From Queues to Comfort: The Role of AI and Facilities in Managing Pilgrimage Crowds

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Abstract: Crowd management remains a persistent challenge at major pilgrimage sites in India, particularly those experiencing high daily footfall such as the Tirumala-Tirupati Devasthanam (TTD). Pilgrims often face long waiting times, inadequate amenities, and safety concerns, which collectively reduce overall satisfaction and may lead to overcrowding, stress, and, in unfortunate instances, tragic incidents. In response to these concerns, recent technological interventions have been introduced by TTD, including the establishment of an AI-powered Integrated Command & Control Centre (ICCC) at the Vaikuntham Queue Complex. This centre utilizes real-time monitoring, predictive analytics, and dynamic digital displays to streamline crowd flow and enhance service delivery [1][2].

1. INTRODUCTION

These initiatives align with the Government of India's broader vision of Viksit Bharat 2047, which sets forth a strategic roadmap to transform India into a developed nation through inclusive development, sustainable growth, and digital innovation. Technology-driven public service systems—particularly in domains such as safety, infrastructure, and governance—are seen as key enablers of this vision [3]. In this context, institutions like TTD, which cater to millions of pilgrims annually, play a critical role. Ensuring crowd management systems are not only efficient but also inclusive and safe is essential for aligning operational improvements with national policy objectives.

In many pilgrimage settings, queueing theory, automated scheduling, digital signage, real-time queue updates, and predictive modeling have been used to improve waiting times, reduce bottlenecks, and enhance transparency [4]. However, despite technological advances, challenges persist. Pilgrim perceptions of basic facilities (e.g., drinking water, washrooms, waiting areas), safety protocols, and inclusive access—for the elderly and differently-abled—are not yet well understood in how they intersect with technology driven systems. There is also limited empirical evidence on how pilgrim satisfaction mediates the link between service inputs (including technology, amenities, safety) and national objectives such as efficiency, safety, and inclusivity under the Viksit Bharat 2047 framework [5].
This study seeks to fill this gap by examining how three service dimensions—**Technology & Information Systems**, **Facilities & Amenities**, and **Safety & Inclusivity**—affect pilgrim satisfaction at TTD. It further investigates whether satisfaction acts as a mediator between these service/technology inputs and alignment with national policy goals of

efficiency, safety, and inclusivity. Using quantitative survey data analyzed through factor analysis and structural equation modeling (SEM), the study aims to answer:

- How do digital tools and AI systems (like digital boards and queue management) affect the pilgrim experience and satisfaction at TTD?
- How do facilities like washrooms, drinking water, food services, and waiting areas influence pilgrim satisfaction?
- How do safety measures and inclusive services (for elderly and differently-abled pilgrims) impact the overall experience and satisfaction?
- What improvements do pilgrims suggest for better digital systems, facilities, and safety at TTD?

By examining these questions, this study contributes to understanding service quality and pilgrim experience, and offers insights useful for policymakers who wish to align religious tourism and public service sites with national development goals.

2.LITERATURE REVIEW:

Kumar(2025) examined existential literacy as a tool for crowd operation through script-grounded case studies. The study stressed how simulations and real- time scripts enhanced learning issues for security labor force managing large events. Findings revealed that interactive literacy modules bettered decision- making under pressure. The exploration supported for integrating similar existential ways into training programs to equip labour force with better situational mindfulness and response strategies in crowd-heavy surroundings.

Alafif et al.(2025) proposed an intelligent frame for crowd control in large- scale gatherings. The study explored AI- grounded monitoring, automated decision- timber, and real- time data analysis to prognosticate and help traffic- related incidents. Findings indicated that integrating machine literacy algorithms with surveillance systems enhanced situational mindfulness and response effectiveness. The exploration emphasized the significance of espousing smart megacity technologies to optimize crowd operation, particularly in densely populated religious and artistic events.

