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From Sensing to Impact: LiDAR-Based Parking Guidance for Narrow Streets in a Coastal Tourist Village

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Response to Reviewers:	Thank you for your revision. We revised our paper as follows, given all review comments. 1)Comparison with Alternative Vehicle Counting Methods We added a discussion comparing conventional methodologies and our LiDAR method in the 3rd and 4th paragraphs of section 2.2. 2)Clarification of Advantages and Supporting Evidence 2-1) To explain that our system worked well, we added a statistical t-test in the final part of section 3.2. This also answers comment 4, “Statistical Validation of Results”. 2-2) We modified the 7th paragraph of the Introduction section to show how many sensors were required in a previous case. 3. Strengthening the Discussion on VMS Limitations We added other studies' results showing the relationship between the driver’s behavior and VMS messages (see the final part of “4. Discussion”). 4. Statistical Validation of Results As answered above, we added a statistical t-test in the final part of section 3.2. 5. Typographical Correction We modified the section title on page 5 (section 3.3). Thank you very much again for your review.

From Sensing to Impact: LiDAR-Based Parking Guidance for Narrow Streets in a Coastal Tourist Village

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Abstract

In tourist destinations with limited road and parking capacities, seasonal surges in private vehicle traffic often cause external diseconomy, including congestion and traffic calming issues. Conventional infrastructure-based solutions for tourist parking management are frequently too large or inflexible to address spatially and temporally localized problems effectively. This study investigates a compact, deployable parking guidance system designed to mitigate traffic issues caused by private tourist vehicles accessing a narrow street. A field experiment was conducted in Apr 2025 at Higashi-Hazu Beach, Nishio City, Japan. A real-time vehicle counting system is developed for an ungated seaside parking lot using only two roadside Light Detection and Ranging (LiDAR) sensors to monitor the entries and exits at access points. Accuracy validation against video recordings confirms consistent detection performance even under high-traffic and mixed pedestrian conditions. To proactively guide drivers, a Variable Message Sign (VMS) dynamically displays the congestion status ("Congested", or "Full") at a key intersection preceding a narrow access street. The display content is automatically updated based on real-time vehicle counts obtained from the LiDAR sensors. Comparative analysis between periods with and without the VMS reveal a significant increase in vehicles diverting to a fringe parking lot during "Congested" conditions when the sign is active. This study demonstrates that a compact and deployable LiDAR-based guidance system can affect driver behavior and contribute to more sustainable parking management in tourism-heavy regions, mainly in areas where the conventional methodology is too extensive to implement.

Keywords Variable Message Sign, parking management, traffic calming, LiDAR, tourism

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1 Introduction

Tourism demand plays a crucial role in urban economic activity. In Tokyo, Japan, domestic visitors contribute approximately 84 trillion Japanese Yen (JPY) to the annual economic output [1]. Similar impacts were observed in non-metropolitan areas. For example, several regions in Shizuoka Prefecture, Japan, are estimated to generate over 80 billion JPY in tourism demand [2].

Investments aimed at attracting tourists positively affect the number of visitors. Particularly effective are investments in information provision and improvements to secondary transportation systems [3]. A correlation between accessibility and economic benefits has also been observed in other regions. Mexico's "Magic Town" initiative found that areas with higher accessibility tended to experience more substantial financial benefits by consuming complementary tourism services [4].

However, an excessive concentration of tourism demand can result in an external diseconomy for local communities. This phenomenon has long been recognized, and the term "overtourism" was introduced to describe it in the early 2000s [5]. The World Tourism Organization (UNWTO) defines over-tourism as "the impact of tourism on a destination, or parts thereof, that excessively influences the perceived quality of life of citizens and/or quality of visitors' experiences in a negative way" [6]. However, when there is limited congestion disutility for tourists, they may be unaware of this issue [7]. It is essential to implement balanced measures that allow communities to benefit from tourism, while maintaining a livable environment and ensuring sustainability.

