

TECHNOLOGY AND USER SATISFACTION IN HARBIN'S SMART SPORTS VENUES: RELATIONSHIPS AND A CAUSAL MODEL

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ABSTRACT

This paper extracts and develops a subset of objectives from a thesis on smart sports venues in Harbin. The aims are: (1) to analyze how technology investment and intelligent infrastructure—operating through technology integration—relate to user satisfaction, and (2) to specify and test a causal model with technology integration as a mediator. A mixed-methods design was used; the quantitative arm surveyed 240 sports-venue users in Harbin and applied structural equation modeling (SEM) with Bootstrap mediation tests. The model achieves strong fit on key blocks (e.g., $\chi^2/df \approx 1.315$; GFI ≈ 0.955 ; CFI ≈ 0.988 ; RMSEA ≈ 0.036). Path estimates show positive effects from technology investment and intelligent infrastructure on technology integration, and from technology integration on user satisfaction; Bootstrap results support significant mediation of technology integration between both investment/infrastructure and satisfaction.

Keywords: Smart sports venue; user satisfaction; user experience (UX); sports management

INTRODUCTION

Smart sports venues have emerged as living laboratories where sensing, connectivity, analytics, and service design converge to enhance user experience and operational performance. In the broader “Internet and digital age” of sport, digitalization reshapes value creation across venue operations, fan engagement, and data-driven decision-making (Jiawu, 2019). At the facility level, intelligent construction integrates networked infrastructure, computational platforms, and interoperable systems—an “Internet+” approach—to deliver seamless, real-time services at scale (Jingyun, 2021; Li, 2019). Parallel advances in IoT, AI, and cloud architectures provide the technical backbone for “smart stadiums,” enabling automation, monitoring, and responsive user interfaces that can lift satisfaction when effectively integrated (Mahdi et al., 2021; Molanes et al., 2018; Panchanathan et al., 2019).

Despite these advances, the mechanism linking technology investment and intelligent infrastructure to user satisfaction remains under-specified unless we account for the integration layer—how systems, processes, and staff capabilities knit technologies into a smooth, end-to-end service. Recent scholarship emphasizes digital technologies as enablers of new service scenarios and performance uplift across the sports service industry, but it also implies that benefits materialize through coherent integration rather than isolated hardware upgrades (Liu et al., 2022; Li & Li, 2021; Li et al., 2021). In entertainment-oriented deployments, IoT-led modernization can transform spectator experience and venue efficiency, reinforcing the need to model both direct and mediated pathways from investment and infrastructure to satisfaction (Navandar et al., 2025; Mahdi et al., 2021).

This study responds to that gap by focusing on technology integration as a mediating mechanism in Harbin's smart sports venues. Using structural equation modeling (SEM), we jointly estimate measurement and structural relations among technology investment, intelligent infrastructure,

technology integration, and user satisfaction. SEM is well-suited to this task because it tests theoretical fit and directional paths simultaneously while benchmarking model adequacy against stringent criteria (e.g., χ^2/df , RMSEA, GFI, CFI, TLI) that guide interpretability and generalizability. Consistent with recommended thresholds (e.g., $\chi^2/df \approx 1-3$; $RMSEA \leq .08/.05$; $GFI/CFI \geq .90$ with $\geq .80$ acceptable), our model attains very good fit, supporting subsequent inferences about direct and indirect effects (Hou & Wen, 2005; Wu, 2012, as summarized in the thesis).

Together, these considerations motivate two aims presented in the accompanying paper: (1) to analyze how technology investment and intelligent infrastructure—operating through technology integration—relate to user satisfaction in Harbin's venues; and (2) to specify and test a causal model in which integration mediates the upstream effects on satisfaction. By centering the integration layer, the study clarifies where managers should concentrate resources to translate digital capacity into meaningful user outcomes. (See Results and Discussion sections in the main paper for fit indices and path estimates.)

OBJECTIVE

1. To identify and quantify the relationships among technology investment (TI), intelligent infrastructure (II), technology integration (TIN), and user satisfaction (US), distinguishing direct and indirect links.
2. To create and validate a causal prediction model (SEM) in which TIN mediates the effects of TI and II on US, reporting fit indices, reliability/validity, and total effects for decision use.

METHODOLOGY

Research Design

This study employs a quantitative, cross-sectional survey design to examine relationships among technology investment (TI), intelligent infrastructure (II), technology integration (TIN), and user satisfaction (US). Measurement quality is established through confirmatory factor analysis (CFA), followed by structural equation modeling (SEM) to estimate direct, indirect, and total effects and to assess overall model fit. Fit benchmarks (e.g., χ^2/df , RMSEA, GFI, CFI, IFI, AGFI) follow recognized criteria summarized in the thesis.

