Collective Dynamics

Tracer Observation of Queuing Behavior During New Year's Visits to Shrines/Temples Using GPS Log Data

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Abstract Crowd behavior during customary New Year's visits to shrines/temples in Japan was investigated. During these mass gatherings, visitors form a queue along the approach to the Main Hall of the shrines/temples. The queue was managed to have a unidirectional flow. The author observed two examples of queuing by joining the procession and tracked his position over time using a GPS logger. These time and location data can be regarded as representative of the crowd behavior. Crowd behavior, such as when, where, and why the crowd was almost stopped, or the stop-and-go walking emerged, was analyzed using these data. The data revealed that the queues were generated at gates, praying areas, and cordons. The "everyone is welcome" aspect of New Year's visits required not only cordons at those bottlenecks but also extra queuing space to accommodate for expansion of the crowd size. This feature was compared with those of building/fire evacuations. In building/fire evacuations, occupancy can be estimated or controlled by ticket quantity or expected density. Therefore, the accumulation of evacuees at bottlenecks can be predicted and should be considered in the building design and management phase. Different events or facilities require distinct crowd management approaches.

Keywords New Year's Visit · crowd management · tracer observation · building · fire evacuation

1 Introduction

In Japan, people celebrate the New Year by visiting shrines or temples and praying for health and happiness in the coming year. Major shrines and temples have several hundred thousand visitors over three days during the New Year's holiday [1]. Based on past accidents involving crowds, such as the Yahiko Shrine Accident in Japan in 1956, which was caused by counterflow at the stairs in front of the entrance gate to the main court of the shrine [2–4], police enforce strict crowd management. Crowd-related accidents can be seen worldwide [5], such as during Halloween [6], music festivals [7, 8], fireworks festivals [9], and religious gathering [10]. However, data on accidents at mass gatherings [5–10] or pedestrian traffic [11–19], are limited, especially regarding New Year's visits to shrines or temples in Japan [20]. This kind of data will contribute to more effective building/fire evacuation design or event management plans [10, 21–25]. As an attempt to acquire such data, the author measured the queuing behavior of visitors to shrines and temples during New Year's visits and analyzed the behavior of the crowd. Results of the observations were used to compare the differences between crowd control at mass gatherings and during building/fire evacuation design.

2 Materials

The author observed a queue at shrine/temple X for a New Year's visit at midnight on December 31, 2022 to the morning of January 1, 2023. The author also observed a queue at shrine/temple Y in the early afternoon on New Year's Day. Both time periods are the two major peaks related to the arrival of visitors. Shrines/temples X and Y are ranked among the top 10 shrines/temples in Japan in terms of the number of visitors during the New Year's holiday [1]. At the praying areas in front of the shrines/temples, visitors conduct rituals, such as tossing coins, bowing, and clapping, which can last up to tens of seconds. Anyone who wants to visit the shrines/temples, which are also tourist attractions, can do so without reservations, tickets, or paying an entrance fee, regardless of religious background. At both shrines/temples X and Y, the police enforce unidirectional flow of people in queues to prevent counterflow-related accidents.

3 Methodology

To examine the movement of the visitors, the author joined the queue at each shrine/temple and measured his changes in position over time using GPS log data on a smartphone, as a tracer of the queuing crowd [26]. The smartphone acquired position data continuously; however, the author used log data recorded in photographs taken periodically using the smartphone to confirm the validity of the data via comparisons of the photographed scenery (Fig. 1). Crowd behavior, such as when, where, and why the movement was almost stopped, or stop-and-go walking emerged, was examined using this periodic data. The moving situation and the almost-stopped situation were confirmed by the calculated average velocity and flow rate (the quantity of people that pass a certain point per minute). The author also observed the geometrical features around the queues and procedures used by police for crowd management, such as the use of cordons. The simple method of assessing crowd management used in the present study is limited to only a single set of observational data obtained by the author. Acquiring smartphone data from several vis-