One such approach is to apply the Tourism Carrying Capacity (TCC). In a simulation study using digital data from Dubrovnik, the mobility and transportation facilities were identified as subsystems with capacity constraints [8]. Various strategies have been proposed to address limited transport capacities. For example, in congested tourist destinations, stated preference surveys have shown that introducing new mobility services can reduce the share of private car usage to < 20% [9]. However, parking remains an important issue. There is evidence that expanding parking facilities in response to tourist demand can undermine the mobility of residents [10].

Parking policy studies have involved extensive perspectives, such as economics [11] and connections to land-use policies [12]. Among these, the provision of information remains a significant focus. Many studies have hypothesized that providing parking information influences parking lot choice behavior and reduces cruising time. These effects have been modeled and generalized [13] [14], and simulations have suggested that dynamic information provision can reduce cruising times by up to 17% [15]. Empirical demonstrations have also been conducted. A pilot project in Nottingham, UK, provided static parking information through newspaper advertisements and real-time information via radio broadcasts. The results showed that drivers who received this information were more likely to choose peripheral park-and-ride facilities instead of parking in the city center [16].

Although some proposals monitor visitor flows in tourist areas, using a combination of pyroelectric sensors and survey data. One example is the application of 39 pyroelectric sensors, which requires extensive equipment and infrastructure [17]. Such methods may be excessive when addressing spatially and temporally localized issues. Detecting the number of parked vehicles in parking lots with gates or marked spaces is relatively straightforward. However, in ungated lots where vehicles park in an ad-hoc manner, traditional methods, other than manual counting, struggle to yield accurate counts.

However, in recent years, advances in autonomous driving technologies have made it possible to use Light Detection And Ranging (LiDAR)-based sensing systems to detect the vehicle size, direction, and speed in real-time. Previous studies counted vehicle passages with an accuracy of 83–94% [18]. Applying this technology to detect the total number of vehicles within a parking area enables real-time parking management, even for ungated lots, with smaller and more mobile sensing infrastructure than conventional systems.

This study focuses on the Higashi-Hazu Beach in Nishio City, Japan, where local overtourism due to private car use has been an issue, particularly during peak seasons, and countermeasures have been insufficient. A real-time vehicle counting system is implemented using LiDAR and its accuracy is evaluated along with a dynamic guidance system using a Variable Message Sign (VMS) to guide drivers based on parking situations. This study aims to verify whether such a compact and mobile system can effectively guide behavior in tourist spots that have struggled with effective parking management.

2 Methodology

2.1 Target District

This study focuses on the Higashi-Hazu Beach, located in Nishio City, Japan. The beach lies within the Nagoya metropolitan area, approximately 60 km from the center of Nagoya.

Higashi-Hazu Beach is a popular destination for recreational clamming, particularly during Japan's long holiday period from late Apr to early May, attracting many tourists who travel via private vehicles.

However, this beach is in a traditional fishing village with narrow streets. The parking area adjacent to the beach has limited capacity, and no system exists to provide real-time occupancy information. These parking spaces lack gates and marked stalls, making it impossible to track the number of parked vehicles in real-time using conventional methods. Consequently, even when seaside parking is full, drivers continue to enter the area in search of parking despite the availability of fringe parking facilities located outside the narrow streets. This behavior leads to various issues, including traffic deadlocks owing to vehicles being unable to pass each other, conflicts between cars and pedestrians, and problems in residential environments.

2.2 Real-Time Vehicle Detection Using LiDAR Sensors

To address these issues, a field experiment was conducted involving the following components. Figure 1 illustrates the structure of the system tested in this study.

In this seaside area, individual parking spaces are not clearly defined, making it unfeasible to obtain occupancy for each space using cameras or similar devices. Counting vehicles within an area rather than per lot is more appropriate. Since the parking area spans multiple zones, installing gates at the entrances is not a viable option, as doing so would require installing them on public roads.

Instead of gates, an effective approach to counting vehicles is to define cordon lines at the points where vehicles enter and exit. Manual observation is costly, while camera-based monitoring raises privacy concerns due to the retention of video footage. Furthermore, camera detection accuracy can deteriorate under varying sunlight intensity and angles, although recent advancements in detection technologies have mitigated this issue to some extent [19][20]. Considering these factors, LiDAR technology offers a promising solution, as it enables unmanned observation without recording images and is less affected by sunlight conditions.

