Integrating Threshold Analysis with Simulation of Intelligent Agents for Enhancing Space Experience

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Abstract: India is a diverse country in terms of culture, language, religion, region, festivals, and beliefs. According to Vedic literature, Hinduism is one of the oldest and most celebrated religions. Temples are the integral core of its identity. The collective worship at different occasions attracts a humongous crowd, making devotee management an arduous task. These gatherings foster community feeling and attachments through celebration and beliefs, but present substantial risks if not administered effectively. Undoubtedly, modern crowd monitoring systems and crowd simulation have eased the management of crowds, but crowd-related disasters highlight a need for more efficient investigation. This paper aims to assess the role of agent-based simulation in enhancing devotees' experience, even in an overcrowded scenario. The results show that intelligent agent-based modeling not only highlights the problems with current operational procedures but also yields an efficient crowd management strategy that may help reduce stampedes and stampede-like scenarios and enhance the space experience.

Keywords**:** crowd management, crowd simulation, intelligent agents, religious gathering, temple complexes, India.

1. Introduction

India is a land of nearly 6.48 lakh mesmerizing temples (Ghosh, 2023) that form an integral part of the identity of the Hindu religion. Hindu temples have significantly shaped the socio-cultural, political, and economic development of Indian societies, both historically and currently. There are five types of temples according to the scriptures, like Padma-purana and Parmesvara-samhita: (Rao, 2005).

a) Svayam – vyakta – where the image is self-defining the divine.
b) Daivika – where the heavenly beings established temples.
c) Arsa – temples built by the sages.
d) Purana – temples mentioned in the Puranas
e) Manusa – recent temples established in recent times.

These temples are the nuclei of cultural and social arenas, acting as magnets that draw countless devotees to experience divinity beyond the mundane world. The crowd that assembles in the temple complex is referred to as a religious crowd (Taneja, 2019). The smallest unit of the crowd is an individual devotee. The devotees are among the most critical stakeholders in the complex, and the study aims to understand the role of technology and how it can support the formulation of a standard operating procedure strengthened by these tools to enhance the temple journey. Religious Pilgrimage is a well-established custom in India (Mishra, 2020). The bond between religion and tourism is ancient, and that is why religious tourism is also called "faith tourism" (Aziz, 1987). Crowd management is a significant challenge, especially at religious gatherings. To understand crowd characteristics, the entire venue, including its areas and zones, needs to be studied, as these gatherings are highly prone to pushing, crushing, and stampede-like incidents. The government and various NGOs have issued guidelines for safe crowd management in enclosed areas, including those specifically for temple complexes. The recurrence of stampede-like incidents at famous temple complexes makes this a crucial topic for analyzing the problems faced by devotees, including long wait times, pushing, crushing, and trampling.

The list below elaborates on the need for study on this particular topic:

Mansa Devi Temple, Haridwar Stampede: July 27, 2025 (Mishra, 2025)
8 people died, 30 injured
Reason – Overcrowded scenario and a rumor created panic
• Sri Lairai Temple, Goa Stampede : May 3,2025 (Sah, 2025)

7 people died, 80 injured
Reason – Few devotees who stood on slope fell causing others to tumble and fell
• Bankey Bihari Temple, Mathura Stampede: December 24,2023 (Team, 2023)
2 women died
Reason – Overcrowding and suffocation
• Bankey Bihari Temple, Mathura Stampede: November 6,2022 (Rawat, 2022)
11 trapped in crowd, 4 severely injured
Reason – Failure in crowd management
• Bankey Bihari Temple, Mathura Stampede: August 20,2022 (Service, 2022)
2 killed, 7 injured
Reason – Janamashtami
• Khatu Shyam ji Temple, Rajasthan : August 8,2022 (Temple entrance) (Sikar, 2022)
3killed, 2 injured
Reason – Auspicious Day
• Kashi Vishwanath Temple, Varanasi, UP : July 24,2022 (Jaiswal, 2022)
Scuffle between devotees and temple staff over darshan
• Meenakshi Temple, Madurai : April 17.2022 (News, 2022)
2 killed, 1 severely injured, 7 injured
Reason – Chithirai festival
• Jagannath Puri, Odhisha : 18 March,2022 (Sharma, 2022)
Many trapped in scuffle
Reason – devotees aggrieved of long waiting and deprived of ritual darshan.

The reasons mentioned in all the cases reveal a gap in the formulation of crowd management policies. The management of the crowd mainly encompasses three key aspects: i) Analysis of crowd flow, ii) Monitoring of the crowd, and iii) Crowd control. If the flow of the crowd, in relation to the movement at the entry, exits, and within the enclosure, is thoroughly examined, with advanced monitoring systems such as RFID tags (Almeida et al., 2018), CCTV cameras (Al-Shaery et. al., 2020) and control rooms (Srivastava, 2012) there will be a significant reduction in the requirement of physical crowd control.

Crowd-related disasters typically arise from overcrowding (Lee et al., 2005; Prasunamba & Muralidhar, 2017) struggles with deity observance, and the immediate desire to leave the shrine as soon as possible after observance. In a country such as India, during a religious gathering in a temple complex, the number of devotees often exceeds expectations (Prasunamba, 2018). Therefore, a detailed analysis is required to explore intelligent strategies for safely accommodating the maximum number of devotees during deity observance. The researchers achieved this objective through computer-generated simulation models.