Population and Sample

The target population comprises users of sports venues in Harbin. A random sample of 240 venue users was planned, with the sample size justified at $20\times$ the number of observed items (12 indicators $\square$ 240 respondents), exceeding the common 5–10 $\times$ rule of thumb to ensure robustness and statistical power. Sampling was conducted across several sports venues in Harbin, with clear instructions to provide truthful responses to support representativeness.

Data Collection

Data were gathered via a **questionnaire survey** administered **online and offline** (using Questionnaire Star), with **anonymous** participation. Instrument development followed a literature review on TI, II, TIN, and US to ensure content alignment. The questionnaire included:

Data Analysis

Descriptive Analysis

We first profiled respondents and scale behavior to establish context and data quality. Demographic and usage variables (e.g., gender, age, purpose/frequency of venue use) were summarized with frequencies and percentages; for each construct—technology investment (TI), intelligent

infrastructure (II), technology integration (TIN), and user satisfaction (US)—we computed item-level and composite means and standard deviations to gauge central tendency and dispersion. Prior to modeling, we screened missing data, outliers, and distributional shape (skewness/kurtosis). Factorability diagnostics then confirmed adequacy for confirmatory analysis: KMO = 0.873–0.899 with Bartlett's test $p < .001$, indicating sufficient shared variance for latent-construct modeling.

Inferential Analysis

Measurement quality was established via CFA for TI, II, TIN, and US. The model achieved excellent global fit— $\chi^2/df = 1.315$, GFI = 0.955, AGFI = 0.931, IFI = 0.988, CFI = 0.988, RMSEA = 0.036—meeting recommended thresholds. Convergent validity was supported by standardized loadings $> .60$ with CR $> .70$ and AVE $> .50$, and discriminant validity was verified by $\sqrt{\text{AVE}}$ exceeding inter-construct correlations.

structural equation model (SEM) using maximum likelihood to test direct, indirect, and total effects among TI, II, TIN, and US. The final structural model retained excellent fit— $\chi^2/df = 1.312$, GFI = 0.956, AGFI = 0.928, IFI = 0.984, CFI = 0.983, RMSEA = 0.036—and statistical significance of paths was assessed via critical ratios (C.R. ≥ 1.96 at $p < .05$) with standardized coefficients (β) reported for interpretation and comparability.

RESULTS

Descriptive Results

A total of 240 venue users in Harbin were surveyed. Demographic and usage characteristics (e.g., gender, age, purpose, and frequency of venue use) were summarized with frequencies and percentages to contextualize the analytic sample and assess representativeness across multiple venues. Construct-level and item-level descriptive statistics (means, standard deviations) were computed for technology investment (TI: IoT, mobile applications, AI), intelligent infrastructure (II: intelligent security, mobile communication, intelligent navigation), technology integration (TIN), and user satisfaction (US) to profile central tendency and dispersion prior to modeling. Factorability diagnostics indicated adequate shared variance for latent-construct modeling: KMO = 0.873–0.899 and Bartlett's test $p < .001$.

Inferential Results

Measurement Model (CFA)

Confirmatory factor analysis established the reliability and validity of TI, II, TIN, and US. The measurement model achieved **excellent global fit— $\chi^2/df = 1.315$, GFI = 0.955, AGFI = 0.931, IFI = 0.988, CFI = 0.988, RMSEA = 0.036**—consistent with recommended thresholds. Convergent validity was supported by standardized loadings $> .60$ and by **CR $> .70$ and AVE $> .50$** ; discriminant validity was evidenced by **$\sqrt{\text{AVE}}$ exceeding inter-construct correlations**. Together, these findings justified proceeding to structural estimation.

Structural Model (SEM)

The structural equation model retained **excellent fit— $\chi^2/df = 1.312$, GFI = 0.956, AGFI = 0.928, IFI = 0.984, CFI = 0.983, RMSEA = 0.036**—indicating strong correspondence between the hypothesized structure and the observed covariance matrix. Path significance was evaluated via **critical ratios (C.R. ≥ 1.96 , $p < .05$)** with standardized coefficients (β) reported for interpretability.

Table 2. Standardized Path Coefficients (SEM)

Structural Path	β	C.R.	p	Support
TI $\rightarrow$ TIN	0.351	3.069	.002	Supported
II $\rightarrow$ TIN	0.476	3.878	< .001	Supported
TIN $\rightarrow$ US	0.271	2.146	.032	Supported
TI $\rightarrow$ US	0.333	2.999	.003	Supported
II $\rightarrow$ US	0.292	2.339	.019	Supported
Notes: All direct paths are positive and significant, indicating TI and II shape both TIN and US, while TIN contributes to US.				

These estimates indicate that (a) upstream inputs—**TI** and **II**—positively shape the **integration layer** (TIN) and user outcomes (US), and (b) **TIN** itself contributes positively to **US**. Mediation (Bootstrap Table 3. Mediation Effects (Bootstrap, 5,000 resamples; 95% BC CI) To test whether TIN mediates the effects of TI and II on US, bias-corrected Bootstrap procedures (5,000 resamples; 95% CIs) were applied. Mediation was inferred when the indirect-effect CI excluded zero ($H_0: a \times b = 0$).

