

Orchestrating the Passenger Journey: Digital Foundations for Total Airport Management

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Author bio:

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Today, Kelly advises major airport operators across the United States and Asia, while leading global engagements in aviation, water ports, smart cities, municipalities and utilities. His work focuses on helping organizations break down operational silos and implement data-driven frameworks that improve work management, change management, forecasting, optimize resource allocation, and enable predictive, real-time decision-making across complex environments.

Introduction: Managing Motion in Constrained Environments

As global passenger volumes surge toward a projected 10.2 billion in 2026¹, the aviation industry faces a structural paradox: physical infrastructure is increasingly constrained, yet demand for seamless travel has never been higher. Airports now operate as complex, continuously shifting ecosystems where airline schedule fluctuations, seasonal surges, and irregular operations (IROPS) create constant operational volatility.

To maintain operational integrity, airports must move beyond reactive management. The traditional response—expanding gates, terminals, or other physical assets—is often

constrained by cost, space, or construction timelines. The more immediate imperative is to extract greater performance from every square inch of existing infrastructure and resources. Doing so requires an agile decision-making framework built on high-fidelity data, combining real-time situational awareness with historical patterns to improve forecasting, allocate resources more precisely, and respond dynamically to changing conditions.

The Business Problem: The Cost of Passenger Flow Friction

Passenger flow friction creates hidden costs across the airport ecosystem. What appears to passengers as a long queue or a delayed transition between touchpoints often signals a deeper operational problem—one that suppresses commercial revenue, destabilizes day-of-operations performance, and weakens the overall passenger experience. As traffic volumes grow and physical expansion remains constrained, the ability to reduce friction across the journey becomes a core business requirement rather than a customer service aspiration.

These impacts typically appear in three interconnected areas: commercial performance, operational stability, and passenger experience:

Revenue Erosion (The Dwell Time Tax):

Industry research confirms a direct correlation between dwell time and passenger spend.. A stressed passenger trapped in a 20-minute security line is psychologically "closed" to commercial engagement.

A passenger survey conducted by ICF found that “**spending decreases 30% for every 10 minutes standing in a screening line.**”² Conversely, according to The Moodie Davitt Report, Milan Malpensa Airport concluded in 2023 that **one additional minute of dwell time increased spend per passenger by 3% to 5%.**³

Operational Instability:

Poorly managed flow leads to missed flight connections and gate delays. This creates a "tail-chase" for staff, forcing teams to re-accommodate passengers while straining labor resources and damaging airline relationships.

Experience & NPS:

Customer service scores influence an airport's Net Promoter Score (NPS) and are formally measured through Airports Council International's (ACI) Airport Service Quality (ASQ) program, a globally recognized benchmark for passenger satisfaction, business performance, and airport service quality.⁴ High service-quality and passenger satisfaction scores can strengthen stakeholder confidence and support the broader case for investment, while helping airports maintain competitive hub positioning.

The Multi-Touchpoint Journey: Mapping the Friction

Achieving a frictionless curb-to-gate journey requires identifying where motion intelligence can have the greatest operational impact. Each touchpoint can trigger downstream effects across the entire journey:

- **The Curb & Check-In:** Predicting landside congestion before it spills into the terminal.
- **Security & Border Control:** The high-stress "choke point" where predictive behavior modeling is essential.
- **Concessions & Services:** Tracking flow into airline lounges, restrooms, and premium passenger services.
- **Retail Strategy:** Monitoring wayfinding efficiency to ensure passengers have time for premium services, mobile ordering, or click-and-collect retail fulfillment.
- **Facilities Management:** Using real-time occupancy data to drive "smart cleaning" schedules for restrooms.
- **Gate Activity:** Monitoring seating availability, localized concourse congestion, and real-time wait times for specific boarding processes.
- **Apron Management:** Extending the twin to the tarmac to track ground support equipment (GSE), aircraft turnaround progress, and safety compliance.

Yet even as airports digitize schedules, transactions, assets, and building systems, the physical movement of people and vehicles through the airport often remains invisible to operational platforms. This is the missing layer that Motional Digital Twins bring into the

Total Airport Management model: a real-time understanding of motion that connects passenger behavior, vehicle activity, resource demand, and operational decision-making.

Total Airport Management and Motional Digital Twins

The evolution of airport operations is moving toward **Total Airport Management (TAM)**: a holistic concept that integrates airside, landside, and terminal processes.⁵ Historically, these domains have operated in silos. TAM breaks down those barriers by connecting airport operators, airlines, ground handlers, and Air Traffic Control (ATC) through coordinated operational planning, shared data, and cross-stakeholder decision-making.⁶ By integrating operational data, business systems, and stakeholder workflows, TAM supports a unified source of truth for airport operations.

