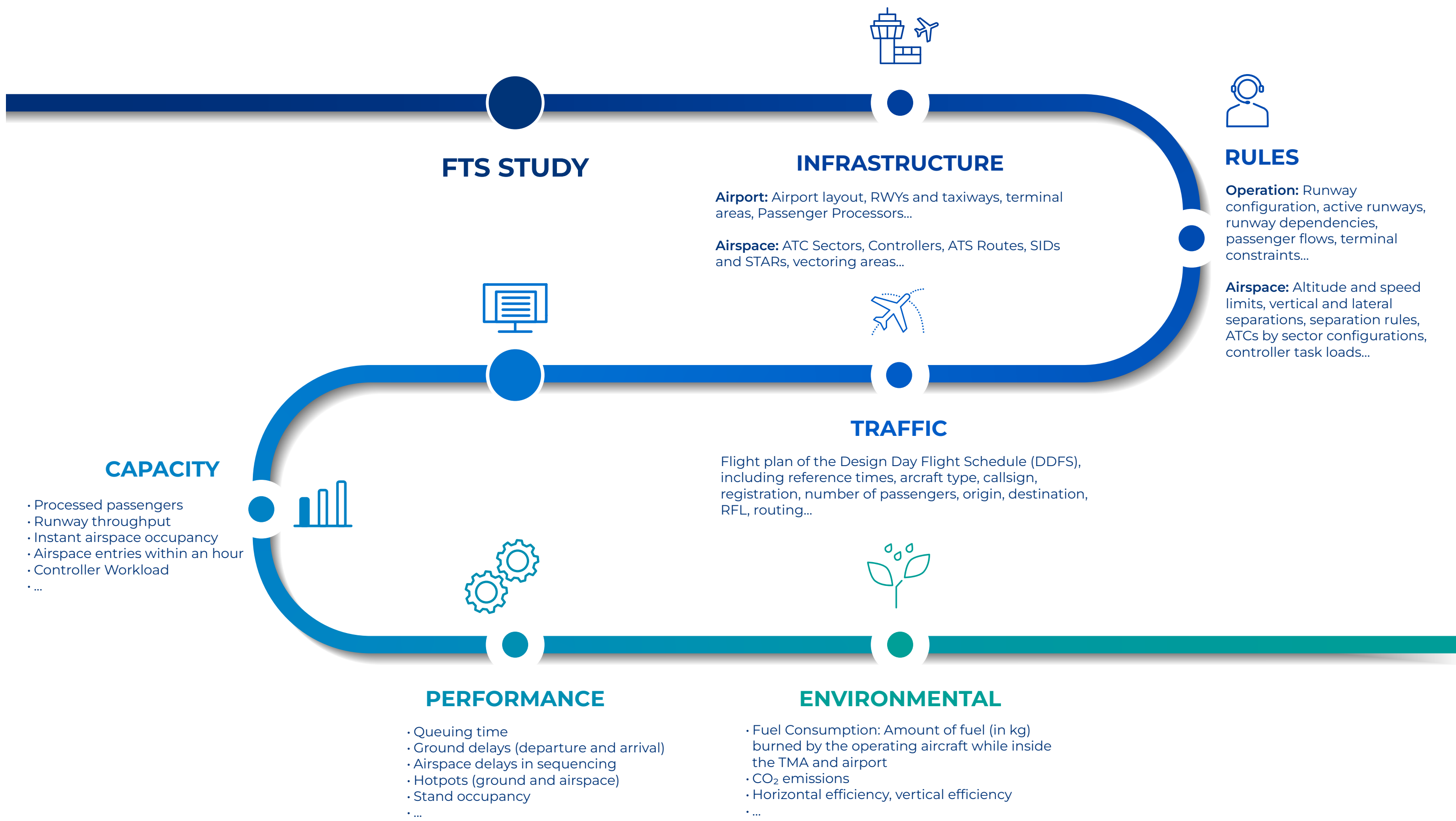
Before alternative scenarios can be assessed, the model undergoes a calibration and validation process. During calibration, key parameters are adjusted until the simulated behavior closely reflects actual or expected operations. Validation then confirms that the model can reproduce representative system performance by comparing its outputs with observed operational indicators such as traffic throughput, delays, taxi times, queue lengths, occupancy levels, and resource utilization.

After the baseline model has been validated, alternative scenarios can be developed by modifying infrastructure, operating procedures, traffic demand, fleet composition, resource allocation, or other relevant assumptions. Each scenario represents a potential future operating environment, enabling planners and decision-makers to assess the consequences of proposed changes before they are introduced into the real system.

Because aviation operations involve inherent variability, each scenario is typically simulated multiple times using different random inputs. This approach captures a range of possible operational outcomes rather than producing a single deterministic result, increasing the statistical reliability of the analysis and providing a more representative understanding of system performance.

The outputs from each scenario are then analyzed and compared using a consistent set of predefined key performance indicators aligned with the study objectives. These indicators may include capacity, delays, taxi times, passenger service levels, controller workload, resource utilization, fuel consumption, and environmental impacts.

By objectively quantifying the benefits, limitations, and trade-offs associated with each alternative, FTS provides decision-makers with robust, evidence-based insights. This supports the selection of solutions that offer the most appropriate balance among operational performance, cost, implementation complexity, resilience, and long-term sustainability.



WHERE FAST-TIME SIMULATION CREATES VALUE

The value of Fast-Time Simulation extends far beyond its ability to replicate airport operations. Whether supporting the development of new facilities, optimizing existing operations, or evaluating future growth strategies, FTS allows decision-makers to quantify the expected benefits and trade-offs associated with each alternative. This evidence-based approach replaces assumptions with objective analysis, enabling organizations to prioritize initiatives that deliver the greatest operational, financial, and strategic value.

This section presents some of the most common applications of FTS and demonstrates how it creates value across different areas of airport and airspace planning and operations.

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Capacity assessment: evaluates the capacity of airport infrastructure and airspace under different operating conditions. By replicating aircraft movements, passenger flows, and operational procedures, FTS enables planners to identify current and future bottlenecks, quantify available capacity, and assess the impact of traffic growth or operational constraints on overall system performance.

Infrastructure development: assesses proposed infrastructure projects before implementation. Developments such as new runways, taxiways, aprons, terminals, and gate layouts can be modeled to compare design alternatives, estimate operational benefits, and support investment decisions based on measurable performance improvements.

Operational procedure evaluation: tests changes to operational procedures without affecting live operations. Alternative runway configurations, taxi routes, air traffic control procedures, gate-allocation strategies, turnaround processes, and collaborative decision-making concepts can be analyzed to determine their impact on capacity, delays, resource utilization, and overall efficiency.

Future demand assessment: evaluates how future traffic growth may affect existing infrastructure and operational concepts. By modeling different traffic forecasts and demand scenarios, the simulation helps determine when additional capacity will be required and supports the development of long-term expansion strategies.

Resource optimization: evaluates the utilization of critical airport resources, including gates, stands, runways, taxiways, check-in facilities, baggage systems, ground handling equipment, and operational personnel. This enables organizations to identify inefficiencies, optimize resource allocation, and improve operational performance while minimizing unnecessary investments.

