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Evaluation of the Planet constellation's daily coverage for estimating the number of vessels at Daikoku Pier automobile terminals, Port of Yokohama, Japan

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The automotive industry is a key industry in Japan; however, the worker shortage has affected transportation in the ports and harbors, including that of automobile shipping. Automobiles are shipped using roll-on/roll-off (Ro-Ro) ships. When many Ro-Ro ships dock at the same time, problems related to the shortage of workers and limited storage space for automobiles are exacerbated, decreasing transportation efficiency. The spatial resolution and temporal frequency of satellite imagery have improved with Planet Labs satellite constellations making daily observations of the Earth's surface. Moreover, the field of remote sensing is seeing an increasing number of logistic applications. As such, this study aimed to evaluate the Planet constellation's daily coverage for estimating the actual usage of seaport automobile terminals by counting the number of vessels in each image. Here, we focused on Daikoku Pier automobile terminals in the Port of Yokohama, Japan, from 2018 to 2023. Images were classified by visual interpretation into three categories: data available for analysis, data not available for analysis due to cloud, and lack of data. Over the 6-year period, 37.1% of the data were classified as data available for analysis; 21.2%, data not available for analysis due to cloud; and 41.8%, lack of data. The visual inspection survey was conducted twice, with an agreement rate of 90.5% between the two surveys. The number of vessels were then counted two times from "data available for analysis" class, and the discrepancies were corrected. This result was compared to the actual schedule information and the accuracy was 89.0%. The number of vessels docked at the same time tended to be lower in August than in other months. The days from the 25th to 31st tended to have a higher number of vessels than other days, regardless of the month. It seems difficult to use Planet constellation for daily site progress management because data was sometimes available 1 day per month. Planet constellation can be useful in estimating the actual usage through long-term monitoring. We expect that the results of this study will be helpful to those interested in using daily satellite imagery for improving work conditions and efficiencies.

KEYWORDS

finished vehicle, Planet Dove/SuperDove satellites, port and harbor, pure car carrier, seaport automobile terminal, remote sensing

1 Introduction

The automotive industry is a key industry in Japan, and the tremendous amount of automobile production and sales contribute significantly to the economy (Shigeta and Hosseini, 2020). However, the shortage of workers in ports and harbors has a significant impact on port logistics (Ports and Harbours Bureau, Ministry of Land, Infrastructure, Transport and Tourism, 2021), including that related to automobile shipping. Automobiles are shipped using roll-on/roll-off (Ro-Ro) ships; thus, many workers such as stevedores are needed to load and unload automobiles in the seaport automobile terminal. When many Ro-Ro ships dock at the same time, the shortage of workers and storage space for automobiles is exacerbated, decreasing transportation efficiency. A few studies have reported on automobile terminal issues, such as the berth allocation, storage location optimization, and planning and scheduling (e.g., Chen et al., 2021; Dkhil et al., 2021; Mattfeld and Kopfer, 2003) in an effort to improve efficiency. However, more information on the actual daily port usage around automobile terminals is necessary, but lacking to date. This information will help to provide better policies for sustainable logistics and support to the automotive industry for improving work conditions and efficiencies.

Satellite remote sensing is widely applied in environmental monitoring fields such as agriculture, forestry, oceans, coastal waters, and disaster prevention (e.g., Carter et al., 2024; Li et al., 2022; Murata et al., 2021; Sakuma et al., 2021; Shevyrnogov et al., 2021; Yonezawa et al., 2012). As the spatial resolution of satellite images has improved considerably, remote sensing efforts have extended to logistics applications. Satellite imagery has been used to study maritime logistics in relation to container terminals (e.g., Murata et al., 2023; Yasuda et al., 2024; Yu et al., 2023); automobile detection in seaport automobile terminals (e.g., Hamamoto et al., 2021); and vessel detection (e.g., Ping et al., 2021; Reggiannini et al., 2024; Štepec et al., 2019; Xie et al., 2022). Satellite observation has the advantage of covering a large area at once, allowing vessels and cargo, such as containers and automobiles stored in terminals, to be detected simultaneously. However, to date, this approach has been limited by the frequency of observation data.

The temporal frequency of satellite image observation has recently improved. Planet Labs (San Francisco, CA, USA) has built Planet satellite constellations for daily observation of the Earth's surface. Planet Dove and Dove-R satellites observe 4-band (blue, green, red, and near-infrared) and SuperDove satellites observe 8-band (coastal blue, blue, green 1, green, yellow, red, red-edge, and near-infrared) spectral bands (Planet. PlanetScope, 2024). The ground sample distance is approximately 3.7 m and the revisit time is daily in nadir (Tanya, 2024). In 2018, +100 Planet Dove satellites were in the orbit fleet (Planet, 2018). Since then, new satellites have been launched. Recently, Planet Labs launched 48 SuperDove satellites on 24 January 2021, 44 SuperDove satellites on 13 January 2022, and 36 SuperDove satellites on 2 January 2023. About 200 Dove/SuperDove satellites are currently in orbit (Planet, 2021; Planet, 2022; Planet, 2023). Thus, the number of satellites and the temporal frequency have increased from 2018 to 2023. Frazier and Hemingway (2021) reported that Planet images present challenges with regard to geometric and radiometric quality that the remote sensing community has come to expect from 'analysis ready' datasets (i.e., Landsat, MODIS, etc.). On the other hand, the Planet constellation has an advantage with regard to temporal frequency of image observations. However, the optical sensors cannot observe under cloud; thus, even if data are acquired, analysis may not be possible. Roy et al. (2021) analyzed the temporal availability of the Planet constellation in global. They mentioned that more detailed