A **Motional Digital Twin** is a real-time, often AI-powered digital replica of how people and vehicles move, behave, and interact within a physical environment. Within a TAM strategy, it becomes the heartbeat of operational decision-making. While a traditional digital twin may show a static 3D model, a Motional Digital Twin shows the pulse of the airport environment, connecting passenger flow, vehicle activity, flight data, and resource demand into a live operational view.

- **Synchronized Flow (Vehicle, Aircraft, Passenger, & Baggage):** TAM achieves its highest value when these four flows are synchronized. If LiDAR detects a security bottleneck, the Motional Digital Twin can alert baggage handlers and gate agents of potential boarding delays.
- **Asset Interaction:** Beyond counting, LiDAR can track how passengers interact with assets and services—such as time spent at digital wayfinding kiosks, security checkpoints, retail areas, and concessions—providing the Motional Digital Twin with deeper behavioral analytics for the TAM framework.
- **Live Synchronization:** If a flight schedule changes, the Motional Digital Twin instantly reflects the shift in passenger load, allowing the **Airport Operations Center (APOC)** to reallocate resources before a bottleneck forms.
- **Predictive Response:** Motional Digital Twins use historical and real-time data to run “what-if” simulations, testing the impact of weather delays or checkpoint

closures on terminal-wide flow to continuously optimize an operation's TAM strategy.

Spatial Technologies: A Technical Reality Check

A credible evaluation of spatial technologies must begin with technical reality rather than market positioning. In airport environments, where crowd density, line-of-sight constraints, and changing operational conditions can materially affect performance, technology selection should be guided by a physics-first assessment. The critical questions are not simply what a system promises to detect, but how consistently it measures movement, how it performs under operational stress, and whether its outputs are robust enough to support real-time decision-making within a broader digital twin ecosystem.

Performance for any sensing modality ultimately depends on the specific use case, deployment design, sensor configuration, and operating environment; technology characteristics should therefore be evaluated in the context of the airport's intended operational objective.

1. Device Tracking (Wi-Fi/Bluetooth)

Primary strength:

Device tracking can provide broad visibility into movement patterns across large areas without requiring dense sensor deployment.

Best-fit use case:

This modality is most effective for long-term trend analysis, origin-destination studies, and macro-level planning where directional insights are more important than precise person-level tracking.

Key limitations:

Because it only detects devices rather than people, it captures a partial and variable sample of total passenger movement. Detection rates can fluctuate based on device settings, opt-out behavior, and signal conditions, limiting precision in fast-changing operational environments.

Operational implication:

These systems typically capture only a representative sample of passengers, with

detection rates varying by environment, device settings, and methodology. Wi-Fi and Bluetooth data can support strategic planning, but they are generally insufficient as a standalone source for real-time operational management, life-safety decision-making, or precise resource allocation.

2. Machine Vision (Surveillance Video Analytics, e.g., BriefCam)

Primary strength:

Video analytics are effective for visual observation, incident review, and object or person identification within a camera's field of view.

Best-fit use case:

This approach is well suited for security monitoring, forensic analysis, and defined-zone occupancy measurement where visual confirmation is important.

Key limitations:

Standard 2D video can struggle to maintain persistent tracking in dense crowds or across multiple camera zones. Transitions between camera views may interrupt continuity of an individual's path, and performance can degrade in situations involving occlusion, overlap, or behaviors such as tailgating. In many deployments, queue definitions also depend on manually configured polygons, which can limit adaptability in dynamic spaces.

Operational implication:

Video analytics can provide valuable situational insight, but their effectiveness for continuous passenger flow measurement depends heavily on camera placement, calibration, and the complexity of the environment.

3. Stereographic Imagery

Primary strength:

Stereographic imaging improves on standard 2D video by estimating depth, enabling more accurate counting and zone-based occupancy measurement.

Best-fit use case:

It is typically effective for fixed monitoring points such as queue measurement, threshold counting, and controlled indoor areas with stable mounting conditions.

Key limitations:

Because depth is estimated through triangulation rather than measured directly, accuracy can degrade with distance and environmental complexity. These systems also tend to be

more dependent on specific mounting geometry, often requiring overhead or near-nadir placement for optimal performance. In some deployments, proprietary hardware and software ecosystems may also limit broader integration flexibility.

Operational implication:

Stereographic imagery can perform well in bounded, well-defined environments, but its flexibility may be limited where airports require broader coverage, variable mounting options, or integration into an open digital twin architecture.

4. LiDAR

Primary strength:

LiDAR directly measures 3D geometry using time-of-flight sensing, enabling accurate detection of movement, speed, and object classification across complex environments.