Operational resilience and contingency planning: assesses the airport's ability to respond to disruptions such as adverse weather, equipment failures, infrastructure closures, maintenance works, and temporary traffic peaks. By testing contingency scenarios in advance, stakeholders can develop mitigation strategies that strengthen operational resilience and business continuity.

Environmental assessment: quantifies the environmental impact of operational and infrastructure changes by estimating indicators such as fuel consumption, aircraft emissions, engine running time, and taxi times. This supports the evaluation of initiatives intended to improve operational efficiency while contributing to broader sustainability objectives supports the evaluation of initiatives aimed at improving operational efficiency while contributing to sustainability objectives.

Beyond its quantitative outputs, one of the greatest strengths of FTS is its visual representation of airport and airspace operations. Dynamic animations allow stakeholders to directly observe aircraft, passenger, vehicle, and traffic flows, making congestion, queues, and operational conflicts immediately identifiable. These visualizations are valuable not only for communicating results to non-technical audiences but also as analytical tools in their own right, often revealing operational patterns and bottlenecks that may not be immediately evident from performance indicators alone.

Capacity assessment

Understanding the true capacity of an airport is one of the most important challenges in airport planning and operations. As air traffic demand continues to grow, decision-makers need to determine not only how many aircraft or passengers the existing infrastructure can accommodate, but also which operational constraints will ultimately limit future growth.

Airport capacity depends on the interaction of multiple interconnected subsystems, including passenger terminals, runways, taxiways, aprons, and surrounding airspace. Traditional analytical methods may not fully capture these complex operational interactions. FTS addresses this limitation by providing a realistic representation of airport operations, enabling planners to evaluate capacity under different traffic scenarios and identify the factors that constrain overall system performance.

The assessment begins with a calibrated and validated simulation model representing current operations. Traffic demand is then progressively increased while monitoring a predefined set of key performance indicators, such as delays, queue times, occupancy levels, taxi times, throughput, or controller workload. Practical capacity is reached when one or more indicators exceed their predefined level of Service thresholds.

This methodology not only determines the airport's practical capacity but also identifies the subsystem that becomes the operational bottleneck, whether the passenger terminal, runway system, airfield, or airspace. These insights support infrastructure planning, operational improvements, traffic-management strategies, and capacity declarations.

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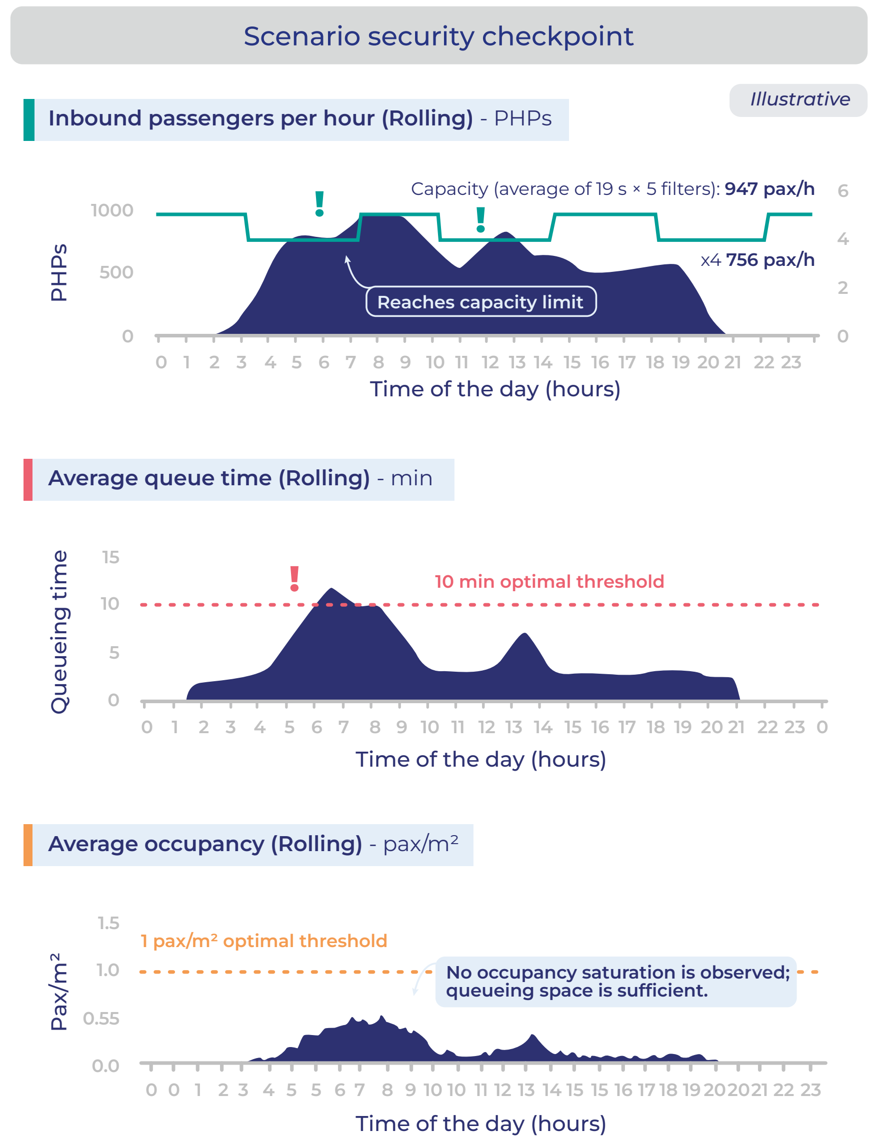
Terminal capacity

Passenger terminal capacity is determined by the terminal's ability to process passengers throughout their complete departure or arrival journey while maintaining the required Level of Service. This journey consists of a sequence of interconnected processing points, including terminal access, check-in, security screening, passport control, boarding, baggage reclaim, and customs, depending on the passenger flow being analyzed.

FTS evaluates the performance of each terminal subsystem using operational indicators such as passenger throughput, waiting times, queue lengths, processing times, and occupancy levels. These indicators are compared with predefined service-level criteria, typically based on the IATA Airport Development Reference Manual (ADRM)[1].

As passenger demand increases, queues and occupancy levels progressively build until one or more processing areas approach their acceptable operational limits.

Because passengers move sequentially through multiple processing areas, congestion develops over time and propagates across the terminal. When a subsystem reaches its maximum capacity, the passengers responsible for that demand have already generated queues in upstream processes. Consequently, terminal capacity cannot be defined by the performance of a single subsystem but must be evaluated considering the behaviour of the entire passenger processing chain.