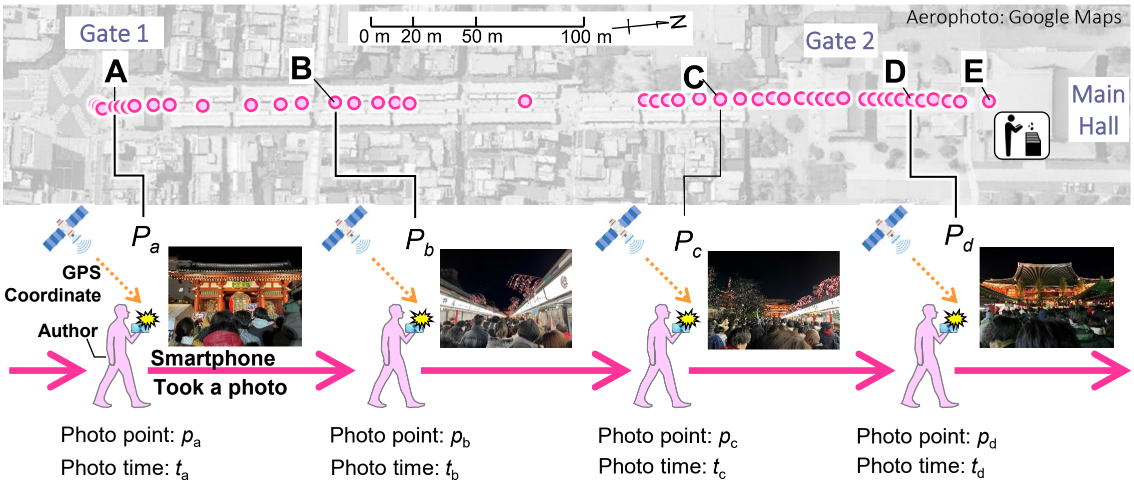

Figure 1 Methodology for tracking changes in position over time.

itors [27], or using multiple tracer observers would overcome this limitation. However, the author attempted to use easily available data to analyze the mechanisms of crowd behavior and control. It is also advantageous that this method does not require measuring, counting, or recording other visitors. Hence, the method does not invade the privacy of other visitors.

4 Results

Fig. 2 shows the changes in position within the queue over time at shrine/temple X during the New Year's visit at midnight on December 31, 2022 to the morning of January 1, 2023. Shrine/temple X has a straight, approximately 400-m approach to the Main Hall where visitors lined up. The author entered Gate 1 at 23:16 then proceeded along the approach to the Main Hall, encountered congestion at point C, and came to a standstill until midnight. The visitors counted down for the New Year and then proceeded again. The queue moved in a stop-and-go manner [28–30] at this point. The main bottlenecks were Gate 2 and the stairs leading to the Main Hall where visitors prayed. The police deployed cordons at these locations to regulate the flow of the crowd. When the rate of incoming visitors exceeded the rate of outgoing visitors (i.e., number praying people per unit of time), the queue became longer. However, the density was relatively constant (approximately 4.5 people/m^2, based on the author's estimation) because the police restricted the incoming crowd from a wide area to a narrow bottleneck. The wide road outside the premises of the shrine/temple, which led to Gate 1, was closed to vehicle traffic and transformed into a designated queuing space for visitors. With an estimated width of approximately 10 m for the waiting line from Gate 2 to the Main Hall. The distance and time between Gate 2 and the Main Hall was 38.7 m and 18.65 min, respectively. The density of visitors between these points was approximately 4.5 people/m^2. Therefore, the number of praying visitors per minute can be roughly estimated as $38.7 \times 10 \times 4.5/18.65 = 93.4$ people/min. An

