JOURNAL OF MARITIME RESEARCH

Vol XXII. No. II (2025) pp 151–160

ISSN: 1697-4840, www.jmr.unican.es

Application of AIS Data and Analytics in Bunkering and Marine Spatial Planning

N. Newaliya[1], V. Siwach[2,*], H. Sehrawat[3], Y. Singh[4]

ARTICLE INFO

Article history:
Received 18 Sep 2024;
in revised from 20 Sep 2024;
accepted 08 Oct 2024.

Keywords:
AIS, Bunkering, Data Analytics, Marine Spatial Planning, Sustainable Development.

ABSTRACT

This paper examines the role of Marine Spatial Planning (MSP) in achieving sustainable development in the maritime domain, particularly by utilizing Automatic Identification System (AIS) data to improve decision-making processes for establishing bunkering zones at sea. The environmental and economic challenges associated with traditional port-based bunkering have been highlighted and a novel solution of strategically located bunkering stations at sea is proposed. The study brings out the use of AIS data analytics in determining optimal locations for these bunkering zones and monitoring. This involves analysing historical AIS data to identify high-traffic shipping routes and areas with low traffic density suitable for establishing bunkering zones. This has been explained with a case study in the northern Indian Ocean. Further, using real-time AIS data, monitoring vessel movements, predicting bunkering needs, and ensuring safety within the designated bunkering zones has been recommended. The proposed approach recommends creating designated "Bunkering Separation Lanes" (BSLs) within these zones to facilitate safe and efficient refueling operations while minimizing disruption to regular traffic. This method aims to reduce the environmental impact of bunkering, enhance efficiency, and generate economic benefits for stakeholders. The study brings out that relocating bunkering activities to designated zones at sea, supported by AIS data analytics, offers a promising solution to maritime development challenges.

1. Introduction.

Sustainable development is essential, particularly in the present - day context. The fragile environment is already being stretched to its limits and under strain. While the environment definitely needs to be protected, it is also important that development activities are progressed vigorously to enhance quality of life. Both these activities can be undertaken concurrently if due regard is taken to the sensitivities involved and striking a good balance. One domain that requires considerable attention to ensure the progress of both development and the protection of the environment to achieve sustainable development is the maritime world. To ensure the sustainability of the marine environment, various marine activities need to be planned properly to provide adequate space for each as well as protect the environment. Marine Spatial Planning (MSP) enables the segregation of various activities in regions based on a number of factors to enable mutual growth.

AIS data, which provides information on the position and movement of ships at sea, is an important tool for MSP. Data analytics undertaken on the AIS information provides valuable insights which can help in planning maritime activities and segregating zones. The incorporation of AIS data into MSP has many potential applications.

[1]Research Scholar, Department of CSE, UIET, Maharshi Dayanand University, Rohtak, Haryana, India.
[2]Associate Professor, Department of CSE, UIET, Maharshi Dayanand University, Rohtak, Haryana, India.
[3]Associate Professor, Department of CSE, UIET, Maharshi Dayanand University, Rohtak, Haryana, India.
[4]Professor, Department of CSE, UIET, Maharshi Dayanand University, Rohtak, Haryana, India.
*Corresponding author: V. Siwach. E-mail Address: vikas.siwach,uiet@mdurohtak.ac.in.

Specifically, a novel bunkering methodology is presented in detail as a use case that has environmental and economic significance, such as the identification of optimal bunkering locations, reduction of risks of pollution, enhancement of efficiencies, and monitoring of compliance by various entities. Bunkering is the activity of refuelling ships, which is commonly undertaken in ports. This essential activity can, however, lead to environmental damage in case of a spill while fuelling and also affects the environment in the port cities. Bunkering at sea is also undertaken, though it is not as popular. It is proposed to designate areas specifically for Bunkering at sea, and Bunkering lanes are suggested. A preliminary assessment of this concept was presented at the IEEE Oceans Conference 2022 (Newaliya et al. 2022) and the International Conference on Research and Innovation for Sustainable Development 2024 (ICRISD 2024). This paper examines the concept of bunkering lanes and explains its functioning. Bunkering lanes have been proposed to enable efficient refuelling while in motion without much deviation from the normal transit path, enabling saving time and costs, apart from other advantages. It brings out the nuances to be considered and how this can enhance sustainable development activities and the protection of the environment. It considers AIS data analytics to be an important bedrock based on which bunkering at sea can be satisfactorily achieved.

The study brings out certain significant aspects and new features of the proposed method for bunkering at sea. Shifting bunkering away from the coast alleviates pressures on coastal zones and unlocks significant economic and environmental advantages for all stakeholders. This includes reducing noise pollution and the risk of spills in port areas. Since the proposed method designates bunkering stations near high-traffic shipping lanes, it allows ships to refuel without significant detours, saving time and costs associated with port fees and bunkering charges. Additionally, ships can optimise fuel quantities, leading to increased cargo capacity and better fuel efficiency. The novel concept of Bunkering Separation Lanes involves creating designated lanes within bunkering zones to streamline refueling operations, which minimises disruption to regular traffic and allows for safer and more efficient refueling. Additionally, the implementation of oil booms around these lanes aids in containing potential spills. By analysing historical AIS data, optimal bunkering zone locations are determined based on high-traffic routes and areas with low traffic density. Furthermore, real-time AIS data facilitates the monitoring of vessel movements, predicts bunkering needs, and enhances safety within designated zones.

The proposed method offers several advantages over traditional port-based bunkering by combining strategic location planning, innovative bunkering lanes, and the effective use of AIS data analytics. This approach aims to transform bunkering operations, making them more sustainable, efficient, and economically viable while minimising environmental impact.

The paper comprises of the following sections: Section 2 examines the related works, Section 3 describes the AIS applications in MSP, Section 4 explains the proposed Bunkering at Sea approach with AIS data, Section 5 discusses the outcomes of the study and Section 6 presents the conclusion.

2. Related Works.

The study aims to address the limitations of traditional port-based bunkering by proposing a novel approach: establishing designated bunkering zones at sea, supported by AIS data analytics. This shift in bunkering operations seeks to foster sustainable development in the maritime domain, balancing economic growth with environmental protection.