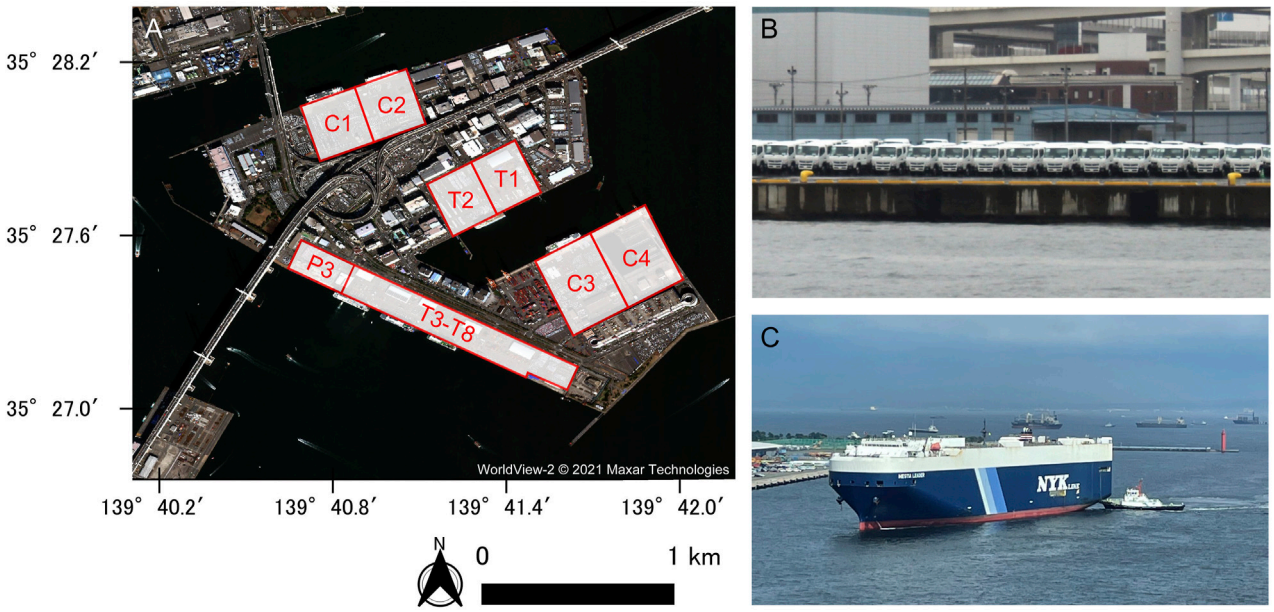

FIGURE 1
Map of the study site Daikoku Pier, Port of Yokohama, Japan **(A)**. The red polygons indicate the seaport automobile terminals. Photos of stored automobiles **(B)** and roll-on/roll-off (Ro-Ro) ship **(C)**.

