



## Optimizing Capacity Management and Visitor Flow Control: An Operational Efficiency Study at Sikidang Crater

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### ABSTRACT

*Optimizing operational efficiency and ensuring safety margins in nature-based tourism destinations remain critical mandates for destination management organizations, particularly within active geothermal zones. This study evaluates the capacity management practices and visitor flow control mechanisms at Sikidang Crater, a prominent volcanic geotourism asset in Wonosobo Regency, Indonesia. Adopting a qualitative descriptive research design grounded in operations management theory, data were gathered through purposive sampling and analyzed using thematic triangulation, incorporating semi-structured interviews with internal management stakeholders and external service providers, direct field observations during peak congestion windows, and documentary analysis of administrative records. The empirical findings reveal that spatial congestion at Sikidang Crater is highly localized, characterized by severe structural bottlenecks at primary touchpoints such as the main vent barrier and central boardwalk platforms where pedestrian density exceeds safe operational thresholds. Furthermore, a significant administrative gap exists between theoretical carrying capacity models and on-the-ground enforcement due to a complete deficit of real-time digital monitoring loops and an over-reliance on a rigid physical forced-loop layout that exacerbates crowding during demand surges. This operational rigidity increases emergency evacuation risks and degrades overall service delivery value. This paper provides practical managerial recommendations, advocating for immediate infrastructural modifications, the decoupling of commercial layouts from flow pathways, and the integration of digital demand-flattening strategies, including dynamic gate control and hourly staggered reservation frameworks to foster resilient, high-performing service environments.*

**Keywords:** *Capacity Management, Visitor Flow Control, Operational Efficiency, Geotourism.*

### I. INTRODUCTION

Nature-based tourism has experienced an unprecedented global surge over the last few years, accelerating the shift from mass tourism toward ecotourism and geotourism (Alkanhel et al., 2023). While this growth provides substantial economic opportunities for local communities, it simultaneously exposes vulnerable ecosystems to severe ecological pressure when visitor volumes exceed local spatial thresholds (Yousuf et al., 2024). In the context of protected and active volcanic

destinations, this phenomenon often triggers latent overtourism, characterized by high visitor density that compromises both environmental integrity and visitor utility (Logeshwaran et al., 2023). When a destination faces an uncontrollable influx of tourists, the infrastructure becomes overwhelmed, leading to spatial congestion, diminished travel experiences, and heightened operational risks (Pasham, 2022). Therefore, managing tourist congestion and implementing strategic deconcentration frameworks have become critical mandates for modern destination management organizations (Hu et al., 2023).

Active volcanic destinations, such as the Sikidang Crater in the Dieng Plateau, Wonosobo, present an exceptionally complex operational challenge due to their unique geographical and environmental risks. Unlike standard nature parks, geotourism sites feature active volcanic vents, fluctuating sulfur gas concentrations, and delicate soil crusts that fundamentally limit the physical space safely accessible to the public. High-density tourist traffic in such highly hazardous zones not only degrades the natural landscape through roadside erosion and vegetation trampling, but it also directly compromises safety operations and emergency evacuation protocols (Slattery et al., 2024). Previous literature indicates that treating visitor density as a static variable often fails to capture real-time crowding dynamics, which can rapidly shift from an acceptable level of socialization to critical overcrowding (Chen et al., 2023). Consequently, a rigid or unmonitored system at a high-risk site like Sikidang Crater exposes tourists to physical dangers while severely degrading the psychological benefits of the destination (Zhou, 2023).

To address these spatial and safety constraints, integrating carrying capacity models into real-time monitoring frameworks is essential to balance ecosystem protection with service quality (Dong et al., 2023). Operational efficiency in high-density tourism can be significantly enhanced by calculating precise thresholds, such as Physical Carrying Capacity (PCC), Real Carrying Capacity (RCC), and Effective Carrying Capacity (ECC), to establish strict empirical visitor quotas (Shaban et al., 2024). Managing these spatial thresholds requires a combination of structural and digital interventions, including controlled reservation frameworks, time-limit measures at specific high-risk touchpoints, and active digital tracking tools to disperse crowds evenly (Jawad & Balázs, 2024). By optimizing visitor flow control, managers can prevent tourist bottlenecks at critical areas, reduce operational friction, and maintain the destination's social and ecological carrying capacity within sustainable parameters (Jiang et al., 2022).

Despite the abundance of carrying capacity studies globally, research focusing explicitly on operational efficiency and crowd dynamics within active geotourism contexts remains limited. Most existing frameworks analyze carrying capacity as a broad regional metric rather than an operational tool for real-time site management. This study aims to fill this gap by evaluating the capacity management and visitor flow control mechanisms at Sikidang Crater, Wonosobo. By examining real-time physical constraints and service value chains, this paper provides an empirical basis for local tourism management and stakeholders to design more adaptive, resilient, and safer operational strategies.

