Assessing Beach Carrying Capacity: Appling Object Detection Technology at Sai Kaew Beach, Koh Samet Thailand

Chomchid P. [1*], Kunlasatee P.[1], Benjamapawn K.[1] Nanticha P.[1] and Punyanut T. [1]

[1] Kasetsart University, Department of Geography, Faculty of Social Science, Bangkok, Thailand

*fsoccci@ku.ac.th

Abstract *Coastal destinations worldwide are experiencing unprecedented tourism growth, intensifying the challenge of balancing economic benefits with environmental sustainability. Carrying capacity assessment has become a critical tool for ensuring that visitor numbers do not exceed the ecological and social limits of a destination. In Thailand, Sai Kaew Beach on Koh Samet is among the most visited coastal areas, facing mounting pressures from high visitor density. Traditional manual counting methods for estimating beach carrying capacity are often labor-intensive, susceptible to human error, and potentially disruptive to the visitor experience, highlighting the need for more efficient and accurate approaches. This study applies Mask R-CNN, an advanced deep learning–based object detection framework, to quantify visitor numbers using high-resolution images captured in situ. Without interfering with beach activities, the model delivered high detection performance, achieving an accuracy of 96.44%, a precision of 96.50%, and a recall of 92.16%. Analysis of the people-at-one-time (PAOT) metric revealed an average of approximately 4,048 visitors per day within an 8,580 m² area—exceeding the estimated Physical Carrying Capacity (PCC) by 89.16%. Such an exceedance indicates a sustained risk of environmental degradation, overcrowding, and reduced visitor satisfaction if current visitation levels persist. The findings carry important implications for policy and management. Real-time, image-based monitoring using Mask R-CNN can serve as a scalable and non-intrusive decision-support tool for tourism authorities. By integrating automated detection into regular monitoring systems, managers can better anticipate peak loads, implement targeted interventions such as timed entry or zoning, and develop adaptive strategies to maintain both environmental quality and the visitor experience. This research demonstrates that advanced object detection technology can enhance the precision and efficiency of carrying capacity assessments, offering a viable pathway for sustainable tourism management in high-demand coastal destinations. The methodological framework presented here is transferable to other contexts, supporting global efforts to balance tourism growth with the long-term resilience of fragile coastal ecosystems.*

Keywords: *Carrying capacity, Object detection, Sai Kaew Beach, Koh Samet, Thailand*

Introduction

Tourism is a significant economic driver in many countries, enhancing people's lives and supporting local communities. Among various tourism sectors, beach tourism plays a crucial role in attracting both domestic and international visitors, generating revenue from entrance fees, accommodations, restaurants, and water-based activities. It also creates job opportunities for local communities in tourism-related services, such as local guides, hotel staff, and boat operators. (Astina et.al., 2021)

Despite these economic and social benefits, beach tourism also presents environmental challenges. One major concern is its contribution to carbon emissions through transportation, resort energy consumption, and waste generation, which in turn accelerates global warming. Beach tourism activities have profound effects on coastal and marine ecosystems, putting natural resources at risk. For instance, sunscreen containing harmful chemicals can damage coral reefs and marine life, while walking on or anchoring boats in coral reef areas can degrade reef structures and reduce biodiversity.(National Oceanic and Atmospheric Administration, 2020) Additionally, plastic waste from food and beverage packaging is a leading cause of marine pollution, further threatening the coastal environment. Beyond marine pollution, human activities on the beach itself can disrupt natural coastal processes. Beach sports, walking, and other recreational activities may affect the stability of coastal structures, accelerating coastal erosion over time. Furthermore, beach tourism often leads to issues such as over-tourism, detrimental wildlife interactions, and excessive waste accumulation, all of which pose serious conservation challenges. Addressing these concerns requires a clear understanding and effective management of the carrying capacity of tourist destinations (Basterretxea-Iribar et al., 2019).

Samet Island, or Koh Samet, located in Rayong Province, is a highly significant marine national park in Thailand, renowned for its well-preserved coastal resources. The island boasts several breathtaking beaches, with Sai Kaew being the most spectacular. These coastal resources serve as a crucial component of the ecosystem while simultaneously attracting a large number of tourists. Although the COVID-19 pandemic caused a temporary pause in tourist activity, the number of visitors to national parks in Thailand reached an impressive 20,819,396 during the fiscal year 2019, (October 2018 – September 2019) with 14.9 million Thai and 5.3 million foreign tourists. (Department of National Parks, Wildlife and Plant Conservation, 2020.) Samet Island, in particular, was Thailand's most popular tourist destination that year, welcoming 1,619,908 visitors. Koh Samet has many popular beaches, but one of the most famous is Hat Sai Kaew. It is well-known for its long shoreline, soft white sand, and clear water. Because of this, the area has the most facilities, such as hotels and restaurants, to serve visitors. (Department of National Parks, Wildlife and Plant Conservation, 2020.) Like many other beaches in the tourism industry, Koh Samet faces challenges in balancing the growth trend of the industry with the environment's capacity to sustain tourism and visitor satisfaction. However, a clear understanding of sustainability and carrying capacity in tourism can help achieve tourism and sustainable development