As per the definition of UNESCO, MSP involves the analysis and assignment of activities in marine areas, taking into account various aspects, including spatiotemporal, for commercial, societal, environmental, security, and other purposes (Marine Spatial Planning | Intergovernmental Oceanographic Commission 2024). It facilitates marine area development in a controlled and sustainable methodology and arrives at decisions that are well-considered. It also helps resolve activities that may involve vying for the same space or marine resource.

While the importance and awareness of MSP have increased over the years, it is essential that the required data is available for planning activities, and in this, AIS plays a significant role (Tixerant et al. 2018). It has been used in various MSP use cases. While resolving competing marine spatial resource requirements in Taiwan, AIS has been used to identify primary shipping paths, determine real-time positions of vessels, generate density maps and determine other insights using various data analytic techniques with an aim to develop regional MSP (Yang et al. 2024). Proposing a method of valuating the marine areas towards MSP, AIS has been used for spatial analysis by rasterisation for determining mean profit on a daily basis and also for assessing the time spent by each ship in a defined Polish sea area (Czermański et al. 2024). AIS data has been used to determine the temporal characteristics of the port network in Korea with an aim to arrive at the seasonal changes in the volume of port arrivals towards informing MSP efforts (Kim et al. 2023). AIS can also be used along with other datasets. It has been combined with VIIRS DNB imagery to provide a better understanding of the marine activities and the impact these would have on the environment, thus aiding MSP aspects, such as conservation and management (Kaewpoo et al. 2023). In order to ensure and monitor vessels and their areas of operations in the Adriatic Sea, AIS has been used, which enables determining if fishing vessels are in regions where they are not supported to be (Ferrà and Scarcella 2023). AIS data has been used for spatial and statistical assessments towards mapping fishing efforts and creating an enhanced situational awareness of the fishing activity by combining it with VMS data, which is crucial for MSP (Thoya et al. 2021). In an effort to understand the spatial distribution of fishing effort and its potential effect on the marine environment for MSP activities, AIS data has been used to map the intensity of fishing over monthly and yearly periodicities and also the determination of fishing gear types based on ML algorithm (Farella et al. 2021). It has been brought out that AIS data is critical for MSP since it enables tracking of the movement of vessels and understanding the utilisation of areas, thus allowing planners of MSP to make informed decisions regarding sustainable marine activities management (Dupont et al. 2020). While using the Republic of Congo-Brazzaville as a case study, it has been brought out that AIS can assist in identifying stakeholders, mapping vessel activities and understanding behaviours, identifying threats to ecosystems and determining overlaps with other applications, amongst others (Metcalfe et al. 2018). It has been shown how, by integrating AIS data with other sources of information, such as LRIT (Long Range Information and Tracking) and VMS, a robust MSP can be created, which can facilitate monitoring activities, assessment of risks and arriving at informed decisions in marine operations (Greidanus et al. 2016). Other preliminary studies have also explored AIS data in MSP, such as in small-scale fisheries management (James et al. 2018) and AIS Data Visualization in MSP (Fiorini et al. 2016).

The existing research exploring the interactions between bunkering and AIS data is limited but holds significant potential. Identifying conduct of bunkering activities from a providing vessel to a receiving vessel using AIS data have been brought out in (Fuentes 2021). Utility of AIS data in determining bunkering activities using parameters like vessel speed and stationary durations has been presented in (Wu and Aarsnes 2017). Further, research by (Ford et al. 2018) brings out the potential of AIS data in detecting illegal fishing activities linked to bunkering.

While bringing out that fuelling of maritime vessels is generally in ports, this activity not only ends up utilising premium space within the harbour and also considerable time, it may also lead to detrimental environmental effects within the harbour, in addition to noise and pollution effects (Tichavska and Tovar 2015). This is also an expensive activity since port charges need to be paid by the vessel. There is also a tendency for the vessels to be topped up in fuel in the journey commencement ports rather than in between their journeys (Schneider and Vis 2016). While this may save some time and port charges, it results in the vessels starting their travel fully loaded, thus reducing efficiency, increasing tonnage and limiting the maximum carriable cargo. Further, prices of bunkering in ports, port charges and the detour that the vessel needs to take from the optimum route play a significant role in determining bunkering alternatives. These aspects are particularly significant in long journeys.

Reduction of environmental effects of shipping is a high priority activity and towards reduction of impact on the environment by vessels entering ports, four Emission Control Areas have been promulgated by IMO, with some countries issuing enacting similar directives enforcing use of more expensive lower sulphur fuel within these areas (Ma et al. 2021). This would therefore result in further increasing the bunkering cost in ports. There is, of course, the perineal danger of oil spills occurring while bunkering in ports, which not only affect the environment and port infrastructure, result in harming the environment further and also imposing a penalty onto the shipping company (Bunker Spills: A brief overview of cause, effect and prevention - SAFETY4SEA 2018). These aspects thus strengthen the case for seeking alternatives for bunkering within the port areas, while being efficient in cost and time.

Bunkering at sea is presently being undertaken and its advantages have also been presented, which include saving of time from deviating from route, elimination of additional costs which come into play when entering a port for refuelling, etc. (Riviera - News Content Hub - High seas bunkering is cost effective and safe 1 2009). However, it remains an unorganised activity as of now.

Due to the ongoing crisis in the Red Sea, a large amount of traffic has been diverted from the Suez Canal to the Cape of Good Hope, causing an increase in volumes of vessels bunkering in Colombo (Bunkering, TS volumes surge in Colombo | Print Edition - The Sunday Times, Sri Lanka 2024). This has led to an increase in the price of fuel at Colombo, and would have also stressed the environment and infrastructure there.

As can be assessed, there is increasing interest in the utilisation of AIS in MSP activities. It is also seen that the majority of the applications of MSP utilising AIS data are concerned with closer-to-coast activities. An unsupervised learning method, DBSCAN Data Clustering, attempts to segregate data into groups wherein some element of commonality exists between each data point of an individual group. There is no requirement to train a model on the data to determine clusters using Clustering methods. DBSCAN requires two parameters as inputs, viz. Eps (a point's neighbourhood indicated by an appropriate distance measure) and MinPts (minimum number of points required within the neighbourhood). DBSCAN has the ability to detect clusters which may be of arbitrary shape and, therefore, is well suited for clustering AIS data.