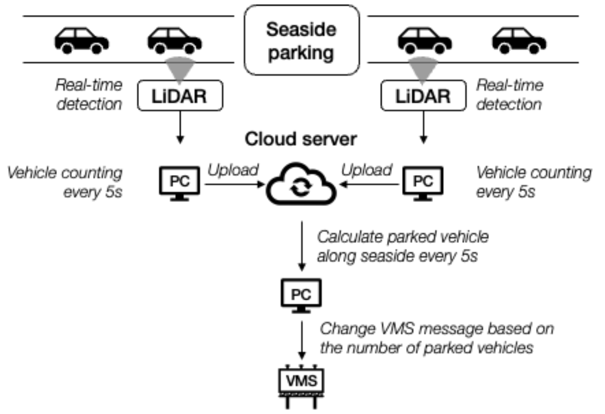

Figure 1. Sensing and calculation system structure

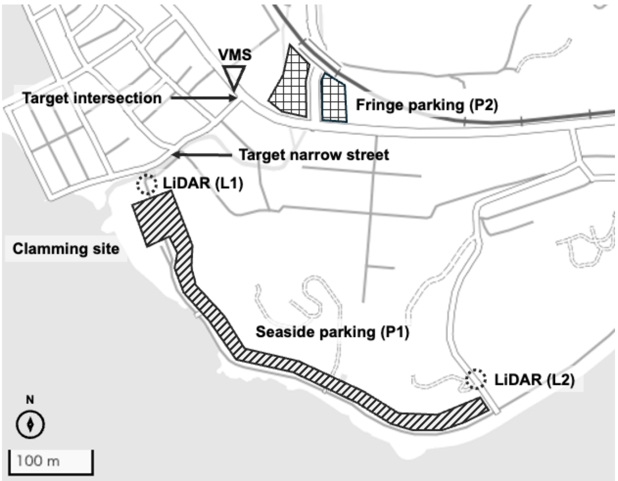

Figure 2. Field experiment site and the location of each device

First, to enable real-time monitoring of the number of vehicles in the seaside parking area, LiDAR sensors were installed on two access routes to the beach (locations L1 and L2 in Figure 2) (Figure 3). An algorithm developed by the authors enabled the automatic detection of the number of passing vehicles based on the data collected from these roadside LiDAR units. As the targeted streets are narrow and do not have lane separation by direction, the algorithm was further enhanced to detect vehicle direction and distinguish vehicles from pedestrians. These enhancements represent technical advancements from previous studies [18].

Each computer connected to a LiDAR sensor aggregated the number of passing vehicles in each direction every 5 s to estimate the net number of cars entering or exiting each monitoring point.

The calculated results from each computer were transmitted to a cloud server in real-time via mobile communication. By aggregating these data on the server, the number of vehicles in the seaside parking area (P1 in Figure 2) was computed every 5 s in real-time. Instead of detecting occupancy at the level of individual parking spaces, vehicle counts were derived based on entries and exits, significantly reducing the number of sensors required.

A computer connected to the VMS receives the resulting data from a cloud server via mobile communication. Based on this information, the VMS display was automatically updated as described in the following section.


Figure 3. Roadside LiDAR equipped at location L2


Figure 4. VMS at the target intersection displaying "Seaside Full"

2.3 Guidance with Real-Time Information on the Variable Message Sign

In this study, a VMS was installed at the intersection of the narrow street and the seaside parking area. Based on the real-time vehicle count, the VMS displayed either "Seaside Congested" or "Seaside Full" (Figure 4). Although the seaside parking area does not have a clearly defined parking capacity, an approximate capacity of 320 vehicles was assumed, based on the analysis presented in this study.

Thresholds followed the capacity of the seaside parking area: "Seaside Congested" was displayed when the number of vehicles was > 170 (approximately 50% of the capacity), and "Seaside Full" was displayed when the vehicle count was > 240 (approximately 75% of the capacity). These thresholds were defined based on manually collected vehicle count data from the previous year.

