International Journal of Religious Tourism and Pilgrimage

Volume 8 | Issue 8 Article 8

2020

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© International Journal of Religious Tourism and Pilgrimage
ISSN : 2009-7379
Available at: http://arrow.tudublin.ie/ijrtp/ Volume 8(viii) 2020

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Crowd Management is always a challenging task when people gather in large numbers. Crowd disasters in India, including recurring incidents at religious venues, demands a crowd management system developed on the characteristics of the place, event, and participants. Assessment of carrying capacity is the prime process to design crowd management protocols and regulations. Carrying capacity assessment of religious gathering venues in India is often an overlooked process. The present study assessed the crowd carrying capacity of Sabarimala pilgrimage, Kerala, India. Physical carrying capacity assessment methods used for tourism venues have been applied and contextualised for crowd carrying capacity assessment. Characteristics of the venue, pilgrimage and pilgrims were studied to map the active crowd area and space utilisation zones. The physical carrying capacity was estimated based on the comfortable crowd density and threshold crowd density assessments. The study identified two factors influencing pilgrim movement within the venue viz. service level at the holy step and capacity of the darshan facility. Service level at the holy step is the prime factor that regulates the flow of the pilgrim within the venue including the pilgrim movement for deity darshan and hence the comfortable capacity of the holy step was distinguished as the effective carrying capacity of the venue. Physical carrying capacity at the comfortable crowd density has to be maintained throughout the event to avoid the triggering of crowd crushes. The crowd carrying capacity assessment (CCCA) method applied in this study is a simple process. Considering the crowd density and crowd regulation factors, the CCCA method can be applied to design crowd management protocols of other religious pilgrimage destinations in India.

Key Words: crowd capacity, crowd safety, pilgrimage crowds, Sabarimala, carrying capacity

Introduction

Festivals and religious pilgrimages attract thousands of people and the event organizers face numerous challenges in effective crowd management. Mass gathering venues are prone to crowd hazards such as crushing, trampling, suffocation and public health issues (HSE, 2000). The world crowd disaster web has a record of 260 crowd disasters across the world since 1950, which has accounted for 14,989 deaths and 28,242 injuries (Asgary, 2019). Out of the various classes of crowd disasters in the database, 27.69 % occurred at entertainment venues, 23.85% at religious places and 23.08% at sports venues. Crowd disasters of religious origin (62 in number) have caused the death of about 8,000 people, which is 53% of the total fatalities. The global database reveals that 51 % of religious crowd disasters have occurred in India.

Mass gatherings of a religious nature are quite common and frequent in India. The crowd size is generally much higher in religious congregations compared to entertainment and political meetings. Crowd disasters are becoming routine in India and even recur at the same venues. Sixty-seven percent of human stampedes in India are reported from religious mass gatherings venues. Thus, the inadequacy of crowd risk management strategies is a serious concern in India. This demands effective and comprehensive crowd management systems to address all facets of religious events (Gayathri *et al*., 2017; Illiyas *et al*., 2013; Ngai *et al*., 2013).

In most of the non- conventional mass gathering venues such as cine halls, metro stations and bus depots, organisers weigh the operational capacities at the design stage itself. But in the religious mass gathering destinations in India,

the capacities have not been pre-defined for articulated planning. The amount of space available to the participants and the capacity of the venue are important factors for planning, preparedness, monitoring and safe conduct of mass gathering events (HSE, 2000; Fruin, 1993; NDMA, 2014). In India, entries to some religious mass gathering venues are regulated based on the spatial capacity, where prior registration and entry passes are administered for the visitors / pilgrims. The majority of religious mass gathering venues lack such pre-registration processes, and no restrictions exist to regulate the size of the crowd. The massive influx of visitors exceeding the maximum venue holding capacity and high crowd densities are inherent reasons for crowd disasters in India (Gayathri *et al*., 2017; Holman & Balsari, 2017; Burkle & Hsu, 2011; Ankita & Prashansa, 2015). Crowd density and crowd carrying capacity for maintaining mass gathering safety has received greater acceptance in the recent past (Keith Still, 2014), and based on this, the present study is aimed at developing a simple method for religious venues whereby administrators or event managers can systematically assess the crowd carrying capacity. The study is based on tourism carrying capacity assessment methods and developed religious crowd carrying capacity assessment methods for the Sabarimala pilgrimage, a popular religious mass gathering venue in India.

