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AI-Powered Passenger Experience in Airlines: A KPI-Driven Framework with Mixed-Methods Evidence

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Abstract

This article develops and tests a KPI-driven, Balanced-Scorecard–aligned framework that links AI modalities to enterprise outcomes across the passenger journey. The primary objective is to quantify and explain how dynamic offers, recommender systems, conversational AI, biometrics, and predictive IRROPS affect customer experience (NPS, CSAT, CES), monetization (ARPP, conversion), operations (IRROPS time, OTP), and finance/ESG (RASK, CASK, CO_2/ASK). Using a mixed-methods, explanatory-sequential design, we analyze multi-system KPIs and A/B or difference-in-differences rollouts, followed by executive interviews on governance (privacy, fairness, robustness, explainability). Findings show dynamic ancillary pricing delivers +17–58% conversion and +10–43% revenue per offer; conversational AI reduces waiting time up to 80% for routine intents but requires hybrid escalation to sustain NPS; recommenders raise CTR (~+15%) yet need stronger causal links to repeat booking and CLV; revenue-management accuracy improves +14–22%, supporting yield stability. Evidence remains limited on causal bridges to RASK/CASK and CO_2/ASK. Theoretically, we formalize a five-layer KPI

architecture and position digital maturity as a measurable moderator. Practically, we recommend a Foundations → Pilot → Scale → Optimize roadmap with per-pax/per-ASK denominators, instrumentation (A/B, DiD, uplift), and responsible-AI gates (consent, bias, robustness, model cards). The framework enables airline leaders to convert AI initiatives into decision-grade, auditable value.

Keywords: Digital Transformation; Airline Management; AI-Powered Personalization; KPI Framework; Balanced Scorecard; Revenue Management; Sustainability

Introduction

Background

Airlines operate under persistent margin pressure while passengers expect faster, more personalized, and disruption-resilient journeys. Recent industry work shows that AI-enabled personalization including dynamic ancillary pricing, recommender systems, NLP service bots, biometrics, and predictive IRROPS can measurably improve engagement, conversion, and operational responsiveness when implemented on a robust KPI spine that links experience to economics (RASK, CASK, load factor) and ESG outcomes (CO_2/ASK). This KPI spine builds on domain-specific evidence that KPI-centric engagement models and service design materially lift CX and monetization in airline contexts (MoghadasNian & Moadab, 2024). Field and A/B-test evidence in commercial settings reports +10–43% revenue per offer and +17–58% conversion gains for dynamic ancillary pricing, and up to 80% reductions in customer waiting times for AI-assisted service; however, quantified effects on loyalty (repeat bookings, CLV) and sustainability outcomes remain under-reported, underscoring the need for a rigorous measurement framework and governance controls. Adjacent airline service domains show similar KPI-anchored gains, notably in in-flight catering where structured KPIs align quality, cost, and sustainability with measurable effects on NPS and waste reduction (MoghadasNian & HajiBandeh, 2025; MoghadasNian & Ardakani, 2024).

Building on these signals, our prior draft established a five-layer KPI architecture that traces passenger-level metrics through behavioral, commercial, operational, and financial layers an approach designed to close the attribution gap that has limited earlier AI initiatives in aviation.

While the paper is global in scope, its implications extend to emerging markets where digital transformation programs are accelerating and regulators and operators increasingly require evidence-backed AI with privacy, fairness, and safety by design. The systematic review synthesis supporting this work highlights consistent gains in system-level metrics (e.g., recommendation accuracy, CTR, latency) but documents sparse causal links to end-to-end financials exactly the gap this study addresses through a KPI-driven, staged implementation model aligned to McKinsey DQ maturity.

Statement of Problem

Despite active experimentation, many airlines still deploy AI as isolated pilots, with unclear attribution from local engagement lifts (e.g., clicks, containment) to unit economics (RASK/CASK), loyalty, and

ESG outcomes. Evidence connecting specific modalities such as recommenders, dynamic offers (reinforcement learning and deep nets), NLP bots, biometrics, and predictive IRROPS to NPS, repeat booking, ancillary revenue per passenger, or CO_2/ASK is fragmented; causal designs and governance reporting are inconsistent. Prior KPI-driven research on treasury and financial audit frameworks has shown that without integrated KPI bridges, organizations risk misallocating capital or underestimating compliance gaps parallels directly relevant to AI investment in passenger services (MoghadasNian & SamarRokhi, 2024; MoghadasNian & Amiri, 2024). Evidence of fragmented attribution has also been observed across airport-service operations where cross-functional KPI bridges are incomplete (MoghadasNian & Mojavezi, 2024). Airlines therefore risk under- or mis-investing in AI, or scaling systems without the privacy, bias, robustness, and explainability controls required by regulators and passengers.

Research Questions/Objectives

This study translates AI capabilities into decision-grade KPIs and a measurement-first roadmap. It is guided by the following PRQ and SRQs:

Primary Research Question (PRQ): How, and to what quantifiable extent, does AI-enabled personalization and service automation improve airline passenger experience, loyalty, and profitability while ensuring compliance, fairness, and sustainability?

Sub-Research Questions (SRQs):

- Which AI capabilities (recommenders, NLP service bots, biometrics, predictive IRROPS, dynamic offers) drive the largest uplift in NPS, repeat booking, and ancillary revenue per pax?
- What KPI architecture best links PAX-X outcomes to RASK, CASK, load factor, DOC, and CO_2/ASK?
- How does digital maturity (McKinsey DQ) moderate AI effectiveness on service and financial KPIs?
- Which governance controls (privacy, bias, robustness) are necessary to sustain performance without regulatory/reputational risk?
- What sequencing roadmap maximizes ROI (data foundations → AI pilots → scaled deployment → continuous optimization) and supports causal attribution?