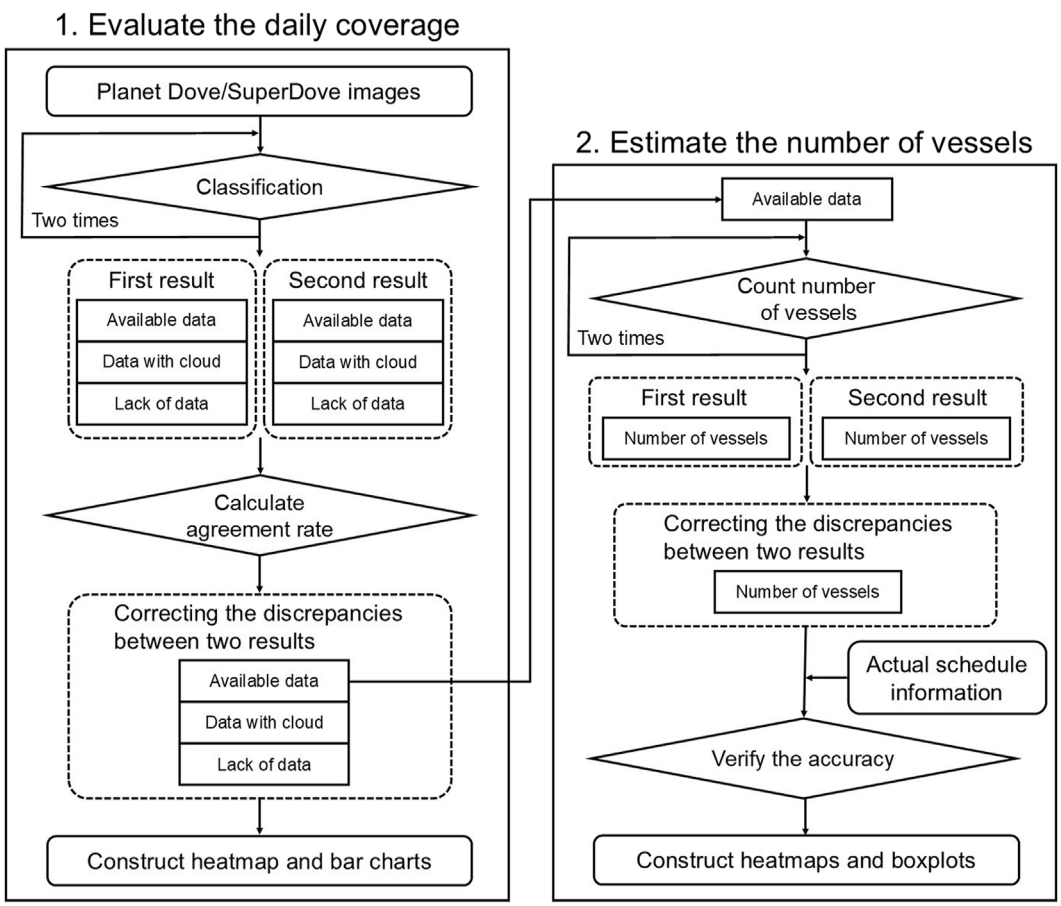

FIGURE 2
The flowchart of the analysis procedure.

analysis at the local and regional scales should be performed for the cloud availability of the Planet constellation.

Cloud coverage varies by region. It is important to evaluate the daily coverage in satellite imagery, to assess the applicability of the data for logistics studies. As such, in this study, we evaluated the daily coverage of the Planet constellation in a local area, specifically, Daikoku Pier in the Port of Yokohama, Japan, from 2018 to 2023. Satellite imagery was used to estimate the actual usage of seaport automobile terminals by counting the number of vessels.

2 Study site and methods

2.1 Study site

This study examined the Daikoku Pier in the Port of Yokohama, Japan (Figure 1). At Daikoku Pier, T1, T2, C1–4, P3, and T3–8 terminals are currently used as seaport automobile terminals. The terminals have gradually been converted from container terminals to automobile terminals. A maximum of 11 Ro-Ro ships can dock at the same time (City of Yokohama, 2022). The terminals that have recently been renovated or reopened as automobile terminals include C3 on 4 August 2020; C4 on 1 April 2022; and P3 on 15 April 2022 (Yokohama Kawasaki International Port Corporation, 2020; Yokohama Port Corporation, 2022; City of Yokohama, 2022). P3 and T3–T6 have been used as both automobile terminals and cruise ship terminals (Keihin Port Office, Kanto Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism, 2022).

2.2 Methods

The flowchart of the analysis procedure is shown in Figure 2. Planet Dove/SuperDove images (Planet Team, 2017) are commercial data. Planet Explorer, a platform that subscribers can use to search and download images, was used to evaluate the daily coverage and to estimate the number of vessels.

First, we searched all images of the study site from 2018 to 2023 and classified the imagery via visual interpretation into three categories: (1) data available for analysis (available data), (2) data not available for analysis due to cloud (data with cloud), and (3) lack of data. The standard for visual interpretation was based on whether the automobile terminals, as well as vessels, were visible in the images. Even when the data were with cloud, if the automobile