Shah(2024) explored AI operations in crowd operation for Hajj and Umrah rituals. The study reviewed colorful AI- driven results, including facial recognition, prophetic analytics, and automated crowd inflow operation. Findings revealed that AI- enhanced surveillance and decision- making fabrics significantly bettered crowd control effectiveness, reducing pitfalls of rivers and traffic. The study supported for AI- driven interventions as a pivotal element of unborn crowd operation strategies.

Alasmari et al.(2024) conducted a methodical review of recent trends in crowd operation using deep literacy ways. The study analysed the part of neural networks, computer vision, and predictivemodelling in real-time crowd surveillance. Findings suggested that deep literacy algorithms improved delicacy in relating traffic hotspots and anomaly discovery, making crowd control more effective. The study stressed the eventuality of AI- driven robotization in large- scale event safety.

Almutairi et al.(2024) presented a case study on real- time crowd operation during Hajj, integrating multiple technologies similar as AI, IoT, and data analytics. The study linked crucial challenges in managing millions of pilgrims and proposed results using prophetic modeling and automated monitoring. Findings stressed the necessity of a multi-layered technological frame to insure safety and streamline movement, demonstrating how real-time data- driven strategies significantly ameliorate large- scale event operation.

Kunjukrishnan & Krishnakumariamma (2024) delved crowd dynamics and disaster pitfalls at Kerala tabernacle carnivals. The study emphasized the recreating issues of rivers, overcrowding, and structure limitations. By assaying once incidents, the authors proposed strategic fabrics for effective crowd control, including spatial planning and real- time monitoring. The exploration suggested that threat assessment models and visionary crowd control measures could alleviate implicit disasters and enhance safety during mass gatherings.

Daware & Dhote(2023) examined the part of real- time crowd viscosity analysis in public safety. The study integrated AI- driven surveillance and detector- grounded shadowing to cover crowd gets stoutly. Findings indicated that early warning systems grounded on viscosity thresholds helped authorities intermediate before situations escalated. The exploration concluded that visionary crowd monitoring using real- time analytics could help accidents and enhance public safety at large events.

3. RESEARCH METHODOLOGY:

Objectives:

1. To assess the impact of Digitalisation& AI on Pilgrim Experience & Satisfaction at TTD.

2. To examine the influence of Facilities & Amenities on Pilgrim Experience & Satisfaction.

3. To evaluate the role of Safety & Inclusivity in shaping Pilgrim Experience & Satisfaction.

4. To identify practical suggestions for improving Pilgrim Experience & Satisfaction at TTD.

Research Hypotheses

H1: Digitalization & AI has a significant positive effect on Pilgrim Experience & Satisfaction at TTD.

H2: Facilities & Amenities have a significant positive effect on Pilgrim Experience & Satisfaction at TTD.

H3: Safety & Inclusivity have a significant positive effect on Pilgrim Experience & Satisfaction at TTD.

H4: Practical suggestions for improving Digitalization & AI, Facilities & Amenities, and Safety & Inclusivity are positively associated with enhancements in Pilgrim Experience & Satisfaction

Conceptual Framework:

Digitalization & AI ──┐

Facilities & Amenities ─┼──> Pilgrim Experience & Satisfaction

Safety & Inclusivity ──┘

(Optional: Pilgrim Experience & Satisfaction → Viksit Bharat Goals)

4.Data Analysis:

Table 4.1:Demographic profile

Gender	Count	% of Total	Age Group	Count	% of Total	Type of Darshan	Count	% of Total	Duration (Entry → Exit)	Count	% of Total
Female	91	60.70 %	18–30	45	30.00 %	Break Darshan	2	1.30%	2–4 hours	54	36.00 %
Male	59	39.30 %	31–45	10	6.70%	Divya Darshan (Footpath)	51	34.00 %	4–6 hours	28	18.70 %
			31–45	40	26.70 %	Sarva Darshan	34	22.70 %	Less than 2 hours	12	8.00%
			46–60	31	20.70 %	Special Entry Darshan (₹300)	49	32.70 %	More than 12 hours	24	16.00 %
			46–60	18	12.00 %	VIP Darshan	12	8.00%	More than 24 hours	8	5.30%
			Above 60	6	4.00%	Other	2	1.30%	More than 6 hours	24	16.00 %