While the 75% threshold for the "full" status may initially appear low, it should be noted that the estimated capacity of 320 vehicles includes those moving along the seaside road to find an available parking lot. Therefore, when the number of cars reaches 240, the seaside parking area is already experiencing significant congestion, and it becomes challenging to find a new parking space, except at locations far from the clamming site.

As illustrated in Figure 1, the VMS was connected to the internet to automatically update the display based on sensor input. A temporary fringe parking lot is available outside the narrow street (P2 in Figure 2). Therefore, the message on the VMS was updated to instruct drivers divert to this alternative lot, thereby reducing traffic on the narrow street (target narrow street in Figure 2).

The experiment was conducted over five days from 26 Apr to 30 Apr 2025, coinciding with the peak clamming season. During this period, the VMS unit was operational for three days and deactivated for two days, allowing for comparative analysis. Additionally, video cameras were installed at the target intersection, enabling observation of driver behavior to assess the effect of the VMS guidance.

3 Results

3.1 Vehicle Count Observations

Vehicle counting was conducted for five days during the experiment (Table 1). The peak hours of visitor arrival varied depending on the timing of the low tide. The weather and temperature also influenced the number of visitors. Although all dates fell within Japan's Golden Week holiday period, the designation of a day as a holiday varied depending on the company. 26 and 27 Apr were weekends, and 29 Apr was a national holiday, making it likely that more people were not working on those days.

The observations began before the peak arrival time and ended after most vehicles had departed. Table 1 lists the observation schedule, with low tide times sourced from the Higashi Hazu Fishery Cooperative and weather data. The maximum temperature (HIGH) and maximum hourly precipitation (MHP) were obtained from the nearest Japan Meteorological Agency station in Gamagori. All time notations in this study used the 24 h clock.

At the beginning of the observation period for each day, the number of parked vehicles were manually counted and entered as the initial values. From this point onward, the system recorded the real-time vehicle count using the LiDAR sensor system described in Section 2.2.

Figure 5 illustrates the number of vehicles parked along the coast over five days. As expected, the highest numbers were recorded on 27 and 29 Apr, corresponding to the weekend and a national holiday, respectively.

Table 1. Vehicle count observation schedule

Date	26 Apr	27 Apr	28 Apr	29 Apr	30 Apr
Days	Sat	Sun	Mon	Tue	Wed
Low tide	10:49	11:27	12:07	12:47	13:29
HIGH (°C)	22.0	24.4	22.8	18.0	25.4
MHP (mm)	0.0	0.0	4.0	0.0	0.0
Obs. start	11:46	08:11	08:07	08:08	07:58
Obs. end	14:58	15:40	14:37	15:55	16:06
VMS	With	With	With	Without	Without

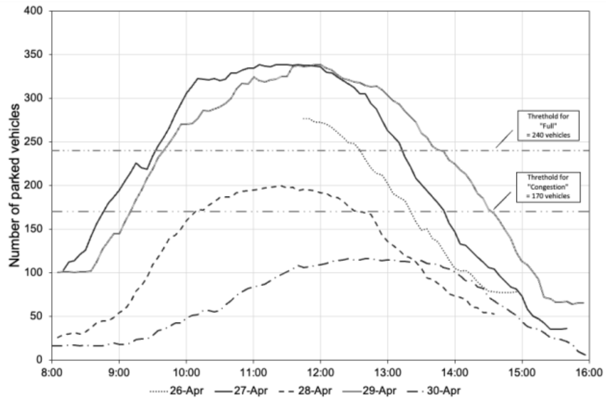

Figure 5. Result of the vehicle count observations

Across all observation days, the number of parked vehicles consistently plateaued at approximately 320, indicating that this range likely represents the maximum parking capacity of the seaside parking area. Furthermore, the peak time shifted later each day. This trend closely followed the shifting low tide times, as indicated in Table 1, suggesting that visitors timed their arrival to coincide with optimal clamming conditions.

Overall, the vehicle count results obtained using the LiDAR system reflected reasonable trends following the holiday calendar and tidal patterns. These results confirmed the effectiveness and reliability of the LiDAR-based vehicle counting methodology during the study period.