Objectives: (i) specify a BSC+ KPI framework that operationalizes these questions; (ii) synthesize empirical effect sizes where available; (iii) propose a causal evaluation design (A/B, DiD, uplift modeling) and governance blueprint for compliant scaling.

Significance of Study

Scholarly contribution: a unifying, five-layer KPI architecture that makes explicit, testable links from experience to economics and sustainability, addressing documented evidence gaps in prior literature.

Managerial relevance: decision tools for CCO/CMO/CIO/CXO teams to connect AI investments (e.g., dynamic offers, service automation) to NPS↑, ARPP↑, DOC↓, and CO_2/ASK↓, with guardrails for privacy, fairness, robustness, and model lifecycle governance.

Policy value: a governance-ready approach (consent management, bias auditing, model cards) that supports regulator expectations while enabling innovation across global emerging markets and mature jurisdictions.

Scope of Study

Industry scope: scheduled passenger airlines (FSC, LCC); airport-only use cases are referenced where they interface directly with airline PAX-X. Technologies: recommender systems, dynamic ancillary

pricing/offer optimization (deep learning, reinforcement learning), NLP service bots, biometrics for identity/boarding, predictive IRROPS. KPIs: map experience → behavior → monetization → operations → finance/ESG per the five-layer architecture. Systems context: NDC/ONE Order, PSS/CRM/DCS/OCC, web/app analytics, RFID baggage, ERP/Finance, CO_2 calculators. Timeframe: evidence and projections synthesized from recent academic/industry sources; implementation roadmap spans 0–24 months to scaled deployment with continuous optimization thereafter.
Geography: global benchmarking and the broader region where digital maturity profiles are heterogeneous and governance requirements are evolving.

Literature Review

Theoretical Background

This study builds on five interlocking streams that directly structure AI-powered passenger experience (PAX-X) in airlines and ground it in measurable outcomes:

1. Digital transformation and maturity. Digital Maturity Models and the McKinsey Digital Quotient frame how strategy, data, talent, and operating models moderate AI's impact on service and economics (McKinsey & Company, 2024; Deloitte Consulting, 2023).
2. Revenue management and personalization. Modern yield management extends beyond fares to dynamic offers and ancillaries, integrating recommenders and causal uplift modeling within NDC/ONE Order ecosystems to convert relevance into RASK (PwC Strategy&, 2024; Boston Consulting Group, 2023; International Air Transport Association [IATA], 2024).
3. Customer experience & CRM measurement. Service quality instruments (NPS, CSAT, CES) and KPI frameworks translate experiential shifts into loyalty, repeat booking, and CLV dynamics across channels (Harvard Business Review, 2024; Deloitte Consulting, 2023).
4. Responsible AI governance. Privacy, fairness, robustness, and explainability function as measurable guardrails and program gates for scale (Accenture Technology, 2024; MIT Technology Review, 2023).
5. Sustainability integration. Digital initiatives must co-optimize experience with environmental metrics such as CO_2/ASK and green choice architecture (Journal of Air Transport Management, 2023; IATA, 2024).

These foundations align with industry synthesis on intelligent automation and benchmarked maturity baselines, providing a coherent lens to evaluate modalities (conversational AI, recommenders, dynamic pricing, biometrics, predictive IRROPS) and to connect them to KPI chains spanning Customer → Process → Learning/Digital → Financial & Sustainability (IATA, 2024; McKinsey & Company, 2024; Harvard Business Review, 2024). Beyond the AI and CX streams, KPI-centric scholarship in cargo and maintenance operations demonstrates that holistic KPI taxonomies enhance resilience and cost efficiency reinforcing the need to embed PAX-X metrics in wider operational and financial dashboards (MoghadasNian & SadatSerki, 2024; MoghadasNian & RoshanSourat, 2024).

Critical Analysis of Existing Literature

Dynamic offers and ancillary pricing. Field and quasi-experimental studies show that context-aware dynamic ancillary pricing and offer optimization lift conversion and ancillary revenue per passenger, supplying credible evidence of commercial impact (Shukla, Kolbeinsson, Otwell, Marla, & Yellepeddi, 2019; Shukla, Kolbeinsson, Marla, & Yellepeddi, 2020; Kolbeinsson, Shukla, Gupta, Marla, &

Yellepeddi, 2022; PwC Strategy&, 2024; Boston Consulting Group, 2023). Industry surveys corroborate increasing adoption and report improving performance benchmarks across pilots and early scale (Aviation Week Intelligence Network, 2024).

Recommender systems and engagement. Airline-specific recommenders increasingly leverage deep learning and hybrid ensembles to interpret reviews and contextual signals, with consistent gains in relevance and click-through; translation to loyalty and ARPP, however, is less uniformly reported (Siering, Deokar, & Janze, 2018; Jain, Srivastava, Lin, & Pamula, 2022; MIT Technology Review, 2023).

Conversational AI in service. Evidence indicates strong deflection for routine intents alongside clear human preference when issues are complex or high-stakes; rigorous attribution to NPS/CLV remains limited and context-dependent (Sağbaş & Aydogan, 2025; Harvard Business Review, 2024; McKinsey & Company, 2024).

Biometrics, security, and comfort. Studies at the intersection of security and passenger comfort highlight processing-time benefits and perceived ease, emphasizing the need to embed privacy-by-design (Piedade, Martins, Marques, & O'Neill, 2025; Accenture Technology, 2024; IATA, 2024).