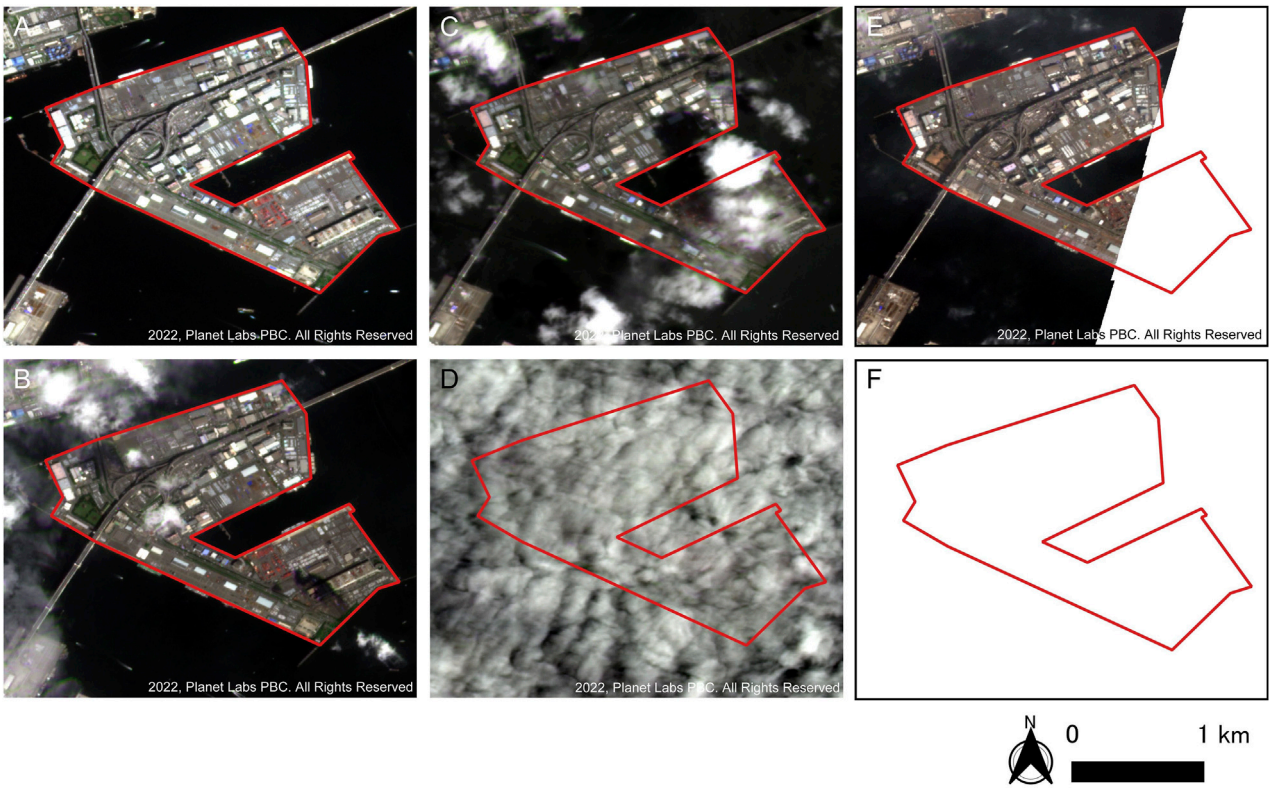

FIGURE 3
Planet constellation images; available data **(A, B)**, data with cloud **(C, D)**, and lack of data **(E, F)**. The red polygon indicates the edge of Daikoku Pier.

terminals and vessels were visible then the images were classified as available data. Our survey was conducted twice for confirmation. We evaluated the agreement rate between the two surveys; then any discrepancies were corrected.

Second, we counted the number of vessels at automobile terminals from corrected 'available data' using Planet Explorer. Although it was possible that vessels other than Ro-Ro ships (non-Ro-Ro ships) may call at the automobile terminals, this was not considered to be the majority, so no distinction was made. We counted the number of vessels two times, and then the discrepancies were corrected. This result was compared to the actual schedule information provided by the Yokohama Port Information System at the time of Planet Dove/SuperDove images observed to verify the visual interpretation accuracy. This schedule information was publicly available on the website and included the name of the vessel, type of vessel, and arrival and departure times by terminal in Japanese. However, the container vessels in C3–4 terminals, before being in service as automobile terminals, and the cruise ships in P3 and T3–T6, were excluded because it was not directly related to the automobile terminals targeted in this study. The length of the cruise ships that call at Daikoku Pier range from 290 to 315 m (e.g., Cunard, 2024; Princess Cruise, 2024; MSC, 2024); notably, these cruise ships are much longer than the standard-size Ro-Ro ship of ~200 m (e.g., K-Line, 2024; NYK Line, 2024; Wallenius Wilhelmsen, 2024).

Finally, the number of vessels counted by Planet constellation were used to analyze the actual usage of the study site. R version 4.22 (R Development Core Team, 2019) was used to construct a heatmap, bar charts, and boxplots of our findings.

3 Results

3.1 Daily coverage results obtained from the Planet constellation

Planet Dove/SuperDove images were classified into three classes: available data (Figures 3A, B), data with cloud (Figures 3C, D), and lack of data (Figures 3E, F). As a supplement, Figure 3B was classified as available data due to the absence of cloud cover of the automobile terminals, while Figure 3C was classified as data with cloud due to cloud cover over T1, C3 and C4 terminals. The daily results are presented as a heatmap in Figure 4A and bar charts aggregated by year in Figure 4B. The agreement rate between the first and second visual interpretation was 90.5%. The number of days in a year for the three data classes were 105–155 for available data, 67–86 for data with cloud, and 124–194 for lack of data, from 2018 to 2023. The results over the 6-year period showed the following percentages for the class types: 37.1% available data, 21.2% data with cloud, and 41.8% lack of data. The overall available data ranged from 1 to 22 days per month. There was a period of up to 11 consecutive days with available data from February 3–13, 2018, and a period of up to 29 days without available data from June 27–25 July 2019. On average, the available data was available once every 2.7 days.