Carrying Capacity Assessment-Framework

Carrying capacity is a fundamental concept in resource management (Stankey, 1973). The idea of carrying capacity is broad, involving several disciplines (Stankey, 1990). The term 'capacity' explains the ability to contain or accommodate, or the amount that can be contained in a certain space or area (O'Reilly, 1986). People understand carrying capacity in different ways that make it difficult to quantify and use it as a planning tool for spatial management (Barkham, 1973; O'Reilly, 1986). Carrying capacity as an instrument can derive the upper limits of physical, environmental and demographic abilities of various systems. Currently, crowd carrying capacity is widely discussed, particularly soon after any crowd-related incident. Wager in 1964 reported that outdoor recreation in the United States has increased tremendously since the World War II and hence managers of congested areas faced problems of defining, understanding and augmenting the carrying capacity of recreation lands. As a result, guidelines specifying the spacing permits for outdoor recreation areas issued by various Government agencies in the US ensure the quality and comfort of visitors (Wager, 1964; Boy Scouts of America, 1950; USNPS, 1941; USFS, 1957). It was believed that consideration of the carrying capacity concept in planning would improve the quality of service concerning the available resources and the acceptable limits of a recreation area (Wager, 1964; Manuel and López, 2008).

O'Reilly in 1986 defined tourism carrying capacity as the maximum number of tourists that can be contained in a certain destination area. Carrying capacity is not an absolute value waiting to be discovered, but instead, is a range of values which must be related to specific management objectives for a given area. It is not just limited to the number of visitors but is determined by various factors such as characteristics of the visitors and attributes of the destination. Socioeconomic factors such as visitor profile, group size, attitudes, expectations, income, behaviour patterns, perceptions and safety consciousness form the elements of the visitor characteristics. Other aspects such as natural environment (geography, weather), physical factors (accommodation, transportation, amenities), economic factors (investment, technology, expenses), and political factors (visitor use restrictions) all address the venue characteristics (O'Reilly, 1986; Jin, 2009).

Carrying capacity assessment methodology for protected areas in the tourism sector (Cifuentes, 1992) has been widely applied to carrying capacity assessment of recreation and pilgrimage areas (Ravinder, 2016; Zacarias *et al*, 2011; Ceballos-Lascuráin, 1996). The tourism carrying capacity formula developed by Cifuentes in 1992 was modified by Tran Nghi in 2007. This modified formula for Physical Carrying Capacity (PCC) has been used for the crowd carrying capacity assessment in the present study. PCC is the maximum number of visitors, which can physically fit a specific area in a particular period:

$$PCC = A \times D \times Rf$$

Where:

A = available area for use (m^2);

D = tourist density (tourists/m^2);

Rf = Rotation factor (number of visits per day).

Particular attributes of the considered area are important in influencing / determining its value. For a geographical area, this parameter can be delineated by a natural boundary such as a mountain range, stream or safety demand. The tourist density or the area required per

tourist - 'D' is the area required for a tourist who can undertake activities comfortably. Rotation factor is the number of permissible visits over a specified time (usually calculated by daily open hours) and expressed by:

Rf= Open period / average time of visit

This method can help organisers to identify and evaluate the maximum number of visitors an area can accommodate at a particular time (Zacarias *et al*, 2011).

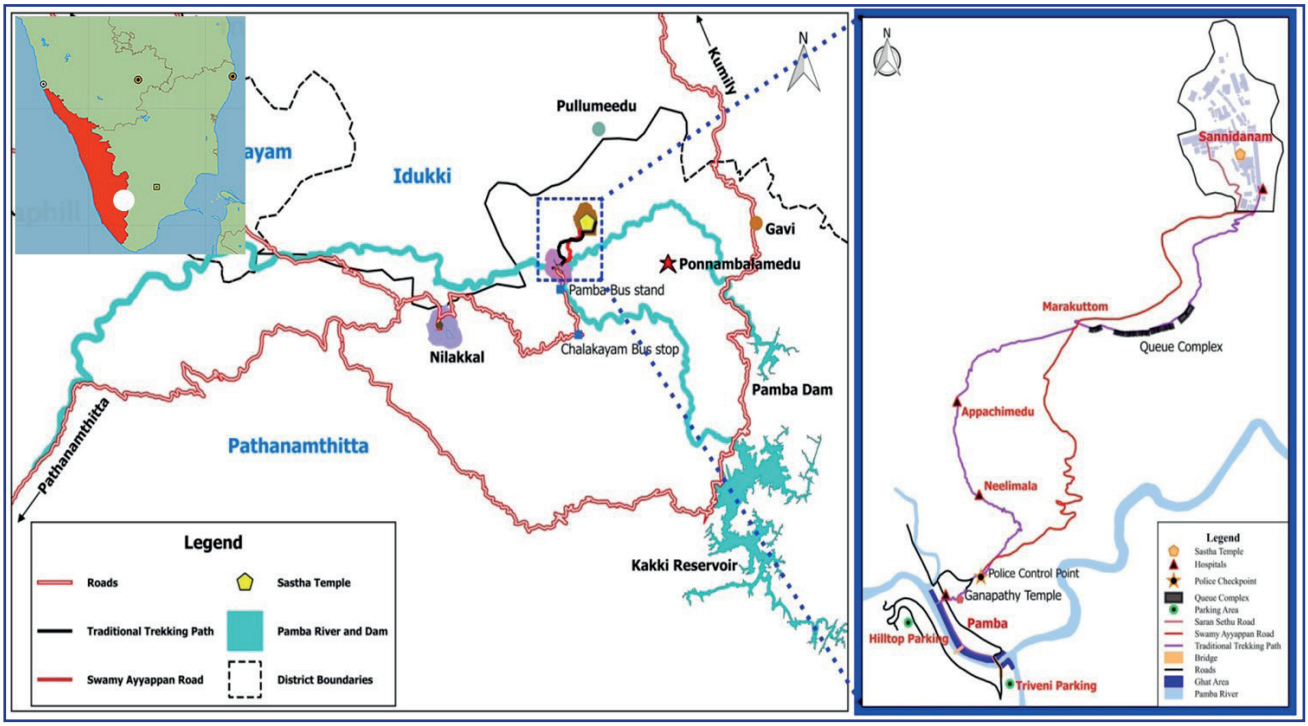
Effective Carrying Capacity (ECC) is the maximum number of individuals who can be permitted in a tourist spot based on the local conditions and management capacity with little interference on the tourists' demand (Tran Nghi, 2007). In a crowd movement system, ECC is determined by the crowd regulation factors which negatively influence the carrying capacity of the venue. In this study, effective carrying capacity was assessed contextually by identifying the service level capacity of crowd regulation factors.