Overtourism occurs when visitor numbers surpass a destination's carrying capacity, leading to environmental degradation, resident discomfort, and a diminished tour experience. The concept of carrying capacity, defined by the World Tourism Organization (WTO) and the United Nations Environment Programme (UNEP) as the maximum number of tourists a destination can handle without harm, is crucial for sustainable tourism management. (Castellani et.al, 2012) This framework assesses the limits of tourist activity across economic, social, ecological, and physical dimensions, ensuring resources are not degraded and visitor satisfaction remains high (Castellani et al.,2007). Several studies in Thailand have indicated that during the COVID-19 pandemic, reduced travel and a decline in tourist numbers contributed to the recovery of marine resources. For instance, research conducted at Patong Beach, Phuket, found that the cessation of tourism activities led to an improvement in environmental conditions, including a positive trend in biochemical oxygen demand (BOD) levels in wastewater. (Isarangkun Na Ayutthaya, 2021)

Assessing carrying capacity is essential for managing ecological systems and tourism destinations, encompassing economic, social, ecological, and physical aspects. (Ajuhari, 2023) Physical carrying capacity (PCC) refers to the maximum number of visitors sustainable within a specific area, like a beach. Determining PCC is challenging due to the traditional reliance on manual visitor counts, which are time-consuming and impractical. Therefore, innovative methodologies are needed for effective PCC evaluation. In coastal areas, the assessment of carrying capacity represents the threshold at which a beach's resources, environment, and infrastructure can no longer sustainably support the number of visitors and activities.

In Thailand, the assessment of carrying capacity in national parks is conducted regularly. (Panpumpho, 2024) However, the evaluation of Physical Carrying Capacity (PCC) still primarily relies on manual visitor counting. (Aphihirantrakun, 2023) This method is prone to several limitations, including human error due to fatigue, leading to miscounting or duplication. The mobility of visitors further contributes to inaccuracies, as individuals frequently move in and out of designated areas, increasing the likelihood of overcounting or undercounting. Additionally, in large areas, a significant number of staff is required, resulting in resource inefficiency. During peak visitation periods, crowd density may obstruct visibility, further compromising the accuracy of manual counting. Therefore, to enhance the accuracy and efficiency of carrying capacity assessment, the adoption of modern technology should be considered. Utilizing advanced tools can help minimize errors associated with manual counting and improve the precision of data collection, making it a promising alternative.

Technological advancements, particularly in computer vision, are pivotal in evaluating carrying capacity. Object detection models like Mask R-CNN can efficiently count and monitor visitor numbers, overcoming the limitations of manual counting methods and ensuring data accuracy (Lee,2021). This technology enhances the accuracy and efficiency of carrying capacity assessments, crucial for managing tourist destinations like Sai Kaew Beach in Thailand, where maintaining ecological integrity and balancing visitor load is essential.

This study explores the application of object detection technology, specifically the Mask R-CNN model, to identify and track human visitors in camera images captured at Sai Kaew Beach. By accurately classifying and locating objects within the beach area, this approach aims to provide valuable insights into the potential carrying capacity (PCC) of Sai Kaew beach, facilitating sustainable tourism planning and management. The findings of this study contribute to the existing body of research on tourist carrying capacity assessment and shed light on the utilization of computer vision technologies in environmental and geographic studies. The ultimate objective is to advocate for responsible tourism practices that preserve the ecological and environmental integrity of Sai Kaew beach and similar coastal destinations.

Study Area

Koh Samet, part of the Khao Laem Ya – Mu Ko Samet National Park, is located in Ban Phe Subdistrict, Mueang Rayong District, in the southern part of Rayong Province. Situated about 6.5 kilometers from the coastline and approximately 200 kilometers from Bangkok, (Figure 1) this small island is a well-known tourist destination, attracting both Thai and international visitors (Department of National Parks, Wildlife and Plant Conservation 2020).