This approach not only distinctly demarcates congested zones using density maps, travel times from the starting point to destinations, and bottleneck formation, but also enables the development of agents capable of decision-making. The inferences derived from this research will validate the application of pedestrian simulation (Lakr, 2015) as an efficient tool to address overcrowding and assist policymakers in developing a detailed strategy for managing crowd movement, thereby enriching the existing database on devotee management in temple complexes. The objectives of the research are:-

· To explore the role of advanced technological pedestrian simulation software in understanding the conventional flow of devotees that suggests:

i. The points of congestion inferred through experience density maps.

ii. Time interval during which the threshold limit exceeds.

· To apply intervention by exploring the best suitable intelligent route choice methods, to infer results in the safe zone.

· To analyze in detail the most appropriate method that emerges from the above objectives.

2. Literature Review

India is the most populous country (Neil, 2024). It hosts religious congregations that are very rich in culture and traditions. According to statistics, 79% of disasters in India are caused by religious mass gatherings (Illiyas et al., 2013). People have a lot of faith in old temples, but sometimes these areas lack infrastructure, and for this, the researchers advocate for a well-planned framework for safe, secure mass gatherings. Another researcher in the same context as Sabrimala studied the crowd carrying capacity (CCC), including the rotation factor, which accounts for the number of permissible visits over a specified time.

In high-density areas, individual behavior plays an integral role in shaping the behavior of the whole crowd. Especially during religious gatherings, an emotional trigger can influence the entire crowd. If this emotion is negative, it can lead to crowd-related disasters such as stampedes; for this reason, various researchers have developed many simulation models. The basis of these models is generally three approaches such as (i) fluid approach that simulate crowd as fluid and consider the overall movement, ii) entity based approach that simulate crowd with homogenous agents having similar behavior, focusing on collective behavior iii) and agent based approach that treats every agent in an unique way as natural humans with unique behavior and interactions (Zhou et al., 2010; Singal, 2024). In addition to crowd simulation, microscopic, macroscopic, and hybrid simulation methodologies are employed (Al-Nabhan et al., 2021; Dang et al., 2024).

Microscopic Model: It accounts for the behavior and interactions of individual agents. The results include individual agents' motivation towards the defined goal, their queuing properties, their collision avoidance, and a detailed analysis of the crowd.

Macroscopic Model-It is used to simulate large-scale crowds over long periods, such as urban areas, where crowd behavior as a whole is analyzed.

Hybrid Model- This approach combines the positive aspects of the two models above.

Within a temple complex, the space has a definite dimension, but the number of devotees fluctuates on festive and non-festive days. During a festival or auspicious days dedicated to the deity, proper observance, closeness to the deity, and hindrance-free movement are among the concerns of the devotee. Therefore, an agent-based modeling approach is employed to study the movement of the religious crowd. Various software packages enable the holistic study of agents, their environment, and agent behavior. The software that stands out from the others is PTV Viswalk, which allows agents to make decisions while in the environment, thereby making them intelligent agents. The resultant model will thus enable decision makers to comprehend strategies for ingress, movement within a complex, and egress.

2.1 Selection of Banke Bihari Temple,Vrindavan as Case Study

Vrindavan maintains its cultural identity through its plethora of temples. Banke Bihari is one of the oldest and most celebrated temples of Lord Krishna. It was built in 1864 with contributions from the Goswamis. The devotees worship the childhood form of Lord Krishna in the temple. There are many colorful festivals (Deshwal, 2025) celebrated at the temple, so the temple witnesses heavy footfall year-round. The temple has no bells or conch so that the young Lord is not disturbed by sounds; therefore, it is devoid of bells and conch (MVDA, 2023). The temple of Banke Bihari features arches typical of the city's distinctive architectural style (Kapoor et al., 2022).The temple complex hosts 30,000-40,000 devotees daily, rising to 150,000 on weekends. This number goes up to 500,000 on special days and festivities (Prakash, 2025).The temple is open for 8.15 hours in the summer and 9.15 hours in the winter for deity observance (Tourism, 2025). The temple has great spiritual and cultural value, but news of crowd-related disasters in recent history, as discussed in the Introduction, prompted the researchers to analyze it.

The temple complex is approached by two entry gates, Gate 2 and Gate 3, and exit from the main shrine is through Gate 1 and Gate 4. Gate 5 is used for VIP movement. In medical emergencies, the authorities use this gate. It also serves as an exit gate for females, old devotees and especially able devotees during periods of heavy devotee footfall. The temple authorities provide holding barriers at eight points to manage the heavy crowd at: a) Vidyapeeth, b) Market, c) Jaipuria Lane, d) Phalari Baba Gali, e) Lane no 3, f) Phalari Baba Rassa Barrier, g) Gopal Ghat, h) 8 Khamba Barrier, i) Rangeeli Kund. High-definition CCTV cameras continuously monitor the complex and its entrances. There is a control room inside the temple for consistent monitoring. While advanced monitoring systems track crowd movement, reports of crowd-related issues were the second reason the researchers conducted an in-depth analysis of devotee movement.

Table 1. Detailed Description of Festivities and Duration.