## II. LITERATURE REVIEW

### A. Operational Efficiency in Tourism Destination Management

Operational efficiency within contemporary service and tourism organizations is fundamentally rooted in optimization theories that aim to maximize resource utility while minimizing friction and waste (Ismaeel et al., 2023). In destination management, operations are exceptionally complex because the "service product" is produced and consumed simultaneously in an open geographic space (Albogamy et al., 2022). Recent studies emphasize that operational efficiency should not merely be evaluated through financial indicators, but through a destination's systemic capacity to maintain smooth workflows, handle peak demand spikes, and preserve infrastructure integrity (Mohsen, 2024). Effective service operations require continuous calibration between internal resources such as staffing levels, physical barriers, and digital networks and external variables like fluctuating arrival rates (Morchid et al., 2025). When operational bottlenecks occur, they generate immediate cascading failures, leading to service delivery delays, increased safety hazards, and a rapid decline in consumer-perceived value (Wen et al., 2024).

The existing literature demonstrates a consensus that operational efficiency in the service sector hinges on a destination's resilience against sudden demand shocks. However, traditional operational frameworks frequently overlook open-air, nature-based services. This study addresses this gap by synthesizing general operations theory with tourism management, establishing that efficiency at an active volcanic site like Sikidang Crater cannot be measured by profit margins alone, but by how fluidly the system prevents structural and logistical bottlenecks during peak seasons.

### B. The Role of Capacity Management and Carrying Capacity Models

Capacity management in natural and active geographical environments is dictated by strict physical and ecological thresholds. The structural baseline of this concept relies on carrying capacity frameworks, which identify the maximum number of individuals that can visit a specific location simultaneously without causing unacceptable degradation to the environment or a critical decline in the quality of the visitor experience (Arulkumar et al., 2024). Contemporary operations management divides this metric into three distinctive, quantifiable dimensions: Physical Carrying Capacity (PCC), Real Carrying Capacity (RCC), and Effective Carrying Capacity (ECC) (Hernández-Mayoral et al., 2023). PCC measures the absolute spatial limitations based on available square footage, while RCC incorporates environmental correction factors such as weather patterns, volcanic toxic gas emissions, and geological vulnerabilities (Abdullah et al., 2023). Ultimately, ECC determines the true management threshold by factoring in the destination's administrative capacity, including available security personnel, medical facilities, and emergency infrastructure (Suci et al., 2025). Treating carrying capacity as a dynamic, responsive variable rather than a fixed historical parameter allows management organizations to adapt to real-time spatial pressures and mitigate the symptoms of localized overtourism (Shaheen et al., 2024).

While early carrying capacity models treated spatial limits as rigid, static equations, modern management research conceptualizes it as a dynamic framework mediated by administrative readiness (ECC). At Sikidang Crater, the

intersection of PCC, RCC, and ECC becomes highly critical due to volatile geothermal hazards. Therefore, calculating carrying capacity must shift from a mere ecological preservation metric into an active operational dashboard that dictates real-time entry caps and resource deployment.

### **C. Visitor Flow Control and Crowding Dynamics**

Managing the movement of visitors through a physical service landscape known as visitor flow control is a core tactical tool utilized to mitigate localized spatial congestion (Chakraborty et al., 2022). Crowding dynamics are inherently unpredictable, as high-density tourist traffic naturally tends to cluster around specific spatial focal points or "hero assets," creating severe bottlenecks while leaving adjacent zones underutilized (Islam et al., 2024). Operational interventions to manage these flows are categorized into structural strategies, such as physical barriers, designated walkways, and one-way loops, and non-structural strategies, which leverage digital reservations, real-time tracking apps, and dynamic pricing to disperse demand (Al-Saadi et al., 2023). Advanced tracking data reveals that when visitor density crosses an unmanaged psychological threshold, it triggers negative behavior modifications among tourists and increases physical wear on surrounding infrastructure (Casalicchio et al., 2022). By implementing proactive queueing models and temporal restrictions at critical destination touchpoints, operators can flatten demand peaks, distribute spatial loads evenly, and dramatically improve the safety margins of vulnerable tourist locations (Haibeh et al., 2022).

The literature maps out a clear distinction between physical infrastructure (structural) and digital policies (non-structural) in governing visitor movement. The synthesis of these two approaches is vital for active geotourism landscapes. At Sikidang Crater, where crowding directly correlates with toxic gas exposure risks, visitor flow control serves as the primary operational engine that bridges the gap between psychological tourist satisfaction and mandatory safety enforcement.