3.2 Accuracy of the Vehicle Counting

This section presents a comparative analysis using video clips from exact angles to evaluate the accuracy of the vehicle counting using LiDAR sensors. A video camera was used to capture each of the two LiDAR sensors (L1 and L2) during the designated observation periods listed in Table 2. The L1 sensor, in particular, was expected to face greater detection challenges owing to its complex location; therefore, video recording was conducted over a longer period.

Manual vehicle counting using the video clips provided the ground truth, that is, the total number of vehicles entering and exiting during each observation interval. These values were then compared with the LiDAR results for the same time intervals to calculate the accuracy rate (AR).

Table 2. Accuracy verification of vehicle counting with LiDAR

Sensor	Date & Time	Video	LiDAR	AR (%)
L1	27 Apr 08:18-09:13	85	67	78.8
L1	27 Apr 11:32-12:53	-25	-22	88.0
L1	28 Apr 09:41-10:17	50	45	90.0
L1	29 Apr 08:25-10:25	198	154	77.8
L2	27 Apr 09:48-10:48	12	12	100
L2	27 Apr 11:44-12:14	-7	-7	100

As shown in Table 2, the L2 sensor achieved perfect accuracy (100%) over a total observation time of 90 min. This result confirmed that the LiDAR system functioned reliably and precisely at this location. Each counting result was the aggregate number of vehicles entering and exiting the seaside parking area. A positive value indicated that entering vehicles exceeded exiting vehicles.

In contrast, the L1 sensor was closer to the clamming site, resulting in higher traffic volumes and a greater number of pedestrians. In addition, during periods of congestion, vehicles traveling in opposite directions often exhibit complex behaviors, including deadlocks and yielding on narrow streets. Owing to these factors, accurate observation of the L1 sensor location was technically challenging. On the mornings of 27 and 29 Apr, both periods with a high visitor volume, the accuracy dropped to approximately 77–78%.

There were three main factors that reduced the accuracy during these peak periods:

- High traffic densities resulted in short headways between vehicles, occasionally causing the system to detect two or more cars as a single unit.
- Pedestrian interference, in which there was an overlapping movement between vehicles and pedestrians within the field of view of the sensor, led to misclassification.
- Complex vehicle maneuvers, such as vehicle deadlocks and yielding on the narrow street in front of the sensor.

Despite these challenges, the L1 sensor maintained accuracy levels of approximately 88–90% during non-peak periods. The overall accuracy for L1 remained > 77%, indicating that the system operated reasonably well, even under challenging conditions. We converted each observation in Table 2 into 30-minute intervals and conducted a paired t-test. The resulting p-value was 0.17, indicating no statistically significant difference between the LiDAR-based observations and the ground truth from video recordings. Combined with the L2 results, the system demonstrated overall performance comparable to that of prior LiDAR-based studies, which reported detection accuracies of 83–94% [18].

3.3 Impact of the Variable Message Sign on Driver Behavior

As shown in Figure 5, on 27 and 29 Apr, the number of visitors reached the parking capacity. As listed in Table 1, a VMS was available on 27 Apr but not on 29 Apr. Based on this setup, this section verifies the impact of the VMS by comparing driver behaviors between these two days. The VMS automatically operated in response to vehicle counts in the seaside parking area. Specifically, the following messages were displayed based on the number of parked vehicles: "Seaside Congested" when the count was > 170 cars, "Seaside Full" when the count was > 240 vehicles, and no display when the count was < 170.

According to the vehicle counting results, the congestion or full-capacity conditions corresponded to the periods listed in Table 3.

Table 3. Periods with VMS active and inactive for verification

Date	27 Apr	29 Apr
VMS	With	Without
Low tide	11:27	12:47
Periods with 170–240 cars	08:50-09:35 13:15-13:55	09:10-09:45 13:50-14:35
Period under verification	09:05-09:35	09:10-09:40
Period with 240+ cars	09:35-13:15	09:45-13:45
Period under verification	09:45-10:15	09:45-10:15

A T-junction intersection was targeted by the VMS to reduce entry into the narrow road segment. At this intersection, the incoming vehicles could follow the paths illustrated in Figure 3 and were categorized as follows (Figure 6):

- A: Entering from the west and moving straight.
- A': Entering from the west, signaling a right turn, but moving straight.
- B: Entering from the west and turning right.
- B': Entering from the west and making a U-turn.
- C: Entering from the east and moving straight.
- C': Entering from the east and making a U-turn.
- D: Entering from the east and turning left.