Rituals/Festivities	Duration	Description
Phool Bangla	3 months (mid April – mid July)	Intricate decoration of temple with flowers to cool the temples during the hot summers
Hariyali Teej	1 day festival	Jhula festival-Lord bought out in Jagmohana Mandap
Sharad Purnima	1 day festival	Lord holds the Basuri & mukut
Holi	2-3 day festival	Celebrates festival with Flower Holi, Dhol Holi culminating on main Holi festival
Janamashtami	1 or 2 day festival	Mangala Aarti done
Akshay Tritiya	1 day festival	Charan and Sarvang Darshan

3. Research Methodology

This research involved three stages: i) Analyzing the conventional devotee movement through threshold analysis that highlighted the areas that required interventions. For this the researchers took pedestrian input above the daily footfall to get an idea of the devotee flow pattern and the generation of the overcrowding issues, ii) Incorporating the different route choice method to achieve the maximum number of simulated agents and iii) Running the simulation for attaining the values for maximum number of devotees and also the value of experience density and density to infer the risk zone of devotee movement. Thus, the researchers developed the architectural plans for the temple complex in AutoCAD because PTV Viswalk allows easy import of CAD plans.

3.1 Agent based Modeling in PTV Viswalk

Efficient devotee crowd movement is a challenging issue on the days dedicated to the deity and during celebrations. Their entry, directed towards the main shrine, deity observance, and movement towards the exit of the main shrine are essential points for the formulation of the framework. Crowd simulation provides an opportunity to analyze problems of pushing and crushing caused by overcrowding. Agent-based simulation (ABS) is based on the social force model, in which agents interact with one another, avoid collisions, and move towards their destinations. Therefore, in ABS, the agents, their interaction with others, and the environment are the main components. Significant progress has been made in applying agent-based modeling in the built environment to study crowd movement, evacuation processes, and bottleneck formation. However, far less has been done to research agent dynamics in crowded scenarios. The ability to make decisions just like real humans would in real-world phenomena makes the agent an intelligent agent.

PTV Viswalk is microscopic pedestrian simulation software that offers features such as density maps, travel time, speed, color-coded pedestrian representation, and nearest-neighbor distance. The software assesses all the above points throughout the journey from the start area to the destination area. Mandatory routes are depicted as static routes, whereas choice-based routes are partial routes. In addition, it has advanced features such as:

Static Route & Partial Routes: A static route is the main route that commences from the start area with agent input to the destination area. Partial routes allow agents to move within the static routes. They do not change the origin and destination areas.

Experience Density: It is a unique feature that provides a density result based on the agent's immediate vicinity (Manual, 2024). Experience density is a dynamic attribute in which areas with high density receive a higher value, depicting a packed scenario that results in involuntary movement. Therefore, density is just a static measure, whereas experience density evaluates a more detailed experience. This attribute provides a more nuanced analysis of the devotee's behavior and comfort. Consequently, the researchers decided to analyze experienced density in Threshold analysis. The software uses the LOS (Level of Service) scheme to generate experience density maps, which color-code grid cells to highlight critical points (Manual, 2024).

Threshold Analysis: This feature shows the time interval during which each marker exceeds the threshold. The threshold limit clearly indicates the exact time when pedestrian density exceeds it, highlighting the need for intervention. The threshold limit for Experience density is 3 agents /sqm (Golas, 2014). The pedestrian density of 2 agents /sqm is in the safe zone; at 4 agents /sqm is density is within the space's capacity; 5 agents /sqm indicates moderate risk and start of congestion; and ≥5.5 agents /sqm indicates a high-risk zone (Bamaqa, 2022).

Range of influence: PTV Viswalk provides this attribute to compute the pedestrian behavior and ease of movement. As discussed earlier, the software operates on the Social Force Model, so pedestrian interaction and personal spaces are very important factors in assessing the density parameters. To analyze the crowd experience density, in a proper queue, the researchers have used 2 as range of influence of a single devotee which means one person on the left and right and one in front and behind to understand the impact on the behavior.

Queuing attribute: The software enables the agents to walk in the queue within static routes. A queue facilitates movement in a defined manner rather than randomly. It provides attributes such as queue straightness (which defines the queue's shape) and queue order (which establishes the queue's orderliness).

Indeed, all the above attributes will reduce hindrance to personal space, pushing and crushing, ensuring a pleasant space experience.

3.2 Assessing Conventional Crowd Flow

The movement of devotees in the main shrine is a flocking movement (Sanjjamts, 2025), without a queue, in which devotees move in a highly congested manner toward the same goal: deity observance. The entry and exit gates are shown in Figure 8, and the researchers have retained them while applying the intervention. One simulation cycle was of 3600 Hrs.

The researchers divided the entire complex into a grid, with each cell measuring one sqm. The main shrine consists of several boxes called Hundi for offering sweets and flowers to the deity. The main shrine has two zones divided by barriers to direct devotees to their respective exits. The researchers did the simulation for 95,375 devotees in a day. In one hour, 11,026 devotees were simulated.

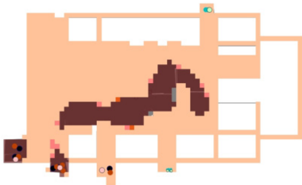


Figure 1. Experience Density map exceeding Threshold (0-500 seconds).

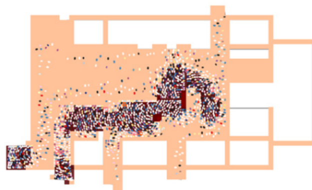


Figure 2. Experience Density map showing agents (0-500 seconds).