Khao Laem Ya – Mu Ko Samet National Park is classified as a coastal and marine national park located along the eastern Gulf of Thailand. The landscape features granite mountains, with elevations reaching up to 108 meters above sea level. On Ko Samet, the terrain consists of low hills and slopes, with the western side being steeper than the eastern side. The eastern coastline is characterized by long, continuous sandy beaches, with the widest section in the north measuring approximately 2,500 meters and extending 6,500 meters toward the southern end of the island. The central area consists of gently rolling hills, while flatlands along the northern and eastern shores serve as residential and commercial zones. (Department of National Parks, Wildlife and Plant Conservation 2025) Despite its size, Koh Samet boasts 15 beaches, with Sai Kaew Beach being the most popular. The beach located in the northern part of the island, features fine white sand and is free of rocky formations. Visitors can enjoy a range of marine activities, including snorkeling, scuba diving, coral viewing, and kayaking. With its natural beauty and vibrant coastal environment, Koh Samet remains a key destination for those seeking a seaside escape in eastern Thailand.

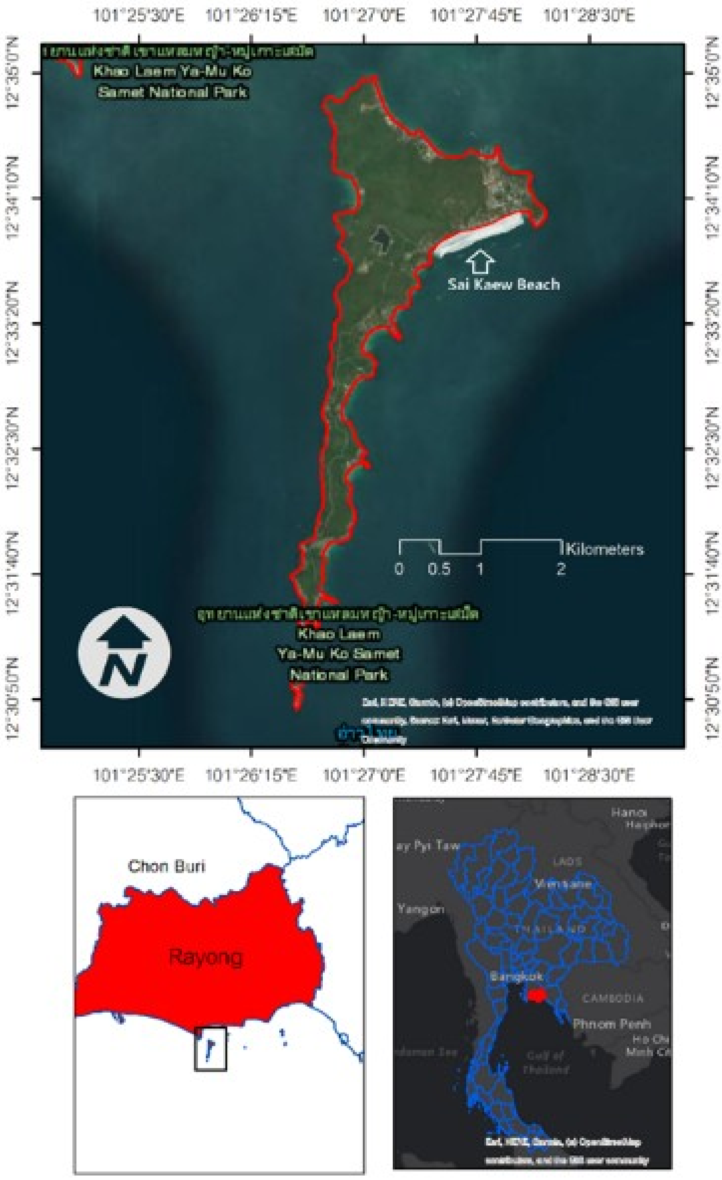

Figure 1: Example of a Figure Caption.

The study focuses on Sai Kaew Beach, the most developed beach on Koh Samet, drawing mass tourists. The beach spans about 8,580 m², with a width of 13 meters and a length of 660 meters. The beach area is divided into a dry beach zone for sunbathing and relaxing and a wet beach zone for swimming and water activities. The division of the beach into wet beach and dry beach is influenced by tidal fluctuations throughout the day. This study uses the arrangement of beach chairs as a reference and marks the designated areas with GPS, defining the boundaries of the dry beach and wet beach based on fixed reference points. Researchers collected data by walking along the beach, capturing images every 200 meters on December 2019 and February 2020. (Figure 2)

Figure 2 Left image: photo capture path and right image: beach boundary for photography. (source: research study)

Methodology

a. Apply Mask R-CNN:

This study demonstrates the use of the Mask R-CNN algorithm to determine the Physical Carrying Capacity (PCC) of a beach. The Mask R-CNN model classifies targets, such as humans and objects, enabling accurate identification and tracking. By counting detected individuals, it estimates visitor activity levels and assesses the beach's carrying capacity. Data collection involved four daily walks, each lasting about three hours, covering different beach sections. The captured images were processed using the Mask R-CNN model to classify targets and track individuals. This data allowed for categorizing the beach's capacity levels as below capacity, approaching capacity, exceeding capacity, or over capacity. By applying the Mask R-CNN algorithm, gathering extensive data, and assessing PCC levels, this study provides a comprehensive method for managing tourist activities at the beach. The research process's sequential steps are illustrated in Figure 3.