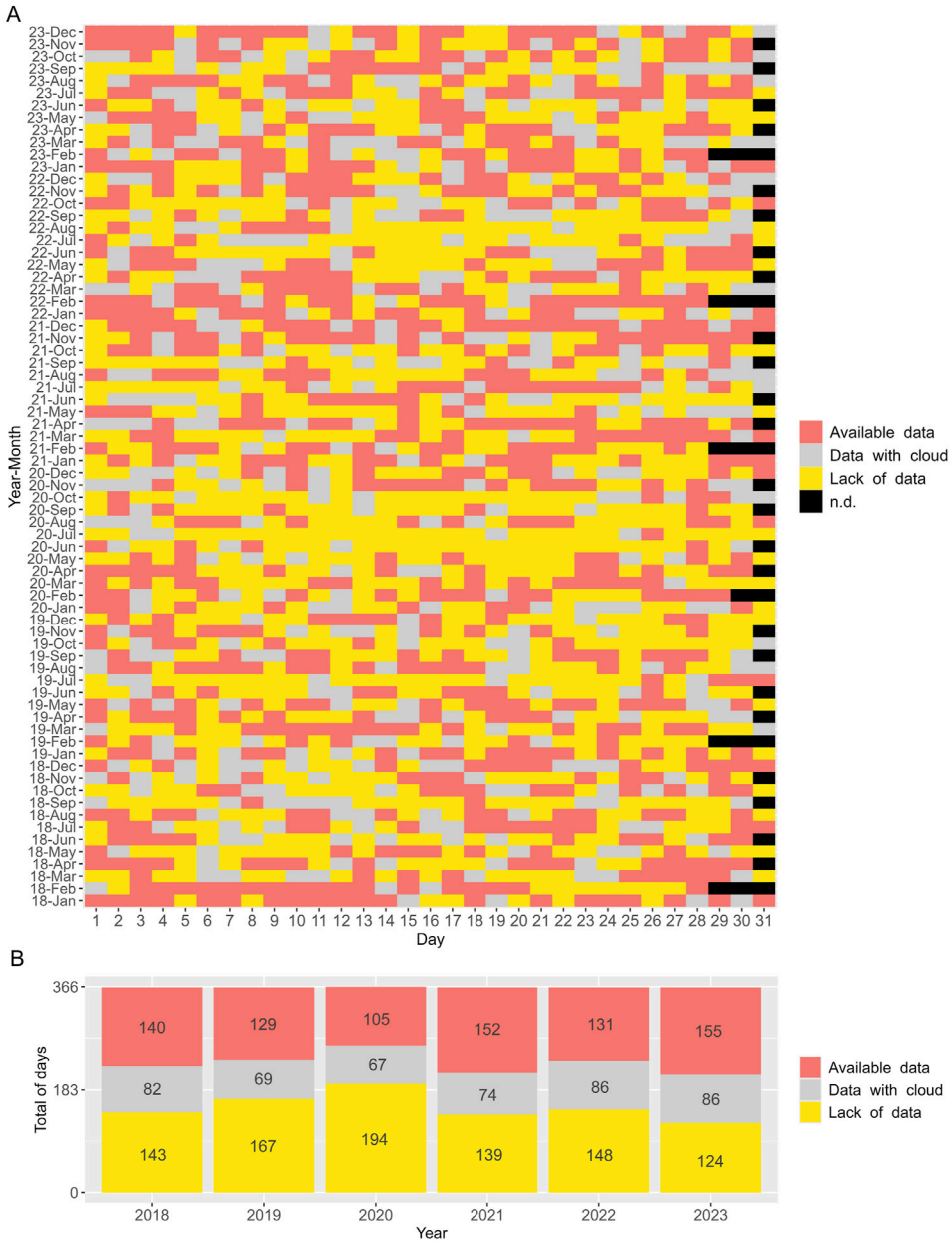

FIGURE 4
Heatmap of the results classified into three categories: available data, data with cloud, and lack of data **(A)** and the bar charts aggregated by year **(B)**.

3.2 Verifying the accuracy of the vessels count by visual interpretation

The daily number of vessels counted from available data is shown as a heatmap in Figure 5A. The agreement compared to the actual schedule information is shown as heatmap in Figure 5B, and the accuracy was 89.0%. The remaining 11.0% mismatch were due to misses in visual interpretation, as some general cargo vessels were not counted due to their small size. From the actual schedule information, non-Ro-Ro ships such as general cargo vessels, work vessels, cement carriers, tugboats, and container vessels were sometimes called at the Daikoku Pier's automobile terminals. Hence, this visual interpretation result of the number of vessels include non-Ro-Ro ships as well as Ro-Ro ships. In a few other cases, the visual interpretation results were considered more accurate than the actual schedule information.