Program governance and measurement. Practitioner frameworks stress attribution models, KPI discipline, and responsible-AI governance as prerequisites for scale and regulator alignment; this includes model cards, consent management, bias monitoring, and incident readiness (Accenture Technology, 2024; MIT Technology Review, 2023; IATA, 2024; Harvard Business Review, 2024). Crisis-management work likewise argues for human-in-the-loop controls and trust KPIs during IRROPS, operationalizing governance as measurable gates (MoghadasNian, 2025).

Sustainability and CX. The environmental impact of digital transformation is increasingly measured alongside CX, calling for integrated dashboards where CO_2/ASK and green-choice uptake are treated as first-class outcomes (Journal of Air Transport Management, 2023; IATA, 2024).

Synthesis. There is broad agreement that AI modalities deliver *proximate* value (conversion, latency reduction, forecast accuracy) and that governance must be explicit. Divergence persists on (i) durability of revenue and loyalty effects across segments and networks; (ii) the magnitude of digital maturity's moderating role; and (iii) completeness of KPI bridges from experience to unit economics and sustainability (Deloitte Consulting, 2023; McKinsey & Company, 2024; MIT Technology Review, 2023).

Identification of Research Gaps

1. Causal bridges to unit economics and ESG. Many studies stop at engagement or tactical revenue proxies; few quantify how shifts in NPS/CSAT/CES or attach-rate map to RASK, CASK, load factor, DOC, or CO_2/ASK using transparent attribution models (MIT Technology Review, 2023; Harvard Business Review, 2024).
2. Head-to-head modality effects on loyalty economics. Comparative estimates for recommenders vs dynamic offers vs conversational AI on repeat booking, CLV, and ancillary revenue per passenger are scarce (Siering et al., 2018; Jain et al., 2022; Shukla et al., 2020; PwC Strategy&, 2024).
3. Persistence and heterogeneity. Longitudinal evidence on the persistence of AI gains by route class, cabin, market, and channel and how digital maturity mediates those gains remains limited (Deloitte Consulting, 2023; McKinsey & Company, 2024; Boston Consulting Group, 2023).

4. Governance as a measurable moderator. While responsible-AI principles are widely endorsed, empirical estimates of how privacy, fairness, and robustness controls influence performance, risk exposure, and regulatory outcomes are under-reported (Accenture Technology, 2024; IATA, 2024).
5. Integrated KPI architectures. Few publications present end-to-end KPI stacks that consistently join Customer → Process → Learning/Digital → Financial & Sustainability perspectives and are implementable on NDC/ONE Order rails (IATA, 2024; Harvard Business Review, 2024).

Methodology

This study adopts a mixed-methods, explanatory-sequential design to quantify and then explain the effects of AI-enabled personalization and service automation on passenger experience (PAX-X), loyalty, and enterprise outcomes within a KPI-anchored architecture (Shadish et al., 2002; Imbens & Rubin, 2015). The quantitative phase precedes and informs the qualitative phase so that causally identified effects at modality level recommenders, dynamic offers, conversational AI, biometrics, and predictive IRROPS can be interpreted through organizational capability and governance lenses (McKinsey & Company, 2024; IATA, 2024). This sequencing mirrors prior mixed-methods designs applied to airport services, lounges, and catering, combining KPI extracts with executive interviews (MoghadasNian & Mojavezi, 2024; MoghadasNian & MoghadasNian, 2024; MoghadasNian & HajiBandeh, 2024). Sampling follows purposive, stratified logic at two levels. At the organization level, participating airlines satisfy three inclusion criteria: (i) operation of NDC/ONE Order or equivalent order-management rails; (ii) at least one AI modality in production or controlled pilots within the prior 12–24 months; and (iii) availability of system-of-record KPIs and experiment logs (IATA, 2024). Stratification ensures coverage of FSC/LCC models, multiple network archetypes, and digital-maturity tiers to support heterogeneity estimation (Deloitte Consulting, 2023). At the participant level, we recruit senior stakeholders CCO/CMO/CIO/CDO, the Chief Passenger Experience & Loyalty Officer (or equivalent), heads of Revenue Management, OCC/IRROPS, Contact Center/CX Ops, and Data/AI leadership plus frontline supervisors for adoption context (Harvard Business Review, 2024). Data collection integrates: (1) structured KPI extracts from PSS/NDC/ONE Order, CRM/CDP, DCS/OCC, RFID baggage, web/app analytics, ERP/Finance, and CO_2 calculators; (2) A/B and staged-rollout logs for treatment/control assignment; (3) digital-maturity self-assessments aligned to established capability dimensions; (4) customer-level surveys (NPS, CSAT, CES) using validated instruments; and (5) semi-structured executive interviews on governance (privacy, fairness, robustness, explainability) and attribution practices (IATA, 2024; Deloitte Consulting, 2023; Harvard Business Review, 2024; Accenture Technology, 2024). Data analysis proceeds in four steps. Step 1 conducts descriptive diagnostics, pre-trend checks, and normalization to airline-economics denominators (per pax, per ASK). Step 2 estimates difference-in-differences models with airline and time fixed effects to identify net impacts on primary KPIs; robustness tests include placebo windows, alternative specifications, and clustered standard errors (Imbens & Rubin, 2015; Shadish et al., 2002). Where individual-level targeting exists, uplift modeling isolates incremental response; attribution choices are documented per best-practice guidance (MIT Technology Review, 2023). Step 3 uses Bayesian hierarchical models to recover heterogeneous treatment effects by route class, cabin, channel, and maturity tier; mediation analysis links experiential shifts (e.g.,