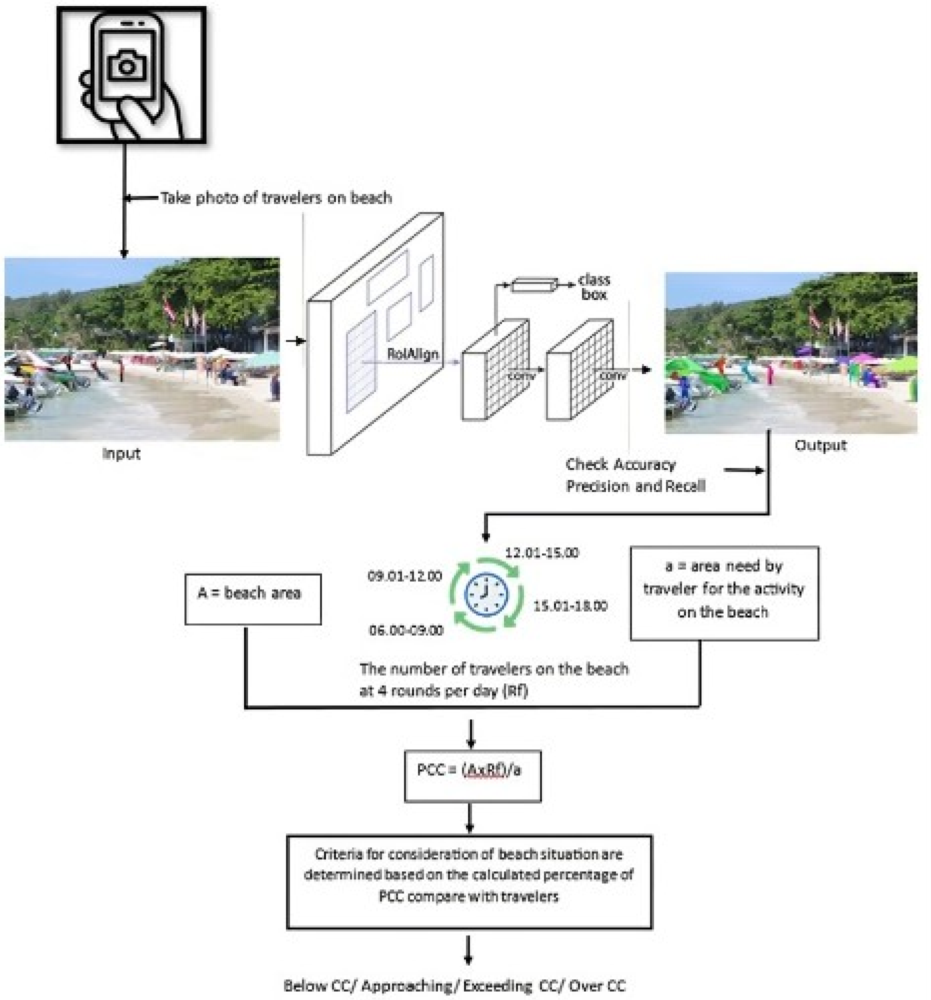

Figure 3 Research methodology framework.

Mask R-CNN, a powerful model developed in 2017 (He et.al.,2017), excels in object detection, recognition, and segmentation, offering high speed and accuracy. Its structure involves two key steps: first, generating candidate regions of interest (ROI) using a region proposal network (RPN) to reduce computational complexity. The RPN identifies potential object areas based on pre-defined bounding boxes. Second, Mask R-CNN refines initial region proposals by simultaneously predicting class labels, bounding box offsets, and binary masks. This step involves convolutional and fully connected layers to perform classification, bounding box regression, and mask prediction in parallel, enabling precise segmentation of objects at the pixel level. By combining these processes, Mask R-CNN achieves remarkable accuracy in object detection tasks, making it widely adopted across various fields.