3. AIS Data in Brief.

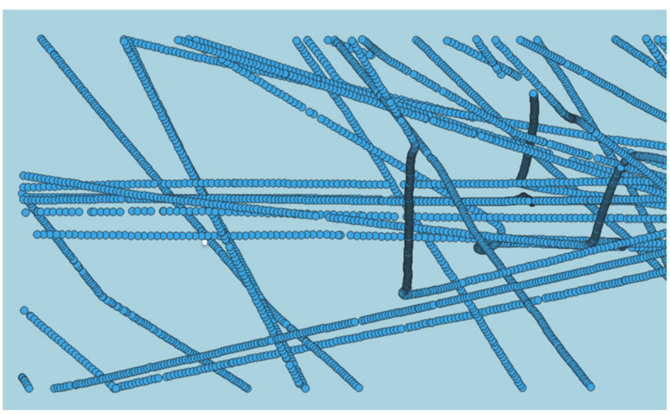
The AIS system is an electronic device installed on the vessel and interfaced with a suitable VHF radio. Four frequencies have been allocated for the AIS system in the VHF spectrum (Use of Appendix 18 to the Radio Regulations for the maritime mobile service M Series Mobile, radiodetermination, amateur and related satellite services. 2014). AIS system details have been specified in (Technical characteristics for a universal shipborne automatic identification system using time division multiple access in the VHF maritime mobile band (Question ITU-R 232/8). 1998). A total of 27 message types have been defined, segregated into three categories. Static category includes those messages which generally do not change for considerable amount of time, e.g. vessel identity, dimensions, type, etc. Dynamic messages are those that change continuously during the passage of the ship and include positional and movement information. Voyage category of messages is those that concern the journey being undertaken presently, viz. time of arrival at destination. An AIS message extract is presented in Fig. 1 and plotted on a GIS software in Fig. 2. The data has been downloaded from MarineCadastre (AccessAIS - MarineCadastre.gov 2024). The periodicity of each of the 27 messages has been defined and can be upto 2 seconds for certain movement related messages. This AIS data is amenable to assessment using data analytic methods such as Rules-based, Clustering, classification, Pattern identification, etc. (Guillarme and Lerouvreur 2013; Hadzagic et al. 2013; Schmitt et al. 2021). While certain open sources of AIS data are available, these are generally confined to specific regions and not real time. Most comprehensive AIS data sources are commercial or government owned. Generally, the AIS data needs to be pre-processed to remove erroneous information, and adapted for the specific use case.

Figure 1: Extract of AIS Data.

MMSI	BaseDateTime	LAT	LON	SOG
235076283	04-10-2022 01:...	34.23407	-121.55728	0.51162790697...
538008452	06-10-2022 14:...	34.23409	-121.84982	0.42790697674...
338371000	05-10-2022 23:...	34.2341	-121.7787	0.71162790697...
369567000	05-10-2022 00:...	34.23435	-121.62474	0.39534883720...
636021005	06-10-2022 10:...	34.23446	-121.78094	0.53023255813...
369040000	04-10-2022 14:...	34.23454	-121.8798	0.46976744186...
538008452	06-10-2022 14:...	34.23471	-121.84633	0.42325581395...

Source: MarineCadastre.

Figure 2: Plot of AIS data on QGIS.



Source: Authors.

4. Proposed High Seas MSP: Bunkering at Sea approach with AIS datag.

It is observed from the survey of MSP activities that regional and coastal MSP activities have been prioritised. This is definitely of great significance since these areas are highly susceptible to ecological effects, and many stakeholders compete for the same areas. Authorities and planners are thus putting a great deal of effort into optimising these limited resources. This, however, will always have limitations, with either the coastal areas coming under immense stress or not all stakeholders being satisfied. Therefore, beyond-coast MSP needs to be looked at with much more focus, moving away from traditional outlooks. While it may not be possible to shift some applications and stakeholders away from the coast, it is feasible to draw out a construct wherein certain applications may be moved, freeing up space closer to the coast and also playing a part in preserving the fragile ecosystem as well as being more economically efficient. This could be a win-win situation for all.

In this regard, it is proposed that one such application that can be shifted away from the coast is bunkering, i.e., the fuelling of ships. This is extensively undertaken across the world in various ports, and shifting this activity away from the coast could, by itself, alleviate pressures on coastal zones and also unlock significant economic and environmental advantages. Bunkering within ports has considerable disadvantages. It is a time-consuming process, and the berth in the port is occupied until the bunkering process is completed. This leads to delays and congestion in high-density ports, leading to disruptions in productivity and supply chains. The vessels entering a port for bunkering also result in an increase in pollution in the port region, including noise. There is also the danger of accidental spills, which are very difficult to clear up in a port, at times leading to permanent damaging effects. The port where the bunkering is scheduled may not be on the optimum route for the vessel while it is on its journey to its destination. This would require it to take a detour, resulting in a loss of time and involving an additional cost. This cost is apart from the port charges and bunkering charges that would need to be paid in ports, thus proving to be rather an expensive affair for the shipowners, which would translate into higher operational and shipping costs. A workaround to this that is generally taken is for the ships to fuel up fully at the origin port to avoid bunkering in between the transit. However, this results in lesser cargo carrying capacity and also a lower fuel efficiency due to the increased fuel that is being carried.

With the challenges and limitations linked with traditional port-based bunkering, a novel solution is proposed in this study, which involves suitably located bunkering stations at sea. These would not be limited to port areas but would be located in close proximity to long-distance or frequented traffic routes. There are a number of advantages that this approach would materialise in, including reduction of environmental impact, enhanced efficiencies, and economic benefit across all stakeholders.

While the need for bunkering away from the coast emerges to be justified, it needs to be planned and implemented strategically to ensure optimum benefit. Bunkering at sea is already being undertaken through the deployment of tankers, which facilitate refuelling at sea. The position of the tankers is available, and these can be requisitioned for bunkering. Fig. 3 shows the position of tankers from one such provider (High-Seas Tanker Positions - Clipper Oil Marine Fuels 2024). However, it is not an organised activity and is dynamic in nature, with uncertainties attached. A number of factors need to be considered while arriving at the nuances of this activity. Some aspects that need to be factored in include the distance from the coast, the depths in the region, the weather conditions, marine and bio-life in that area, and, of course, the location with respect to the traffic routes. The assessment with respect to the traffic route is needed from two perspectives. One, the identified region needs to be close enough to the predominant traffic route to make it lucrative for the ships to not deviate too much from their optimised journey, and secondly, the exact location needs to be in a location where there is no routine traffic to ensure that it does not interfere with the normal traffic behaviour.