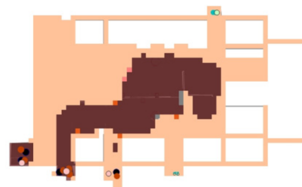


Figure 3. Experience Density map exceeding Threshold (500-1000 seconds).

The Threshold Analysis above exhibited the experience density (Figure 1-5) for different time intervals of 1 hour. The map in Figure 2 showed the devotees in form of colored circles and the dark brown color depicted the areas that were above the threshold limit at the end of first time interval of 500 seconds.

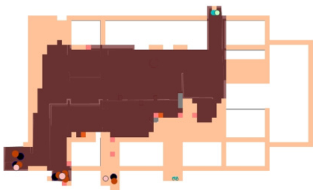


Figure 4. Experience Density map exceeding Threshold (3000-3500 seconds).

Figure 5. Total Experience Density map exceeding Threshold.

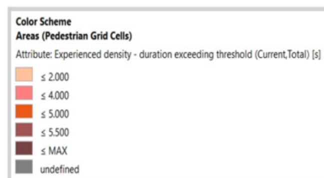


Figure 6. Legend showing the color code according to number of agents/sqm.

The experience density legend in Figure 6 showed the total experience density of the shrine, which was slightly lower at Gate 1(exit gate), because it had not reached the point where the next group of devotees entered. The movement wave created by the new group that entered forced the already present group to leave.

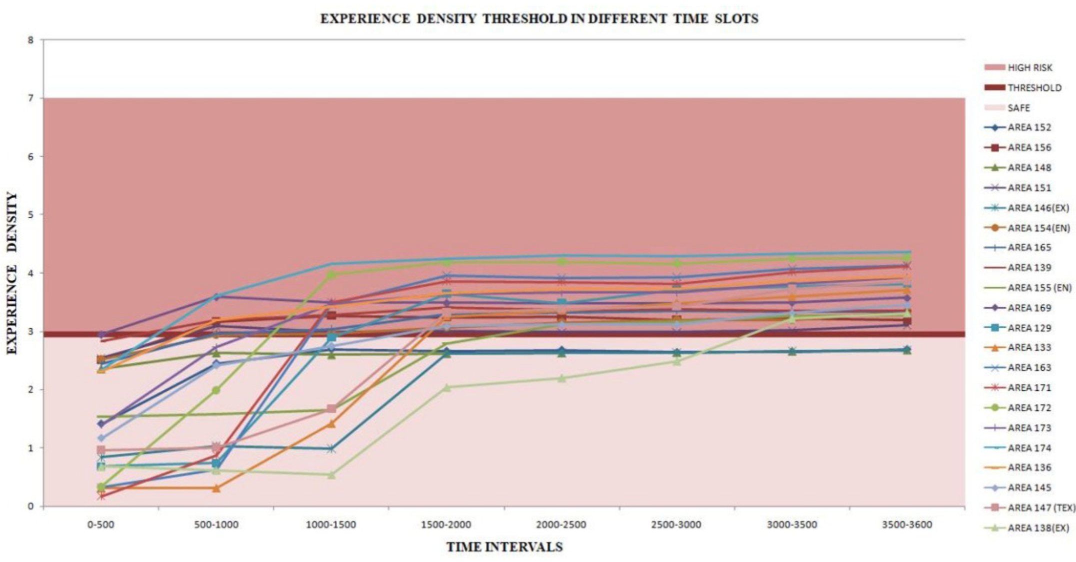


Figure 7. Threshold Analysis of Experience Density in different Time Intervals.

The graph in Figure 7 clearly shows that few areas reached the threshold of 3 agents /sqm, and the maximum areas were at or below the safe zone marker (2 agents/ sqm) after the first time interval. The graph also depicted a significant shift in experience density above the threshold by the end of the fourth time interval (1500-2000).

4. Implementing Intervention and Analyzing the Capacity of Intelligent Agents

The intervention was applied to achieve two objectives:

1. The maximum number of devotees who did the deity observance.

2. To ensure the safe movement of devotees within the safe zone, with an increased number.

PTV Viswalk generates performance results for agents who completed their journey (Agents Arrived) and for active agents in the network (Agents Active). All the intervals together infer the total number of agents. Thus, the total number of agents is obtained from the summation of the pedestrians who arrived (agents who finished their journey) and the active agents in the last interval.

Total Agents= Agents Arrived + Active Agents (Last Interval)

PTV Viswalk also provides information on average speed over various time intervals (km/hr), the average number of stops per time interval, and the average standstill time per agent during the evaluation interval (seconds).The researchers divided the observance area of the main shrine into three zones (Figure 8) and did the simulation for 3600 seconds.