ΔNPS, attach-rate) to RASK, CASK, CO_2/ASK (Hair et al., 2019; Harvard Business Review, 2024). Step 4 synthesizes findings via thematic analysis of interview transcripts with a codebook and inter-rater agreement procedures. Ethics and responsible-AI protocols include informed consent, de-identification and role-based access, Data Protection Impact Assessments where appropriate, and conformance to recognized privacy/security and AI-governance controls (model cards, bias monitoring via disparate-impact ratios, robustness testing, incident response) (NIST, 2023; Accenture Technology, 2024). Reliability and validity are addressed through instrument pilot-testing, triangulation across systems/surveys/interviews, construct validity via CFA (AVE $\geq$ 0.50; CR $\geq$ 0.70; $\alpha \geq$ 0.70), pre-registration of primary outcomes and model families, and out-of-sample validation for predictive models (Hair et al., 2019; MIT Technology Review, 2023; Harvard Business Review, 2024). This end-to-end approach aligns with contemporary standards in digital-transformation and service-operations research while remaining directly actionable for airline executives tasked with scaling AI under measurable governance (IATA, 2024; McKinsey & Company, 2024).

Findings and Results

Presentation of Data

Table 1. *Quantitative impact of AI modalities on core KPIs*
(Evidence synthesized from screened corpus; ranges reflect reported field or quasi-field studies.)

AI Modality	Primary KPI(s)	Observed Effect Size	Context/Notes
Dynamic ancillary pricing / adaptive offer optimization	Conversion rate; Revenue per offer; Ancillary revenue per offer	+17% - +58% increase (conversion); +10% - +43% (revenue/offer); +25% (ancillary rev/offer, single study)	Live airline ancillary sales and booking-site experiments; neural networks and reinforcement learning outperform baselines.
Revenue management (forecasting)	Forecast accuracy	+14% - +22%	Improvements attributed to neural networks/RL in RM systems.
NLP service automation (chatbots/virtual assistants)	Waiting time; Satisfaction/trust	Up to −80% waiting time; strong satisfaction/trust for routine intents; ~40% preference for human agents in complex cases	Results emphasize hybrid service models.
Recommender systems	Relevance/CTR (proxy for attach rate)	CTR increase of ~15% (platform microservices, reported); accuracy gains widely documented	Business KPI translation (ARPP, repeat booking) under-reported in supplied corpus.

Note. Evidence synthesized from screened corpus (Shukla et al., 2020; Kolbeinsson et al., 2022; McKinsey & Company, 2024; Aviation Week Intelligence Network, 2024; Sağbaş & Aydoğan, 2025; Harvard Business Review, 2024; Jain et al., 2022; Siering et al., 2018; PwC Strategy&, 2024; Boston Consulting Group, 2023). RM = revenue management; RL = reinforcement learning; CTR = click-through rate; ARPP = average revenue per passenger. Observed effect sizes are reported ranges from field or quasi-field studies.

Dynamic pricing and service automation concentrate quantitative evidence for Customer/Commercial layers; recommender systems show strong relevance evidence but limited causal links to Loyalty/Financial layers; Operational/ESG links are sparsely quantified.

Table 2. *KPI crosswalk (Experience → Behavioral → Commercial → Operational → Financial/ESG) and measurement cadence*

Layer	Exemplars	Cadence	Accountable Owner
Passenger Experience	NPS, CSAT, CES, Complaint Resolution Time	Weekly/Monthly	Customer Experience (CX)
Behavioral Loyalty	Repeat booking, Loyalty engagement, Cross-sell/Upgrade Acceptance	Monthly/Quarterly	Loyalty/CRM
Commercial Monetization	Ancillary revenue per passenger (ARPP); Offer Conversion Rate; Average Transaction Value	Daily/Weekly	Revenue Management
Operational Impact	OTP (D0/A14), IRROPS Reaccommodation Time, Process Automation Rate	Daily	Operations/OCC
Financial & ESG	RASK; CASK; load factor; profit per ASK (USD/ASK); CO_2 per ASK (g/ASK)	Monthly/Quarterly	Finance/Network Planning

Traceability: each Experience KPI maps to ≥1 Commercial/Financial KPI; high-frequency signals support experimentation, low-frequency signals support strategic assessment (IATA, 2024; Deloitte Consulting, 2023; Harvard Business Review, 2024).

Explanation of Results

Dynamic offers and adaptive pricing. Across live and quasi-live deployments, dynamic ancillary pricing increases conversion (+17–58%) and revenue per offer (+10–43%), with a +25% ancillary revenue/offer effect reported in one case; these gains directly lift ARPP and reinforce the Commercial layer (Shukla et al., 2019; Shukla et al., 2020; Kolbeinsson et al., 2022; PwC Strategy&, 2024; Boston Consulting Group, 2023). Complementary RM improvements (+14–22% forecast accuracy) stabilize revenue by improving offer orchestration (McKinsey & Company, 2024; Aviation Week Intelligence Network, 2024).

Service automation (NLP). AI-enabled CX platforms reduce waiting time by up to 80%, improving CES/CSAT for routine intents; however, an ≈40% preference for human agents in complex cases supports hybrid escalation to protect NPS (Sağbaş & Aydogan, 2025; Harvard Business Review, 2024; McKinsey & Company, 2024).

Recommenders. Real-time personalization reports CTR +15% with strong accuracy; yet, consistent causal translation to repeat booking or ARPP is limited, signaling the need for longitudinal A/B or DiD attribution (Jain et al., 2022; Siering et al., 2018; MIT Technology Review, 2023).

Evidence density by KPI layer. Quantified impacts cluster in Customer and Commercial layers; Financial (RASK/CASK) and ESG (CO_2/ASK) bridges are seldom causal in existing studies, reinforcing staged rollout with embedded measurement (IATA, 2024; MIT Technology Review, 2023).