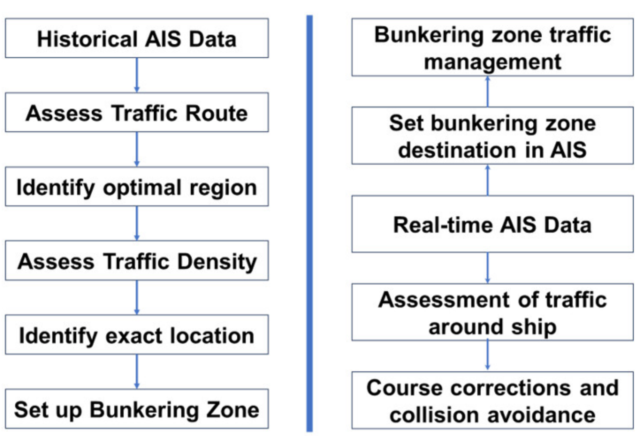
Figure 3: Location of tankers at sea.

Source: Clipper Oil.

AIS data analytics plays an important role in arriving at such a location. A large amount of AIS data is generated daily by the various ships that are moving along their routes. The quantum of data that is being collected has increased considerably using satellite AIS (Chen et al. 2023). This not only enables a better real-time estimate of the traffic situation but also enables historical analysis of maritime traffic.

This study proposes the utilisation of AIS data in two ways to facilitate bunkering at sea. Firstly, using the historical AIS data, traffic patterns and routes, as well as traffic densities, are assessed to arrive at the optimal location of a bunkering station at sea. Secondly, real-time monitoring of the traffic situation from a safety aspect and also assessing the destination of vessels to the bunkering stations can be undertaken using AIS data. The workflow for these two methods is shown in Fig. 4 and explained in succeeding paragraphs.

Figure 4: Workflow for proposed utilization of AIS data.



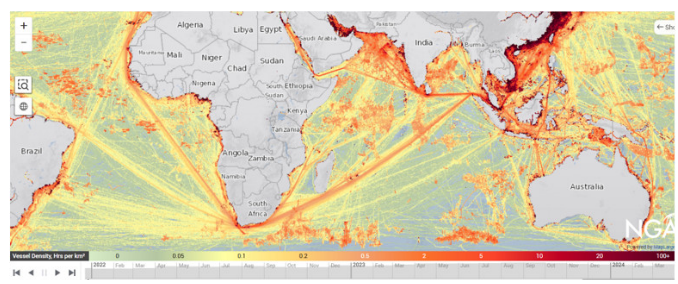
(a) Historical Assessment (b) Real-Time Assessment

Source: Authors.

4.1. Historical AIS Data Assessment.

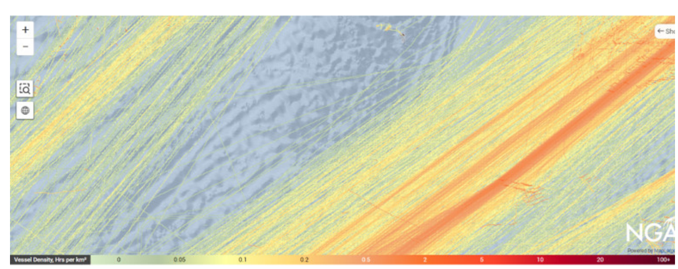
This involves undertaking data analytics techniques on historical AIS data to arrive at valuable insights. The historical data is first assessed to ascertain the most popular routes followed by vessels. This can be assessed by undertaking a density analysis of the AIS data. One overview of the traffic density is shown in Fig. 5, which shows the maritime traffic for the month of Apr 2024 (GMTDS | Maps of Global Maritime Traffic Density Service 2024). The darker the tone of the red colour, the higher the density in the region. From the density map, the major traffic routes normally followed by the vessels are readily evident. While this gives a global perspective, regional and local assessments can also be undertaken to understand the traffic densities and the common routes in the defined areas. This step enables arriving at a suitable traffic route to consider for bunkering at sea and also evaluates the general location where the bunkering arrangement is to be located. It would be preferable to establish the bunkering location at an approximate midpoint of a major route being followed. At times, the location may not necessarily be the midpoint, but it may be somewhere more convenient to address logistics, environmental, territorial, and other such issues. Once the traffic route and general area have been established, the next step would be examining the area in more detail, again using the AIS data density analysis. The aim would be to identify a suitable location where the bunkering zone can be established. This zone needs to be close to the traffic route but in a region that does not interfere with the shipping route. A zoomed-in section of the traffic density map in the Indian Ocean is shown in Fig. 6, which shows the predominant traffic route, along with areas around it that are reasonably clear of traffic and can be used to establish a bunkering zone.

Figure 5: Maritime Traffic Density.



Source: GMTDS.

Figure 6: Detailed examination of the region.



Source: GMTDS.

4.2. Historical AIS Data Assessment.

A novel methodology for creating a bunkering zone is proposed. In the region identified using the AIS data analytics as described above, an area is segregated as the bunkering zone in which mobile bunkering is undertaken in defined lanes, similar to TSS (Traffic Separation Schemes). This methodology is illustrated in Fig. 7. The bunkering zone is segregated into virtual lanes (Fig. 7(a)), termed as Bunkering Separation Lanes (BSL), which define the direction of travel of vessels. A vessel requiring to be refuelled aligns itself in one of these lanes depending on the direction of its travel. (Fig. 7(b)). At the extreme ends of the BSLs, a bunkering barge waiting point is established. The fuelling barges will supply fuel to the ship station themselves at this point. Once the ship requiring the fuel approaches the entry of the appropriate BSL, a fuelling barge is assigned to it, departs from the waiting point and closes the ship to be refuelled (Fig. 7(c)). The two vessels then connect up the hoses and equipment required to transfer the fuel while continuing to move in the BSL. The fuelling thereafter commences in motion. Once the fuelling is completed, the hoses are disconnected, and the ships being refuelled continue on their journey while the fuelling barge joins the bunkering barge waiting station at the other end until it is tasked to refuel a ship in the other direction. Further, there is always a likelihood of oil spills while undertaking fuelling. Since there will be considerable distance from the shore, there will be enough time and resources to clean up the spill. However, an oil boom can be set up on the periphery of the BSL, as shown in Fig. 7(d), which will contain any spill of debris within this zone until it is cleared up completely. The bunkering could be undertaken as astern or abreast fuelling. As an adaptation, mooring points within the BSL could be established, wherein the fuelling is undertaken while both ships are stationary. Such bunkering zones, when established at defined strategically located points, would enable certainty in planning the transits and thereby optimise the fuel quantity to be carried.