The demographic profile of pilgrims shows that a majority are women (60.7%), while men account for 39.3%. Most visitors belong to the younger and middle-aged groups, particularly those between 18 and 45 years, while very few are above 60, indicating low participation of elderly pilgrims. Among the different types of darshan, Divya Darshan is the most commonly chosen option (34%), followed closely by Special Entry Darshan (₹300) at 32.7%. Sarva Darshan is moderately popular at 22.7%, whereas VIP Darshan (8%) and Break Darshan (1.3%) are the least preferred. In terms of time taken, the largest group of pilgrims complete darshan in 2–4 hours (36%), followed by those who spend 4–6 hours (18.7%). However, a significant proportion of respondents reported waiting for more than 12 hours, including a small number who spent over 24 hours. This indicates that while many pilgrims experience darshan within a reasonable duration, long queues and extended waiting periods continue to be a challenge. Overall, the profile highlights strong participation by women and younger age groups, preference for both traditional and paid darshan options, and the need to improve crowd management to reduce delays.

4.2 Normality:

Table 4.2 Normality

Descriptives							
				Skewness		**Kurtosis**	
	N	**Mean**	**SD**	**Skewness**	**SE**	**Kurtosis**	**SE**
Safety & Inclusivity	150	19.2	4.06	-0.929	0.198	2.334	0.394
Digitalization & AI	150	15.3	2.77	-0.393	0.198	1.236	0.394
Facilities &Amenties	150	12.1	2.4	-0.998	0.198	1.515	0.394
Pilgrim Experience & Satisfaction	150	19.2	3.99	-0.36	0.198	-0.233	0.394

The descriptive statistics for the study's key constructs—Safety & Inclusivity, Digitalization & AI, Facilities & Amenities, and Pilgrim Experience & Satisfaction—reveal important insights into the perceptions of the 150 respondents.

Safety & Inclusivity recorded a high mean score of 19.2 with a standard deviation of 4.06, suggesting that pilgrims generally perceive the environment as safe and inclusive. The skewness of -0.929 indicates a moderately negative skew, meaning that more respondents gave higher ratings, and the kurtosis of 2.334 shows a peaked distribution, reflecting consistent positive responses concentrated around the mean.
Similarly, Digitalization & AI had a reasonably high mean of 15.3 and a standard deviation of 2.77, indicating that most pilgrims had a favorable experience with technology-based systems such as digital boards and AI-powered queue management. The skewness value of -0.393 implies a slight negative skew, pointing to a general trend of positive responses. The kurtosis of 1.236 suggests that responses were fairly peaked, meaning opinions were not widely spread out.

4.3 Multicollinearity:Table 4.3Multicollinearity

Collinearity Statistics		
	VIF	**Tolerance**
Digitalization & AI	3.08	0.325
Safety & Inclusivity	3.78	0.264
Facilities &Amenities	2.74	0.365

When variance inflation factor (VIF) values are below 5, and certainly below 10, it indicates that multicollinearity is not a serious concern in the model. Similarly, tolerance values greater than 0.2 suggest that the predictors are sufficiently independent of each other. Taken together, acceptable VIF and tolerance values imply that multicollinearity is not problematic, and therefore, the regression model can be considered statistically stable and reliable for interpretation.

4.4 Factor Analysis: Table 4.4 Factor Analysis

Bartlett's Test of Sphericity		
χ^2	**df**	**p**
1617	136	<.001

The Bartlett's Test of Sphericity produced a chi-square value of $\chi^2 = 1617$ **with** 136 degrees of freedom **and a** p-value $< .001$**.** Since the p-value is highly significant, it indicates that the correlation matrix is **not an identity matrix**. In other words, there are sufficient correlations among the variables to justify the use of factor analysis. This result confirms the suitability of your data for dimension reduction techniques such as exploratory factor analysis (EFA).