Religious Crowd Carrying Capacity Assessment- Application to Sabarimala

The chosen religious mass gathering site for the present study on crowd carrying capacity assessment is Sabarimala Sree Dharma Sastha Temple, which is an ancient and prominent temple in India. Sabarimala Pilgrimage has a history of two major crowd disasters, one in 1999 which caused 52 deaths (Illiyas *et al*., 2013) and the second incident in 2011 causing 102 deaths (Ngai, 2013). The significant conditions causing health risk in Sabarimala religious mass gatherings are human stampedes and outbreak of person-to-person disease (Joseph *et al*., 2016).

Sree Dharma Sastha Temple is located in the hilly terrains of ecologically sensitive Periyar Wild Life Sanctuary in Pathanamthitta district, Kerala, India. The temple is at an altitude of 467 meters above sea level (Ministry of Forests, 2005). The pilgrimage season in Sabarimala begins in November and ends by January every year. The name of the deity at Sabarimala is '*Lord Ayyappa'*. The temple attracts about 6 to 10 million pilgrims per annum from the Southern Indian States, namely, Kerala, Karnataka, Tamilnadu, Andhra Pradesh and Telangana (Osella & Osella, 2003; Pillai, 2007). The geography, rituals and worship schedule make the temple unique in many ways. Pilgrims visiting Sabarimala travel by road to reach the foothill base camp located at 'Pamba River' bank where pilgrims perform ablution in the river. After the ablution and customary rituals at the base camp, pilgrims trek barefoot along the traditional path which stretches 4 kilometres through the hilly forest of Western Ghats to reach the Sanctum Sanctorum in Sabarimala known as 'Sannidanam'. Figure 1 shows Pamba, Sannidanam,

Figure 1: Sabarimala Sannidanam, Trekking Paths, and Pamba Base



and other Trekking paths. As a tradition, pilgrims visiting Sabarimala bring coconuts filled with ghee and offer them to the deity as a consecration ritual. Pilgrims consider these as sacred items, and they carry them overhead until they have undertaken the deity *Darshan* (an opportunity for a devotee of hinduism to see or an occasion of seeing a holy person or the image of a deity). At Sannidanam, pilgrims are regulated in queues for visiting the deity. During the peak period of the pilgrimage, visitors remain in queues for up to 15 hours for *Darshan*. After *Darshan*, pilgrims return via another trekking path which runs parallel to the onward track, whereby they reach back to Pamba (base camp location) for their return journey.

The number of pilgrims visiting Sabarimala is a subject of debate (Aji, 2003) and no scientific estimates are available yet. According to Sankar *et al*., 40,000 to 50,000 pilgrims visit Sabarimala in the initial days of the pilgrimage season, and the figure reaches 150,000 to 200,000 pilgrims in peak days leading to a total number of 7 to 8 million pilgrims per year (Sankar, 2000). Osella and Osella in 2003 reported that 6 to 10 million pilgrims visit Sabarimala annually (Osella & Osella, 2003). Pillai in 2007 calculated that the numbers of visitors are more than 6 million in a pilgrim season. Other estimates available are 50 million (Sajudeen, 2014; Bindu, 2015) and sixty million pilgrims annually (Nithya, 2016), which are much higher than the above estimates. When it comes to crowd carrying capacity, the same ambiguity exists as there are no published scientific studies for a pilgrimage venue (Baby, 2003; Radhakrishnan, 2011).

Methodology

No standardized method exists for estimating the crowd carrying capacity of a religious venue. Developing a commonly applicable procedure is a difficult task as the assessment needs to be contextual, and the method applied for one area may not be suitable for other venues. The crowd carrying capacity assessment involves four stages as shown in Figure 2 and explained subsequently:

Area: The total study area and the area available for the crowd movement has been calculated through field survey and GIS mapping.