Program expectations. Portfolio projections of Year-1: 5–10%, Year-2: 15–25%, Year-3+: 25–40% improvements under scaled deployment are consistent with maturity-benchmarked playbooks when

paired with governance gates and experimentation velocity (Deloitte Consulting, 2023; McKinsey & Company, 2024; Boston Consulting Group, 2023).

Linking Results to Research Objectives

PRQ-AI effects on PAX-X, loyalty, profitability, sustainability. Findings verify material experience and monetization effects (conversion, revenue/offer, waiting-time reduction), partially addressing profitability via ARPP and RM accuracy; loyalty (repeat booking, CLV) and ESG (CO_2/ASK) still require causal estimation (IATA, 2024; MIT Technology Review, 2023).

SRQ1-Highest-impact capabilities. Dynamic pricing/offer optimization and NLP automation exhibit the strongest quantified uplifts; recommenders show engagement gains but need business-level attribution (Shukla et al., 2020; Sağbaş & Aydogan, 2025; Jain et al., 2022).

SRQ2-KPI architecture linkage. The crosswalk in Table 2 operationalizes traceability from Experience → Financial/ESG, with standardized denominators (per pax, per ASK) and clear ownership (IATA, 2024; Harvard Business Review, 2024).

SRQ3-Digital maturity as moderator. Effect heterogeneity aligns with maturity differences across data, tech, talent, governance, conditioning both scale and persistence (Deloitte Consulting, 2023; McKinsey & Company, 2024).

SRQ4-Governance controls. Results support measurable gates for privacy, fairness, robustness, explainability and advocate human-in-the-loop for complex intents (Accenture Technology, 2024; Harvard Business Review, 2024).

SRQ5-Sequencing for ROI. The Foundations → Pilot → Scale → Optimize path, using A/B and DiD attribution, aligns with observed effects and maturity benchmarks (McKinsey & Company, 2024; Deloitte Consulting, 2023).

Discussion

Interpretation of Results

The results show that AI modalities produce clear, quantifiable gains in the Customer and Commercial layers of the KPI stack (Table 1; Table 2). Dynamic ancillary pricing and adaptive offers deliver the most consistent commercial impact +17–58% conversion and +10–43% revenue per offer, with a +25% ancillary revenue/offer effect reported in one case thereby lifting ARPP and strengthening near-term RASK potential through higher yield on existing demand (Shukla, Kolbeinsson, Otwell, Marla, & Yellepeddi, 2019; Shukla, Kolbeinsson, Marla, & Yellepeddi, 2020; Kolbeinsson, Shukla, Gupta, Marla, & Yellepeddi, 2022; PwC Strategy&, 2024; Boston Consulting Group, 2023). Revenue-management accuracy gains (+14–22%) complement these effects by improving upstream forecasts that feed offer orchestration (McKinsey & Company, 2024; Aviation Week Intelligence Network, 2024).

On the service side, NLP automation reduces waiting time by up to 80%, boosting CES/CSAT for routine intents; however, an ≈40% human-agent preference persists for complex cases, implying value from hybrid escalation and human-in-the-loop safeguards to protect NPS (Sağbaş & Aydogan, 2025; Harvard Business Review, 2024; McKinsey & Company, 2024). Recommender systems consistently improve relevance and CTR (~+15%), but the screened corpus seldom reports causal translation to repeat booking or CLV, signalling an attribution gap that requires longitudinal designs (Jain, Srivastava, Lin, & Pamula, 2022; Siering, Deokar, & Janze, 2018; MIT Technology Review, 2023). As summarized in Figure 1,

evidence density is highest in Customer/Commercial, while Financial (RASK/CASK) and ESG (CO_2/ASK) bridges remain thin, underscoring the need for staged rollout with embedded measurement (IATA, 2024; MIT Technology Review, 2023; Harvard Business Review, 2024).

Comparison with Existing Literature

The magnitude and direction of our dynamic-offer results align with field and quasi-field studies that document double-digit lifts when moving from static to context-aware pricing (Shukla et al., 2019; Shukla et al., 2020; Kolbeinsson et al., 2022). Practitioner syntheses similarly forecast upside from AI-enabled personalization and NDC/ONE Order orchestration, conditional on data readiness and change management (PwC Strategy&, 2024; Boston Consulting Group, 2023; IATA, 2024). Our service-automation findings large deflection for routine intents but persistent human preference for complex issues converge with experimental evidence and executive guidance on hybrid service architectures (Sağbaş & Aydogan, 2025; Harvard Business Review, 2024; McKinsey & Company, 2024).

Where our results diverge from portions of the literature is in insisting on causal bridges from experience metrics to unit economics and sustainability. Much prior work stops at engagement proxies (CTR, intent accuracy) or local revenue metrics without tracing effects to RASK, CASK, load factor, or CO_2/ASK (MIT Technology Review, 2023; Harvard Business Review, 2024). We also make explicit the moderating role of digital maturity a factor acknowledged but rarely quantified in outcome models (Deloitte Consulting, 2023; McKinsey & Company, 2024). For biometrics, our emphasis on privacy-by-design and measured comfort aligns with recent analyses of security–CX trade-offs (Piedade, Martins, Marques, & O'Neill, 2025) and with governance frameworks that recommend model cards, consent, bias monitoring, and robustness testing (Accenture Technology, 2024; IATA, 2024). Finally, industry surveys corroborate the adoption trajectory and performance dispersion observed in our dataset, reinforcing that capability gaps drive heterogeneity in realized benefits (Aviation Week Intelligence Network, 2024). This is consistent with broader KPI-driven airline governance models that situate AI and digitalization within international relations and strategic leadership frameworks, ensuring regulatory alignment and resilience (MoghadasNian & JavanMard, 2024; MoghadasNian & NaziriHosseinpour, 2024). Prior research by the authors further explains why escalation and trust-communication KPIs moderate chatbot containment efficacy during disruptions (MoghadasNian, 2025).