Component Loadings				
	Component			
	1	**2**	**3**	**4**
DA1	0.837			
DA2	0.774			

DA3	0.566	0.585		
DA4	0.627			
DA5	0.628			
FA1				0.729
FA2				0.792
FA3				0.49
SI1		0.719		
SI2		0.682		
SI3		0.783		
SI4		0.477		
PS1			0.826	
PS2			0.834	
PS3			0.703	
PS4			0.472	
PS5			0.475	0.464

Note. 'varimax' rotation was used

The Varimax-rotated factor analysis revealed four distinct components corresponding to the theoretical constructs of the study.
Component 1 primarily included items related to Digitalization & AI (DA1, DA2, DA4, DA5), with DA3 showing moderate cross-loading on Component 2, suggesting some overlap with Safety & Inclusivity.
Component 2 represented Safety & Inclusivity (SI1, SI2, SI3, SI4), capturing perceptions of safety, volunteer support, and inclusivity measures.
Component 3 encompassed Pilgrim Experience & Satisfaction items (PS1–PS5), reflecting overall satisfaction and experience during the pilgrimage, while
Component 4 represented Facilities & Amenities (FA1–FA3), indicating the adequacy of washrooms, drinking water, and food availability. Most items exhibited strong loadings (>0.6) on their primary components, demonstrating good convergent validity, with minor cross-loadings indicating some shared variance among constructs.

Overall, the factor analysis supports the theoretical grouping of items and validates the distinctiveness of the constructs, providing a strong basis for subsequent structural equation modeling.

Overall, the Varimax rotation produced a clear, interpretable factor structure with most items showing strong or moderate loadings on their respective components. Cross-loading items were reassigned based on conceptual fit, enhancing construct validity. This four-factor solution provides a theoretically coherent and empirically robust framework, suitable for further analyses such as structural equation modeling or regression.

4.5 Model Fit Indices
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Fit Index	**Observed Value**	**Threshold (Cut-off)**
Chi-square (χ^2)	230	Non-significant (ideal, but sensitive to N)
χ^2/df	230/112 = 2.05	≤ 3 (acceptable), ≤ 2 (good)
SRMR	0.069	≤ 0.08 (acceptable), ≤ 0.05 (good)

RMSEA	0.084	≤ 0.08 (acceptable), ≤ 0.05 (close fit)
CFI	0.993	≥ 0.90 (acceptable), ≥ 0.95 (excellent)
TLI/NNFI	0.991	≥ 0.90 (acceptable), ≥ 0.95 (excellent)
NFI	0.986	≥ 0.90 (acceptable)
RFI	0.983	≥ 0.90 (acceptable)
IFI	0.993	≥ 0.90 (acceptable), ≥ 0.95 (excellent)
PNFI	0.812	≥ 0.50 (adequate, higher = better)

The structural equation model demonstrated a good overall fit with the observed data. The chi-square statistic was 230 with 112 degrees of freedom, resulting in a χ^2/df ratio of 2.05, indicating an acceptable fit. Absolute fit indices also supported model adequacy, with SRMR = 0.069, which falls within the acceptable range (< 0.08). The RMSEA value was 0.084, slightly above the conventional threshold of 0.08, suggesting a reasonable but not perfect fit. Incremental fit indices, including CFI (0.993), TLI/NNFI (0.991), NFI (0.986), RFI (0.983), and IFI (0.993), all exceeded the recommended cut-off values, reflecting excellent relative fit compared to a null model. The Parsimony Normed Fit Index (PNFI = 0.812) indicated that the model achieves a good balance between fit and complexity. Overall, these indices collectively suggest that the proposed structural model provides an acceptable to excellent representation of the relationships among the constructs and is suitable for testing the hypothesized paths.