3.3 Estimating the actual usage of daikoku pier automobile terminals from daily Planet satellite images

The number of vessels were counted from the available data of Planet Dove/SuperDove imagery from 2018 to 2023 at Daikoku Pier in the Port of Yokohama, Japan. While these numbers include Ro-Ro ships, non-Ro-Ro ships and a few mistakes, the analysis was

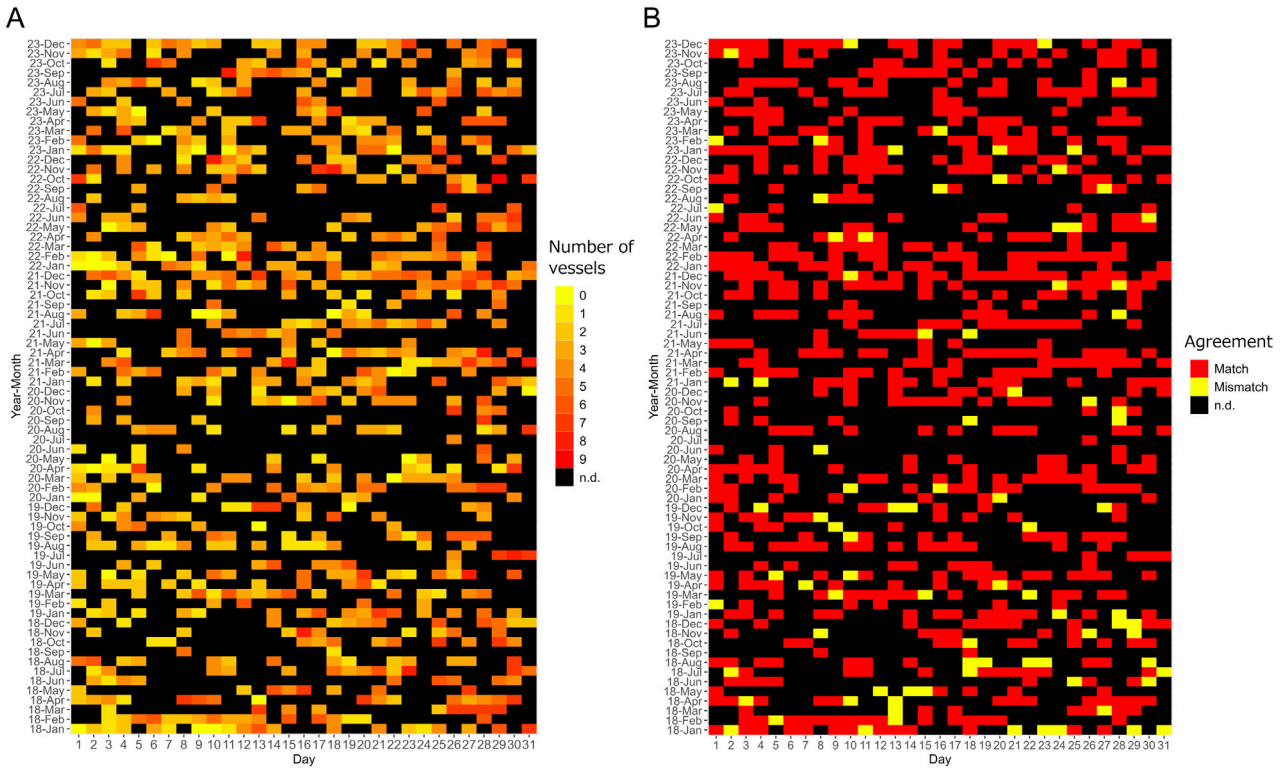

FIGURE 5
The results of daily counts of vessels from 2018 to 2023 Planet Dove/SuperDove images by visual interpretation **(A)** and the agreement between visual interpretation results and actual schedule information **(B)**.

generally good and accurate reflected the actual situation. We investigated how these results could be used for actual daily port usage of automobile terminals.

The boxplots of the number of vessels by month and by day are shown in Figures 6A, B, respectively. The number of vessels ranged from 0 to 9. The median number of vessels was three–four per month. The interquartile range was smaller in August than in other months. The average number of vessels by month was low in August, January, and May (in the order of 2.8, 2.9, and 3.3, respectively) and high in July, June, and September (4.1, 4.0, and 4.0, respectively). In terms of the number of vessels per day, the average tended to be higher from the 25th to the 31st of the month, compared to other days. The average number was particularly high from the 28th onwards. The average for the 1st–24th was 1.9–4.1; for the 25th–27th, 4.4–4.6; and for the 28th–31st, 4.7–5.3. These results suggest that many vessels were docked in automobile terminals at the same time toward the end of the month, regardless of the actual month.

