Designing Vertical Transportation for Modern Airports: Performance, Capacity, and Passenger-Centric Planning

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Abstract: This paper presents a comprehensive framework for vertical transportation (VT) design in modern airports, where lifts, escalators, and moving walks form mission-critical infrastructure that directly influences passenger satisfaction, accessibility, and operational resilience. Airports are among the most demanding VT environments, required to absorb intense, scheduled surges – where a single wide-body aircraft may deliver more than 800 passengers within minutes – creating circulation pressures far exceeding those in commercial buildings.

Unlike predictable up-peak and down-peak conditions in offices, airports operate with continuously variable demand shaped by flight schedules, aircraft mix, immigration and security processing, and the growing complexity of multi-modal transfers. VT must therefore accommodate a highly diverse user group: business travellers, families with prams and heavy luggage, elderly and reduced-mobility passengers, airline crew, and staff operating across secure and landside zones.

A defining challenge is designing VT systems not just for people but for people-plus-luggage. Suitcases and trolleys consume significant car area, reduce effective capacity, slow passenger exchange, and alter flow patterns. Consequently, airport VT requires conservative loading assumptions and simulation calibrated to real passenger behaviour rather than commercial norms.

This paper emphasises the importance of early, integrated design between architects and engineers to ensure that circulation pathways, system sizing, and operational strategies are validated through reliable data and performance-based modelling. The framework incorporates airport-grade service KPIs, including waiting times, handling capacity, availability, and response targets. It also addresses accessibility and inclusivity, prioritising wide-door lift configurations, large car sizes, and alternatives such as inclined moving walks. Key resilience strategies – such as N+1 redundancy, dual power feeds, and generator backup for life-safety systems – are examined alongside sustainability measures including regenerative drives, auto-start/stop controls, and LED lighting. Finally, the paper explores digital integration, highlighting future trends such as Digital Twins and AI-optimized traffic flow.

1 INTRODUCTION

The design of vertical transportation systems for airport terminals presents a distinct set of engineering challenges that differ fundamentally from those encountered in commercial or residential buildings. Airports impose highly variable, schedule-driven demand profiles, complex circulation hierarchies, and stringent requirements for availability, safety, and resilience. In this context, VT systems function as capacity-critical infrastructure whose performance directly affects overall terminal efficiency.

However, current practice frequently treats airport VT as a downstream engineering exercise, developed after key architectural and systems-level decisions have been made. This sequential

approach limits the ability of designers to optimise system capacity, redundancy, and passenger service levels, and it constrains the use of performance-based analysis during early design stages. The result is a persistent gap between theoretical handling capacity and observed operational performance.

This paper contends that early, integrated design involving VT specialists, architects, and MEP engineers is essential to closing that gap. Vertical circulation performance is strongly influenced by upstream design parameters – including level geometry, structural constraints, fire zoning, power and control strategies – that fall outside the remit of VT engineering alone. Without early interdisciplinary coordination, system performance targets such as waiting time, throughput, and recovery from disruption cannot be reliably achieved.

Importantly, early integration also enables analytical tools – such as passenger-flow simulation and demand modelling – to be used as design drivers rather than post-hoc verification tools. By applying these methods at concept and schematic stages, VT systems can be sized against explicit, airport-specific service criteria, with assumptions that reflect real passenger behaviour and operational conditions.

The research presented in this paper proposes a performance-based framework for airport VT design that embeds interdisciplinary coordination, behavioural modelling, and measurable service metrics into early project delivery. By reframing VT as a system-level engineering problem rather than an isolated equipment solution, the paper contributes to a more robust and reproducible approach to designing lifts, escalators, and moving walks for modern airport environments.

2 PLANNING PRINCIPLES & PASSENGER FLOW

Airport passenger flows are characterised by highly variable, schedule-driven demand, with arrival and departure peaks generating significant short-duration surges. Vertical transportation design shall be based on schedule-linked population modelling and discrete-event simulation of lift cores, escalators, and moving walk systems.