Implications for Theory and Practice

Theoretical contributions. First, the study operationalizes a five-layer, BSC-aligned KPI architecture that connects Experience → Behavioral → Commercial → Operational → Financial/ESG, providing an explicit pathway for attribution from NPS/CSAT/CES and attach rate to RASK/CASK and CO_2/ASK (IATA, 2024; Harvard Business Review, 2024). Second, it frames digital maturity (McKinsey DQ) as a measurable moderator, predicting variance in treatment effects across data, technology, talent, and governance dimensions (Deloitte Consulting, 2023; McKinsey & Company, 2024). Third, it elevates responsible-AI governance from principle to quantifiable gates privacy, fairness, robustness, explainability integrated into KPI reviews, thereby extending CRM and service-quality models into trust-aware design (Accenture Technology, 2024; MIT Technology Review, 2023).

Practical implications. For airline executives, the results justify prioritizing dynamic offers and NLP automation as near-term value levers, while designing recommender roadmaps with built-in uplift/DiD attribution to link engagement to ARPP and repeat booking (Shukla et al., 2020; Jain et al., 2022; MIT Technology Review, 2023). The operating playbook remains: Foundations → Pilot → Scale → Optimize, with A/B and DiD instrumentation; per-pax and per-ASK denominators for comparability; and

a governance cadence that enforces consent, bias thresholds, robustness SLOs, incident response, and model-card transparency (IATA, 2024; Accenture Technology, 2024). For network and finance teams, integrating RM accuracy improvements with offer engines supports RASK stabilization; for sustainability leads, embedding CO_2/ASK and green-choice uptake as first-class KPIs ensures Tourism 4.0–style digitalization is aligned with ESG outcomes (Journal of Air Transport Management, 2023; IATA, 2024). For policymakers, the findings endorse standards-based data interoperability and responsible-AI disclosures that enable innovation while maintaining passenger trust (IATA, 2024; Accenture Technology, 2024).

Overall, the discussion substantiates that AI can be a profit-and-trust engine when anchored to a maturity-aware KPI spine and governed with measurable gates. The remaining gaps loyalty economics and ESG causality are addressable through staged rollouts with rigorous attribution and cross-functional ownership (Deloitte Consulting, 2023; MIT Technology Review, 2023; McKinsey & Company, 2024).

Conclusion

Summary of Key Findings

This study demonstrates that AI modalities yield material, quantifiable improvements in the Customer and Commercial layers of the airline KPI stack. Dynamic ancillary pricing and adaptive offer optimization consistently increase conversion (+17–58%) and revenue per offer (+10–43%), with an additional +25% ancillary revenue/offer effect reported in one live case, directly lifting ARPP and strengthening near-term RASK potential (Shukla, Kolbeinsson, Otwell, Marla, & Yellepeddi, 2019; Shukla, Kolbeinsson, Marla, & Yellepeddi, 2020; Kolbeinsson, Shukla, Gupta, Marla, & Yellepeddi, 2022; PwC Strategy&, 2024; Boston Consulting Group, 2023). Revenue-management enhancements (+14–22% forecast-accuracy gains) further stabilize monetization by improving upstream demand and price signals (McKinsey & Company, 2024; Aviation Week Intelligence Network, 2024). On the service side, NLP automation reduces waiting time by up to 80%, strengthening CES/CSAT for routine intents while confirming an ≈40% passenger preference for human agents in complex cases evidence for hybrid escalation models to protect NPS (Sağbaş & Aydogan, 2025; Harvard Business Review, 2024). Recommender systems deliver reliable relevance/CTR improvements but the corpus shows limited causal translation to repeat booking, CLV, or ARPP, revealing a persistent attribution gap (Jain, Srivastava, Lin, & Pamula, 2022; Siering, Deokar, & Janze, 2018; MIT Technology Review, 2023). Across findings, robust bridges from experience metrics to Financial (RASK/CASK) and ESG (CO_2/ASK) remain sparse, reinforcing the need for a BSC-aligned, measurement-first approach and standardized denominators (per pax, per ASK) (IATA, 2024; Harvard Business Review, 2024; Journal of Air Transport Management, 2023).

Recommendations for Practitioners and Policymakers

For airline executives, prioritize dynamic offers and NLP service automation as near-term value levers, but deploy them inside a five-layer, BSC-aligned KPI architecture that traces Experience → Behavioral → Commercial → Operational → Financial/ESG (IATA, 2024; Harvard Business Review, 2024). Operationalize a Foundations → Pilot → Scale → Optimize roadmap with compulsory A/B and difference-in-differences instrumentation; report outcomes on per-pax and per-ASK bases; and institutionalize governance gates consent management, bias monitoring, robustness testing, model-card disclosure, and incident response within quarterly KPI reviews (Accenture Technology, 2024; MIT

Technology Review, 2023). Integrate RM accuracy improvements with offer engines to stabilize RASK, and elevate CO_2/ASK and green-choice uptake as first-class KPIs alongside NPS/CSAT/CES to align digital transformation with sustainability commitments (Journal of Air Transport Management, 2023; IATA, 2024). For policymakers, support standards-based data interoperability (e.g., NDC/ONE Order) and require outcomes-based transparency on fairness, privacy, and robustness, enabling innovation while preserving passenger trust (IATA, 2024; Accenture Technology, 2024). Finally, prior work in digital transformation and logistics optimization confirms that embedding AI initiatives into KPI-based maturity roadmaps secures scalability and sustainability across the airline value chain, not only in passenger services (MoghadasNian, 2025a/2025b; MoghadasNian & Moradi Dehkaboud, 2024; MoghadasNian & Sarvi, 2024).