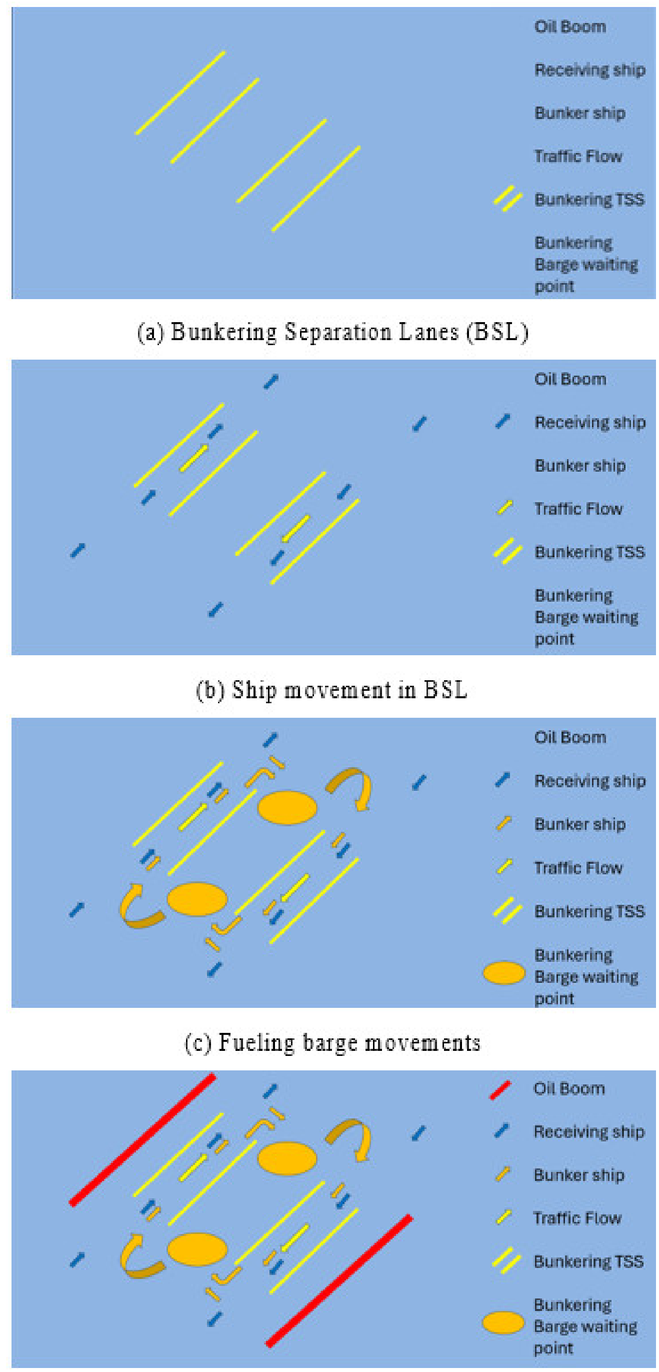
4.3. Algorithm for Bunkering Location Identification.

The foremost activity is the preparation of the AIS data and preprocessing it to remove outliers, errors and missing information. Thereafter, an appropriate period for the data needs to be selected. The time duration should be sufficient to present a realistic estimation of the shipping traffic and should also not be influenced by abnormal conditions, such as seasons of rough weather, which may alter the ship traffic pattern temporarily. Based on this selected data, density analysis is to be undertaken. There are various methods of determining the shipping density. One method is to divide the area of interest into equal-sized cells to form a grid. The number of AIS messages received for each grid cell is counted and divided by cell area to determine the density. Thereafter, to determine the shipping routes, clustering algorithms such as DBSCAN are used to cluster high-density AIS points. Another method is to first determine individual trajectories using some identifier like MMSI or unsupervised methods and then clustering the trajectories. Following this, the major shipping lanes are to be identified and the approximate midpoint of the journey between two major distant ports determined. Around the midpoint, determine an area of low density by setting a threshold and filtering the density data. This region can be examined for setting up a Bunkering Lane Zone.

4.4. Real-time AIS Data Assessment.

The bunkering zones established above are to be designated unique names. Such names would then serve as the destination

Figure 7: Bunkering Zone.



(a) Bunkering Separation Lanes (BSL)

(b) Ship movement in BSL

(c) Fueling barge movements

(d) Containment zones

Source: Authors.

that a ship would set in its AIS metadata. This information can be used by the control centres in the bunkering waiting areas to determine the ships that are planning to undertake bunkering and thereby prepare accordingly and monitor the real-time progress of the approach. This information in the AIS data would also enable another method of assessing the intentions of the vessel while it is in the shipping lane and its likelihood of deviating when approaching the BSL. It will, therefore, assist in better awareness of the situation and prevention of accidents. Meanwhile, in the BSL, AIS would continue to be used in the usual manner to enhance awareness of other ships around and take appropriate actions. The control room would also monitor the traffic with the BSL through AIS data to ensure safety and that the lanes and separation distances are being appropriately maintained.

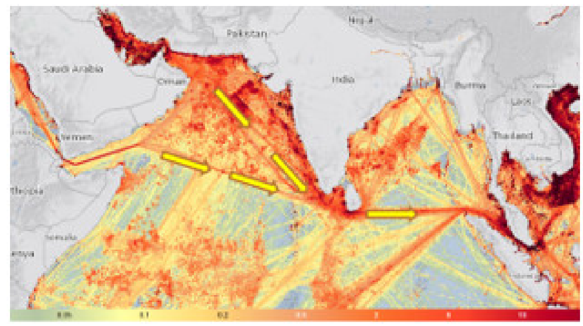
5. Experimental Implementation of the methodology.