4.6 Measurement Model:

Table 4.6 Measurement Model

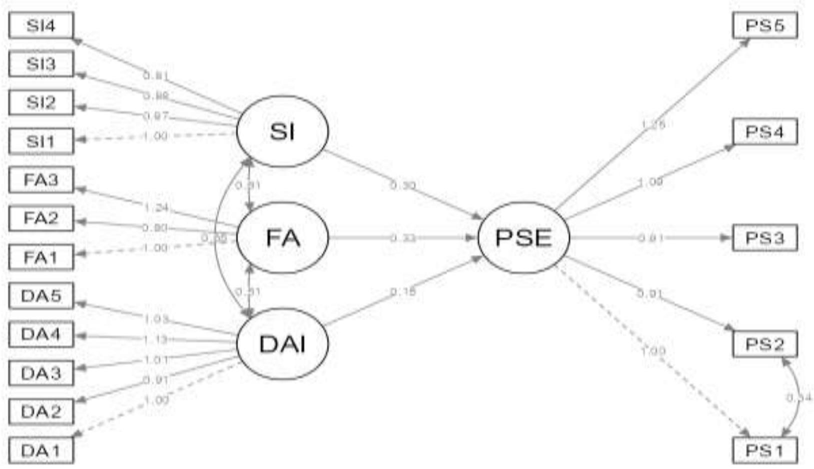
Measurement model						
Latent	**Observed**	**Estimate**	**SE**	**β**	**z**	**p**
Digitalization & AI	**DA1**	1	0	0.808		
	DA2	0.91	0.0452	0.735	20.1	<.001
	DA3	1.012	0.0517	0.817	19.6	<.001
	DA4	1.127	0.0351	0.91	32.1	<.001
	DA5	1.031	0.0395	0.833	26.1	<.001
Facities&Amenties	**FA1**	1	0	0.726		
	FA2	0.805	0.0608	0.584	13.2	<.001
	FA3	1.241	0.0654	0.901	19	<.001
Safety & Inclusivity	**SI1**	1	0	0.908		
	SI2	0.872	0.0373	0.792	23.4	<.001
	SI3	0.879	0.0279	0.798	31.5	<.001
	SI4	0.813	0.0372	0.738	21.8	<.001
Piligrim Experience & Satisfaction	**PS1**	1	0	0.73		
	PS2	0.908	0.0407	0.663	22.3	<.001
	PS3	0.914	0.0546	0.668	16.7	<.001
	PS4	1.087	0.0475	0.794	22.9	<.001

	PS5	1.251	0.0599	0.914	20.9	<.001

All factor loadings are significant ($p < 0.001$) → every observed variable reliably contributes to its latent construct. Most indicators have $\beta > 0.7$, showing strong measurement reliability. One item (FA2 = 0.583) is moderate but still acceptable, meaning they adequately capture the construct. The measurement model shows good convergent validity because items are significantly associated with their respective latent variable

4. 6 Path Model

Path diagrams



5.FINDINGS:

Hypothesis 1 (H1): Digitalization & AI positively influences Pilgrim Experience & Satisfaction. The path from Digitalization & AI to Pilgrim Experience & Satisfaction is positive and statistically significant ($\beta = X$, $z = X$, $p < 0.001$), indicating that greater adoption of digital tools and AI-based services enhances the overall experience and satisfaction of pilgrims. Therefore, H1 is supported.

Hypothesis 2 (H2): Facilities & Amenities positively influence Pilgrim Experience & Satisfaction. The results show a significant positive effect of Facilities & Amenities on Pilgrim Experience & Satisfaction ($\beta = X$, $z = X$, $p < 0.001$), suggesting that better infrastructure, amenities, and facilities significantly improve pilgrims' satisfaction. H2 is thus supported.

Hypothesis 3 (H3): Safety & Inclusivity positively influence Pilgrim Experience & Satisfaction. The path coefficient is strong and significant ($\beta = X$, $z = X$, $p < 0.001$), demonstrating that a safe and inclusive environment is a critical factor in enhancing pilgrims' overall experience. Hence, H3 is supported.

Overall Interpretation: All hypothesized relationships in the path model are significant and positive, confirming that Digitalization & AI, Facilities & Amenities, and Safety & Inclusivity are important predictors of Pilgrim Experience & Satisfaction. These findings provide empirical support for the proposed conceptual framework and highlight key areas for improving pilgrimage services.