This study employed a streamlined and efficient implementation of the Mask R-CNN algorithm to enhance the precision and efficiency of tourist detection on Sai Kaew Beach.The accuracy of the outcomes was assessed and quantified using a confusion matrix. The confusion matrix serves as a crucial evaluation tool for gauging the performance of classification programs in solving complex classification problems (Wang et.al., 2020)

- True Positive (TP): Program predicts true and actual result is true.
- True Negative (TN): Program predicts false and actual result is false.
- False Positive (FP): Program predicts true but actual result is false.
- False Negative (FN): Program predicts false but actual result is true.

The objective is to achieve accuracy and precision both exceeding 90 %, along with recall, while detecting breeding grounds. These metrics serve as key performance indicators and acceptance criteria. Certainly, here are the equations for calculating Accuracy, Recall (Sensitivity) and Precision (Positive Predictive Value), using the True Positive (TP), True Negative (TN), False Positive (FP), and False Negative (FN) values: (Phromsin. and et.al 2023)

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN} \quad (1)$$

$$\text{Precision} = \frac{TP}{TP + FP} \quad (2)$$

$$\text{Recall} = \frac{TP}{TP + FN} \quad (3)$$

b. Calculating the Physical Carrying Capacity:

The physical carrying capacity (PCC) determines the maximum number of visitors an area can accommodate at a given time. In this study, PCC refers to the maximum number of Thai and foreign tourists Sai Kaew Beach can sustain. Using Equation 4, this study quantifies the PCC, offering insights into the optimal visitor numbers for sustainable tourism management. This balance ensures visitor satisfaction while preserving the beach's ecological integrity.

$$\text{PCC} = \frac{(A \times Rf)}{a} \quad (4)$$

To calculate the PCC, Eq (4) is employed, building upon previous research (Zacarias et al., 2011, Insani et.al.,2020 and Setiadji et.al., 2022). This equation incorporates various factors and parameters that contribute to assessing the beach area's capacity:

- PCC: Physical Carrying Capacity, the maximum number of visitors that a specific area can accommodate within a given period.
- A: The area used for tourism or the beach area.
- a: The space one tourist requires for beach activities. In this study, a value of $10m^2$ per user is utilized. A general guideline for beach carrying capacity suggests allowing at least 10 square meters (m^2) of beach area per person to maintain a comfortable and sustainable experience. (Zacarias et.al., 2011) and Diniz et.al., 2024) Figure 4
- Rf: The number of times a person may visit the beach in a day, considering the visitation schedule and the time required for each visit.

By incorporating these variables, the equation provides a quantitative estimation of the maximum number of visitors the beach area can accommodate within a given time frame. This information is crucial for managing tourism activities and ensuring a balance between visitor enjoyment and the preservation of the beach's ecological and environmental integrity.

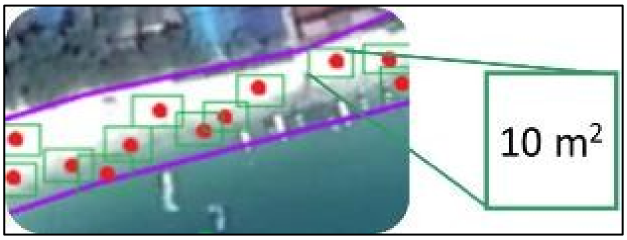

Figure 4 Breadth per Visitor for Beach Activity

The Rf in this study is calculated using the Eq (5):

$$Rf = \frac{TT}{Ta} \tag{5}$$

The parameters "TT" and "Ta" in the equation are crucial for understanding the physical carrying capacity (PCC) of Sai Kaew Beach:

- TT (Total Time): This represents the total hours visitors are active on the beach, set at 12 hours from 06:00 to 18:00. This ensures comprehensive data collection on visitor behavior throughout the day. (Huamantinco et.al.,2016, and Isarangkun Na Ayutthaya and Yasane, 2021)
- Ta (Activity Time): This is the time an individual spends on beach activities, set at 3 hours per person per day, reflecting the average time spent by visitors. (Huamantinco et.al.,2016, and Isarangkun Na Ayutthaya and Yasane, 2021 and Arinta, 2022) In the study of time allocation for sea-related activities, various durations were observed, ranging from 45 minutes to 3 hours, depending on the location. For this study, Rf is 4.

These parameters help calculate the PCC, which categorizes the beach's utilization into four levels:

- Over CC: This category indicates that the daily number of visitors on the beach exceeds the defined Physical Carrying Capacity (PCC). It implies that the beach is accommodating more visitors than it can sustainably handle within a given period.
- Exceeding CC: This category represents a situation where the daily number of visitors on the beach falls between 81% and 100% of the PCC. It signifies a high level of visitor activity approaching the maximum carrying capacity.
- At & Approaching CC: This category signifies that the daily number of visitors on the beach ranges from 50% to 80% of the PCC. It indicates a moderate level of visitor activity, suggesting that the beach is operating at a sustainable level close to its carrying capacity.
- Below CC: This category indicates that the daily number of visitors on the beach is less than 50% of the PCC. It suggests a low level of visitor activity, indicating that the beach has the capacity to accommodate more visitors without reaching its maximum capacity.