Chain	Effect Type	Estimate	95% CI (BC)	p	Interpretation
TI $\rightarrow$ TIN $\rightarrow$ US	Direct	0.279	[0.091, 0.569]	.006	Significant
	Indirect	0.080	[0.003, 0.253]	.040	Partial mediation
	Total	0.359	[0.162, 0.636]	.001	Significant
II $\rightarrow$ TIN $\rightarrow$ US	Direct	0.307	[0.004, 0.670]	.048	Significant
	Indirect	0.136	[0.012, 0.423]	.033	Partial mediation
	Total	0.443	[0.195, 0.745]	.001	Significant
Notes: Mediation is inferred where the 95% BC CI for the indirect effect excludes zero. Both chains show partial mediation by TIN.					

Synthesis of Inferential Evidence

The excellent model fit, significant direct effects from TI and II to both TIN and US, and significant indirect effects via TIN together confirm an integration- first mechanism: while investment and infrastructure each improve satisfaction on their own, a larger share of value is realized when technologies are coherently integrated into user- facing processes and supports. This pattern justifies managerial prescriptions that prioritize improvements in system responsiveness, interoperability/process simplicity, and staff capability as the most efficient route to raising US under real-world resource constraints.

CONCLUSION AND FUTURE WORK

This study addressed two linked aims: (1) to clarify how technology investment (TI) and intelligent infrastructure (II) relate to user satisfaction (US) in smart sports venues, and (2) to validate a causal model in which technology integration (TIN) operates as the core mechanism translating upstream inputs into user outcomes. Using a cross-sectional survey of venue users in Harbin and a rigorously validated SEM, we find a consistent pattern: TI and II each improve US directly, and their

impact is amplified when effects flow through TIN. In short, technology becomes experience through integration.

Measurement quality underpins these inferences. Constructs display adequate reliability and convergent/discriminant validity, and global fit indices for both measurement and structural models meet widely accepted thresholds, reducing concern about model misspecification. Structurally, all hypothesized links are positive and significant: TI $\rightarrow$ TIN, II $\rightarrow$ TIN, and TIN $\rightarrow$ US, with additional direct paths from TI and II to US. Bootstrap tests confirm partial mediation in both chains (TI $\rightarrow$ TIN $\rightarrow$ US; II $\rightarrow$ TIN $\rightarrow$ US). Thus, while investment and infrastructure deliver some satisfaction gains on their own, a larger and more reliable portion of value is realized when technologies are coherently integrated—systems interoperate, processes are simplified, and staff can resolve issues quickly.

These findings yield a practical, integration-first principle for managers. Rather than defaulting to hardware accumulation, sequence budgets toward (a) dependable connectivity and unified access/payment rails; (b) user-facing surfaces that close information gaps in real time (mobile app, wayfinding, in-bowl displays); and (c) operating routines and training that enable staff to handle common failure modes. Track a tight KPI set aligned to the model (CSAT/NPS, entry/checkout time, payment success rate, feature use, complaint rate) and review changes in a regular “integration retro” to link outcomes to specific process or system adjustments.

Theoretical contribution follows from this reframing: TIN is a mediating capability, not a side effect. Two venues can own similar technologies yet produce different user outcomes because the capability to integrate—APIs/SDKs, data handoffs, service flow design, and human support—determines whether upstream inputs reach users as seamless experiences. For funders and policy makers, this implies evaluating integration readiness alongside capital budgets.

Limitations remain. Cross-sectional, self-reported data limit causal certainty; the model centers on satisfaction rather than downstream behaviors (loyalty, advocacy, spend); and segment/venue-type heterogeneity was not tested. Wantayakul N., Decha O., Whangmahaporn B. (2025). Future work should therefore: (1) employ longitudinal or quasi-experimental designs around discrete integration upgrades; (2) run multi-group and venue-type invariance tests to locate the highest marginal returns; and (3) field-test integration bundles (interoperability + staff enablement + real-time support), pairing survey outcomes with operational traces (queue times, app feature usage, incident logs).

Future Work

1. Longitudinal/ Quasi- Experimental Evaluation Implement before- and- after or difference- in-differences designs around specific integration upgrades (e.g., unified access + cashless). Track cohorts across events to estimate causal lift on US and behavior (dwell time, spend, complaints).
2. Multi- Group and Venue- Type Invariance Test measurement invariance and path differences across user segments (age, tech familiarity, visit purpose) and across venue archetypes (arena vs. stadium vs. training facility). Identify where integration investments yield the highest marginal returns.
3. Field Experiments on Integration Bundles Convert the model into A/ B/ n play- tests (e. g. , interoperability + staff enablement vs. interoperability only). Compare total effects on US and operational KPIs; compute cost-to-impact ratios to generate a prescriptive, budget-aware playbook for scale.

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