Best-fit use case:

This modality is particularly well suited for real-time passenger flow intelligence, dynamic operational management, and digital twin applications that require persistent, high-fidelity spatial awareness.

Key limitations:

LiDAR deployments may involve higher upfront technical complexity than simpler sensing approaches and require a software layer capable of translating raw spatial data into operationally meaningful intelligence. As with any sensing modality, performance also depends on the quality of system design, calibration, and integration.

Operational implication:

Where the objective is continuous tracking, accurate measurement in dense conditions, and a privacy-preserving foundation for real-time decision-making, LiDAR can offer a stronger technical basis than modalities that infer depth or rely on sampled device data.

For TAM use cases, the critical distinction is not whether a technology can detect presence, but whether it can continuously measure movement with enough accuracy, persistence, and interoperability to support operational decisions in real time. Airport leaders should evaluate spatial technologies based on their ability to sustain reliable tracking across dynamic, crowded, and operationally complex environments—not simply on their ability to count people at isolated points.

Why LiDAR Stands Apart for Passenger Flow Analytics in Motional Digital Twins

Against these criteria, several technical characteristics can make LiDAR especially relevant for airport Motional Digital Twin environments, depending on the use case, deployment design, and operating conditions—particularly where the objective is to track motion, speed, occupancy, and object classification based on geometry.

Direct 3D measurement:

Unlike stereographic systems that estimate depth through triangulation, LiDAR directly measures distance using time of flight. This supports consistent spatial accuracy across a wider range of conditions and distances.

Persistent Tracking:

LiDAR operates from a unified 3D point cloud, making it better suited for tracking movement continuously through space rather than inferring continuity between separate camera views.

Flexible Deployment:

LiDAR is less constrained by strict overhead mounting requirements and can be deployed on walls, poles, or high ceilings depending on the environment and operational objective.

Operational Efficiency:

In many environments, LiDAR can achieve broader coverage with fewer sensors than alternative approaches, particularly where ceiling height, geometry, or required field of view would otherwise increase sensor density.

Privacy by Design:

Because LiDAR captures geometry rather than facial imagery or color pixels, it provides a privacy-preserving data foundation that can reduce compliance risk relative to image-based systems, making it better aligned with privacy-by-design principles and potentially easier to govern under GDPR, CCPA, and similar privacy frameworks.

Environmental Resilience:

As an active sensing modality, LiDAR can operate across a wide range of lighting conditions, including darkness and variable sunlight, making it more robust for continuous operational use.

Open Architecture: Modern LiDAR solutions follow an open-data philosophy. In this model, the sensor layer becomes increasingly modular, while the software layer serves as the core intelligence engine.

The comparison below summarizes how the major sensing modalities align against common airport passenger-flow and Motional Digital Twin requirements. These comparisons are directional; actual performance will vary based on the use case, sensor selection and configuration, deployment geometry, environmental conditions, and supporting analytics software.

Technology	Modality	Best-Fit Use	Primary Limitations	Integration Profile	End-to-End Journey Reconstruction
Wi-Fi / Bluetooth	Device Tracking	Macro-level planning, origin-destination analysis, long-term trend analysis	Captures only a partial and variable sample; depends on passenger devices being active and detectable; limited precision for real-time operations	Variable	Partial
Video Camera	Machine Vision	Security monitoring, identification, forensic review, defined-zone observation	Performance can degrade with lighting conditions, occlusion, crowd density, and weather in outdoor deployments; continuity can be lost between camera views; often requires manual zone configuration	Typically Open, Varies by Platform	Partial to Moderate
Stereographic Imaging	Depth-Based Counting and Occupancy	Queue monitoring, counting, and controlled indoor areas with stable conditions	Depth is estimated rather than directly measured; accuracy can degrade with distance; mounting is less flexible; often more proprietary and harder to scale across environments	Often Closed, Varies by Vendor	Moderate in bounded zones
LiDAR	Direct 3D Spatial Sensing	Continuous tracking, dynamic queue measurement, real-time flow monitoring, digital twin inputs	Higher implementation complexity than simpler sensing approaches; requires a software intelligence layer; limited native color/texture context	Open	High, with sufficient coverage and software integration

How to Select a Sensor Analytics Provider

Selecting a sensor analytics provider is a long-term strategic decision, not a short-term technology purchase. Airports should prioritize partners that combine proven airport experience, operational maturity, and open, adaptable architecture—favoring solutions that are advanced enough to deliver meaningful performance, but stable enough to support enterprise deployment over time. A useful rule of thumb is to look for the “leading edge,” not the “bleeding edge.”