Additionally, a p suffix indicates vehicles parked in the fringe parking (P2) as follows: A_p, A'_p, and C'_p. Among these, A'_p and C'_p are of particular interest, as they likely represent drivers who initially intended to park at the main seaside lot (P1) but diverted to P2 upon reaching the intersection.

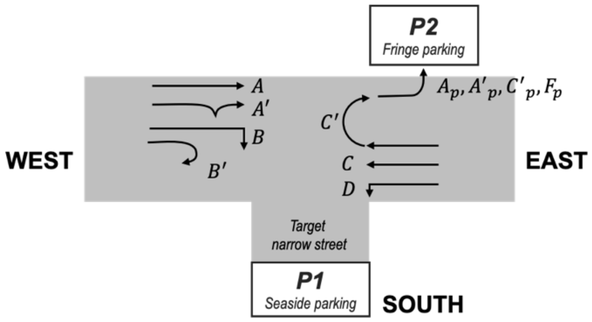

Figure 6. Definition of incoming routes to the target intersection

Table 4 compares the number of A'_p and C'_p route users under the "Congested" and "Full" conditions, both with and without the VMS: For A'_p, the number of vehicles following this route increased both under congestion and full capacity when the VMS was present. For C'_p, an increase was observed under congested conditions when the VMS was active.

Although the number of observed vehicles was relatively small, these results suggest that the VMS effectively encouraged drivers to divert to the fringe parking lot (P2) when the seaside lot (P1) was congested or full.

Table 4. Number of vehicles diverted to the fringe parking

Route	Status	Without VMS	With VMS
A'_p	Congested	1	5
	Full	11	16
C'_p	Congested	0	4
	Full	5	5

Table 5. Proportion of fringe parking users among all traffic

Status	Congested		Full	
VMS	Without	With	Without	With
P2 users	8	29	21	38
All traffic	175	206	176	226
P2 user ratio (%)	4.6	14.1	11.9	16.8

Table 6. Proportion of fringe parking users among visitors

Status	Congested		Full	
VMS	Without	With	Without	With
P2 users	6	28	17	36
Non-P2 users	66	58	40	55
P2 user ratio (%)	8.3	32.6	29.8	39.6

Table 7. Proportion of fringe parking users (eastbound) among visitors

Status	Congested		Full	
VMS	Without	With	Without	With
P2 users	6	24	16	31
Non-P2 users	39	36	18	34
P2 user ratio (%)	13.3	40.0	47.1	47.7

Among all defined trajectories, A_p, A'_p, and C'_p represent vehicles that used the fringe parking (P2). As this study focused on the number of fringe parking users among all traffic volumes at the intersection, its ratio increased in both the congestion and full cases when the VMS was activated (Table 5). In particular, under congestion, the increase was statistically significant at the 1% level according to a chi-square test.

In addition, the following were considered likely to be clamming visitors: A_p, A'_p, B, C'_p, and D. The proportion of vehicles using P2 among the assumed clamming visitors was calculated (Table 6). The results showed that the proportion of fringe parking users was significantly higher when the VMS was active under the "Congested" conditions, with a chi-square test indicating statistical significance at the 0.1% level. The trend was the same under the "Full" condition; however, the difference was not statistically significant at the 10% level.

Additionally, given the location of the VMS and fringe parking, its influence was expected to be particularly strong for vehicles approaching from the west (eastbound). Therefore, the ratio of fringe parking users among the eastbound vehicles for clamming (A_p, A'_p, and B) was analyzed separately (Table 7). Under congested conditions, the VMS again resulted in a significantly higher proportion of fringe lot users, with the chi-square test confirming significance at the 1% level. Under the full condition, no significant difference was found at the 10% level, whereas the trend was the same as that in the congested condition.