5.1. Bunkering at Sea in the Northern Indian Ocean: A viable use case.

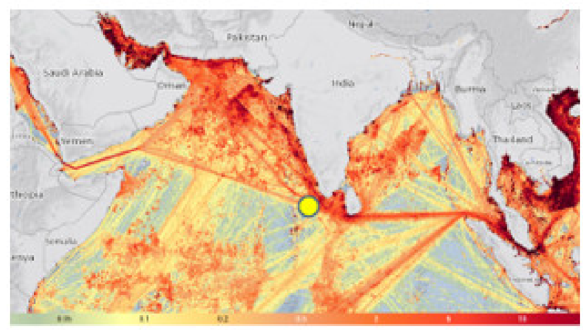
In order to demonstrate the efficacy of the proposed methodology, a preliminary investigation of a viable implementation in the northern Indian Ocean has been undertaken and shown in Fig. 8, with the AIS density maps obtained from the Marine Traffic website (MarineTraffic: Global Ship Tracking Intelligence | AIS Marine Traffic 2024). As brought out in the methodology in Section 4, the first step is to undertake a historical assessment of the AIS data density data. The map in Fig. 8(a) shows prominent shipping lanes marked by arrows between the Gulf of Hormuz as well as Bab-el-Mandeb? and into the South China Sea, covering a distance of approximately 4000Nm up to the Malacca Strait. An ideal location would be equidistance from either side. Using geographical information system tools, this mid-point is near Sri Lanka and the southern part of India, as shown by the circle in Fig 8(b). View various constraints in the bunkering en route, as elucidated earlier; most vessels undertake a non-stop journey. There, however, would be a few that bunker up in one of the Indian sub-continent ports. An analysis of the trajectory using AIS data has been undertaken, and it emerges that establishing a bunkering station south of India will be appropriate in the region marked by a rectangle in Fig. 8(c). This would be near the normal traffic route and also away from the coast to avoid coastal stress. With the certainty of a suitable bunkering location, the vessels can proceed from their origin with about 50% fuel, leading to a positive spiral of higher efficiencies, additional cargo, etc., thus being a more economical solution. This would be a more attractive option than entering a port like Colombo which would be atleast 50Nm one way from the traffic lane.

Investigating this area with a detailed assessment of the traffic density from AIS data reveals that one possible location is the Minicoy Islands. This island is north of the eight-degree channel, which is a dense ship traffic lane, as seen from the densities of AIS data in red. There are two areas of lesser density, which can be seen as a blue region, depicting lower traffic new Minicoy Islands on either side of a predominant shipping lane, as shown in Fig. 8(d). The selected region can be designated as a BSL, enabling ships not to deviate away from the optimal route to the destination and accruing other benefits of bunker at sea. A similar examination of AIS data can also be undertaken in regions near the Cape of Good Hope and Cape Horn, which are also conducive to establishing bunkering stations.

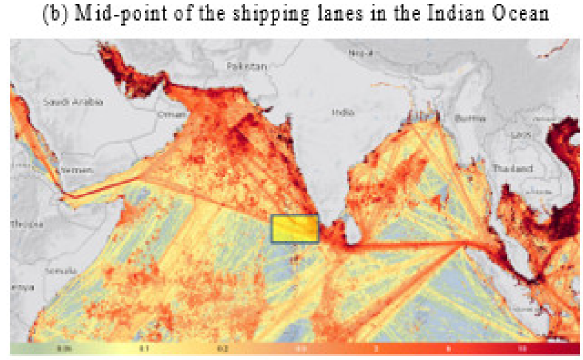
Figure 8: Bunkering Zone.



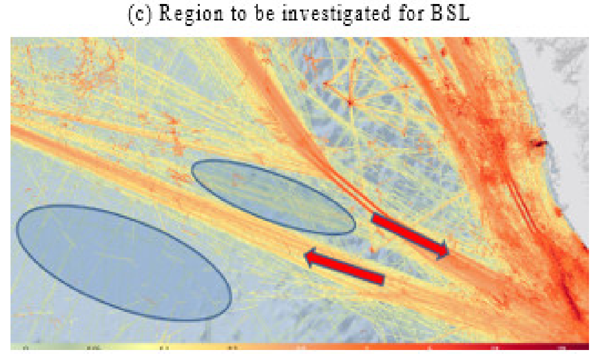
(a) Prominent shipping lanes



(b) Mid-point of the shipping lanes in the Indian Ocean



(c) Region to be investigated for BSL



(d) Likely areas for establishing BSL

Source: MarineTraffic.

5.2. Comparison with Existing Bunkering at Sea.

Bunkering at Sea is being undertaking by various individual firms, who have positioned tankers at various locations, as brought out in Section 4. This dynamic positioning is not organised centrally and is based on the individual assessment of the firms. As can be seen in Fig. 1, only one vessel has been positioned in Maldives in the Indian Ocean and is not in the proximity of the main shipping lanes. As against this, the proposed use case above, identifies the most suitable location for undertaking bunkering and proposed a novel method of BSL to enable efficient and safe operations. Therefore, the proposed method has considerable advantages over the present methodology of bunkering at sea, which is not optimised.

6. Discussions.

In this study, the role of Marine Spatial Planning (MSP) in facilitating sustainable development in the maritime domain has been investigated, specifically exploring the utilisation of Automatic Identification System (AIS) data to enhance decision-making processes in conceptualising the innovative concept of establishing bunkering zones at sea.

Traditional bunkering operations conducted within ports introduce various environmental and economic challenges. By relocating bunkering to designated BSL, these issues are well addressed. AIS data plays a pivotal role in the various MSP activities, providing valuable insights into maritime traffic patterns, vessel movements, and density distributions.

The proposed methodology has demonstrated how establishing bunkering zones at sea would optimise the refuelling of vessels in an innovative manner. It has shown the important role AIS data analytics plays in this process. Historical AIS data analytics enables the generation of density maps, which enable recognition of the dominating sea lanes and selection of the region that would lead to the extraction of maximum benefit from establishing a BSL. Thereafter, a detailed analysis with AIS data results in the location of the area where the BSL can be set up. Real-time AIS data enables the assessment of vessels heading towards a BSL and also enhances safety aspects.