Zones: Physical characteristics and infrastructure provisions of the Study area including crowd movement, building layout, services for the pilgrims, topography, climate, and amenities were mapped. Field observations marked space utilisation by the pilgrims for resting, waiting, and queuing. Pilgrim inward movement, circulation and outward movement were observed for three days, and the pilgrim area has been divided into different zones based on the observed space utilisation values.

Density: Crowd density for each zone has been calculated for standing crowd, moving crowd and resting crowd. The pilgrim density was measured as the number of pilgrims per unit square meter area at various locations.

Capacity: Carrying capacity has been calculated only for the pilgrimage season, while the off-peak season was avoided due to the particular nature of the destination. The pilgrimage is considered as a system containing an input, a process and an output to calculate the effective carrying capacity. The sub-

Figure 2: Crowd carrying capacity assessment process

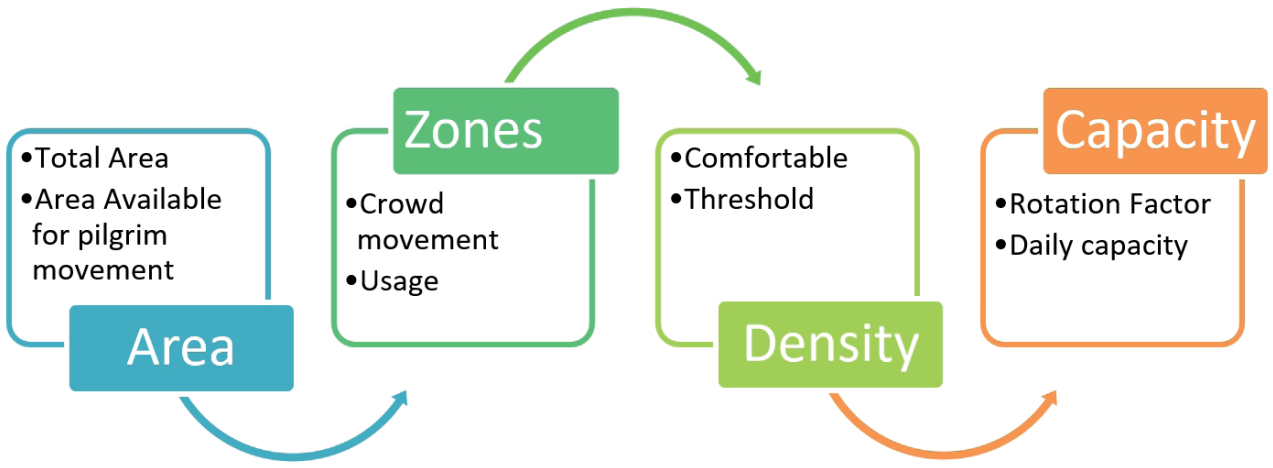


Table 1: Crowd space utilization zones in Sabarimala		
No	Area	Area (Meter^2)
I	Nadappanthal	1504
II	Sopanam and queuing area	1680
III	Resting area/ viri veppu locations	4804
IV	Thirumuttom	2390
V	Vadakke nada barricade	450
VI	Padinjare nada resting and walking area	100
VII	Malikappuram	1987
VIII	Pandithavalam road	1900
IX	Free movement area	3875
X	Way to sarana sethu	910
	Total area used by the pilgrims	19600

systems that function as crowd regulation factors by influencing the total performance of the system have been identified. The maximum capacity of each subsystem at peak times and comfortable capacity of the subsystems when the crowd risk is at a minimal level were studied, and the least comfortable capacity has been considered as the effective crowd carrying capacity.

Result and Discussion

The total area available for the pilgrimage in Sabarimala Sannidanam is 60 Acres. The active open area available for the pilgrim is 19600 m^2. Based on space utilisation mapping, the active crowd movement area has been divided into 10 zones, as given in Table 1. The space within the zones is categorised as a queuing area for *Darshan*, queuing area for other purposes, free walking area and an open resting area for pilgrims. Google earth view of the Sannidanam and space utilisation map prepared using inputs of field observations are given in Figure 3.

The average pilgrim density observed within the barricades at regulated queuing areas is 4 per square meter. The density increases up to 7 per square meter during the peak hours in regulated queuing areas. In resting areas where pilgrims stay overnight, individual pilgrims use an area of 1-meter square. In free movement areas where multi-directional pilgrim movement is permitted, the average density is 2 per square meter. The density increases up to 4 during peak hours, and the stewards restrict pilgrim movement to one direction when cross movements are not possible. During the field visits, the comfort level of the pilgrims has been enquired randomly.

Pilgrims at regulated queues, at the free walking area and at the resting place in various locations are illustrated in Figures 4 to 8. The average and acceptable crowd density for various locations have been calculated and are given in Table 2.