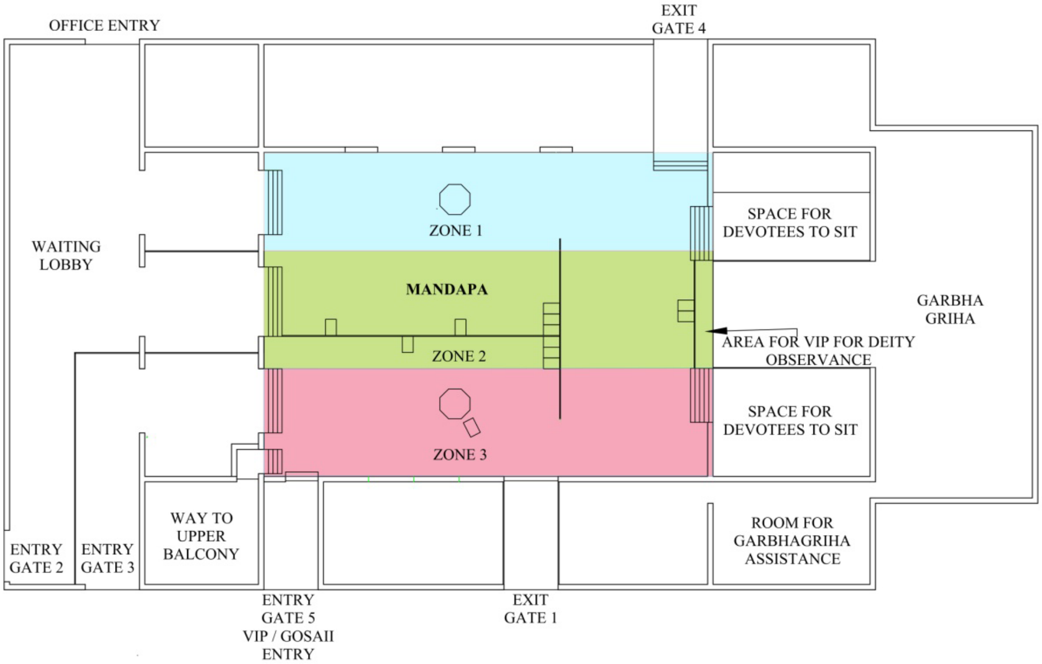


Figure 8. Architectural Plans showing three zones of Banke Bihari Temple, Vrindavan.

The researchers applied interventions to the same 95,375 devotees for 3600 seconds.PTV Viswalk has intelligent agents capable of making decisions in the same way real devotees would in the same physical environment.

To accomplish this, the software equips agents with three decision-making abilities regarding route selection. They are:

i) Density-based route choice method

ii) Travel Time-based route choice method

iii) Dynamic Potential

The explanation of each method and the evaluation results of all three methods are discussed in the sections to follow:

4.1 Density Based Route Choice Method

In this approach, the agents wisely choose less congested areas to move through and avoid crowded spaces, thereby influencing the overall flow pattern. The method provides a decision area along the route where agents perceive the crowd and choose the most suitable path. The software calculates the densities of particular areas, and the agents then make their route choices. Density-based routing is one of the best route choices for simulating and assessing how agents navigate crowded areas at entries and exits (PTV, 2025)

The route choice parameters are:

i) The probability of route choice is decided through the Logit function. The threshold limit applied here, 0.5 peds/sqm, is relatively low and enables agents to respond sensitively to even slight changes in crowd density.

ii) Density Calculation - This approach uses the combination method to calculate total density. If the areas overlap within the routes, the software counts each agent in the overlapping region only once to avoid multiple counting and false interpretations.

Table 2. Agent Network Performance in 3600 seconds Using Density Based Approach.

Time Interval	Agent Ent. (all)	Agent Arr. (all)	Agent Act. (all)	Speed Avg. (all) (km/hr)	Avg no. of stops (all)	Stand still time Avg. (all)
0-500	2330	1540	790	1.76	20.28	35.8
500-1000	2044	2017	817	1.46	27.43	50.82
1000-1500	2042	1978	881	1.36	30.68	59.3
1500-2000	2038	2025	894	1.31	32.89	65.85
2000-2500	1939	1954	880	1.28	32.93	68.19
2500-3000	2043	1949	973	1.27	32.36	68.18
3000-3500	1992	1997	969	1.21	35.97	76.89
3500-3600	408	386	990	1.21	15.42	33.59
Total	14836	13846	7194	10.85	227.96	458.62

The agents' network performance (Table 2) explains that the number of agents simulated at the end of 1 hour is 14,836. Therefore, the cumulative number of devotees who did deity observance at the end of the day was 128, 331.

4.2 Travel Time Based Route Choice Method

This approach distributes pedestrians evenly across each route at different time intervals. The movement of pedestrians at various intervals can be simulated in a desired pattern, with each interval lasting approximately 2 minutes.

The attributes influencing the result are:

i) Best Route Choice- This is the route with the least travel time to reach the destination area.

ii) Travel Time Calculations- Average of travel time taken by agents who arrived at the destination area.

Table 3. Agent Network Performance in 3600 seconds Using Travel Time Approach.

Time Interval	Agent Entry (all)	Agent Arr. (all)	Agent Act (all)	Speed Avg. (all) (km/hr)	No. of stops Avg. (all)	Stand still time Avg. (all)
0-500	1909	1290	619	1.74	20.47	36.42
500-1000	1726	1686	659	1.54	24.53	45.23
1000-1500	1740	1710	689	1.49	26.46	49.83
1500-2000	1760	1739	710	1.43	27.34	54.48
2000-2500	1681	1697	695	1.39	28.4	59
2500-3000	1741	1619	816	1.32	30.92	65.65
3000-3500	1690	1686	820	1.24	33.52	74.55
3500-3600	351	346	825	1.22	14.76	33.7
Total	12598	11773	5833	11.36	206.39	418.85

The agents' network performance (Table 3) explains that the number of agents simulated at the end of 1 hour is 12,598. Therefore, the cumulative number of devotees who did deity darshan at the end of the day emerged as 108,973 devotees.