4 Discussion

4.1 The assessment of the daily coverage of the Planet satellite constellation

The Planet constellation was not able to observe the same location once a day. The number given for the 'lack of data' class increased from 2018 to 2020, whereas it dropped in 2021 and remained at the same level until 2023, despite the increase in the number of launched satellites every year since 2021 (Planet, 2021; Planet, 2022; Planet, 2023). However, 41.8% of the days lacked data over the 6-year survey period. Thus, improving the daily coverage remains a challenge for the satellite constellation. The 'data with cloud' ranged from 67 to 86 days in 2018–2023. The effect of cloud is unavoidable due to the characteristics of the optical sensors onboard. When searching images in Planet Explorer, the cloud cover filter can be set to any percentage. However, even if some part of the image is covered by cloud, the region of interest (in this study, automobile terminals) may not be covered by cloud. Filtering by percentage may exclude data available for analysis. In this study, we examined each image individually, so we considered we have evaluated the available data to the maximum extent possible. However, since the analysis was done by visual interpretation, the results may vary slightly depending on the analyst. Especially when the terminal is covered with thin cloud, the decision will be highly dependent on the analyst. It is desirable to develop a method to check this objectively in order to maximize the use of available data.

More than one Planet satellite image existed per month; however, data were missing for up to a maximum of 29 consecutive days in some cases, as mentioned earlier. Thus, it is necessary to understand the limitations of optical satellite constellations affected by cloud. For applications requiring more stable temporal frequency observations, the

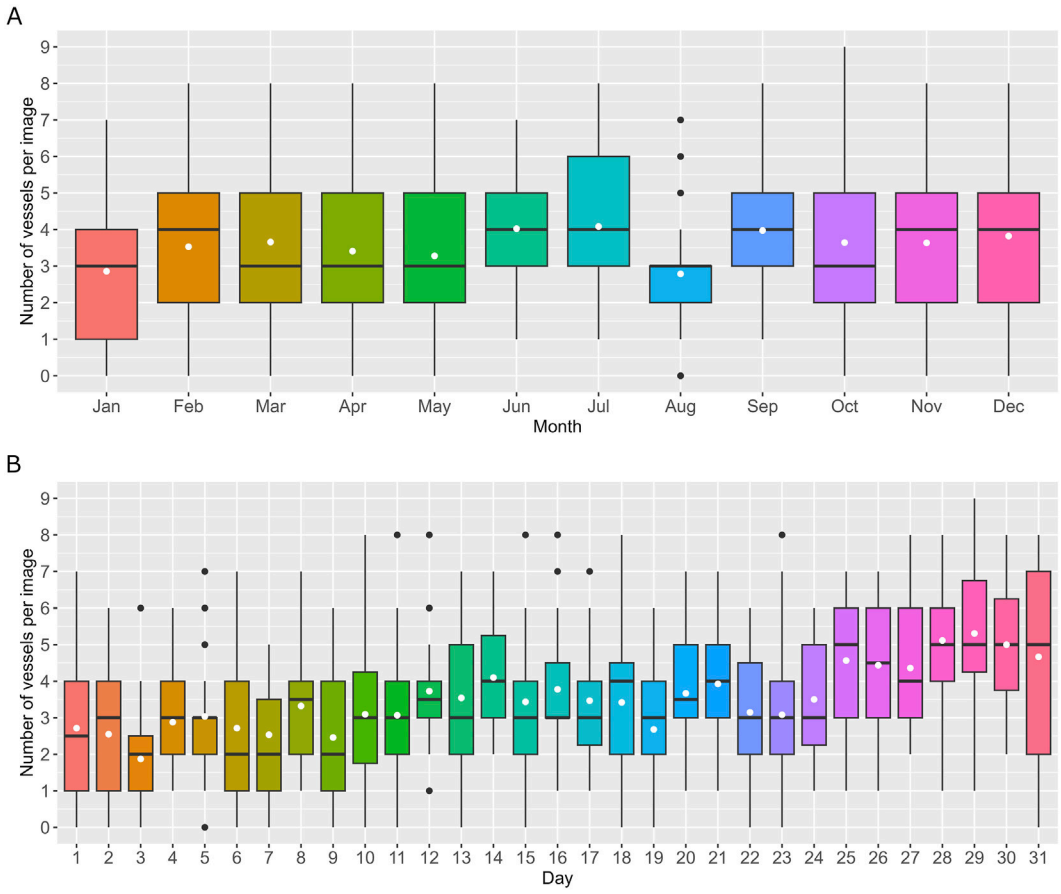

FIGURE 6
Boxplots of the number of vessels counted by Planet constellation images per month **(A)** and per day **(B)** from 2018 to 2023.

synthetic aperture radar (SAR) constellation (i.e., Synspective; iQPS) that provides high-resolution, weather-independent images day and night (Moreira et al., 2013) may be more appropriate and will become more readily available in the near future. There have been many vessel detection studies (Li et al., 2024; Yasir et al., 2023) and several maritime logistics studies using SAR data (e.g., Hamamoto et al., 2021; Johnsen, 2011; Li et al., 2022).