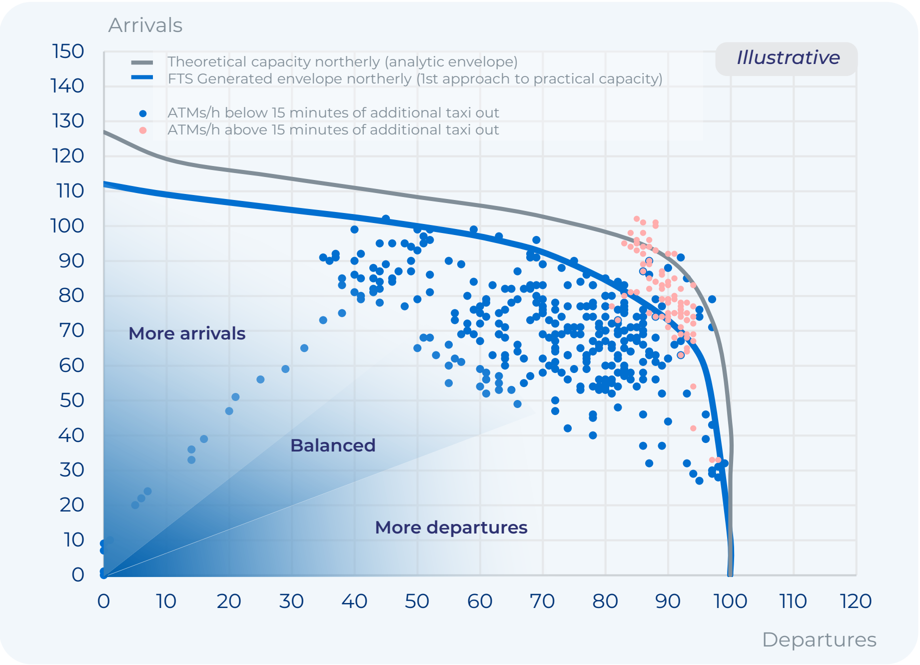
[1]IATA — Airport Development Reference Manual (ADRM). International Air Transport Association. Terminal planning and passenger level-of-service benchmarks used to define acceptable service levels.

Runway capacity

Runway capacity is influenced by both infrastructure characteristics and operational procedures. Key factors include runway layout, rapid-exit taxiways, runway crossings, aircraft mix, wake-turbulence separation requirements, runway dependencies, and the sequencing of arrivals and departures. Together, these elements determine the maximum throughput that can be achieved under each runway operating configuration.

Within an FTS model, runway capacity is assessed by progressively increasing traffic demand while maintaining representative traffic patterns, fleet mixes, and arrival-to-departure ratios. For each demand level, the simulation evaluates operational indicators such as runway throughput, delays, taxi times, and runway occupancy. This process identifies the point at which increasing demand no longer produces a proportional increase in runway throughput and delays begin to rise significantly, indicating that the runway system has reached its practical capacity.

Capacity envelope plot



Unlike a static capacity declaration, runway capacity is inherently dynamic. It varies according to traffic mix, arrival-to-departure ratio, runway configuration, weather conditions, and prevailing operational procedures. For this reason, capacity is typically assessed over rolling time windows, commonly one hour or shorter 10- to 15-minute intervals, to provide a more representative view of the airport's operational capability throughout the day.

One of the key outputs of an FTS analysis is the capacity envelope, which represents the combinations of arrivals and departures that can be accommodated within a given period. This enables planners to verify whether a planned schedule remains within the operational limits of the runway system under different traffic scenarios and operating configurations.

Runway capacity can also be estimated using analytical models based primarily on separation minima and runway occupancy times. While these methods provide a rapid initial estimate, they cannot fully capture the interactions among runways, taxiways, apron operations, and the surrounding airspace.

Based on numerous airport studies, ALG has extensively analyzed the relationship between analytical and simulation-based capacity assessments, quantifying the differences across various runway layouts and operational configurations. This experience provides a robust basis for selecting the most appropriate methodology at each stage of airport planning.

Operational capacity is generally defined at three levels:

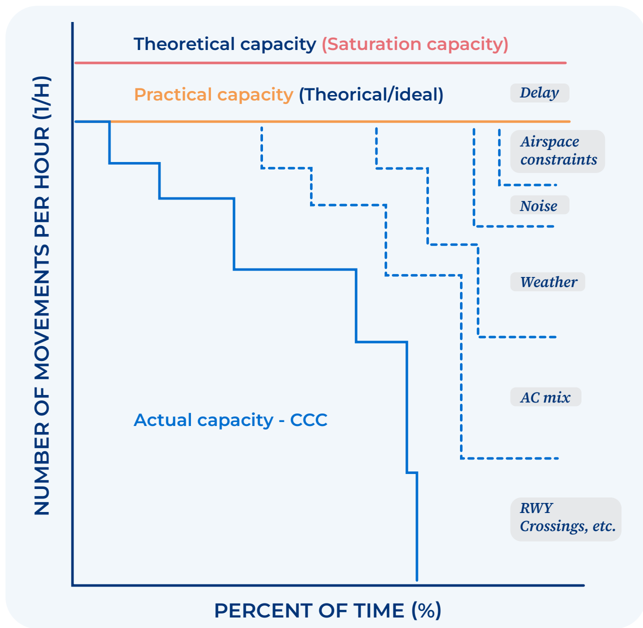
- Saturation capacity: The theoretical maximum throughput that the system can achieve.
- Practical capacity: The maximum throughput that can be sustained while maintaining delays within acceptable operational limits.
- Actual capacity: The throughput effectively achieved under real operating conditions.

These capacity levels are commonly summarized using a Capacity Coverage Chart, which illustrates the proportion of time during which each capacity level can be sustained under different runway configurations, weather conditions, and traffic-demand scenarios. A steep curve indicates that higher runway capacities can be sustained only for a relatively limited proportion of the time, resulting in a lower effective operational capacity.[2]

Published studies have shown that analytical runway-capacity estimates may overestimate achievable operational capacity, with the discrepancy generally increasing as airport layouts and runway systems become more complex. Depending on the airport configuration and methodology applied, this difference may reach approximately 10–20%.[3]

This understanding, combined with ALG's experience in both analytical and simulation-based capacity assessments, supports the selection of the most appropriate methodology according to the study objectives, required level of accuracy, project schedule, and available budget.

Capacity coverage chart



From EUROCONTROL - Airport Capacity Utilisation Methodology

[2] EUROCONTROL - Airport Capacity Utilisation Methodology.

[3] Schinwald, C., and M. Hornung. 2014. "Methodical Approach to Determining the Capacity Utilisation of Airports: The Development of the European Air Traffic System Between 2008 and 2012," November.

Airfield capacity

Airfield capacity evaluates the combined performance of the runway system, taxiways, and apron as an integrated operational environment. Its purpose is to determine how effectively the complete airfield can accommodate increasing traffic demand while maintaining acceptable levels of delay and operational efficiency.