Business Resilience:

Evaluate the provider’s financial stability and history in the airport vertical. Very small technology startups may pose delivery risk if they lack experience with airport installation complexity, long-term support requirements, cybersecurity expectations, and enterprise procurement processes.

Interoperability & Open Architecture:

Avoid vendor lock-in. Ensure software can ingest data from any hardware, allowing for sensor upgrades without rebuilding the analytics layer.

Airport Systems Integration:

Existing APIs and plugins for airport business systems should be prioritized to reduce integration cost and complexity.

Willingness to Co-Develop:

The provider should be willing to tailor the solution to airport-specific business logic. Ask about product roadmaps and release frequency to understand vendor agility and their willingness to support airport-specific requirements.

Hardware Freedom:

As hardware prices drop, an open-architecture platform allows the airport to benefit from the best-performing, lowest-cost sensors without changing their analytics engine. LiDAR and camera markets offer a wide range of competitive makes, models, and price points. Stereographic imaging systems may offer fewer hardware options and can be more purpose-built for specific counting or queue-management applications. The analytics platform should support sensors from multiple manufacturers and technology types, ensuring the airport is never locked into a single hardware vendor and can evolve its sensor fleet as the market matures.

Multi-Vendor Simulation:

Leading providers now offer virtual simulators that allow airports to stress-test sensor layouts in a digital environment before purchasing hardware. This enables teams to validate ROI upfront by comparing performance, coverage, and cost across different sensor models prior to procurement.

Continuous Tracking:

The solution must demonstrate the ability to assign anonymous tracking IDs and maintain continuity across relevant zones where sensor coverage and integrations support it, not just fixed touchpoints.

Customer Service:

Ensure a qualified local or regional team is available for deployment, calibration, maintenance, and ongoing support.

Technical Implementation Considerations

Translating spatial intelligence into operational value requires more than sensor deployment alone. Airports must account for the compute, network, and systems architecture needed to process high-volume data streams in real time and convert them into actionable insights that support the TAM strategy.

Compute and Infrastructure:

High-fidelity spatial sensing can generate significant data volumes, particularly in complex terminal environments. For this reason, edge computing and GPU-accelerated processing should be prioritized to reduce network strain, support low-latency analytics, and enable faster operational response.

Enterprise Integration:

The analytics layer should also be designed to integrate cleanly with airport operational systems, dashboards, and digital twin environments so that sensor outputs become part of day-to-day decision-making rather than a standalone data stream.

Data Governance:

Data governance, retention policies, cybersecurity controls, and integration standards should be defined early so that spatial intelligence can scale from pilot deployment to enterprise operation.

The ROI of Agility

The business case for spatial intelligence and Motional Digital Twins extends beyond sensor performance and retail conversion. Its value comes from improving commercial performance, labor efficiency, service accountability, safety, and operational resilience.

By reducing queue friction and increasing commercially effective dwell time, airports can improve non-aeronautical revenue opportunities across retail, food and beverage, lounges, and premium passenger services.⁷ At the same time, real-time demand signals enable workforce optimization by aligning staffing levels to actual and predicted passenger volumes across security, check-in, border control, restrooms, gates, and curbside zones.

Motional Digital Twins also strengthen SLA enforcement by providing objective data on service provider performance, including queue wait times, cleaning response times, curbside dwell times, and gate-area readiness. For safety and compliance, real-time crowd density monitoring helps operators detect congestion risks, support faster incident response, and manage passenger surges during IROPS or emergency events.

Together, these benefits create an ROI model in which the cost of delay, inefficient staffing, unmanaged service levels, and operational disruption can quickly exceed the cost of sensing infrastructure itself.

Conclusion

The future of Total Airport Management will be defined by how effectively airports translate spatial intelligence into operational action. As passenger volumes rise and physical expansion becomes harder to justify, airports will need to extract greater performance from the infrastructure they already have. That requires more than digitizing schedules, assets, and transactions; it requires a real-time understanding of how people, vehicles, baggage, and aircraft move through the airport as one connected operating environment.

While video remains valuable for identification and forensic review, LiDAR provides a stronger foundation for understanding motion, flow, and congestion in real time. When integrated into a Motional Digital Twin, this spatial intelligence enables airports to anticipate demand, optimize staffing, enforce service levels, improve safety, and reduce friction across the passenger journey.

The transition to a Motional Digital Twin operating model is not simply a technology upgrade. It is an operational shift toward greater agility, precision, and resilience. By separating the sensing infrastructure layer from the intelligence layer, airports gain the flexibility to evolve hardware over time while preserving the analytics environment that drives decision-making.

As infrastructure operators face mounting pressure to do more within existing footprints, real-time awareness of physical movement will become a core operational utility. For the next generation of airports, understanding motion will be as fundamental as power, connectivity, and data itself.

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