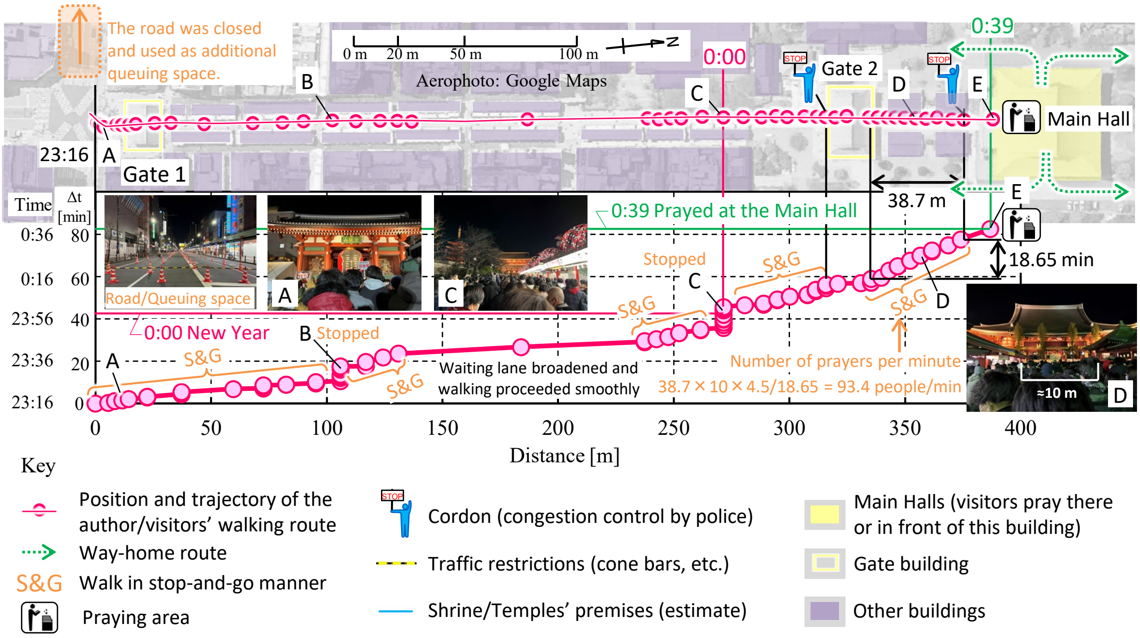

Figure 2 Changes in position within the queue over time during the New Year's visit to shrine/temple X

incoming rate of visitors greater than this value would lengthen the queue.

Fig. 3 shows the changes in position within the queue over time for the visit to shrine/temple Y. The author visited this shrine/temple around 14:00 on January 1, 2023. The author reached the approach to the Main Hall from the nearest train station. There was relatively little queuing initially, so the author was able to proceed freely. The author arrived at the end of the queuing accumulation at point B, approximately 35 m beyond the Torii gate. Subsequently, the author progressed very slowly in a stop-and-go manner [28–30] for more than an hour. Cordons were observed at three locations: (1) just before entering the spacious area with the water ablution pavilion, (2) before the Torii gate and main entrance, and (3) in front of the Main Hall. A wide waiting space at location (1) potentially leads to concentrated flow at location (2). The author presumed that these cordons were put in place to restrict the influx of visitors into the broader square in front of the Torii gate. Cordons at location (3) were to prevent the visitors from rushing to the praying area. The area where visitors seemed to accumulate between point A and the Main Hall was estimated to be approximately 4,200 m^2. The author spent 110.2 min within this area. The density of the crowd was estimated to be 4.5 people/m^2, Therefore, the number of praying visitors per minute can be roughly estimated as $4,200 \times 4.5/100.2 = 188.6$ people/min.

5 Discussion

Both shrines/temples X and Y anticipated that many people would visit during the New Year's holiday, and shrine/temple X expected that the number of visitors would exceed their available space. Therefore, shrine/temple X prepared an extra queuing space by