4.3 Dynamic Potential

This route choice is based on the shortest time to reach the destination. Generally, PTV Viswalk simulation software operates on the principle that agents must take the shortest path, which makes their adaptability to changing conditions more realistic. The agents can dynamically adjust their paths, providing a more natural response to the crowded scenario. The software used the start and destination areas, marked on the architectural plans, for simulation. The attributes influencing the result are:

i) Impact – This weighs the direction of the desired speed when making route choices. The value ranges from 0 (static Pedestrian) to 100 (maximum influence). The researchers kept the default setting of 100.

ii) Calculation Interval- In a crowded scenario, the decision changes in short time intervals. So, the system updates the time interval. The default value is 10 seconds, and the researchers used it in their simulations.

iii) Basic Force (g) - This attribute evaluates the delay for occupied cells in relation to unoccupied cells. The default value of g=1.5 is retained with 100% impact to assess devotee behavior, because at this value, the agents not only choose the shortest path but also avoid collisions with other agents behaving realistically.

iv) Direction Impact (h) - It analyzes the influence of the direction of movement on an agent. The value ranges from 0 (no influence) to 1(walking at free speed). The researchers retained the default value of 0.7 for the simulation.

Table 4. Agent Network Performance in 3600 seconds Using Dynamic Potential.

Time Interval	Agent Ent. (all)	Agent Arr. (all)	Agent Act. (all)	Speed Avg. (all) (km/hr)	Avg. no. of stops (all)	Stand still time avg (all)
0-500	2030	1310	720	1.72	25.77	44.12
500-1000	1865	1750	835	1.4	35.09	58.08
1000-1500	1818	1764	889	1.26	42.11	70.9
1500-2000	1866	1748	1008	1.17	47.86	82.37
2000-2500	1831	1823	1016	1.12	51.86	89.65
2500-3000	1864	1792	1088	1.07	53.26	96.28
3000-3500	1759	1755	1091	1.03	55.53	104.29
3500-3600	377	359	1109	1.02	21.49	41.13
Total	13410	12301	7756	9.79	332.97	586.83

The agents' network performance (Table 4) indicates that 13,410 agents were simulated at the end of 1 hour. Therefore, the cumulative number of devotees who did deity darshan at the end of the day was 115,997.

5. Inferences

The first objective of achieving the maximum number of devotees who completed their journey was accomplished through the Density based route choice method. Therefore, the researchers opted to conduct the threshold analysis for experience density during different time intervals with this method. The movement at entry, exits, and within the shrine was within a safe zone, as indicated by the cumulative map of experience density across all intervals (Figure 9).

Figure 9. Experience Density map exceeding Threshold (Total) for 1 hr simulation run.

The crowd assembled for religious purposes is often referred to as an expressive crowd (Singal, 2024) and is highly emotional during deity observance, then wishes to be the first to exit the shrine. The above observation even corresponded to the simulation result, with high experience density in areas near the exit.

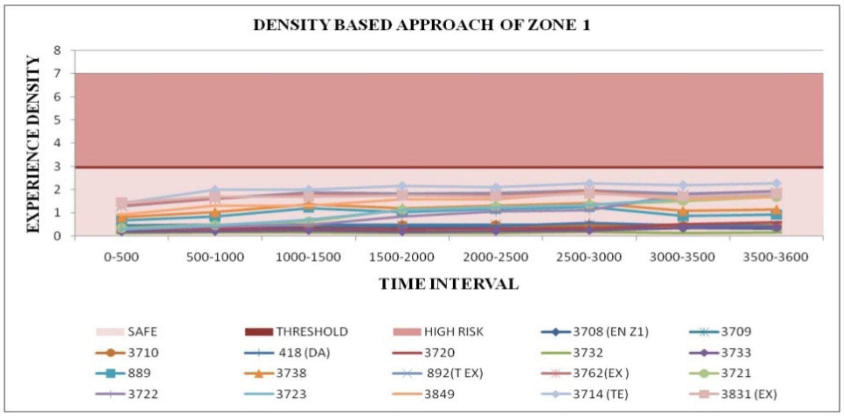


Figure 10. Experience density of zone 1 for different time intervals.

The maximum density was reported to be 2.27 agents/ sqm in the areas leading to the exit (TEX). All the values for experience density were below 3 agents/ sqm.

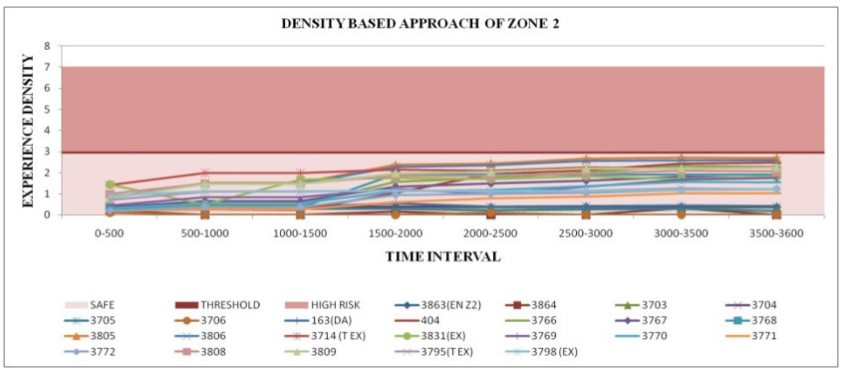


Figure 11. Experience density of zone 2 for different time intervals.