The physical carrying capacity cannot be calculated for the entire area as a single unit because crowd density is dynamic at different points within a zone. Comfortable crowd density is found to vary depending on space utilization of areas. The physical carrying capacity of pilgrim movement areas has been calculated by applying the formula given by Tran Nghi (2007) and are given in Table 2.

The Comfortable crowd carrying capacity of sanctum sanctorum of Sabarimala pilgrimage at a given time is found to be 38,199 pilgrims. The temple is open for 24 hours throughout the pilgrim season, and the Sannidanam will be crowded with visitors during the entire season. However, the deity *Darshan* at Sabarimala is restricted to 16.5 hours per day. A vital ritual followed after deity *Darshan* is '*Neyyabhishekam*' (a hindu ritual, offering ghee to *Ayyappa idol,* the deity of the temple). The period allotted for '*Neyyabhishekam*' is from early morning 4.15 hours to 12.00 hours noon in the temple premises. A section of the pilgrims who reach Sabarimala after 12.00 hours stay back at sanctum sanctorum to perform

Figure 3: Google Earth View of Sannidanam and Space Utilisation Map Based on Field Observations

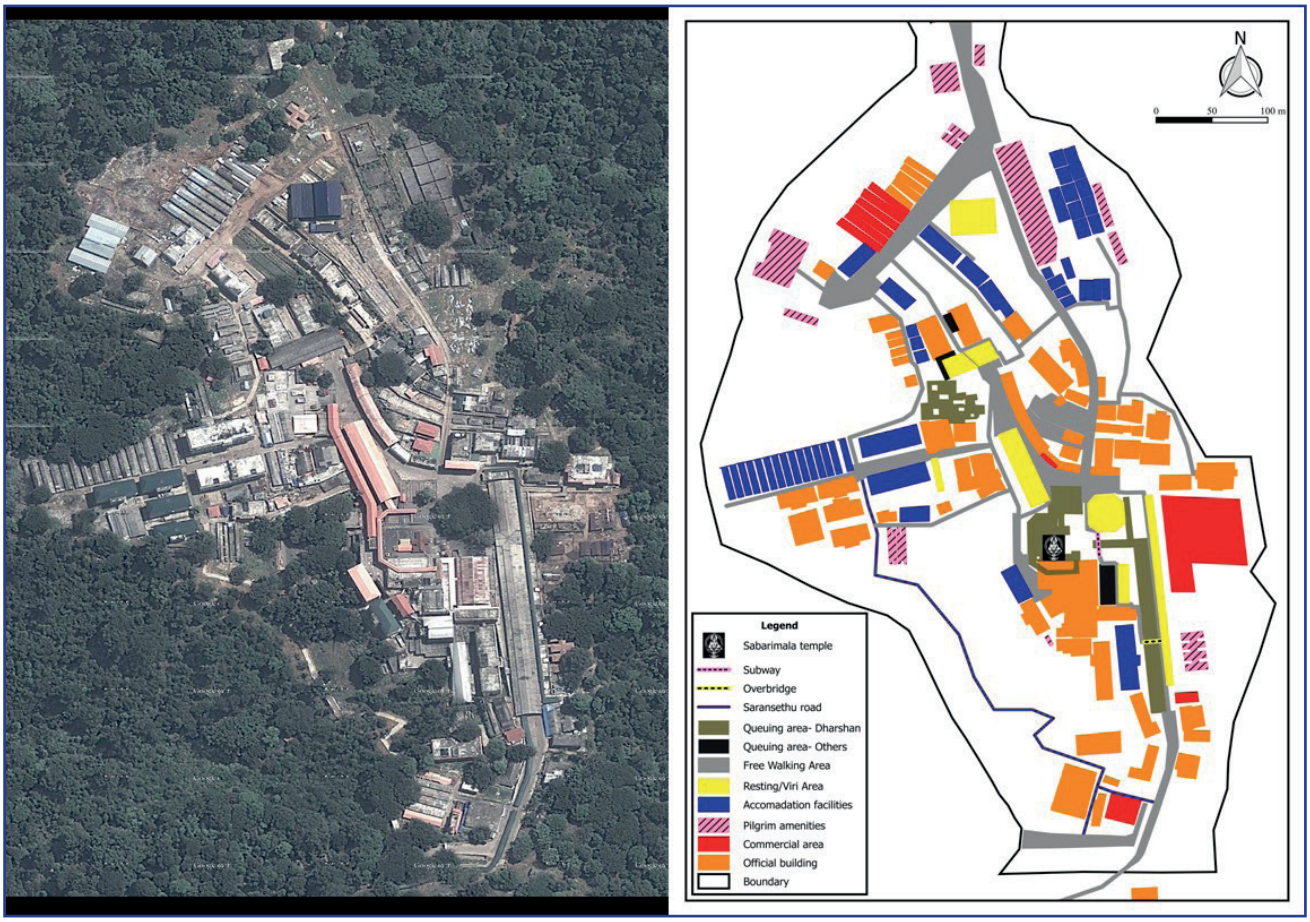


Figure 4: Pilgrims in Traditional Dress Waiting in Regulated Queues for Deity Darshan.