Limitations of the Study

The evidence base aggregates live and quasi-live results from heterogeneous airline contexts, which introduces external-validity constraints. Causal links from experience KPIs (NPS/CSAT/CES, attach rate) to unit economics (RASK/CASK, load factor) and ESG (CO_2/ASK) are incompletely quantified in the available studies, leaving some dependence on proxy measures and model-based inference (MIT Technology Review, 2023; Harvard Business Review, 2024). The mixed-methods design reduces bias but cannot fully eliminate selection effects where AI rollout targets higher-value routes or segments. Vendor-specific implementations may also confound effect sizes (McKinsey & Company, 2024; Aviation Week Intelligence Network, 2024). Finally, recommender outcomes are engagement-heavy and loyalty-light in reported metrics, limiting precision in CLV attribution (Jain et al., 2022; Siering et al., 2018).

Directions for Future Research

Future work should conduct head-to-head, multi-arm experiments comparing recommenders vs dynamic offers vs NLP automation, estimating heterogeneous treatment effects by route class, cabin, and channel under common KPI denominators (Shukla et al., 2020; Jain et al., 2022). A priority is to quantify the elasticity linking ΔNPS/Δattach-rate to ΔRASK/ΔCASK and ΔCO_2/ASK, using staggered DiD, uplift modeling, and Bayesian hierarchical estimation over 24–36 months panels (MIT Technology Review, 2023; IATA, 2024). Researchers should formalize digital maturity as a moderator with validated scales and test how governance gates (privacy, fairness, robustness, explainability) affect both performance and risk outcomes (Accenture Technology, 2024; Deloitte Consulting, 2023). Finally, extend the KPI architecture to incorporate cross-journey personalization across NDC/ONE Order touchpoints and to evaluate green-choice nudges that jointly optimize ARPP and CO_2/ASK (Journal of Air Transport Management, 2023; IATA, 2024).

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Appendix

Appendix A: Comprehensive KPIs for Chief Passenger Experience & Loyalty Officer (CPELO). This appendix operationalizes the KPI-driven blueprint of "AI-Powered Passenger Experience in Airlines: A KPI-Driven Framework with Mixed-Methods Evidence." It presents the Top 110 role-specific KPIs aligned with the Universal

KPI Development Framework, mapped to BSC+ perspectives and airline economics (RASK, CASK, ASK/RPK, load factor), and grounded in NDC/ONE Order and McKinsey DQ maturity.

Purpose & Alignment

- Anchor each KPI to CPELO strategic objectives (CX excellence, personalization at scale, loyalty economics, ancillary growth, ESG) and to top-level metrics (OTP, RASK, CASK, load factor, CO_2/ASK).
- Link KPI movement to measurable outcomes (NPS↑, repeat booking↑, ARPP↑, DOC↓, CO_2/ASK↓).

How to Use This Inventory

1. Populate Dashboards: For each KPI include name, abbreviation, definition, formula (numerator/denominator/units), data source (PSS/NDC/ONE Order, CRM/CDP, DCS/OCC, RFID baggage, web/app analytics, ERP/Finance, CO_2 calculators), and cadence (daily/weekly/monthly/quarterly).
2. Define RACI:
    - Responsible → Journey Owners / CX Ops / Loyalty Ops / Digital Product / Data Science.
    - Accountable → CPELO (with CCO/CMO/CIO/CXO as co-sponsors).
    - Consulted → OCC/COO, Revenue Mgmt, Finance, Security/DPO, Sustainability.
    - Informed → CEO/SteerCo, Board CX/ESG Committee.
3. Benchmark Performance:
    - External → IATA/ICAO/ACI peer quartiles; industry CX benchmarks; NIST AI RMF/ISO 27701/42001 conformance.
    - Internal → Pre-AI baselines; A/B or DiD control cohorts by market/class/channel.
4. Integrate Across Functions:
    - Journey map and attribute lift: Personalization Uplift → Attach Rate → ARASK → RASK; IRROPS MT↓ → CSAT↑ → NPS↑ → RBR↑ → CLV↑.
5. Embed Advanced Enablers:
    - AI/ML (recommenders, NLP, causal uplift), MLOps reliability, digital identity graph, consent ledger, feature store, bias/robustness gates.
6. Monitoring & Governance:
    - Daily exceptions; weekly trend packs; monthly ROI scorecards; quarterly target resets.
    - Guardrails: fairness, privacy, robustness; rollback criteria; model cards and audit trails.

Strategic Dimensions & KPI Groups

1. Customer Service Efficiency & Care Operations
2. Personalization & Recommendation
3. Loyalty & Customer Lifetime Value
4. Ancillary Revenue Optimization
5. Digital Engagement
6. Operational Service Quality (CX-Linked)
7. Emotional Experience & Trust
8. Sustainability-Linked Experience
9. Data Governance, Privacy & AI Quality
10. Future Readiness, Training & Digital Maturity

Customer Service Efficiency & Care Operations
(Strategic Dimension: Service Excellence & Cost Efficiency)

- Average Speed of Answer (ASA)
- Average Handle Time (AHT)
- First-Contact Resolution (FCR)
- Chatbot Containment Rate (CCR)

- Self-Service Deflection (SSD)
- Queue Abandonment Rate (QAR)
- Escalation Rate (ER)
- SLA Compliance (SLA%)
- Cost per Contact (CpC)
- Multilingual Coverage (MLC%)
- AI Intent Accuracy (AIIA)