Using an example of setting up a bunkering zone in the northern Indian Ocean, it is evident that this methodology can enhance the bunkering process, optimising the fuel that needs to be carried while commencing the journey. This optimised fuel regime will enable a higher amount of cargo to be carried and result in better economics and efficiencies, apart from playing a significant role in MSP. The shifting of bunkering away from the shore would result in better marine space management and lesser damage to the environment.

It is to be noted that along with AIS data analysis, additional studies taking into account environmental, climatic variations, logistics, etc. aspects need to be addressed prior to homing on the location of the BSL. Considering the weather variations across the year, a schedule may also need to be promulgated, e.g., restricting bunkering during the monsoon season in the Indian Ocean.

The success of this approach is hinged on intricate planning and coordination between the stakeholders, such as maritime authorities, shipping companies, and environmental agencies. The establishment of bunkering zones at sea will require investment in infrastructure, policy and technology to enable safe and efficient operations.

Future research should focus on refining the methodologies for AIS data analysis and further exploring the integration of other technological advancements in MSP. Additionally, pilot projects implementing sea-based bunkering zones should be conducted to validate the practical feasibility and benefits of this approach. Collaborative efforts among international maritime stakeholders are crucial to realising the full potential of this innovative solution, ensuring the sustainable management of marine resources for future generations.

Conclusions.

The marine environment is a very fragile space, and there is a constant effort to preserve and optimise activities in this domain. MSP plays a significant role in ensuring that the competing stakeholders of this much sought-after space, including marine life, are all well-balanced. Shipping is a major stakeholder in this, and it also requires considerable resources to conduct its activities.

The concept of moving bunkering activities away from ports to designated bunkering at sea zones, supported by AIS data analytics, offers a promising resolution to maritime development challenges. This innovative approach takes into account both environmental and economic aspects, putting forth a strategy to enhance MSP by leveraging AIS data for informed decision-making.

This study has taken advantage of AIS data analytics and demonstrated how bunkering activities can be moved away from the ports into the high seas. This would result in freeing up resources closer to the coast and reducing the stress on the marine ecology. It would further enhance the economy of the shipping transits, resulting in more efficient operations, which has also been demonstrated using examples, showing the additional cargo that can be carried, as well as cost and time savings.

Future research can focus on enhancing the AIS data analysis and integration of other sources of information to arrive at a more comprehensive assessment of the areas to be designated as BSLs. Pilot projects should be undertaken to implement BSL on smaller scales, possibly addressing the local and regional bunkering needs and validating the practical aspects of this approach. Based on these results, large-scale BSL setups can be taken up. It is crucial for all maritime stakeholders to collaborate constructively towards extracting the full potential of this novel solution for sustainable development and MSP.In this section we present the conclusions, at least one for each objective stated in the introduction.

Acknowledgements.

AIS data from the Bureau of Ocean Energy Management (BOEM) and the National Oceanic and Atmospheric Administration (NOAA). MarineCadastre.gov. Vessel Traffic Data. Retrieved July 01, 2022, from marinecadastre.gov/data.

References.

AccessAIS - MarineCadastre.gov. 2024. Available at: https://marinecadastre.gov/accessais/ [Accessed: 17 September 2024].

Bunker Spills: A brief overview of cause, effect and prevention - SAFETY4SEA. 2018. Available at: https://safety4sea.com/bunker-spills-a-brief-overview-of-cause-effect-and-prevention/ [Accessed: 17 September 2024].

Bunkering, TS volumes surge in Colombo | Print Edition - The Sunday Times, Sri Lanka. 2024. Available at: https://www.sundaytimes.lk/240114/business-times/bunkering-ts-volumes-surge-in-colombo-544922.html [Accessed: 17 September 2024].

Chen, J., Chen, H., Chen, Q., Song, X. and Wang, H. 2023. Vessel sailing route extraction and analysis from satellite-based AIS data using density clustering and probability algorithms. *Ocean Engineering* 280, p. 114627. doi: 10.1016/J.OCEANENG.2023.114627.

Czermański, E., Zaucha, J., Oniszczuk-Jastrzabek, A., Pardus, J., Kiersztyn, A. and Czerwiński, D. 2024. Valuation of marine areas for merchant shipping: an attempt at shipping spatial rent valuation based on Polish Marine Areas. *Frontiers in Marine Science* 11. doi: 10.3389/fmars.2024.1352598.

Dupont, C., Gourmelon, F., Meur-Ferec, C., Herpers, F. and Le Visage, C. 2020. Exploring uses of maritime surveillance data for marine spatial planning: A review of scientific literature. *Marine Policy* 117. doi: 10.1016/j.marpol.2020.103930.

Farella, G. et al. 2021. Ecosystem-based MSP for enhanced fisheries sustainability: An example from the northern adriatic (Chioggia-Venice and Rovigo, Italy). *Sustainability (Switzerland)* 13(3), pp. 1–28. doi: 10.3390/su13031211.

Ferrà, C. and Scarcella, G. 2023. Assessment of the current status and effectiveness of area-based conservation measures banning trawling activities in the Adriatic Sea. *Frontiers in Marine Science* 10. doi: 10.3389/fmars.2023.1213211.

Fiorini, M., Capata, A. and Bloisi, D.D. 2016. AIS Data Visualization for Maritime Spatial Planning (MSP). *International Journal of e-Navigation and Maritime Economy* 5, pp. 45–60. Available at: http://dx.doi.org/10.1016/j.enavi.2016.12.004.

Ford, J.H., Bergseth, B. and Wilcox, C. 2018. Chasing the fish oil-do bunker vessels hold the key to fisheries crime networks? *Frontiers in Marine Science* 5(AUG), p. 267. doi: 10.3389/FMARS.2018.00267/BIBTEX.

Fuentes, G. 2021. Generating bunkering statistics from AIS data: A machine learning approach. *Transportation Research Part E: Logistics and Transportation Review* 155, p. 102495. doi: 10.1016/J.TRE.2021.102495.