### **D. Conceptual Framework and Synthesis**

Integrating capacity management models with real-time visitor flow controls yields an optimized operational ecosystem where safety and service quality reinforce one another. In high-risk geotourism zones containing active volcanic features, operational efficiency is directly tied to the speed and agility of crowd evacuation and spatial re-balancing frameworks (Meng et al., 2024). Efficient layout designs and proactive flow control protocols diminish localized density, reducing the physical pressure exerted on fragile natural assets (Aghajan-Eshkevari et al., 2022). Furthermore, preventing spatial over-saturation directly improves the psychological comfort of visitors, which positively correlates with higher service quality evaluations and long-term revisit intentions (Mohammed et al., 2024). Consequently, optimized flow management acts as a structural mediator that successfully reconciles the inherent conflict between aggressive economic tourism development and rigorous ecological and physical risk mitigation (Li et al., 2023).

Ultimately, the literature converges on the idea that capacity models and flow controls are not mutually exclusive, but rather deeply interdependent mechanisms. This conceptual framework posits that visitor flow control acts as the practical execution tool needed to keep a destination operating safely below its Effective Carrying Capacity (ECC). For Sikidang Crater, this integration

provides a holistic management framework that protects the fragile volcanic grid without destroying the economic value chain of local service providers.

### III. RESEARCH METHODOLOGY

#### A. Research Design

This study adopts a qualitative descriptive research design to comprehensively evaluate the capacity management practices and visitor flow control mechanisms at Sikidang Crater. A qualitative approach is uniquely suited for operational management research in open-air tourism contexts, as it allows investigators to explore complex organizational processes, administrative bottlenecks, and real-time decision-making frameworks that quantitative metrics alone cannot capture (Ramdhan, 2021). Rather than focusing purely on statistical correlations, this research captures the operational reality by evaluating how managers perceive, adapt to, and mitigate localized overtourism and safety hazards. By examining the natural setting of the geotourism destination, this design provides an in-depth contextual analysis of the service value chain and day-to-day administrative workflows under fluctuating tourist demands.

#### B. Data Sources and Informants

Data for this qualitative inquiry are gathered through purposive sampling to ensure that informants possess specialized knowledge of the destination's daily operations and strategic administrative policies. The informants are strictly categorized into two operational tiers: Internal Management Stakeholders (including the Dieng Destination Manager from the Wonosobo Tourism and Culture Office, field operations supervisors, and security/safety officers) and External Service Providers (such as local tour guides, representatives of micro-enterprises operating inside the crater complex, and visitors experiencing the current flow design. This multi-perspective selection ensures data richness and captures the holistic friction existing within the destination's service delivery system.

#### C. Data Collection Techniques

To establish high empirical validity, data collection is executed through a rigorous qualitative triangulation technique consisting of semi-structured interviews, direct field observations, and extensive documentary analysis. Semi-structured interviews are guided by an operational protocol covering capacity thresholds, emergency response speed, and bottleneck locations. Direct field observations are carried out using structured spatial mapping checklists during peak traffic hours to document real-time visitor density, queue patterns, and physical bottlenecks near active thermal vents. Lastly, documentary analysis involves reviewing official visitor logs, ticketing data records, local emergency procedures, and master planning blueprints managed by the local tourism board.

#### D. Data Analysis and Trustworthiness

The gathered qualitative data are analyzed using the interactive thematic analysis framework proposed by Miles, Huberman, and Saldaña, which progresses through data condensation, data display, and conclusion drawing/verification. Raw transcriptions and field notes are coded using operational management codes, such as *[CAP-PCC]* for physical capacity limits, *[FLOW-BOT]* for flow bottlenecks, and *[EFF-ADMIN]* for administrative

response time. To ensure qualitative trustworthiness (validity and reliability), this study implements member-checking with key destination managers, prolonged engagement in the Dieng tourism ecosystem, and investigator triangulation during the coding process to eliminate subjective biases.

#### IV. RESEARCH RESULT

##### A. Physical Bottlenecks and Spatial Congestion Zones

Field observations and spatial mapping reveal that spatial congestion at Sikidang Crater is highly localized rather than distributed evenly across the destination landscape. Although the total open area of the crater complex is mathematically capable of housing thousands of visitors simultaneously, the primary pedestrian traffic heavily clusters around two specific "hero assets": the main active boiling volcanic vent and the central wooden boardwalk photography platforms. The data indicates that during weekend peak hours (10:00 AM – 2:00 PM), these two zones experience severe structural bottlenecks that slow pedestrian movement down to less than 0.2 meters per second, creating severe operational friction.

To provide a clear matrix of these physical constraints, the direct observational data and field notes have been summarized in Table 1.