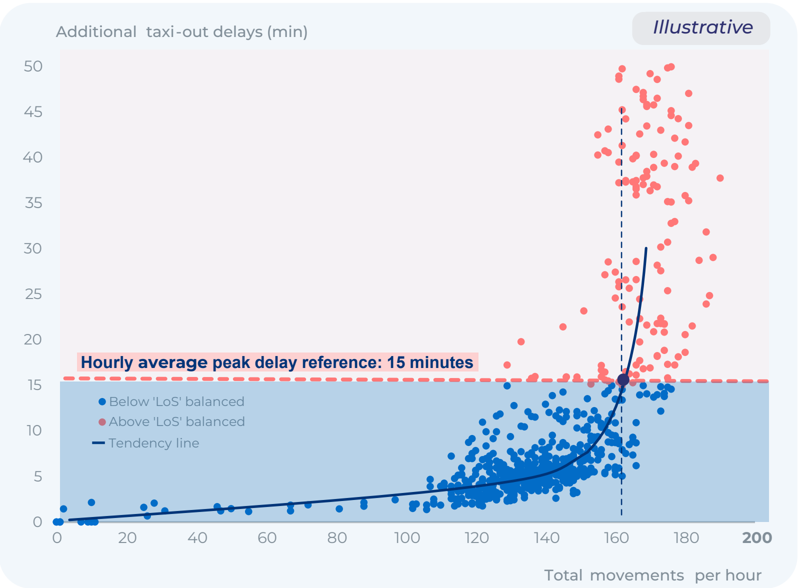
A primary indicator is the relationship between traffic demand, expressed in aircraft movements per hour, and the average ground delay generated across the airfield. The assessment is performed by progressively increasing traffic demand while maintaining representative traffic patterns, fleet mixes, and operating conditions.

For each simulation run, the resulting average ground delay is calculated and compared with a predefined operational threshold, typically ranging between 5 and 15 minutes depending on the airport's characteristics and operational objectives.

The resulting demand-delay curve provides a clear representation of airfield performance. At low traffic-demand levels, average ground delays remain relatively stable. As traffic approaches practical capacity, congestion begins to develop at critical points within the system. Once practical capacity has been exceeded, the curve steepens rapidly and delays increase sharply, indicating that the airfield has entered a saturated operating regime.

This integrated assessment is particularly important because runway capacity alone may not reflect the true operational limitations of the airport. In some cases, the runway system may retain sufficient theoretical capacity while congestion on taxiways, apron areas, runway crossings, or aircraft stands constrains the throughput of the airfield as a whole.

Aircraft movements versus additional taxi-out time



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Airspace capacity

Airspace capacity is defined as the maximum number of aircraft operations that can be safely accommodated while maintaining an acceptable air traffic controller workload. Within a Terminal Maneuvering Area, this is generally expressed as the maximum number of arrivals and departures that can be handled during a given period.

Since Terminal Maneuvering Areas are divided into several air traffic control sectors, overall airspace capacity is ultimately constrained by the sector with the lowest operational capacity. For Area Control Center operations, capacity is assessed independently for each sector within the Flight Information Region. Rather than assigning a single capacity value to the entire region, each sector is assigned its own operational capacity to ensure that controller workload remains within acceptable limits under all traffic conditions.

Within an FTS environment, sector capacity is commonly estimated using EUROCONTROL's Capacity Analysis (CAPAN) methodology.[4]

Workoad thresholds from CAPAN methodology

Recorded working time/hour	Interpretation	Threshold
45 minutes or more	Overload	70% or above
32-41 minutes	Heavy Load	54% - 69%
18-31 minutes	Medium Load	30% - 53%
11-17 minutes	Light Load	18% - 29%
0-10 minutes	Very light Load	0% - 17%

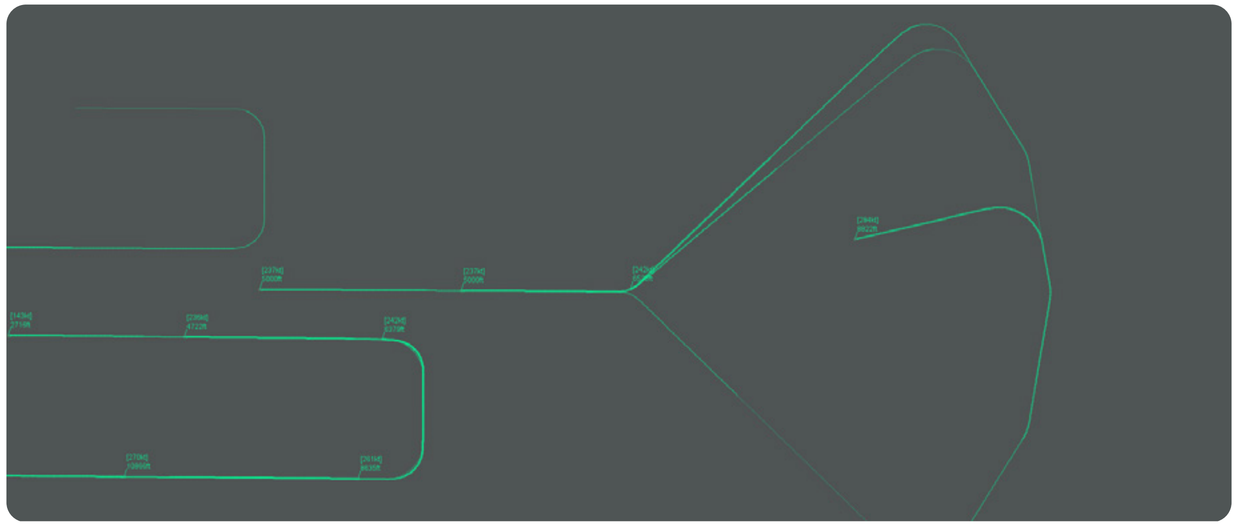
From ATC Capacities and their Costs

[4] Eurocontrol-Capacity analysis methodology

This methodology models controller workload by representing the principal air traffic control tasks performed while handling aircraft. Although workload is influenced by numerous cognitive and human factors that cannot be fully reproduced through simulation, the methodology provides a representative approximation suitable for strategic airport and airspace planning studies.

The workload model groups air traffic control activities into five categories, each associated with an average execution time:

- Flight data management
- Conflict search
- Coordination
- Standard radiotelephony
- Radar tasks



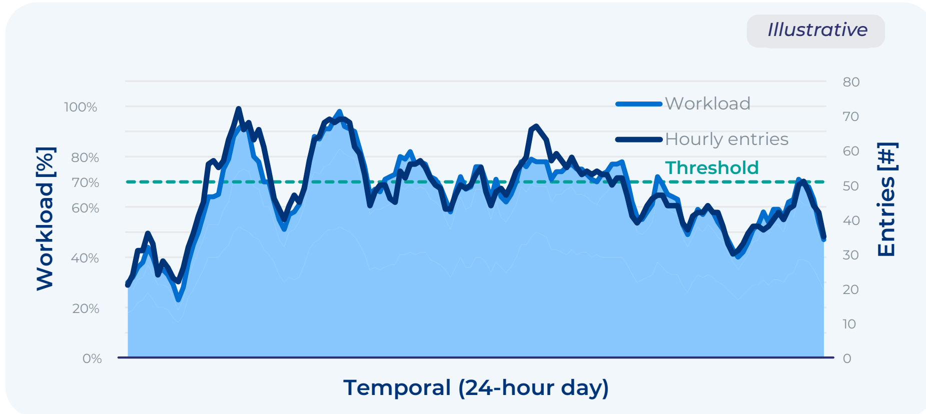
Point-Merge and Trombone. Image from AIRTOP generated by ALG

The accumulated workload over a one-hour period is compared with the capacity analysis workload threshold. Under this methodology, controller workload is considered excessive when it exceeds 42 minutes per hour, although short periods above the threshold may remain operationally manageable when followed by periods of lower workload.