GMTDS | Maps of Global Maritime Traffic Density Service. 2024. Available at: https://globalmaritimetraffic.org/gmtds.html?$root.map.zoom=3&$root.map.center={%22lat%22:0,%22lng%22:0}&$root.projectionSelect=%22EPSG:3857%22 [Accessed: 17 September 2024].

Greidanus, H., Alvarez, M., Eriksen, T. and Gammieri, V. 2016. Completeness and Accuracy of a Wide-Area Maritime Situational Picture based on Automatic Ship Reporting Systems. *Journal of Navigation* 69(1), pp. 156–168. doi: 10.1017/S0373463315000582.

Guillarme, N. Le and Lerouvreur, X. 2013. Unsupervised extraction of knowledge from S-AIS data for maritime situational awareness. *Proceedings of the 16th International Conference on Information Fusion, FUSION 2013*, pp. 2025–2032.

Hadzagic, M., St-Hilaire, M.O., Webb, S. and Shahbazian, E. 2013. Maritime traffic data mining using R. *Proceedings of the 16th International Conference on Information Fusion, FUSION 2013* (November 2015), pp. 2041–2048.

High-Seas Tanker Positions - Clipper Oil Marine Fuels. 2024. Available at: https://www.clipperoil.com/services/bunkering-at-sea/tanker-positions/ [Accessed: 17 September 2024].

ICRISD. 2024. Available at: https://mdu.ac.in/UpFiles/UpPdfFiles/2024/Mar/4_03-20-2024_16-08-01_Brochure%20ICRISD%20Final%2020.03.2024.pdf [Accessed: 17 September 2024].

James, M., Mendo, T., Jones, E.L., Orr, K., McKnight, A. and Thompson, J. 2018. AIS data to inform small scale fisheries management and marine spatial planning. *Marine Policy* 91(September 2017), pp. 113–121. Available at: https://doi.org/10.1016/j.marpol.2018.02.012.

Kaewpoo, N., Suwanlertcharoen, T., Kesdech, W., Kongprom, A. and Payayam, T. 2023. MARITIME ACTIVITIES MAPPING FOR MARINE SPATIAL PLANNING USING GEO-INFORMATICS TECHNOLOGY. In: *44th Asian Conference on Remote Sensing, ACRS 2023*.

Kim, G., Jeong, M.-H., Jeon, S.-B. and Khan, M.S. 2023. Time-Series Analysis of Ship Movements Using Community Detection and Functional Data Analysis across the East Coast of the Republic of Korea. *Journal of Coastal Research* 39(2), pp. 360–365. doi: 10.2112/JCOASTRES-D-22TM-00011.1.

Ma, W., Hao, S., Ma, D., Wang, D., Jin, S. and Qu, F. 2021. Scheduling decision model of liner shipping considering emission control areas regulations. *Applied Ocean Research* 106(December 2020), p. 102416. Available at: https://doi.org/10.1016/j.apor.2020.102416.

Marine Spatial Planning | Intergovernmental Oceanographic Commission. 2024. Available at: https://www.ioc.unesco.org/en/marine-spatial-planning [Accessed: 17 September 2024].

MarineTraffic: Global Ship Tracking Intelligence | AIS Marine Traffic. 2024. Available at: https://www.marinetraffic.com/en/ais/home/centerx:57.6/centery:11.4/zoom:4 [Accessed: 17 September 2024].

Metcalfe, K. et al. 2018. Using satellite AIS to improve our understanding of shipping and fill gaps in ocean observation data to support marine spatial planning. *Journal of Applied Ecology* 55(4), pp. 1834–1845. doi: 10.1111/1365-2664.13139.

Newaliya, N., Agarwal, A. and Singh, Y. 2022. AIS data - Enabler in Marine Spatial Planning. *Oceans Conference Record (IEEE)*. doi: 10.1109/OCEANSCHENNAI45887.2022.9775500.

Riviera - News Content Hub - High seas bunkering is cost effective and safe 1. 2009. Available at: https://www.rivieramm.com/news-content-hub/news-content-hub/high-seas-bunkering-is-cost-effective-and-safe-1-53563 [Accessed: 17 September 2024].

Schmitt, P., Bartosiak, M.L. and Rydbergh, T. 2021. Spatiotemporal Data Analytics for the Maritime Industry. pp. 335–353. doi: 10.1007/978-3-030-50892-0_20.

Schneider, R. and Vis, I. 2016. Maritime Location Decisions for Lng Bunkering Facilities. *Progress in Material Handling Research: 2016*. Available at: https://digitalcommons.georgiasouthern.edu/pmhr_2016/27 [Accessed: 17 September 2024].

Technical characteristics for a universal shipborne automatic identification system using time division multiple access in the VHF maritime mobile band (Question ITU-R 232/8). 1998

Thoya, P., Maina, J., Mollmann, C. and Schiele, K.S. 2021. Ais and vms ensemble can address data gaps on fisheries for marine spatial planning. *Sustainability (Switzerland)* 13(7). doi: 10.3390/su13073769.

Tichavska, M. and Tovar, B. 2015. Port-city exhaust emission model: An application to cruise and ferry operations in Las Palmas Port. *Transportation Research Part A: Policy and Practice* 78, pp. 347–360. doi: 10.1016/j.tra.2015.05.021.

Tixerant, M. Le, Guyader, D. Le, Gourmelon, F. and Queffelec, B. 2018. How can Automatic Identification System (AIS) data be used for maritime spatial planning? *Ocean and Coastal Management* 166(734271), pp. 18–30. Available at: https://doi.org/10.1016/j.ocecoaman.2018.05.005.

Use of Appendix 18 to the Radio Regulations for the maritime mobile service M Series Mobile, radiodetermination, amateur and related satellite services. 2014. Available at: http://www.itu.int/ITU-R/go/patents/en [Accessed: 26 November 2023].

Wu, D. and Aarsnes, M. 2017. An Introduction to Assessing Bunkering Operations Through AIS Data. (December 2017). doi: 10.13140/RG.2.2.21415.04009.

Yang, J.-H., Chang, Y. and Hsiao, S.-C. 2024. Finding harmony in the sea: Resolving conflicts by regional marine spatial planning. *Ocean and Coastal Management* 254. doi: 10.1016/j.ocecoaman.2024.107200.