Figure 5: Pilgrims moving in multiple directions in free walking area

Figure 6: At a resting area pilgrims are in preparation for deity offerings.

Figure 7: Pilgrims waiting in queues at sanctum sanctorum for Darshan
(To manage the crowd, pilgrims are regulated via an overhead flyover)

Figure 8: Pilgrims taking rest in the designated resting area

Table 2: Observed Crowd Density and Comfortable Crowd Carrying Capacity of Various Zones in Sabarimala				
No	**Area**	**Available area (m^2)**	**Observed comfortable density (Pilgrims/m^2)**	**Comfortable crowd carrying capacity**
I **Queue placement area** (called as *Nadappanthal* in local language)				
a	General queue barricade	867	4	3468
b	Virtual queue barricade	449	4	1796
c	Queue from pullumedu end	188	4	752
II **Sopanam and queuing area**				
a	Queue in front of holy step	100	4	400
b	Sopanam flyover	480	4	1920
c	Sopanam	1100	2	2200
III **Resting area/ viri veppu locations**				
a	Nadappanthal extension	1184	1	1184
b	RCC Nadappanthal near vadakke nada	1512	0.5	756
c	Malikappuram nadappanthal	878	0.5	439
d	Magunda viri shed	1230	0.5	615
IV **Thirumuttom**				
a	Holy step-left side-queuing barricade	548	2	1096
b	Holy step-left side-resting area	288	2	576
c	Holy step-left side-free movement area	58	2	116
d	Holy step-right side-queuing area	60	4	240
e	Holy step-right side walking and resting area	1236	1	1236
f	Walking area in front of police control room	200	2	400
V	**Vadakke nada barricade**	450	4	1800
VI	**Padinjare nada resting and walking area**	100	2	200
VII	**Malikappuram**			
a	Malikappuram temple premise	1376	2	2752
b	Malikappuram fly over-one way	611	3	1833
VIII	**Pandithavalam road**	1900	2	3800
IX **Free movement area**				
a	Free movement area in front of media building	1650	2	3300
b	Walking area in front of hotel chains	600	2	1200
c	Area in front of nadappanthal	140	3	420
d	Below malikappuram flyover	147	2	294
e	Nadappanthal free movement area	1338	2	2676
X	**Way to sarana sethu**	910	3	2730
	Total area used by the pilgrims	**19,600**		**38,199**

'*Neyyabhishekam*', the next day morning, which strains the crowd holding capacity of sanctum sanctorum. The estimated number of pilgrims staying back at sanctum sanctorum for '*Neyyabhishekam*' varies from 2000 to 6000 pilgrims per night. Excluding this section, on an average, pilgrims visiting Sabarimala spend 8 hours at sanctum sanctorum. The inputs can be used to find the rotation factor:

Rf= Pilgrim entry allowed time / Average time of visit of a pilgrim

Rf = 24 hours/8 hours = 3

Daily Physical Carrying Capacity of Sabarimala Sannidanam

= Comfortable Crowd Carrying Capacity X Rotation Factor

= 38,199 X 3 = 114,597 pilgrims

Physical Carrying Capacity of Sabarimala Sannidanam for the pilgrimage season

= 114597 pilgrims X 60 days

= 6,875,820 pilgrims

The physical carrying capacity of Sannidanam at a given time has been calculated as 38,199 pilgrims. The figures can be taken as a benchmark point to regulate the flow of the pilgrims to Sannidanam. Whenever the carrying capacity is exceeded, the crowd management team needs to take a proactive approach in implementing a proper crowd management system. This situation requires a system that monitors the pilgrim density and number of pilgrims at Sannidanam. At present, such a system is not in place, and the pilgrim movement is restricted when Sannidanam gets overcrowded, thus the moving crowd becomes stagnant. This may create safety issues, and the situation could lead to crowd crush and human stampedes. A crowd management system to regulate the flow of crowd is to be worked out considering the Physical Carrying Capacity of Sannidanam. Maintaining a comfortable crowd limit would be a difficult task on peak days such as weekends and special prayer days. However, a threshold limit should be fixed as a maximum crowd carrying capacity. The maximum allowable pilgrim density and threshold limit of physical carrying capacity for Sannidanam at a given time is estimated as 55,989 pilgrims (Table 3).

Effective Carrying Capacity

In the study, when a physical or a management subsystem affected the movement of crowd in the venue, it was considered as crowd regulation factor. Crowd regulation factors are unique, and vary between venues. To calculate

Figure 9: Pilgrims waiting in queue in front of holy step.