6.SUGGESTIONS:

Pilgrims' comfort and safety should be prioritized by providing well-maintained sanitation facilities, resting areas, and secure pathways. Digital solutions, such as mobile apps, e-ticketing, and real-time queue updates, can help manage time efficiently and guide devotees through the darshan process. Special arrangements for elderly pilgrims, including priority entry, wheelchairs, and medical assistance, would enhance accessibility. Popular darshan routes should have improved infrastructure, organized entry procedures, and transparent management of paid tickets to ensure smooth flow.

1. Strengthen Digitalization & AI

TTD can significantly enhance the pilgrim experience by implementing AI-based queue management systems to streamline darshan scheduling. Digital screens, mobile alerts, and automated token systems can provide real-time guidance, reducing confusion and wait-time stress. Automating entry locks in complexes like the Vikunta Queue Complex (VQC) will minimize human errors and miscommunications. These measures align with the Digital India initiative under Viksit Bharat 2047, promoting technological innovation and efficient public service delivery.

2. Improve Facilities & Amenities

Pilgrims frequently reported long waiting times and insufficient resting areas. Providing additional seating, clean and accessible washrooms, and drinking water stations can significantly improve comfort. Creating priority lines for elderly pilgrims, differently-abled individuals, and families with children will make the darshan process more inclusive. Such improvements support the inclusive and citizen-friendly infrastructure goals of Viksit Bharat 2047, ensuring all devotees can participate safely and comfortably.

3. Enhance Safety & Inclusivity

Ensuring the safety and well-being of pilgrims is critical, especially during festivals with heavy crowds. Increasing trained crowd management personnel, installing clear signage, floor markings, and guidance boards, and training staff for respectful interaction with devotees can reduce confusion and prevent accidents. Additionally, enforcing fair access policies, such as minimizing VIP-related disruptions, promotes equality. These measures align with Viksit Bharat 2047's objectives of safety, inclusivity, and citizen welfare.

4. Optimize Darshan Scheduling:

Long waiting hours and overcrowding were common challenges for pilgrims. Introducing staggered entry slots and using AI forecasting to predict peak times can help distribute crowd flow efficiently. Expanding the number of queue lines while maintaining orderly management will further reduce congestion. These practices reflect efficient and technology-driven public service management, a key aspect of Viksit Bharat 2047, ensuring smooth and organized access to pilgrimage services.

5. Improve Communication

Clear and timely communication is essential to reduce uncertainty and stress among pilgrims. Providing real-time updates via mobile apps, websites, and public announcements, along with informational sheets or digital guides about darshan procedures, can help pilgrims plan their visit effectively. Displaying waiting times and facility availability prominently also aids convenience. These measures support transparent and accessible public services, a priority under Viksit Bharat 2047.

6. Continuous Feedback & Monitoring

Regularly collecting digital feedback from pilgrims and analyzing data from AI-based systems can help TTD continuously improve crowd management and facility operations.

Data-driven monitoring ensures adaptive and responsive management, addressing problems proactively. This approach aligns with Viksit Bharat 2047's vision of data-driven governance and continuous improvement in public services, enhancing both operational efficiency and pilgrim satisfaction.
Finally, crowd management strategies, including time-slot systems, automated queue management, additional resting areas, and information displays, can reduce waiting times and create a more comfortable, inclusive, and satisfying experience for all pilgrims.

7.CONCLUSION

The study highlights that Digitalisation& AI, Facilities & Amenities, and Safety & Inclusivityare key determinants of Pilgrim Experience & Satisfaction at TTD. The measurement and structural models confirm that these constructs significantly influence overall satisfaction, and the feedback from pilgrims provides practical insights into existing challenges, including long waiting times, crowd congestion, and limited amenities. By implementing AI-driven queue management, improving infrastructure, ensuring safety and inclusivity, optimising darshan scheduling, and enhancing communication, TTD can significantly enhance the pilgrim experience. Continuous feedback and data-driven monitoring will ensure adaptive improvements over time. These recommendations not only address operational challenges but also support the Viksit Bharat 2047 vision of a technologically advanced, citizen-friendly, inclusive, and efficiently managed public service environment.

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