System performance shall target average peak waiting times of 30–40 seconds and a five-minute handling capacity of 12–15% of peak population, ensuring smooth operation during peak flight banks.

Passenger behaviour assumptions shall be incorporated into modelling:

- Airside: ~80% escalator use / ~20% lift use
- Landside: ~80% lift use / ~20% escalator use

Lift car loading factors shall be adjusted to reflect luggage-related occupancy reductions, based on average benchmarking values compiled from a range of comparable international airport projects (see Table 1).

- Airside: 40–50%
- Landside: 15–25%

Table 1 Typical Car Loading Factors – Airport Benchmarking

	CPK Airport Poland	Tocumen Airport Panama	New Phnom Penh Intl. Airport	Kuwait Intl. Airport	Average
Airside lift	~50%	~40%	~60%	~50%	~40-50%
Landside lift	~20%	~15%	~15%	~25%	~15-25%

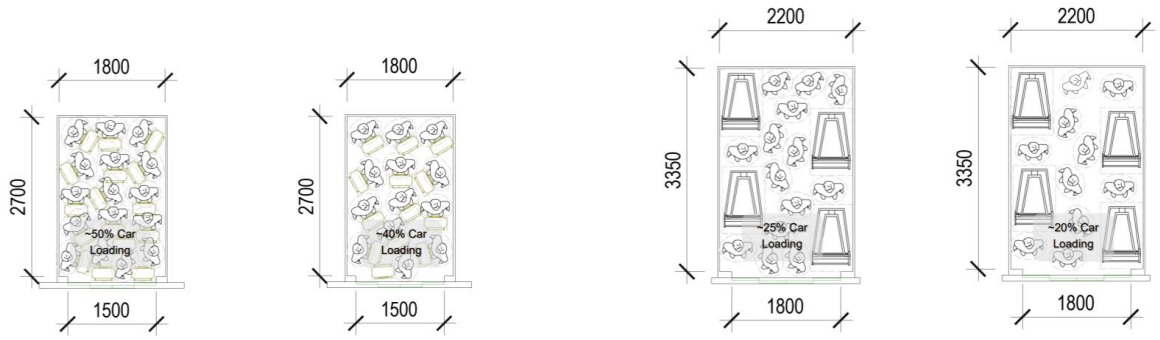


Figure 1 Typical layout of Airside lift 2500kg with 40-50% car loading factor (left) and Landside lift 4000kg with 20-25% car loading factor (right)

VT core locations shall be coordinated with architectural layouts and positioned at key decision points, with minimum ~6 m clear circulation space provided in front of lift and escalator banks to accommodate peak passenger flows.

Horizontal circulation shall be supported by moving walks (≈1400 mm pallet width, 0.65 m/s) arranged in series up to approximately 300–450 m. Longer distances shall consider automated people mover systems. Escalator provision shall be configured to suit demand, with double or triple banks in high-traffic areas.

System capacity shall be verified against five-minute demand intervals aligned with flight schedules. Design shall include segregation of landside and airside flows, accessible lift provision, and resilient power supply (e.g. dual feed with backup systems).

3 ACCESSIBILITY & INCLUSIVITY

Accessibility is a central requirement in airport design, driven by regulatory standards and shifting passenger demographics. The ageing population and increasing prevalence of passengers with reduced mobility necessitate inclusive VT systems that ensure equitable access throughout terminals.

Lifts serve as the primary vertical transport mode for passengers requiring assistance, including wheelchair users, families with strollers, and passengers with heavy baggage. Adequate cabin size (2,500–4,000 kg depending on landside/airside), door width (1,200-1,400 mm), and boarding areas (min 1.5× car depth) are critical to accommodate these needs effectively. Where feasible, dual-entrance (through-car) arrangements eliminate reversing and simplify flows for stroller and wheelchair users.