By categorizing the PCC into these levels, the study aims to provide a clear understanding of the current state of visitor utilization on the beach. This information is crucial for effective management and planning of tourism activities, ensuring that the beach's carrying capacity is maintained and potential negative impacts are minimized.

Results and Discussion

a. Tourist detection using Mask R-CNN:

This study utilized the Mask R-CNN algorithm to detect human bodies in images. A representative image from a dataset of photos taken with iPhone 7 and 8 (12 MP cameras) was selected, and the algorithm successfully marked human bodies with precise segmentation masks. Images were captured along the beach at 200-meter intervals from 06:00 to 18:00, ensuring comprehensive coverage and capturing variations in visitor density and activities throughout the day. In the photography planning process, the area is divided into 200-meter sections for image capturing. Each 200-meter section is assigned a designated observer. Clear reference points, such as entry and exit points, are marked to aid in counting and to cross-check with manual counting to minimize errors.

The visualization results of this experiment are shown in Figure 5. A typical image is selected from the dataset, and the human bodies in the image are marked correctly with a rectangular frame. The program is improving its ability to identify people in complex scenarios, such as distinguishing individuals in crowds or identifying piggyback rides. Figure 5 presents the results of a model training test, which yielded satisfactory outcomes. The detection confidence was set at 0.9. Analysis of Figure 5 indicates that when a full-body person is detected, the confidence score for classifying the object as "person" exceeds 0.9. However, in cases where only part of a person is visible, such as in the sea, the confidence score decreases to approximately 0.7 but is still classified as "person."

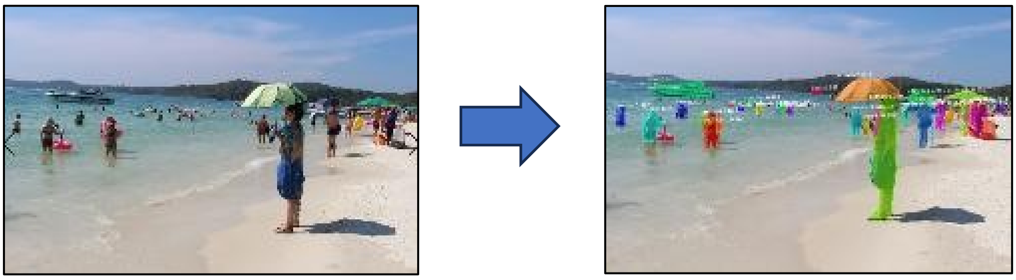

Figure 5. Visualization of results

To validate the results, a comprehensive set of metrics was employed, including true positives (TP), false positives (FP), and false negatives (FN). These metrics were used to compute precision, recall, and accuracy, as shown in Table 1. The findings reveal that the Mask R-CNN algorithm holds great promise for real-world applications as a reliable method for human detection. In most instances of false negatives (FN), the model failed to correctly identify individuals. For example, when a person was squatting on the beach or carrying another person in a piggyback position, the system was expected to detect two individuals. However, it misclassified these cases, recognizing fewer people than present. Similarly, false positives (FP) occurred when the model incorrectly identified non-human objects as people. For instance, life jackets hanging in the background were mistakenly classified as human figures. These errors highlight the limitations of the detection algorithm in differentiating between human and non-human objects, particularly in complex scenarios involving occlusions or overlapping figures.

When both True Positive (TP) and True Negative (TN) are high, it indicates that the model is effective at correctly identifying both target objects and non-target objects. The model accurately detects the desired objects and avoids false predictions for non-targets, resulting in high overall accuracy and reliability in real-world applications.

Table 1: Confusion matrix of mask R-CNN model.

		Actual (no. of image)	
		Positive	Negative
Predicted	Positive	6485(TP)	552(FN)
	Negative	237(FP)	14953(TN)

From Table 1, with an impressive accuracy of 0.9644, the model demonstrates its capability to make correct identifications. The precision score of 0.9650 underscores the model's ability to accurately pinpoint humans without false positives. Additionally, achieving a recall score of 0.9216 indicates the model's effectiveness in capturing the majority of actual human instances. These robust performance metrics collectively suggest that Mask R-CNN is a valuable and practical tool for human detection, showcasing high accuracy and a balanced trade-off between precision and recall.