Table 3: Threshold limits of crowd density and carrying capacity in Sabarimala			
No	**Area**	**Threshold limit of crowd density (Pilgrims/m²)**	**Physical carrying capacity threshold limit at segments**
I **Queue placement area** (Nadappanthal)			
A	General queue barricade	5	4335
B	Virtual queue barricade	5	2245
C	Queue from Pullumedu end	5	940
II **Sopanam and queuing area**			
A	Queue in front of holy step	5	500
B	Sopanam fly over	5	2400
C	Sopanam	3	3300
III **Resting area/ viri veppu locations**			
A	Nadappanthal extension	2	2368
B	RCC Nadappanthal near vadakke nada	1	1512
C	Malikappuram nadappanthal	1	878
D	Magunda viri shed	1	1230
IV **Thirumuttom**			
A	Holy step-left side-queuing barricade	3	1644
B	Holy step-left side-resting area	3	864
C	Holy step-left side-free movement area	3	174
D	Holy step-right side-queuing area	5	300
E	Holy step-right side walking and resting area	2	2472
F	The walking area in front of police control room	3	600
V	**Vadakke nada barricade**	5	2250
VI	**Padinjare nada resting and walking area**	3	300
VII **Malikappuram**			
A	Malikappuram temple premise	3	4128
B	Malikappuram fly over-one way	4	2444
VIII	**Pandithavalam road**	3	5700
IX **Free movement area**			
A	Free movement area in front of media building	3	4950
B	The walking area in front of hotel chains	3	1800
C	The area in front of nadappanthal	4	560
D	Below malikappuram fly over	3	441
E	Nadappanthal free movement area	3	4014
X	**Way to sarana sethu**	4	3640
Physical carrying capacity threshold limit at a given time for Sannidanam		55,989	

Figure 10: Pilgrims Ascending the '18 Holy Steps' (*Pathinettam padi*) for Deity Darshan
Policemen in khaki colour uniform helping the pilgrims to climb up

the effective crowd carrying capacity for Sabarimala pilgrimage, the factors which regulate the flow of the crowd within the system are considered as limiting factors. Based on field observations, two measurable limiting factors that regulate the crowd flow in Sanctum Sanctorum of Sabarimala have been identified and are described below:

Crowd Regulation Factor 1: Service Level at Holy Step

One of the distinctive features of Sabarimala pilgrimage is the '18 holy steps' at sanctum sanctorum. Pilgrims consider the holy steps as sacred and ascending them is believed to be the ultimate part of the pilgrimage. The 18 holy steps have a total length of 4.2 meters, and are built at a gradient of 60 degrees. Each step is 5 feet in horizontal length, 9.2-inches wide and 9.2-inches high. A queuing system at Sabarimala has been put in place in order to guide the pilgrims to ascend the holy steps and reach the 1st floor of the temple to proceed for deity *Darshan*. Pilgrims waiting in queue to ascend the holy steps and pilgrims ascending the holy steps are shown in Figure 9 and Figure 10, respectively. In the entire crowd flow system, the holy step is a bottleneck, which is a dependent factor that regulates the flow of the crowd to sanctum sanctorum.

The mobility of the pilgrims at the holy steps is assisted by 12 Policemen who are deployed to increase the throughput rate of pilgrims. To manage the pilgrim rush, the policemen physically pull the pilgrims along the steep steps, giving stair climbing assistance. During the peak hours, the throughput rate of pilgrims at the Step is managed manually - with police assistance its maximum capacity is 70-75 people per minute at a pilgrim density of 3.5 to 3.8 individuals per square meter. Pilgrims ascending steps walk upstairs very closely with no gaps between individuals. Due to the strenuous physical nature of the job, policemen are deployed for only 20 minutes in a shift.

Average pilgrim ascending velocity (at a density of 3.5 to 3.8 persons/m^2 through the 60-degree slope stair) has been identified as 0.17 m/s. There is a difference in velocity between the first Six Steps and the remaining 12 Steps. Pilgrims organise themselves in the first six steps where the stair ascending velocity is 0.11 m/s. The service of policemen is available from the 7th Step onwards, where the velocity gets increased to 0.23 m/s. The physical effort of the police augments the velocity to two times the observed velocity to of the first six steps.

The throughput of 70 to 75 pilgrims is maintained by the physical efforts of deployed policemen in respective

Table 4: Throughput Rate at the Holy Steps			
Density	Physical assistance	Velocity	Throughput rate (Maximum)
3.5 to 3.8 p/m^2	With physical assistance of policemen	0.17 m/s	70 ±5 per minute
less than 2.80 p/m^2	Without physical assistance of policemen	0.20 m/s	50 ±5 per minute

shifts. This throughput cannot be considered as the optimum service level for the stair stretch. The pilgrim density, when it is not managed is less than 2.80 persons/ m^2, in this situation, the stair ascending velocity was observed as 0.20 m/s, especially during off-peak hours. A reduction in crowd density makes the pilgrims more comfortable when ascending the stairs, without the physical assistance of policemen. The average number of pilgrims passing through the 18 Holy Step at this density would be 45 to 50 pilgrims per minute. Throughput comparison with and without police assistance is given in Table 4.