One of the major advantages of FTS is that the workload model can be adapted to the specific airspace design, air traffic control procedures, traffic characteristics, and operational concept under assessment. This enables the evaluation of alternative sectorizations, new route structures, revised procedures, and future traffic scenarios long before implementation.

The resulting capacity estimates provide valuable input for staffing plans, sector design, procedure development, and long-term airspace planning. Before operational implementation, these concepts are generally validated through Real-Time Simulation, during which operational controllers manage simulated traffic and both objective and subjective workload measurements are collected prior to regulatory approval.

Capacity estimation based on workload and sector rolling entries



Infrastructure development

Airport Master Plans typically define long-term development strategies extending over planning horizons of 10, 15, or even 20 years. These strategies are often structured into several expansion phases that progressively increase airport capacity in line with forecast demand.

While the final vision is usually well established, determining the most effective sequence of infrastructure investments is often a much greater challenge. The order in which new runways, passenger terminals, aprons, taxiways, or airspace concepts are introduced can have a significant impact on operational performance throughout the transition from the existing airport to its final configuration.

Combining ALG's airport-planning expertise with an FTS platform allows multiple development strategies to be evaluated before implementation. Each expansion phase can incorporate changes to different airport subsystems, including passenger terminals, apron layouts, runway systems, taxiway networks, and airspace design.

By modeling each stage independently, planners can assess how the airport performs under intermediate configurations, ensuring that each investment delivers operational benefits while remaining compatible with future development phases.

Once the development scenarios have been defined, a consistent modeling and validation methodology ensures that all simulation models are directly comparable. Operational performance can then be assessed using a common set of indicators, allowing the advantages and limitations of each alternative to be quantified objectively. Depending on the project objectives, the analysis may focus on capacity, delays, taxi times, resource utilization, passenger-processing performance, or environmental indicators.

A recent airport-planning study illustrates the level of detail that can be achieved. The project involved the development of a new international hub through five sequential expansion phases, each introducing additional infrastructure, including a new runway, apron expansions, aircraft parking stands, and progressively more complex airspace designs.

Each phase was evaluated under both northern and southern runway operating configurations because differences in taxi routes, runway utilization, and airspace procedures produced substantially different traffic patterns and operational hotspots.

To isolate the impact of each subsystem, three complementary simulation approaches were developed for every expansion phase. Airport-only simulations assumed unconstrained airspace to analyze airside operations independently. Airspace-only simulations assumed ideal airport infrastructure to evaluate air traffic control performance without airport constraints. Finally, fully integrated airport and airspace simulations provided a complete representation of future operations.

This methodology resulted in 30 highly detailed simulation scenarios.

Managing such a large number of complex scenarios required the development of dedicated automation tools to generate simulation inputs, execute the models, and process the resulting outputs. These tools substantially reduced the modeling effort, improved consistency across scenarios, and accelerated the analysis of simulation results, allowing engineers to focus on interpreting operational performance rather than performing repetitive data-preparation tasks.

This capability proved essential for evaluating a large number of infrastructure alternatives within the project schedule while maintaining a consistent modeling approach across all scenarios.

Although this example represents a particularly complex airport-development program, the same principles apply to infrastructure-planning projects of any scale. Whether comparing a limited number of expansion options or evaluating multiple long-term development phases, FTS provides a structured framework for assessing alternatives consistently, supporting investment decisions with objective performance indicators, and reducing uncertainty throughout the airport-planning process, supporting investment decisions with objective performance indicators, and reducing uncertainty throughout the airport-planning process.

Fast-Time Simulator airside view. Image from Airtop generated by ALG

Operational procedure evaluation

Operational performance does not depend exclusively on airport infrastructure. Many constraints arise from the way existing resources are managed and coordinated. Airports with sufficient theoretical capacity may still experience excessive delays, long passenger queues, inefficient baggage-handling processes, or airside congestion because operational procedures are no longer suited to current traffic patterns.

Identifying these issues and understanding their root causes is often the first step toward improving airport performance. Once an FTS model has been calibrated and validated, it becomes a powerful environment for analyzing operational performance under representative traffic conditions.

The first stage of the assessment consists of defining an operational framework based on a set of measurable key performance indicators and their associated Levels of Service. These may include maximum acceptable passenger waiting times, average taxi delays, runway occupancy, aircraft turnaround performance, controller workload, or baggage-processing times, depending on the objectives of the study.

The simulation then reproduces airport operations under these conditions and identifies the operational hotspots where predefined performance targets are not achieved. Because all airport subsystems interact continuously, the source of a problem is not always located where its effects become visible. For example, congestion observed at a runway holding point may originate from apron-management procedures, gate conflicts, or inefficient departure sequencing.

FTS makes it possible to understand these interactions by analyzing hundreds of operational indicators simultaneously, providing a comprehensive view of system performance.

Alternative operating procedures can then be introduced and assessed under identical traffic conditions. Typical examples include changes to runway configurations, taxi routes, pushback strategies, gate-allocation policies, departure sequencing, arrival-management procedures, collaborative decision-making processes, and aircraft turnaround procedures.

Because each alternative is evaluated using the same traffic demand and operational assumptions, the resulting performance improvements can be quantified objectively and compared directly.

A representative application is an airport-wide operational improvement program intended to optimize the complete passenger and aircraft journey across multiple airport subsystems. These studies typically evaluate passenger terminals, airside operations, baggage-handling systems, airspace procedures, and the interfaces among them to identify processes that perform below the expected service levels.

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Although not every improvement initiative requires simulation, FTS is particularly valuable whenever operational interactions are complex or when changes in one subsystem are expected to affect others.

The outcome of these studies is typically a portfolio of operational improvement initiatives, each assessed according to its expected operational benefit, implementation complexity, cost, and associated investment. This structured evaluation enables airport operators and stakeholders to prioritize the initiatives that deliver the greatest improvements while making the most efficient use of available resources.

Although many operational improvements involve relatively small procedural changes, their impact may extend across multiple airport subsystems. FTS provides the analytical framework required to evaluate these interactions before implementation, allowing airports to introduce operational changes with greater confidence, supported by objective evidence and a clear understanding of their system-wide effects.

Future demand assessment

Long-term traffic forecasts form the basis of most planning activities undertaken by airports, airlines, and Air Navigation Service Providers. Although future demand can generally be estimated with reasonable confidence, understanding how existing infrastructure and operational procedures will perform under those future traffic levels is considerably more challenging.

Capacity constraints rarely emerge simultaneously across all airport subsystems. It is therefore essential to identify which elements will become limiting factors and when those constraints are expected to arise.