The results of the person counting in images processed by Mask R-CNN are categorized by time intervals, as presented in Table 2. This study divides the counting process into four time periods. Notably, at Sai Kaew Beach, visitors begin engaging in water activities as early as the morning, with a relatively even distribution throughout the day. The tourism pattern at Sai Kaew Beach includes both overnight visitors and day-trippers traveling from the Rayong mainland. Throughout the day, the number of tourists does not fall below 2,000, with some days reaching approximately 4,000 visitors.

Table 2: Person counting

Time	Average visitors in the area (persons)
06.00-09.00	685
09.01-12.00	917
12.01-15.00	723
15.01-18.00	735

Adopting advanced detection technologies contributes to streamlining tourism evaluations and optimizing the overall tourism experience. By leveraging Mask R-CNN for human detection, this study highlights the potential for improved monitoring and management of tourist activities, leading to better-informed strategies and enhanced visitor satisfaction.

b. Assessing beach carrying capacity:

The Mask R-CNN object detection technology accurately assesses the number of visitors at various positions on the beach. By precisely recording and mapping visitor distributions, this technology provides a granular understanding of how tourists are dispersed across different areas of the beach. (figure 6). The number of visitors varies across different beach locations between 6:00 AM and 6:00 PM. For instance, the southwest area hosts between 70 and 174 visitors, while the central beach area has the highest concentration, ranging from 350 to 380 visitors. In contrast, the northeast area sees between 175 and 269 visitors. To illustrate the spatial distribution of tourists, the researcher has mapped the visitor count at 200-meter intervals, representing each group as a point, as shown in Figure 6. This counting of visitors provides an overall picture of the distribution of tourists along the beach.

Over the 14-day study, tourist activities at the beach varied by time of day. From 06:00 to 09:00, many Thai tourists gathered in the wet beach area for water activities and to enjoy the sunny weather, while others stayed in the dry beach area, likely having breakfast at beachfront hotels. From 09:01 to 12:00, visitors shifted to the dry beach area, engaging in sunbathing and massages. In the afternoon (12:01 to 18:00), more tourists returned to the wet beach area, drawn by higher temperatures and favorable conditions for swimming and marine sports.