The throughput rate of 50 pilgrims per minute could be considered as the comfortable service level for the 18 stair stretch.

Hence,

Maximum Capacity (Mc): 4200 x 23.5 hours= 98,700 pilgrims

Comfortable Capacity (Cc): 3000 x 23.5 hours = 70,500 pilgrims

Crowd Regulation Factor 2: Darshan *Facility*

Pilgrims after ascending the 18 holy steps are lined up for deity *Darshan*, and they will be allowed to sight the deity while passing in a queue system that consists of three lines. *Darshan* capacity of sanctum sanctorum was studied at different time intervals, and it has been identified that a maximum of 130 pilgrims pass through the queuing system in one minute wherein an individual gets 1.3 seconds to sight the deity. The throughput rate of the maximum 130 pilgrims/minute is regulated by a team of policemen who manage the rush during peak hours. Throughout the pilgrimage season, the sanctum sanctorum is kept open for 16.5 hours in a day for deity *Darshan*, and the *Darshan* duration may occasionally get extended to 17.4 hours when the sanctum sanctorum experiences an astounding rush. Taking the maximum service capacity of Sanctum sanctorum of 1.3 seconds/ individual, 7,800 pilgrims can sight the deity in one hour and hence, Maximum Capacity (Mc) = 7,800 x 16.5 hours = 128,700 pilgrims/day.

While interacting with pilgrims during the present study, they stated that, during the heavy rush they get only one second for *Darshan* and many haven't had the chance to sight the deity. Pilgrims are not satisfied with the 1.3 second *Darshan* time, and whoever tries to spend more time in front of the deity is pushed ahead by the stewards to control the crowd rush. If the sighting time gets increased to 2 seconds, in one line, 30 pilgrims per line would get *Darshan* per minute accounting for 90 people for three lines per minute.

If the average time allotted for *Darshan* is taken as 2.5 seconds/ pilgrim,

Capacity of *Darshan* facility in one hour = 24 pilgrims x 3 line = 4,320 pilgrims/hour,

Hence

Comfortable Capacity (Cc) = 4320 x 16.5 hours = 71280 pilgrims/day

Influence of Sub Systems

In essence, the crowd regulation factors determine crowd inflow, circulation within the system and outflow of the pilgrims. One factor directly influences the second factor and determines the total performance of the system. An increase in crowd throughput ratio at holy step will generate a massive crowd flow to the *Darshan* area where the maximum crowd holding capacity is 5,700 pilgrims. The throughput rate at the *Darshan* area has to be increased to avoid overcrowding and crowd crush. When the crowd regulation factors are interconnected and directly influencing the total performance of the system, it cannot be represented as an individual subsystem. Hence, the effective carrying capacity can be considered as the lowest comfortable capacity of all the subsystems (crowd regulation factor).

Comfortable capacity of the holy steps = 70,500 pilgrims/day

Comfortable capacity of sanctum sanctorum *Darshan* = 71,280/day

Thus, the capacity, i.e. **Comfortable Capacity** of the holy step of 70,500 pilgrims is identified as the effective daily carrying capacity of Sabarimala, which is 61% of the Physical Carrying Capacity.

Conclusion

Carrying Capacity Assessment when applied to local conditions can help in calculating the crowd accommodating capacity of the venue. It can assist venue managers and administrators to plan and regulate the flow of the crowd, thereby averting crowd disasters. The present study assessed the crowd carrying capacity of Sabarimala pilgrimage through calculating the physical carrying capacity and effective carrying capacity. Previously studies, while assessing the carrying capacity of recreation places have considered the entire area as a single unit without scaling down. In religious venues where crowd movements are high, and the potential of crowd crush exists, more focused analysis is required rather than a single unit approach. The present study analysed crowd movement and space utilisation patterns in Sabarimala to arrive at comfortable pilgrim density and threshold limits of crowd accommodation. The physical carrying capacity of Sabarimala is estimated as 114,597 pilgrims per day and 6,875,820 pilgrims in a season. The physical carrying capacity threshold limit at a given time is 55,989 pilgrims. The effective carrying capacity of Sabarimala pilgrimage is 70,500 pilgrims per day.

In crowd safety science, carrying capacity and crowd density are equally important. When the density increases beyond the threshold limits, the moving crowd becomes a standing crowd, and the standing crowd becomes immovable. The crowd density at each segment is to be monitored continuously during mass gathering events rather than just the total physical capacity or effective capacity of the venue. Disaster management practitioners and event planners should meticulously carry out crowd carrying capacity assessment as a benchmark reference when planning mass gatherings.

Crowd management planning without considering carrying capacity assessment will prevent administrators from undertaking risk-informed planning, and this may lead to crowd disasters. The present study is an endeavour to highlight the importance of crowd carrying capacity in risk-informed crowd management planning for religious pilgrimages. The method used in the study could be utilised for modelling purposes and developing crowd management information system for religious mass gatherings.

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