FTS provides a practical framework for assessing the operational implications of future traffic growth. Projected demand scenarios can be incorporated into calibrated simulation models while maintaining realistic traffic patterns, fleet mixes, schedules, and operational procedures.

The resulting analysis allows planners to determine how the performance of terminals, runways, taxiway systems, aprons, and surrounding airspace evolves as traffic increases, identifying the first operational bottlenecks before they become critical.

The assessment is typically performed using multiple demand scenarios covering different planning horizons and traffic-growth assumptions. Operational performance is evaluated using the same set of indicators applied to current capacity assessments, allowing direct comparisons between present and future operations.

This approach supports the identification of infrastructure trigger points, indicating when additional capacity or operational changes will be required to maintain the desired Level of Service. As a result, future demand assessments naturally complement capacity assessments and infrastructure-development studies, since projected demand is often the main driver of long-term investment planning.

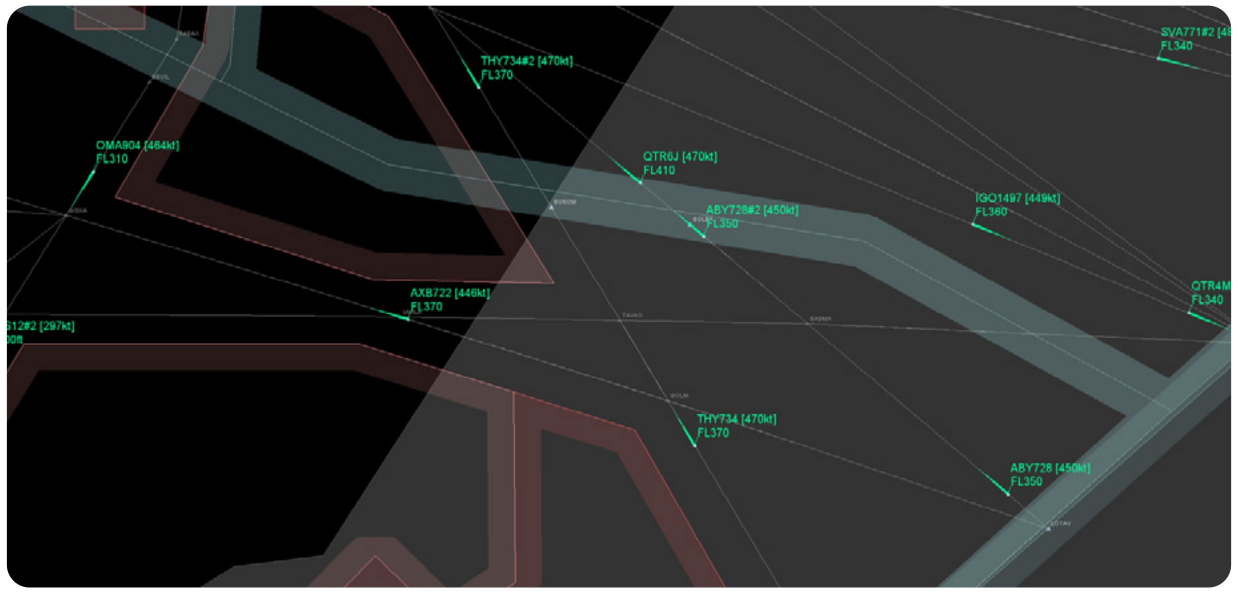
Beyond conventional traffic-growth forecasts, future demand assessments can also evaluate disruptive scenarios that produce sudden changes in traffic levels or traffic distribution.

One recent ALG study examined the operational consequences of geopolitical events resulting in the partial or complete closure of neighboring airspace. Under these circumstances, a significant proportion of overflying traffic was rerouted through the airspace under study, generating an abrupt increase in traffic volumes that far exceeded the expected year-on-year growth.

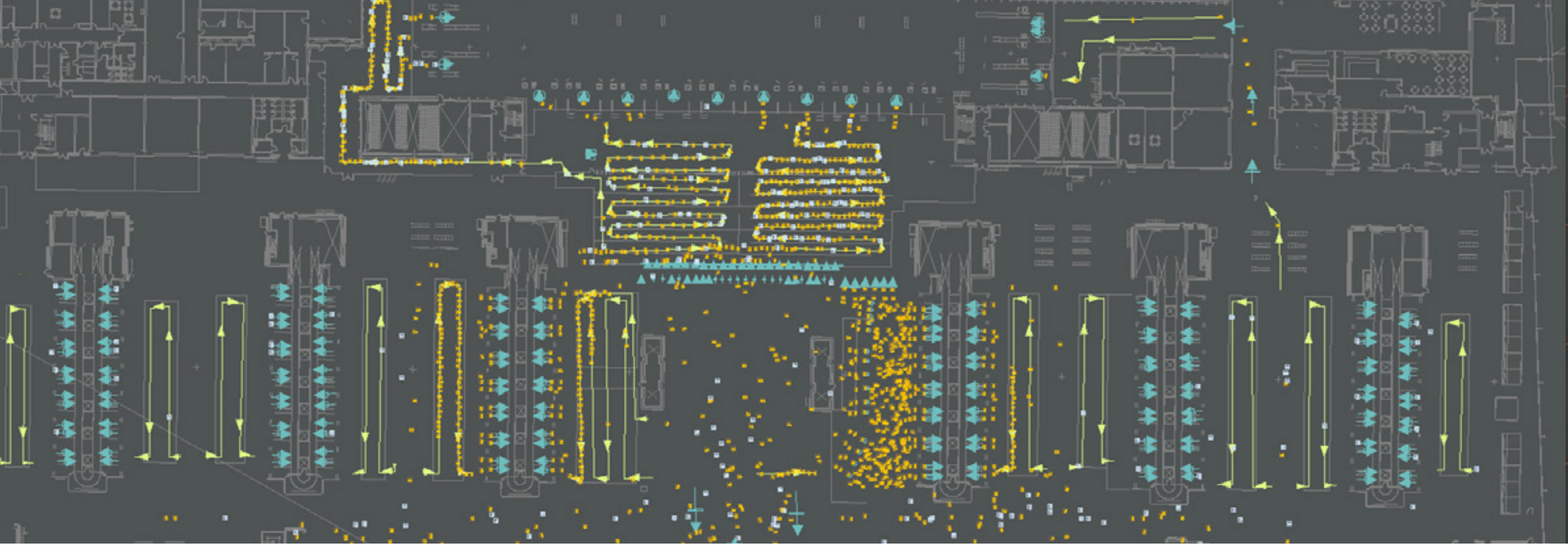
Several rerouting scenarios were simulated to evaluate their impact on sector workload, traffic complexity, and overall airspace performance. The results showed that the additional traffic generated by these disruptions produced operating conditions comparable to those expected approximately five years later under the baseline traffic forecast.

In practical terms, an unforeseen geopolitical event had the potential to accelerate by several years the need for upgrades to communications, navigation, and surveillance infrastructure, airspace design, and operational procedures to maintain safe and efficient operations.