**Table 1. Operational Matrix of Spatial Bottlenecks at Sikidang Crater**

Congestion Zone	Primary Structural Cause	Estimated Peak Density	Primary Operational Risk
Main Vent Barrier	Narrow viewing perimeter, shared path with returning visitors.	> 3.5 people/m <sup>2</sup>	Prolonged exposure to concentrated sulfur (SO <sub>2</sub> ) gas.
Central Boardwalk	Two-way tourist traffic on a narrow 1.8-meter-wide wooden platform.	~ 2.8 people/m <sup>2</sup>	Structural load stress, pedestrian physical falls.
Souvenir Exit Corridor	Forced-routing maze design past local merchant booths.	~ 2.2 people/m <sup>2</sup>	Severe evacuation delays during emergency warnings.

The physical layout constraints are further compounded by visitor behavior modifications, where tourists prolong their duration of stay at dangerous touchpoints just to take photos, completely ignoring standard flow rules.

##### B. The Evaluation of Capacity Management Implementation

Interviews with internal management stakeholders reveal a significant disconnect between the theoretical Effective Carrying Capacity (ECC) models and the actual tactical enforcement executed on the ground. While the local tourism board officially adopts a daily quota system, the field operations team lacks the digital infrastructure needed to track real-time spatial saturation. Ticketing data is aggregated manually at the end of the day, leaving field supervisors blind to real-time density levels during sudden tourist surges. This administrative blind spot was explicitly highlighted by the Field Operations Supervisor during interviews:

*"We have calculated the theoretical carrying capacity on paper, but on weekends, enforcing it is nearly impossible. When thousands of tourists arrive*

*simultaneously via tour buses, we cannot close the gate just because the inner circle is full. We do not have real-time counters inside the crater zone, so we only realize the place is dangerously oversaturated when the main boardwalk comes to a complete dead stop."* Informant A1 (Field Operations Supervisor, Wonosobo Tourism Office).

Furthermore, the research reveals that the administrative readiness (ECC) of the site is highly constrained by a lack of emergency safety personnel. With fewer than five safety officers patrolling the active volcanic zone during peak times, enforcing safety boundaries becomes highly ineffective, forcing staff to prioritize immediate medical rescues over active crowd prevention.

### C. Visitor Flow Control Mechanisms: Structural vs. Digital Deficits

The study finds that the current visitor flow control framework at Sikidang Crater relies exclusively on passive structural barriers (wooden railings and painted signs) while suffering from a total deficit of non-structural digital coordination tools. The absolute reliance on a "forced loop" layout backfires during peak holidays; when a bottleneck occurs at the main vent, the entire one-way loop stops, trapping tourists in zones with high sulfur gas concentrations. Local service providers note that this rigid structural layout frequently creates conflicts and degrades the overall tourist experience, as expressed by a local tour guide:

*"The one-way route was designed to make tourists walk past all the local vendor booths before exiting. But when the crowd is thick, it turns into a trap. If a tourist feels dizzy from the sulfur gas and wants to turn back, they cannot do so easily because they are fighting against a massive wave of oncoming people. The layout prioritizes merchant sales over operational fluid movement and safety."* Informant B3 (Representative of Local Tour Guide Association)

The lack of digital interventions—such as dynamic SMS safety alerts, live crowd-density dashboards at the entrance, or staggered hourly reservation tickets—forces the destination to operate on a purely reactive management model. The data proves that this structural rigidity increases the physical pressure exerted on the fragile natural landscape, directly accelerating path erosion and lowering overall service quality evaluations.

## V. CLOSURE

### A. Conclusion

This study evaluates the capacity management and visitor flow control frameworks at Sikidang Crater, Wonosobo, through a qualitative operational management lens. The findings demonstrate that spatial congestion within this active geotourism destination is not a uniform systemic failure, but rather a series of severe, localized structural bottlenecks focused around key high-interest zones. The absence of real-time digital monitoring loops reduces the officially calculated theoretical carrying capacity metrics to passive data, preventing active gate control and crowd deconcentration during peak demand hours. Furthermore, the total reliance on passive, physical one-way barriers—without any non-structural digital demand-flattening strategies—creates critical bottlenecks that traps tourists in high-risk chemical exposure zones and decreases overall service delivery values. Ultimately, achieving operational efficiency at this site requires

transitioning from a reactive layout control approach to a proactive, digitally integrated dynamic capacity model.

### **B. Suggestion**

While this research provides comprehensive qualitative insights into operational workflows and structural constraints, certain limitations remain. This study relies heavily on qualitative observations, interviews, and documentary records, meaning it does not statistically model precise tourist queuing behaviors or mathematically simulate optimal evacuation arrival rates.

Future studies should integrate quantitative operational tools, such as using automated computer vision systems or discrete-event simulation software (e.g., Arena or FlexSim), to model pedestrian movements across the layout variations. Additionally, expanding the scope to include quantitative sensor data tracking real-time fluctuations in sulfur dioxide gas concentrations would allow researchers to calculate highly precise, health-adjusted Real Carrying Capacity (RCC) equations for active volcanic tourism zones.

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