Passenger behaviour and demographic characteristics further influence the effectiveness of accessibility strategies. Escalators in infrastructure are used with some passengers standing on

one side of the steps to allow others to walk and, in other cases, others standing or walking on both sides of the steps [1] [2].

Older passengers, for example, may avoid escalators due to balance concerns, while families and groups often prefer lifts to remain together during travel. In addition to fixed conveyance systems, supplementary mobility services such as wheelchairs and assist carts are frequently deployed to support passengers over long distances (see Figure 2). While these systems offer flexibility, they must be carefully managed to avoid conflicts with pedestrian flows and to minimise congestion within busy terminal areas. Ultimately, a multimodal approach that integrates various conveyance solutions is required to achieve a fully inclusive environment.



Figure 2 Autonomous Mobility Service transports passengers to their destinations and work in conjunction with a lift at Narita International Airport

4 SAFETY, RELIABILITY & REDUNDANCY

Airports demand a reliability posture closer to mission-critical infrastructure than commercial real estate. Specifications should set system availability and mean time to repair (MTTR) for priority assets, supported by remote monitoring and predictive analytics. Redundancy strategies include N+1 unit counts in critical transfer cores; Figure 3 shows an example of redundant escalator design. Dual electrical feeds with UPS and generator backup sized to run the life safety VT load – Firefighter / Evacuation lifts for ≥2 hours – and emergency features such as rescue drives that enable controlled descent to the nearest floor during power loss.

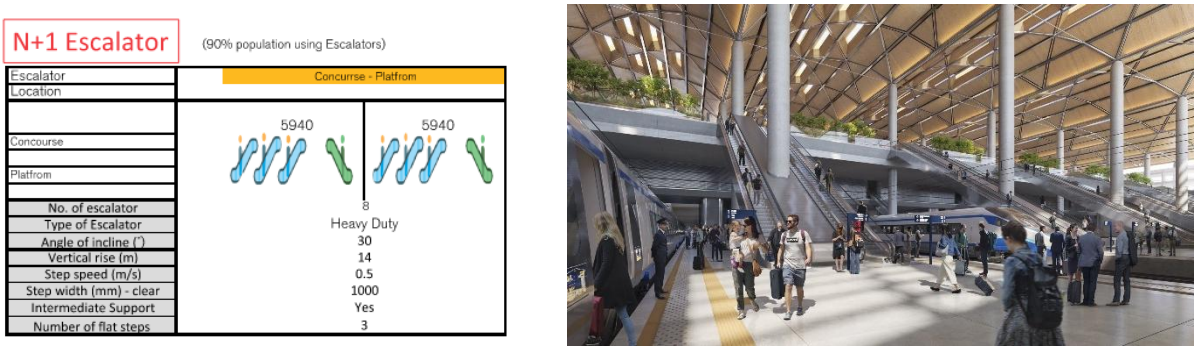


Figure 3 – N+1 Redundancy design and 3 flat steps escalator at CPK airport hub

Key safety risks include boarding and alighting incidents on escalators, falls caused by congestion or loss of balance, and misuse of equipment such as attempting to transport strollers or baggage carts on escalators. These risks are often exacerbated by unfamiliarity with the environment, highlighting the importance of both design and operational strategies to mitigate

hazards. Safety bollards and 3-4 flat steps at both landings improve comfort and reduce incidents.

Reliability is equally important, as airport conveyance systems must function continuously to support uninterrupted passenger movement. Escalators, which operate constantly, are subject to higher wear and maintenance demands, whereas lifts typically operate intermittently but are more sensitive to service disruptions due to their role in accessibility. Maintenance planning must therefore account for lifecycle costs, operational uptime, and system resilience. As a result, the system must be designed with redundancy to maintain service during equipment outages and accommodate sudden surges in demand. Incorporating multiple units and designing for peak-period capacity ensures robustness and continuity of service. [3]

5 EQUIPMENT SELECTION: LIFTS, ESCALATORS & MOVING WALKS

The selection of appropriate conveyance equipment is a key determinant of system performance and must be aligned with passenger flow characteristics, spatial constraints, and operational requirements.