This example illustrates how future demand assessments can support both strategic planning and operational preparedness. By evaluating forecast and contingency scenarios within a consistent simulation framework, organizations can anticipate future constraints, prioritize investments, and prepare operational strategies well before those challenges materialize.



Temporary restricted/segregated areas (TRA/TSA) and ATS routes. Image from Airtop generated by ALG



Resource optimization

Efficient use of airport resources is essential to maintaining high operational performance while avoiding unnecessary investments. Even when sufficient infrastructure is available, the way resources are allocated throughout the day can significantly influence delays, passenger experience, and overall system efficiency.

FTS provides a detailed understanding of how critical resources such as gates, aircraft stands, runways, taxiways, check-in facilities, baggage systems, ground handling equipment, and operational personnel are utilized under different traffic conditions.

Once a calibrated simulation model is available, resource-allocation strategies can be evaluated by comparing alternative operating concepts under identical demand scenarios. The analysis identifies periods of underutilization, resource conflicts, and operational bottlenecks, allowing planners to optimize existing assets before considering infrastructure expansion.

Performance is typically assessed using indicators such as resource utilization, passenger waiting times, aircraft turnaround performance, processing throughput, and operational delays.

A recent terminal-capacity study illustrates this approach. During the simulation, the check-in area was identified as one of the principal sources of passenger congestion.

In this case, the existing check-in counters were permanently assigned to individual airlines, limiting operational flexibility and making it difficult to accommodate fluctuations in passenger demand throughout the day.

Several alternative check-in concepts were evaluated, focusing on the introduction of common-use facilities and optimized airline allocations. The simulations demonstrated that a more flexible allocation strategy could substantially reduce passenger waiting times during peak hours, improve the utilization of existing check-in facilities, and increase the terminal's passenger-handling capability without requiring additional physical infrastructure.

This example demonstrates how resource optimization can unlock additional capacity by improving the way existing assets are managed rather than by expanding infrastructure. FTS provides the analytical framework required to evaluate these alternatives objectively, supporting evidence-based decisions that maximize the value of existing infrastructure while delaying or reducing the need for future capital investment.

Operational resilience & contingency planning

Operational resilience is an essential component of airport planning, particularly when major disruptions or temporary operational changes are expected. FTS provides a controlled environment in which contingency scenarios can be evaluated before implementation, allowing airport operators to validate operational procedures, quantify their impact, and identify potential risks without affecting live operations.

Typical applications include runway or taxiway closures, infrastructure-maintenance works, adverse weather conditions, temporary reductions in airport capacity, equipment failures, and other situations requiring modified operating procedures. Depending on the complexity of the scenario, simulation can be used to assess alternative mitigation strategies and determine which operational concept provides the best overall performance.

A representative example involved a major airport in Central America, where extensive rehabilitation works were planned on one of the main taxiways serving a primary runway and one of the airport's busiest terminal areas. The construction program was divided into nine successive phases, each affecting different portions of the taxiway network and several aircraft parking stands.

A detailed planning process was first undertaken to define the operating scenario associated with each construction phase, including stand reallocations and alternative aircraft taxi routes around the work areas. Whenever operationally feasible, several routing options were developed before being evaluated through FTS.

The simulations quantified the operational impact of every construction phase by analyzing the resulting capacity reduction during peak periods, additional aircraft delays, and increased taxi times. These indicators provided valuable information for planning airline schedules and slot allocation throughout the construction program.

One of the most significant findings concerned the different behavior of narrow-body and wide-body aircraft. While narrow-body aircraft could bypass some work areas using alternative taxi routes, wide-body aircraft were frequently unable to do so because of maneuvering constraints.

During several phases, wide-body aircraft were required to taxi via the active runway, temporarily interrupting runway operations and producing a measurable impact on runway throughput, delays, and overall airside performance.

This example demonstrates how FTS can support the planning of complex operational transitions by quantifying the impact of each implementation phase before construction begins. Operational-resilience studies provide stakeholders with a clear understanding of how planned disruptions may affect airport performance, allowing mitigation measures to be evaluated well in advance.

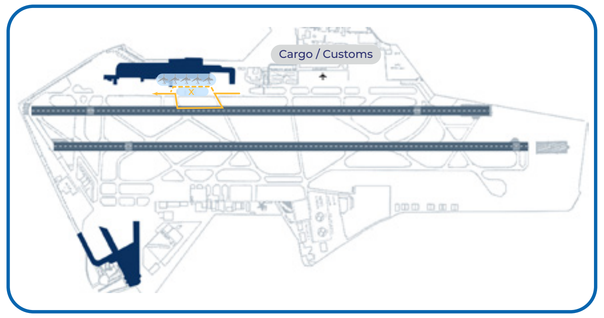
This supports safer implementation, reduces operational uncertainty during construction or contingency events, and enables airports to maintain the highest possible Level of Service throughout periods of disruption.

FIRST SCENARIO: TAXIING ALONG THE RUNWAY

- Utilization of **RWY 05L/23R to taxi for wide-bodies**
- Deviation of **narrow-body taxiing inside the apron (disabling positions)**

Adds complexity to current operation, runway occupancy increase
- Lose of flexibility to use both RWYs for arrivals
- Safety impact

Lost of stand positions



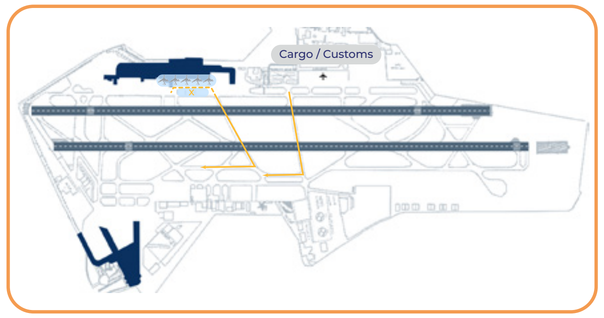
SECOND SCENARIO: RUNWAYS CROSSING

- **Runway crossings for WB operations,** with subsequent circulation through the T2 taxiways
- Deviation of **narrow-body taxiing inside the apron (maintaining positions** for smaller aircrafts when possible)

Type of **operation already known** by the controllers

Greater use/availability of stand positions

May aggravate **T2 apron congestion**



Environmental assessment

Environmental performance has become one of the principal drivers of aviation planning. Airports, airlines, and Air Navigation Service Providers are investing in a wide range of initiatives to support ICAO's Long-Term Aspirational Goal, the Carbon Offsetting and Reduction Scheme for International Aviation, and the aviation industry's Net Zero 2050 objectives.

According to IATA's Net Zero roadmap, operational and infrastructure improvements account for a relatively small proportion of the long-term emissions reductions required—approximately 3%. Nevertheless, they represent some of the measures that can be implemented most rapidly across the aviation system.[5]

Airports are adopting initiatives such as electric ground support equipment, gate electrification, reduced auxiliary power unit usage, and more efficient taxi operations. Airlines are also evaluating concepts such as single-engine taxi and TaxiBot systems to reduce fuel consumption during ground movements.