4 Discussion

Implementing the VMS, which dynamically displayed the congestion status of the seaside parking lot, resulted in an increased number of vehicles diverting to from the narrow street to the fringe parking. This effect was observed during both "Congested" and "Full" conditions (Table 4).

These findings indicate that drivers changed their parking choices in response to the VMS display. Focusing on the proportion of all clamming visitors, the proportion of vehicles that chose the fringe parking was higher when the VMS was active in all cases (Tables 5-7). In contrast, the difference in the installation of the VMS was statistically significant only under the "congested" condition. These trends were consistent, regardless of whether the analysis included all directions or explicitly focused on eastbound vehicles, where the VMS was likely to have a more substantial influence.

One possible explanation for this difference is the observable state of the narrow street under the full-capacity condition. The narrow link often became visibly congested when the lot was full because of cruising vehicles and increased pedestrian activity. In such a scenario, drivers may have chosen to divert to the fringe lot, regardless of the presence of the VMS. Although there was no significant difference between the with-VMS and without-VMS cases, the overall diversion rate to the fringe parking was higher under full-capacity conditions than under congested conditions. In contrast, the narrow street may not have appeared congested during congestion but before reaching full-capacity. Therefore, the VMS effect was more pronounced, with a more evident influence on behavior.

There are several potential reasons why the effect of the VMS on traffic volume reduction was limited, including variations in visitor characteristics across different periods. However, the content and format of the VMS display itself may also have influenced driver behavior. Under the general policy direction of the police, real-world implementation of a VMS is often limited to providing information rather than issuing behavioral directives, which was also the case in this study. As such, the strength of the behavioral impact of signage may be inherently limited. Furthermore, owing to the technical limitations of the VMS in this experiment, while providing real-time information on seaside congestion, no explicit indication of alternative parking options (e.g., location of the fringe parking lot) was available. This may have restricted the range of viable decisions for first-time visitors upon seeing the "Congested" or "Full" messages. Given that messages displayed on VMS are more effective when they provide specific context alongside actionable guidance [21], the content presented in this study still has room for improvement.

5 Conclusion

This study conducted a field experiment in Apr 2025 to evaluate the impact of a VMS parking guidance system with LiDAR sensors aimed at reflecting the local traffic issues caused by private vehicles visiting the Higashi-Hazu Beach in Nishio City, Japan.

For real-time monitoring of parked vehicles, which served as the basis for the guidance system, a sensing setup was implemented utilizing only two LiDAR sensors, drawing on autonomous vehicle technologies. The system successfully enabled directional vehicle counting, and the accuracy of these counts was validated through a comparison with manual video observations, confirming an acceptable level of reliability.

Based on the real-time parking counts, the system dynamically displayed the congestion status ("Congested" or "Full") of the seaside parking lot on a VMS installed at the intersection to a narrow link. The system functioned as expected during the demonstration period.

Changes in driver behavior were observed, with some vehicles diverting to the fringe parking instead of entering the narrow street when the VMS displayed messages. Furthermore, during congested periods, the proportion of cars choosing the fringe parking lot was significantly higher when the VMS was active, providing clear evidence for the guidance effect.

These findings confirm that dynamic guidance based on real-time parking data can be practical for influencing driver decisions. However, during full-capacity periods, the presence of the VMS did not lead to statistically significant differences in driver behavior. It should be noted that this study assessed effectiveness based solely on the vehicle trajectory and did not include direct feedback from drivers through interviews or surveys. Therefore, understanding how drivers perceive information was a limitation of this study.

The compact detection and guidance system validated in this study, which is based on a minimal LiDAR sensor infrastructure, has the potential to offer a practical solution for addressing traffic issues arising under spatial and temporal constraints. Unlike conventional methods, which often require large-scale infrastructure, the proposed approach is more appropriately scaled and readily deployable for real-world applications.

Abbreviations

MHP: Maximum Hourly Precipitation
VMS: Variable Message Sign
LiDAR: Light Detection and Ranging

Statements and Declarations

Competing Interests: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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