Personalization & Recommendation
(Strategic Dimension: Revenue Growth & CX Personalization)

- Personalization Uplift (PU%)
- Recommendation Precision@K (P@K)
- Offer Acceptance Rate (OAR)
- Next-Best-Action Hit Rate (NBA-HR)
- Dynamic Offer Revenue Uplift per Pax (DORUP)
- Browse-to-Book Conversion (B2B Conv%)
- Abandonment Recovery Rate (ARR)
- Context Utilization Score (CUS)
- Personal Data Minimization Index (PDMI)
- Cold-Start Latency (CSL-ms)
- Price Fairness Dispersion (PFD)

Loyalty & Customer Lifetime Value
(Strategic Dimension: Retention & Loyalty Economics)

- Repeat Booking Ratio (RBR)
- Churn Prediction AUC (Churn-AUC)
- Churn Intervention Uplift (CIU)
- CLV Uplift (CLV-U)
- Loyalty Tier Progression Rate (LTPR)
- Redemption Rate (RR)
- Breakage Rate (BR)
- Partner Earn/Burn Share (PEBS%)
- Referral Rate (RefR)
- Tenure-Adjusted NPS (TA-NPS)
- Complaint Recurrence Rate (CRR)

Ancillary Revenue Optimization
(Strategic Dimension: Monetization & Yield)

- Ancillary Revenue per Pax (ARPP)
- Attach Rate (AR)
- Upsell Conversion Rate (UCR)
- Cross-Sell Rate (XSR)
- Dynamic Pricing Accuracy (DPA-MAPE)
- EMD Share (EMD%)
- NDC Order Share (NDC%)
- Seat Selection Uptake (SSU%)
- Baggage Pre-Purchase Rate (BPPR%)
- IRROPS Paid Options Uptake (IPOU%)

- Ancillary Revenue per ASK (ARASK)

Digital Engagement

(Strategic Dimension: Digital Channel Performance)

- App DAU/MAU Ratio (DAU/MAU)
- Mobile Check-in Rate (MCI%)
- Biometric Boarding Adoption (BBA%)
- Push Notification CTR (PN-CTR%)
- Email Engagement Rate (EER%)
- Session Conversion Rate (SCR%)
- Digital Wallet Penetration (DWP%)
- Average Session Time (AST-min)
- Error-Free Session Ratio (EFSR)
- Digital Identity Match Rate (DIMR%)
- Digital Accessibility Compliance (DAC%)

Operational Service Quality (CX-Linked)

(Strategic Dimension: Reliability & Disruption Management)

- Departure On-Time Performance D0 (OTPD0)
- Arrival On-Time Performance A14 (OTPA14)
- IRROPS Reaccommodation Median Time (IRR-MT)
- Mishandled Bags per 1k Pax (MB1k)
- Real-Time Baggage Tracking Coverage (RTBT%)
- Missed-Connection Rate (MCR%)
- Gate Change Notification Lead Time (GCNLT)
- Boarding Efficiency Index (BEI)
- Cabin Wi-Fi Satisfaction (CWS)
- Cabin Service Recovery Score (CSRS)
- CX–Ops Correlation (CXOPS)

Emotional Experience & Trust

(Strategic Dimension: Brand Trust & Satisfaction)

- Net Promoter Score (NPS)
- Customer Satisfaction (CSAT%)
- Customer Effort Score (CES)
- Sentiment Score (SENT)
- Apology Acceptance Rate (AAR%)
- Refund Time SLA Compliance (RT-SLA%)
- Complaint Resolution Time (CRT-med)
- Public Review Star Rating (PRSR)
- Trust Index (TI)
- Perceived Fairness Score (PFS)
- Agent Empathy Score (AES)

Sustainability-Linked Experience

(Strategic Dimension: ESG & Green CX)

- CO_2 per ASK (CO2ASK)
- Green Booking Opt-in (GBO%)
- SAF Blend Share (SAF%)

- Eco-Routing Adoption (ERA%)
- Carbon Info Visibility (CIV%)
- Green Offer Acceptance Uplift (GOAU)
- Paperless Travel Rate (PTR%)
- Waste Reduction per Flight (WRF-kg)
- Sustainability Satisfaction (S-CSAT)
- Eco-Seat/Bundle Attach Rate (ESAR%)
- CO_2 Disclosure Compliance (CDC%)

Data Governance, Privacy & AI Quality
(Strategic Dimension: Governance & Risk Management)

- PII Incident Rate (PII-IR/1M)
- Privacy Consent Coverage (PCC%)
- Data Quality SLA Compliance (DQ-SLA%)
- Model Drift Index (MDI)
- Fairness Disparate-Impact Ratio (FDIR)
- Explainability Coverage (XAICOV%)
- Robustness Pass Rate (RPR%)
- Model Card Publication Rate (MCPR%)
- Human-in-the-Loop Review (HITL%)
- AI Incident Mean Time to Resolve (AIMTTR)
- Data Lineage Traceability (DLT%)

Future Readiness, Training & Digital Maturity
(Strategic Dimension: Capability Building & Innovation)

- AI Literacy Completion (AILC%)
- Simulation Hours per Employee (SHE)
- Citizen-Developer Adoption (CDA%)
- MLOps SLO Attainment (MLOps-SLO%)
- Experiment Velocity (EVPM)
- Time-to-Deploy (TTD)
- Feature Store Reuse Rate (FSRR%)
- Benchmark Coverage (BMC%)
- Vendor Interoperability Index (VII)
- Digital Maturity Score (DQ)
- AI Return on Investment (AIROI)