Lifts are indispensable for ensuring accessibility and accommodating passengers with heavy baggage, and their performance is influenced by factors such as cab size, door opening times, travel speed, and the number of stops served. Service quality is typically measured in terms of waiting time and journey efficiency, with well-designed systems achieving acceptable wait times even during peak periods.

Public passenger lifts in low-rise terminals are predominantly machine-room-less (MRL), which compacts machinery into the shaft overhead and simplifies coordination. Standardised cabin sizes and finishes (durable, vandal-resistant materials) ease procurement and lifecycle maintenance, while wide centre-opening doors (1200-1,400 mm), through-car configurations and large capacities (2,500 kg - 4,000 kg) support baggage trolley use cases.

Escalators, on the other hand, serve as the primary mode of vertical transport for most passengers due to their convenience and continuous operation. Escalators should have a 1,000 mm step width to accommodate passengers, balustrade heights around 1,100 mm for protection in open areas, 0.5 m/s speed and inclinations of 30° for comfortable boarding/alighting. The capacity is largely dependent on passenger boarding behaviour rather than theoretical throughput, with observed capacities in airport environments typically ranging between 50 and 60 passengers per minute. [4]

Moving walkways provide an effective solution for horizontal movement, particularly over long distances where walking alone would lead to fatigue and reduced passenger satisfaction. Although their impact on actual travel speed may be limited by user behaviour, they significantly improve perceived comfort and reduce the physical effort required for transit. Moving walkways reduce travel time for those who are walking/running, which helps to reduce anxiety for those in a hurry.

An effective VT strategy integrates these systems in a complementary manner, leveraging the strengths of each technology to address specific movement needs. Escalators are best suited for high-volume vertical flows, lifts for accessibility and specialised users, and moving walkways for extended horizontal connections. Table 2 summarises the typical selection criteria and key technical characteristics for lifts, escalators, and moving walkways commonly adopted in airport terminal developments.

Table 2 Summary Equipment Selection for Airport Terminals

Equipment Type	Typical Angle	Standard Width	Speed	Primary Selection Drivers
Lift	-	>1800mm	1.0-1.6 m/s	PRM compliance, heavy trolley handling, multi-level hub links
Escalator	30°	1000mm	0.5m/s	High-density inter-floor mass transit, security checkpoint feeding
Moving Walk	0° - 6°	1400mm	0.65m/s	Long concourses (>100m), passenger fatigue mitigation, speed-to-gate optimization

6 BACK-OF-HOUSE & STAFF VT STRATEGY

Unlike Front-of-House (FOH) systems, where the primary objective is to move large volumes of passengers efficiently and comfortably, Back-of-House (BOH) vertical transportation is driven by operational resilience, security segregation, and logistics efficiency. BOH lifts support a diverse range of users and cargo, including airport staff, airline crews, catering supplies, retail goods, baggage handling equipment, and oversized cargo. Consequently, lift selection is governed not only by traffic requirements but also by the physical characteristics of the transported loads, security zoning constraints, and the demanding operating environment of modern airport terminals. Typical BOH lift categories and their design characteristics are summarised in Table 3.

Table 3 – BOH Lift Type in Airport Terminals

Equipment Type	Capacity	Door Type & Width	Dimension Priority
Staff / Crew Shuttles	1600 - 2000kg	2-Panel Center Open (1100mm)	Standard wide or deep configuration
Catering & Retail Goods	2500 - 4000kg	4-Panel Center Open (1400 - 1600mm)	Deep configuration specifically dimensioned to accept standard pallet
Heavy Cargo / OOG Bags	5000 - 8000 kg	Heavy-duty vertical bi-parting or 4-Panel (>1800 mm)	Structural floor reinforcement to withstand highly concentrated wheel-point loads from motorized forklifts or heavy electric pallet jacks

In airport terminal architecture, BOH systems act as the invisible circulatory system keeping operations alive. A breakdown in BOH vertical transportation directly manifests as delayed flights, security breaches, or food service delivery failures.