4.2 Accuracy of counting the number of vessels by visual interpretation

We counted the number of vessels by visual interpretation from Planet constellation's imagery. The results showed good accuracy with the actual schedule information. The discrepancies were mostly a visual misinterpretation. The result of visual interpretation may differ among analysts. On the other hand, nowadays, satellite images are used not only for researchers who analyze satellite images, but also on a daily basis such as in the press (e.g., BBC, 2020). Therefore, it is also important to evaluate how much estimation can be done by visual interpretation. We evaluated the accuracy of the visual interpretation in this study was good. However, it was not a perfect match. Sometimes general cargo vessels were not counted because of their small size. Also, achieving perfect match may be difficult, as in some cases the visual interpretation results seem more accurate than the actual schedule information. It seems that some vessels were not properly registered in the Yokohama Port Information System. Hence, visual interpretation might be more in line with the actual usage in cases.

It is labor-intensive to conduct additional surveys over a wider area. Many methods have been proposed to detect vessels using optical satellite imagery (Kanjir et al., 2018) that may allow for a more efficient count. Alternatively, a vessel's automatic identification system (AIS) that transmits the position information of vessels may be sufficient for counting the number of vessels in ports and harbors. The real-time and historical AIS data provide insights into shipping-derived impacts and conservation planning at multiple spatial and temporal scales (March et al., 2021). However, satellite imagery offers the advantage of detecting cargo such as automobiles stored in terminals with vessels.

4.3 Daily/monthly changes of the number of vessels in automobile terminals

The number of Ro-Ro ships was not constant and, in general, depended on both the day of the month and the month of the year.

Satellite images were taken at certain times of the day, so not all vessels docked in Daikoku Pier automobile terminals were estimated; however, our results had some notable findings. The interquartile range of the number of vessels in August was smaller than that of other months. Notably, August is the Obon holiday period in Japan; companies including maritime logistics offices close temporarily during this time. The average number of vessels was slightly higher in June, July, and September due to the transport of automobiles before and after the terminals closed in August. At Daikoku Pier, the number of vessels increased at the end of month, regardless of the month. Automobiles are transported by car carrier from car factories located inland to Daikoku Pier; increasing traffic on the inland roads may be an issue. Additionally, leveling the number of Ro-Ro ships to call in port at the same time may help to mitigate the shortage of workers and storage space. Moreover, the 6-year period was affected by the 2019 Coronavirus (COVID-19) pandemic. The cruise ship, the Diamond Princess, reached the Port of Yokohama on the evening of 3 February 2020 (Jimi and Hashimoto, 2020; Yamagishi et al., 2020) and then anchored at Daikoku Pier P3 to T3. COVID-19 caused an unprecedented drop in maritime mobility, across all categories of commercial shipping worldwide (Millefiori et al., 2021).

5 Conclusion

We evaluated the daily coverage of Planet constellation at Daikoku Pier automobile terminals, Port of Yokohama, Japan from 2018 to 2023. The result of classification showed that the number of 'lack of data' class was greater than that of 'available data' class. While the effect of cloud is inevitable, improving daily coverage remains a challenge for satellite constellation. From available data, the daily number of vessels were counted by visual interpretation and the accuracy was 89.0% compared to the actual schedule information. The visual interpretation results showed near accuracy to the actual schedule information, although a few misses in the interpretation remained.

Planet constellation was able to identify the changes of number of vessels on a daily and monthly basis. We found that many vessels were called in automobile terminals at the same time toward the end of the month. The actual schedule information at the study site was publicly available but in local language. Hence, satellite imagery would be useful to estimate the actual status of automobile terminals regardless of language. It seems difficult to use Planet satellite images for daily site progress management because data was sometimes available 1 day per month. Rather, the Planet constellation can be useful in estimating the actual conditions through long-term monitoring as demonstrated.

In this study, we did not focus on the analysis of automobiles in terminals, as this is a topic for future work. Cheng et al. (2016) proposed a deep learning algorithm rotation-invariant convolutional neural networks to detect objects including vehicles in very high resolution optical remote sensing images. Ragab et al. (2023) proposed the improved deep learning-based vehicle detection for urban applications. In addition to these studies, many other studies reported methods to detect automobiles using high resolution images (e.g., Bouguettaya et al., 2021; Koga et al., 2020). Hence, further research is needed to detect automobiles from Planet Dove/SuperDove images which are medium resolution (ground sample distance of 3.7 m). Özkan et al. (2016) analyzed the capacity of Ro-Ro terminals and concluded that the number of trucks arriving to terminals mostly affects to the terminal capacity. It may be possible to estimate this from satellite images based on the number of automobiles stored in the terminal. Although further research is needed, the Planet Dove/SuperDove images may be sufficient for resolving the stored area of automotive vehicles at the terminals. Additionally, renovations involving the conversion of container terminals to automobile terminals were confirmed in the collected data. Thus, Planet constellation can be used to monitor the progress of civil construction projects, in addition to maritime logistics, for a variety of stakeholders in port and harbor areas.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://www.planet.com/ Planet Labs (commercial data).

Author contributions

HM: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Validation, Visualization, Writing–original draft, Writing–review and editing. NI: Project administration, Writing–review and editing. KN: Funding acquisition, Project administration, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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