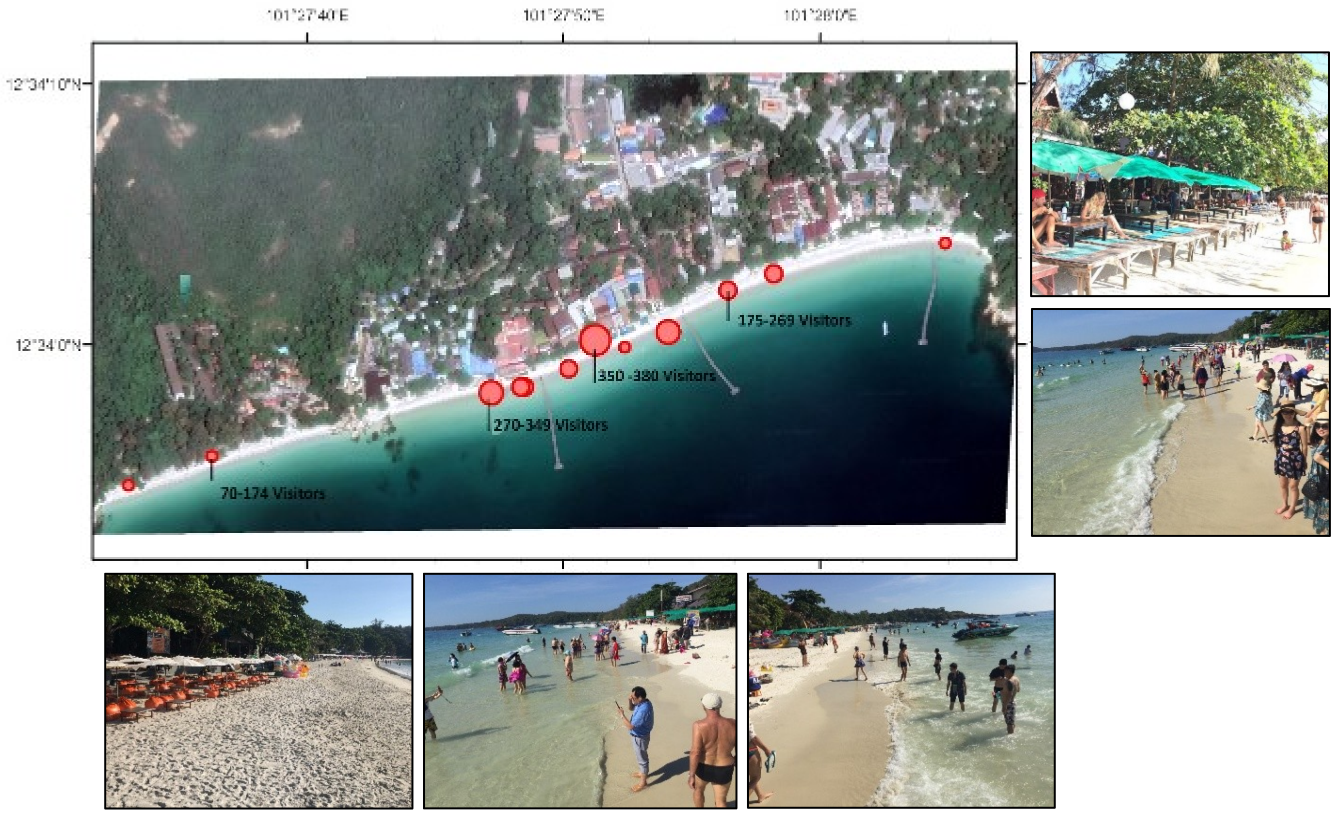

Figure 6. Map showing the density of visitors on the Sai Kaew Beach

The highest average number of visitors occurred in the morning (06:00 to 09:00) with 685 tourists, while the lowest was from 09:01 to 12:00, with 917 tourists. The afternoon period (12:00 to 18:00) saw an average of around 700 visitors. These patterns highlight peak visitation times, emphasizing the need for effective resource allocation and visitor flow management to enhance the overall beach experience.

Using equation 4, the beach area (A) was 8,580 m². With 4 rounds per day (RF) and 10 m² per tourist, the Physical Carrying Capacity (PCC) of the beach was 3,432 people (100% or capacity). The maximum observed number of visitors at one time (PAOT) was 4,048, with a daily average of 3,060. This average exceeded the PCC by 89.16%. These findings highlight the need for effective management strategies to ensure sustainable tourism and maintain a balance between visitor numbers and the beach's capacity. Proper management can prevent negative impacts on the beach ecosystem and enhance the overall visitor experience. (Table 3)

Table 3: Sai Kaew Beach carrying capacity.

Max.no. of visitors on the beach/day	Average no. of visitors/day	Percentage of Visitors on the beach (Physical Carrying Capacity)				Beach Situation
		Below CC <50 %	Approaching CC 50-80 %	Exceeding CC 81-100 %	Over CC >100 %	
4,048	***3,060***	< 1,716	1,716 – 2,746	***2,747 – 3,432***	> 3,432	Exceeding Carrying Capacity

This study is an experimental application of computer-based techniques, with data collected over a short period during the peak tourist season, which, according to the Tourism Authority of Thailand, runs from November to April. However, the data indicates that on the day with the highest number of visitors, the count reached 4,048, suggesting that during periods of maximum tourist influx, the beach may over its carrying capacity. This is due to the limited size of the beach area, with an estimated maximum capacity of approximately 3,500 visitors (over CC is more than 3,432 visitors). Exceeding the beach's carrying capacity leads to several negative impacts in three main areas: ecological, economic, and social. Ecologically, it can cause environmental degradation, such as erosion and littering, and result in overcrowding, which reduces the quality of the visitor experience due to a lack of space, increased noise, and longer wait times for facilities. Economically, the strain on local infrastructure, such as restrooms and waste management systems, can lead to inefficiencies and unsanitary conditions. Socially, it can negatively affect local communities through increased traffic, pollution, and potential conflicts over resource use.

Conclusion and Recommendation

This research tests the efficiency of using object detection technology to assist in detecting and counting the number of tourists. The findings indicate that this technique is reasonably accurate, suggesting that relevant authorities can adopt this approach to develop a real-time system for capturing images or videos and assessing daily tourist numbers. When integrated with data on waste management or ecological systems, this method could significantly contribute to the advancement of sustainable tourism planning.

Compared to manual counting by walking around, using computers for counting people from images, such as with Object Detection technology like Mask R-CNN, offers several clear advantages. First, it reduces errors that may arise from miscalculations or overlooking individuals, particularly in crowded areas or places with fast-moving visitors. Second, it is much faster than manual counting, which requires more time to move through different areas and track people, especially when large crowds are involved. Additionally, this approach eliminates the need for physical presence on-site, preventing any disruption to the tourist experience. By leveraging these technological advancements, this research not only enhances accuracy and efficiency but also presents an innovative solution for real-time, data-driven tourism management, making sustainable tourism planning more tangible and effective.

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