The primary architectural constraint for BOH vertical transportation is the maintenance of strict regulatory borders. According to international aviation security standards, an airport terminal is divided into distinct zones that cannot cross-contaminate the public and secured areas. Staff and goods lifts must **never** inadvertently bridge a public level to a secured level without a controlled checkpoint interface.

If a BOH lift is required to physically serve both landside and airside levels, it should be configured as a dual-aspect lift with an access control system that activates landing calls and

selectively enables landing door operation. In addition, BOH lifts should be integrated with the physical interlock system. When the lift doors are open, the outer security corridor doors should remain electromagnetically locked.

7 WAYFINDING & ARCHITECTURAL INTEGRATION

Wayfinding and architectural integration can significantly influence the effectiveness of vertical transportation (VT) systems. Passengers naturally follow the most visible and intuitive routes; therefore, lifts, escalators and moving walkways should be located along straightforward circulation paths with clear sightlines from key decision points. Consistent architectural treatment, including signage, lighting and finishes, further reinforces route legibility throughout the terminal.

Strategically placing moving walkways within terminal corridors can help reduce minimum connecting times and support their consistent achievement during daily operations [5]. Generous decision plazas prevent crush conditions, support trolley manoeuvres and reduce cross-flows. Avoid routing general circulation corridors directly through lift lobbies or escalator landing zones; instead, position VT slightly off the primary traffic axis with ample forecourt space, with landside/airside segregation kept legible through barriers and glazing.

Digital wayfinding should complement physical wayfinding measures. Screens located near VT facilities can display real-time flight information, walking-time estimates and gate directions, with consistent terminology repeated in the terminal app and on overhead signage visible from 25–50 m away. Visibility and signage strongly influence passenger behaviour. Clear wayfinding encourages greater use of escalators and moving walkways, while prominent lift lobbies help direct passengers with trolleys and bulky luggage towards lifts, improving both safety and passenger flow.

Figure 4 illustrates key wayfinding principles for airport terminals. Straightforward paths with unobstructed sightlines enable passengers to identify their route and destination quickly, while prominent signage helps direct passengers with bulky luggage towards lift facilities.



Figure 4 Straightforward paths with clear sightlines to aid airport navigation (left); Prominent signage directing passengers with bulky luggage to lifts (right).

8 DIGITAL SYSTEMS, ENERGY & SUSTAINABILITY

Modern airport VT systems are data-rich and energy-aware. Group supervisory controls integrate with Building Management Systems (BMS) and lift monitoring platforms to provide centralised alarms, telemetry and analytics, as illustrated in Figure 5 (left). Predictive maintenance uses vibration, current, door-cycle and temperature data to forecast failures and schedule interventions during off-peaks, improving availability, while remote audio/video intercoms shorten rescue times and reassure passengers during incidents.

Energy efficiency is vital for lift systems. Regenerative drives capture descent/braking energy and feed it back to the building; smart standby modes dim lighting and slow speeds when idle, potentially saving 20–30% on energy consumption [6]. Sleep-mode functionality in escalators/moving walks preserves capacity without wasting power. Combined, these features contribute to green-building objectives and measurable operational savings, especially when paired with demand-responsive strategies such as remote check-in at parking/metro that shift loads upstream and reduce terminal congestion.

Looking ahead, digital technologies will further enhance VT operations. As shown in Figure 5 (right), digital twins can model and simulate terminal operations, enabling operators to evaluate the impact of disruptions and optimise dispatch logic across lifts, escalators, moving walks and baggage systems. AI-assisted capacity planning could dynamically adjust resources in response to flight schedules, security queue lengths and gate changes, helping airports maintain efficient passenger flows under varying operating conditions [7].