The maximum density was reported to be 2.72 agents/ sqm in the decision areas to choose suitable route. All the values for experience density were below 3 agents/ sqm.

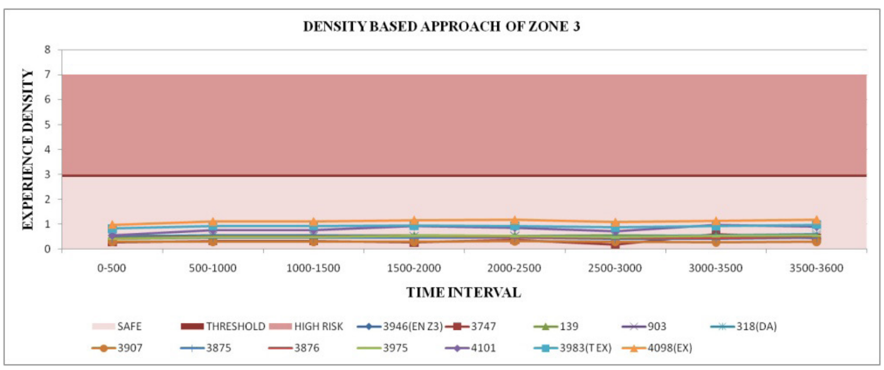


Figure 12. Experience density of zone 3 for different time intervals.

The maximum density was reported to be 1.17 agents/ sqm in the areas of exit. All the values for experience density were below 3 agents/ sqm.

The graphs for all zones (Figures 10, 11, 12) for each time interval showed experienced density below the threshold of 3 agents /sqm. As a result, the researchers further assessed the maximum experience density, along with the maximum densities of the entry, exit, and the main shrine, following the completion of a 1-hr simulation cycle.

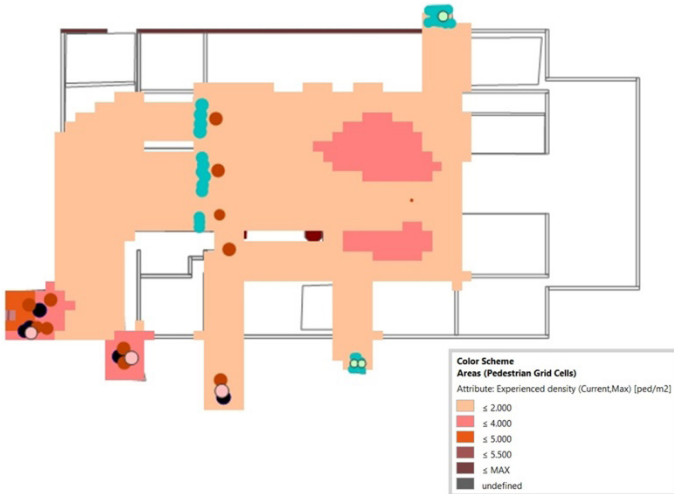


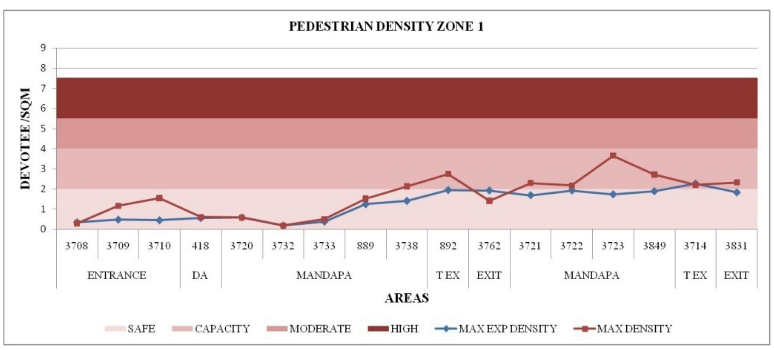
Figure 13. Maximum Experience Density map after 1 hr simulation cycle.

The density map (Figure 13) for maximum experience density showed the movement of devotees in the safe zone, with few areas at the threshold of the safe zone and few reported values above 2 agents /sqm, all within the capacity zone threshold. The graphs for all three zones show the same.

5.1 Devotee Density in Zone 1

The devotees had three entry lanes to the main shrine. The decision area (DA) was area 418, where the devotees chose the least dense route. The decision area is a part of the mandapa, where devotees seek deity worship.

At 3723 (area in mandapa for devotee assembly for deity observance), the density graph reached a maximum of 3.64 agents/sqm. Even this density value was within the space's capacity. The devotee movement towards the exit reported a density of 2.75 agents /sqm at area 892. Regarding experience density, the areas leading to and at the exit, such as 892 and 3714, had the highest values of 1.95 and 2.27 agents/sqm, respectively, followed by 3762 (the shrine's exit area) at 1.93 agents/sqm. Area 3722 (located inside the mandapa) reported an experienced density of 1.94 agents /square m.