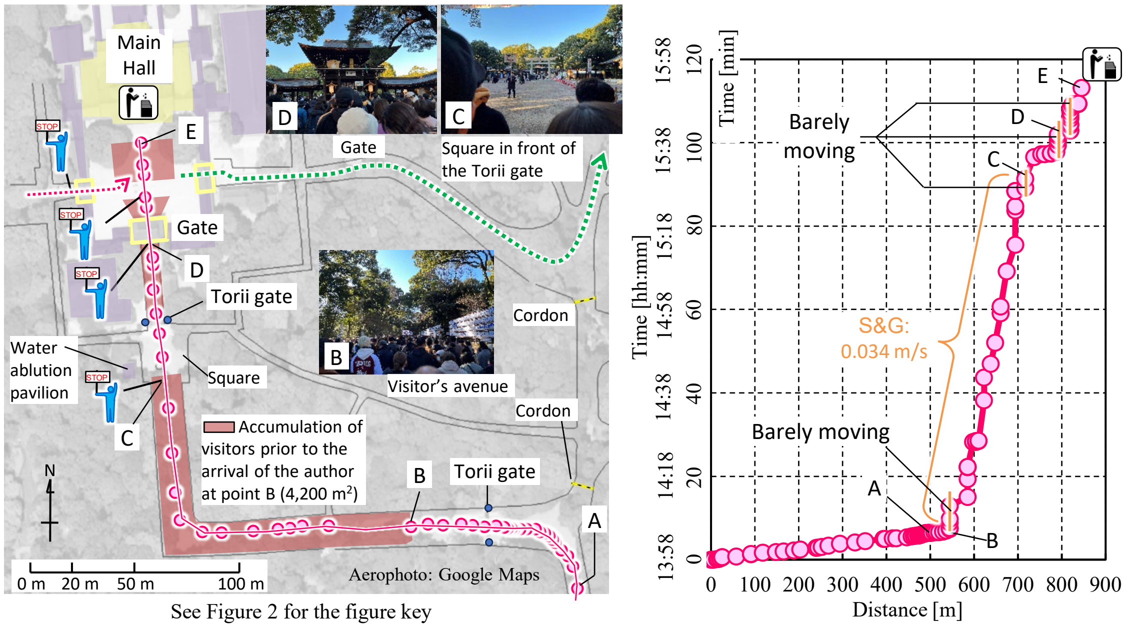

Figure 3 Changes in position within the queue over time during an early afternoon visit to shrine/temple Y on January 1, 2023.

closing the main road at the start of the approach to the Main Hall and deploying cone bars to form a winding path for the queue. Both shrines/temples X and Y used cordons. The purpose of many of the cordons was to direct the flow of visitors and prevent an unsafe increase in crowd density at bottlenecks. However, use of cordons in this way lengthens the queue, which, in turn, requires more queuing space. Shrine/temple Y has a vast premise and a long, wide approach to the Main Hall that can accommodate a substantial number of visitors. In contrast, the premises of shrine/temple X and the approach to its Main Hall are relatively limited in size, so the main road used for vehicle traffic has to be closed if extra queuing space is needed. Characteristics of New Year's visits and building/fire evacuations are compared in Tab. 1. Although, crowd sizes during the New Year's holiday can be estimated based on data from previous years, the actual number of visitors cannot be guaranteed ahead of time because everyone is welcome. In contrast, the number of occupants in enclosed spaces, such as buildings or stadiums, can be estimated according to occupancy limits or controlled by factors such as ticket quantity or available seating. At shrines/temples, the only real limit to visitation is the hours of operation, meaning that not all the total number of visitors who want to visit necessarily can join the prayer activities. On the contrary, during building/fire evacuations, occupants need to evacuate within a short period of time, such as the required safe evacuation time (RSET). During New Year's visits, visitors may feel elated as they welcome the New Year, but they generally follow the directions of the police. In building/fire evacuations, however, deploying staff quickly to guide evacuees is often difficult. Moreover, evacuees may feel rushed during an emergency situation, which could lead to crowd conditions that are unsafe or difficult to control. Countermeasures during New Year's visits include preparing

	New Year's visits	Building/Fire evacuations
Number of visitors/occupants	Uncontrollable / Everyone is welcome	Controllable / Based on number of seats, tickets, or population density
Outflow time limit	Based on closing time	RSET, smoke exposure, etc.
Guidance	Following police instructions is assumed to be easy because it is an non-emergency situation	Evacuees can feel rushed / Difficult to establish a staff instruction system quickly
Countermeasures	Prepare sufficient queuing space using areas such as roads and parks temporarily, in consideration of crowd sizes from previous years.	The degree of accumulation can be designable and controllable by building design, such as bottlenecks and accumulation space

Table 1 Comparison between New Year's visits and building/fire evacuations.

sufficient queuing space using areas such as roads and parks temporarily, in consideration of crowd sizes from previous years. For building/fire evacuations, building configurations such as the widths of doors, corridors, and stairs, and the spaces where evacuees can safely accumulate should be well arranged by designers and engineers during the building design process. These comparisons highlight the importance of recognizing different factors involved in effective crowd management.

6 Conclusion and future work

The author observed New Year's visits to shrines/temples X and Y in Japan. Specifically, the author joined the crowd and measured his position and time using GPS and photo data. These data revealed when, where, and why the crowd could move or was almost stopped. The analyzed crowd behavior was then compared with other crowd behavior, such as during building/fire evacuations. Although both situations involve the flow of people, the controllable and uncontrollable aspects between them differ, suggesting that each event or facility requires a different approach to crowd management. Other than New Year's visits, there are many other types of mass gatherings such as during Halloween, music festivals, fireworks festivals, and religious gatherings. These will also require distinct management approaches. The author hopes to further investigate specific approaches at other types of mass gatherings for a better understanding of safe and effective crowd control.

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