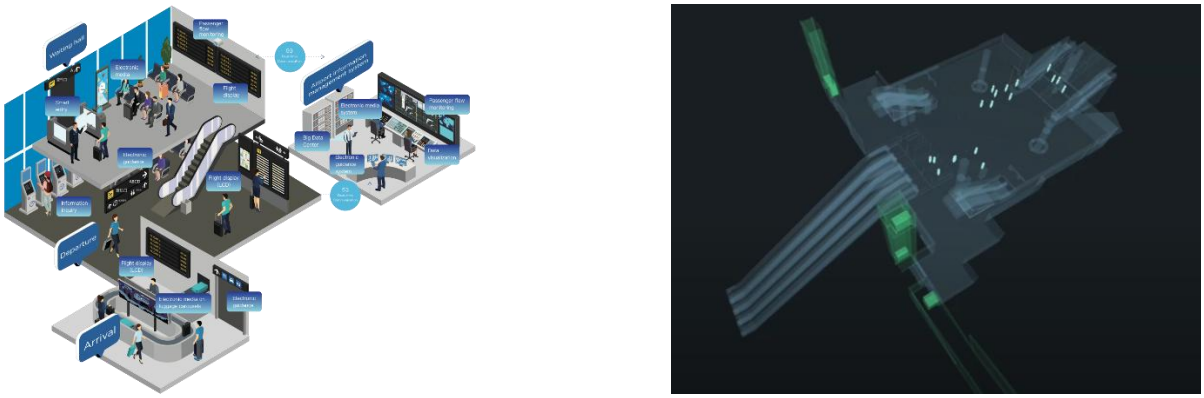


Figure 5 Examples of advanced airport VT management technologies: integrated BMS and lift monitoring platform for real-time system supervision (left); Digital twin model supporting simulation, capacity planning and operational optimisation (right).

9 CONCLUSION

This paper establishes a performance-based framework for vertical and horizontal transportation (VT/HT) design, reframing terminal conveyance from isolated equipment solutions into a system-level, mission-critical infrastructure. The intense, schedule-driven surges and the volumetric footprint of "people-plus-luggage" require a definitive departure from standard commercial design paradigms.

Peak passenger demand is typically derived from flight schedules, aircraft capacities, passenger load factors, and peak flight-bank overlaps. These profiles are assessed over five-minute intervals for VT analysis. Airport benchmarking and lift traffic planning practice indicate that a handling capacity of approximately 12–15% of the peak population within five minutes generally delivers acceptable waiting times and service levels.

To close the gap between theoretical handling capacity and real-world operational performance, VT planning must move upstream. Early architectural and engineering integration allows discrete-event simulation and demand modelling to act as design drivers rather than post-hoc verification tools. This ensures that terminal-level geometry, structural point-loading and security boundaries are optimised concurrently with equipment selection.

Looking forward, the next generation of airport terminal design will be defined by the convergence of sustainability and intelligence. Beyond the immediate energy savings provided by regenerative drives and automated standby controls, data-rich digital networks offer unprecedented operational control. By integrating smart telemetry into centralised Building Management Systems, operators can transition to predictive maintenance models that protect asset uptime. Ultimately, the deployment of predictive Digital Twins and AI-assisted capacity planning will allow terminals to dynamically recalibrate dispatch logic in real time, synchronising the terminal's physical circulation with the volatile demands of flight schedules.

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BIOGRAPHICAL DETAILS



Terry L. K. Fung is a vertical transportation specialist at Foster + Partners, London. His work focuses on the integration of lift and escalator systems within complex infrastructure, with particular emphasis on airport design for CPK Airport Warsaw and King Salman International Airport Riyadh.

He has extensive professional experience in Hong Kong, including involvement in Third Runway System of Hong Kong International Airport, contributing to the development of large-scale aviation infrastructure and passenger-focused design solutions.

Terry holds a Masters degree from Hong Kong University of Science and Technology and is professionally accredited as a Chartered Engineer (CEng) with Institution of Mechanical Engineers (IMechE).