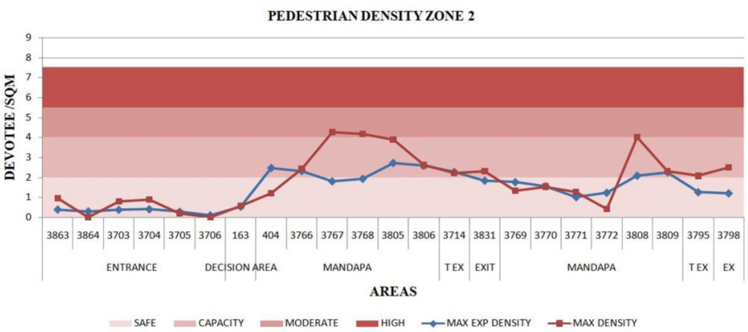


Area 3708 3709 3710	3 Entry Lane
Area 418	Decision Area
Area 889 3720 3732 3733 3738 3721 3722 3723 3849	Area for deity observance
Area 892 3714	Area adjacent to exit
Area 3762 3831	Exit Area

Figure 14. Graph showing maximum density and experience density for zone 1 after 1 hr simulation cycle.

5.2 Devotee Density in Zone 2

The density marker expresses the static number of agents per unit area over a given time interval. The software generates value even if the agents are standing safely in line for their turn. The maximum densities of 4.27 and 4.17 agents /sqm were reported in the decision areas of zone 2, which slightly exceeded capacity and are in a moderate risk zone. The same decision areas showed maximum experience density of 2.72 agents/sqm and 2.52 agents/sqm. This value, a dynamic attribute, was below the threshold of 3 agents /sqm. The experience density in areas 404 and 3766, just after the decision area, was 2.47 and 2.32 agents/sqm, respectively, both above the safe zone threshold.

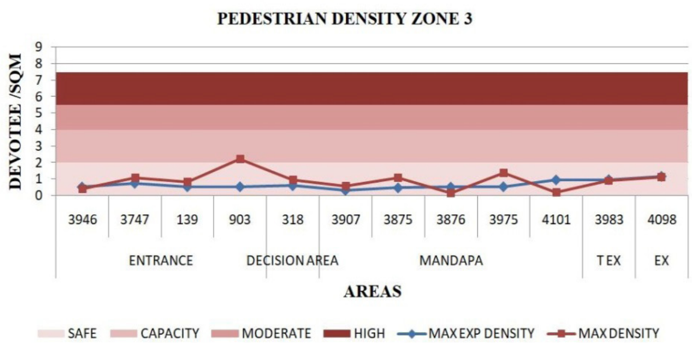


Area 3863-4 3703-6	4 Entry Lane
Area 163	Decision Area
Area 404 3766-68 3805 3806 3769-72 3808 3809	Area for deity observance
Area 3714 3795	Area adjacent to exit
Area 3831 3798	Exit Area

Figure 15. Graph showing maximum density and experience density for zone 2 after 1 hr simulation cycle.

5.3 Devotee Density in Zone 3

Area 903 (entrance to the shrine) reported a maximum density of 2.20 agents/sqm, which was slightly above the safe zone limit of 2 agents/sqm but below the threshold value of 3 agents/sqm. The maximum experience density was 1.17 agents /sqm at area 4098(exit of the shrine).



Area 903 139 3747 3946	4 Entry Lane
Area 318	Decision Area
Area 3907 3875 3876 3975 4101	Area for deity observance
Area 3983	Area adjacent to exit
Area 4098	Exit Area

Figure 16. Graph showing maximum density and experience density for zone 3 after 1 hr simulation cycle.

The threshold analysis highlighted the need for intervention because a few areas of the shrine were in a high-risk zone in the first time interval. The division of space into zones and decision areas in the density-based choice method enabled agents to make decisions based on crowd density. In addition, the zones should have security personnel to guide and manage devotees. There should be a monitoring system equipped with anomaly detection for the smooth movement of devotees. The movement organized in queues will effectively minimize the likelihood of adverse scenarios and ensure that every devotee has a fair chance to observe the deity. In addition, the complex should be equipped with advanced information dissemination systems to inform devotees about wait times, the number of devotees inside the shrine, etc.

6. Conclusions

The study commenced with a focused analysis of crowd-related issues. It confirmed that significant disasters involving crowds occurred due to overcrowding, inadequate policy formulation, and monitoring systems. To visit a temple is not just a ritual; it is a visit of faith, of a profound belief in the reigning deity. Devotee management should therefore not just be about control, but about protecting beliefs and devotees' experiences. Integrating simulation plans with movement protocols and advanced monitoring systems can turn potentially harmful crowd-related scenarios into a well-managed and enhanced experience. The main objective of the study was to assess the role of advanced technological tools, such as crowd simulation software, in highlighting problems related to devotee movement and deity observance. The threshold analysis of the conventional devotee movement at the shrine found that the shrine area was in a high-risk zone, consistent with reports of stampede incidents. The study effectively demonstrated that integrating intelligent-agent-based crowd simulation into PTV Viswalk and creating zones within available space has resulted in a safe flow of devotees. The smooth movement of a crowd, free from pushing and crushing, will undoubtedly enhance the space experience. The study employed the experience density parameter with a range of influence, a concept that has not utilized in other research endeavors. Thus, this study presents a noteworthy framework for enhancing devotees' experience.

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