Reduction in aviation CO2 emissions in 2050 achieved through the different levers of action

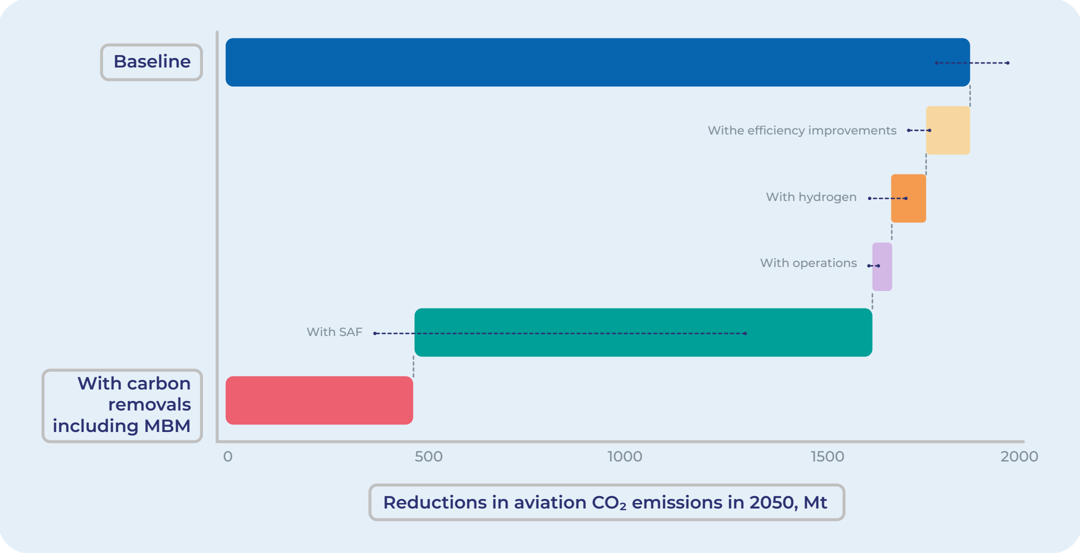


Image from IATA Net Zero CO2 Emsissions Roadmap

[5] Our Commitment to Fly Net Zero by 2050

FTS contributes directly to these initiatives by quantifying the environmental impact of alternative airport and airspace concepts before implementation. Depending on the scope of the study, simulation models can estimate fuel consumption, taxi times, engine running time, and aircraft emissions alongside traditional operational indicators such as delays, capacity, and resource utilization.

Fuel consumption and emissions are typically calculated using aircraft performance models such as EUROCONTROL's Base of Aircraft Data (BADA)[6] or variations, allowing operational and environmental performance to be evaluated within a single analytical framework. The underlying performance models can also be adapted to evaluate emerging technologies, including electric taxi systems and alternative ground-movement concepts.

One representative project involved the redesign of a major airspace structure in the Middle East, where the objective was to increase capacity while improving operational efficiency. An initial simulation model of the existing airspace was developed to evaluate horizontal and vertical flight efficiency and estimate fuel consumption and carbon dioxide emissions.

The proposed airspace design was subsequently assessed under identical traffic conditions, enabling a direct comparison between the existing and future operational concepts.

The redesign addressed two complementary aspects of flight efficiency. The first focused on improving trajectories within the airspace itself by reducing unnecessary track miles and enabling more efficient vertical profiles, including continuous climb operations and continuous descent operations.[7]

The second considered interactions with the surrounding airspace network. Rather than optimizing only the portion of each trajectory contained within the study Flight Information Region, the redesigned route structure ensured that aircraft entered and exited the airspace along trajectories that also improved the overall origin-to-destination flight path.

Considering both the internal efficiency of the airspace and its interfaces with neighboring Flight Information Regions allowed local improvements to generate tangible benefits at the network level. The resulting design achieved an estimated reduction of approximately 10% in fuel consumption and carbon dioxide emissions per flight while simultaneously increasing capacity and generating significant operating-cost savings for airlines.

[6] EUROCONTROL's Base of Aircraft Data
[7] Eurocontrol: continuous climb and descent operations

This example illustrates how FTS can evaluate operational and environmental performance within a single analytical framework, allowing sustainability objectives to be assessed alongside capacity and efficiency improvements.

Environmental assessment is becoming an increasingly important component of airport and airspace planning. Beyond reducing fuel consumption and carbon emissions, it provides objective evidence to support operational decisions that balance efficiency, capacity, and sustainability. This integrated approach enables environmental performance to become a measurable design criterion rather than a separate assessment conducted only at the end of a project.

Looking ahead, one of the most promising areas of research is the mitigation of persistent contrails through operational measures. Unlike ground emissions, aircraft emissions released at cruise altitude also generate non-CO_2 climate effects, including nitrogen oxides, water vapour and contrails, whose overall warming impact depends strongly on atmospheric conditions, flight altitude and time of day. Recent studies indicate that these non-CO_2 effects represent a substantial proportion of aviation's total climate impact.[8-9]

Future Fast-Time Simulation studies are expected to support the evaluation of trajectory optimisation strategies, including temporary flight level or routing adjustments, to minimise persistent contrail formation while maintaining acceptable levels of safety, capacity and operational efficiency.

[8] Operational opportunities and challenges for addressing air transport's non-CO2 environmental impacts.
[9] Contrails: Major climate impact, major opportunity

WHAT'S NEXT?

FTS has become a standard decision-support tool for airport and airspace planning, enabling stakeholders to evaluate capacity, operational concepts, and infrastructure investments before implementation. As aviation evolves toward increasingly complex, data-driven, and interconnected operations, FTS is expected to expand beyond traditional planning studies and become an integral component of strategic, tactical, and operational decision-making.

A key emerging development is the integration of FTS with digital twins, connecting simulation models with live operational data to provide an increasingly dynamic and continuously updated representation of the airport.
By automatically updating based on aircraft movements, passenger flows, weather conditions, infrastructure availability, and operational constraints, these models could support predictive analyses and identify potential bottlenecks before disruptions occur.

Advances in Artificial Intelligence, Machine Learning, and Cloud Computing are expected to further accelerate this evolution. AI could improve forecasting, automate model calibration, detect operational patterns, and generate optimized scenarios, while cloud-based processing would enable large-scale simulations to be executed in parallel, making near-real-time decision support increasingly feasible.

Future FTS platforms are also expected to adopt a more holistic approach by integrating passenger processing, baggage systems, ground handling, landside transportation, airline operations, and air traffic management within a single simulation environment. This broader perspective would help stakeholders understand interactions across the airport ecosystem and support more coordinated planning and investment decisions.

Ultimately, these technological advances may transform FTS into a comprehensive Decision Intelligence platform. By combining digital twins, AI, cloud computing, integrated ecosystem models, and automated data processing, FTS could evolve from an offline planning tool into a continuously operating capability that enables airports, airlines, and Air Navigation Service Providers to anticipate future conditions, evaluate alternatives, and operate more efficiently, resiliently, and sustainably.

Although FTS cannot eliminate uncertainty, it allows organizations to understand, quantify, and manage it with greater confidence. Its greatest value lies not in predicting the future, but in helping decision-makers shape it.

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