Using GIS and Logistic Regression Model for Locating Suitable Anchoring Sites in Sattahip Bay and Approaches, Thailand.

สัณหณัฐ อิสมาแอล[1]
Sanhanat Itsama-ael[1]

Received: May 9, 2023
Revised: May 26, 2023
Accepted: June 2, 2023

Abstract

Sattahip Bay is one of the important maritime regions in Thailand. Consequently, tons of ships port-in and port-out in this area including some ships also anchor in the bay as well. However, selecting the wrong anchoring location led to unexpected incidents. In order to mitigate those issues, the aim of this project is to locate suitable anchoring sites by using Geographic Information System (GIS) and Logistic Regression Model (LRM) to generate a model with 5 main factors, which are water depth, seafloor type, current speed, the availability of communication signal, and clearance from dangerous object. The results from the model imply that the middle area of Sattahip Bay is the most suitable for anchoring since all criteria are met that neither too deep and too shallow water depth, proper holding force from sand and clay, low current speed, average accessibility of communication signal, and no dangerous object. This model is useful to serve as a cross check tool for navigators to mitigate man errors in anchoring.

Keywords: Suitable Anchoring Location, Logistic Regression Model, GIS

[1]ประจำกรมกำลังพล ทหารเรือ
Attached to Naval Personnel Department, Royal Thai Navy
E-Mail: sanhanat@buffalo.edu, mee_sanhanat52@hotmail.com

1. Introduction

Since there are 3 main harbors, which are Laem Thian Naval Base, Chuk Samet Naval Base, and Sattahip Commercial Port located in Sattahip Bay, Thailand as shown in figure 1 [1], so this bay is considered as the one of the most ship-massive regions in Thailand. Although 3 major ports are located, it does not have enough capacity and spaces for all ships. Consequently, some ships that reach those ports ahead of time must save fuel and relax their crews by anchoring nearby and waiting for their turn to dock in those harbors.

However, selecting a right location to drop an anchor is not an easy task for seafarers, because there are several factors to consider, and choosing a wrong one let to an expected incident such as getting ground on an underwater rock, damaging the anchor, etc. Therefore, it is necessary for mariners to choose anchoring locations wisely and carefully. There are 4 main factors related to topography and hydrography that play a significant role in anchoring [2]. Firstly, suitable water depth must be considered to match with anchor chain and under-keel clearance. Secondly, different seabed types, different holding ground levels, so a bottom type is necessary. Then, current and wind are the main causes of scouring, so calm wind and slow current speed is perfect for anchoring. Finally, clearance from dangerous objects (e.g., underwater rocks, shipwrecks, islands) must be considered as well.

In term of communication, the availability of telephone and internet signals is important for selecting an anchoring location as well, because it will be more convenient that crews on the ship can contact to people on the land by using telephone and internet.

As there are powerful techniques in the Geographic Information System (GIS) and statistical method that are suitability index model and logistic regression model, which are useful for decision making, so it is interesting to apply this technology in anchoring tasks. Furthermore, with integration between supported data from Hydrographic Department of Royal Thai Navy (HDRTN) (e.g., Thai nautical charts, historical anchoring locations and bathymetric data) and Geographic Information System software, which is ArcGIS Pro in this case, the suitability location for anchoring in Sattahip Bay and approaches, Thailand can be implemented. Hence, the objective of this project is to locate suitable sites for anchoring in Sattahip Bay and approaches, Thailand using GIS techniques and statistical methods to create and validate the model, respectively. This model can make an anchoring mission safer and faster. Also, this can be used as a cross check tool to mitigate man errors and reduce unexpected accidents in anchoring. Finally, challenges in this project and future research opportunities will be discussed.

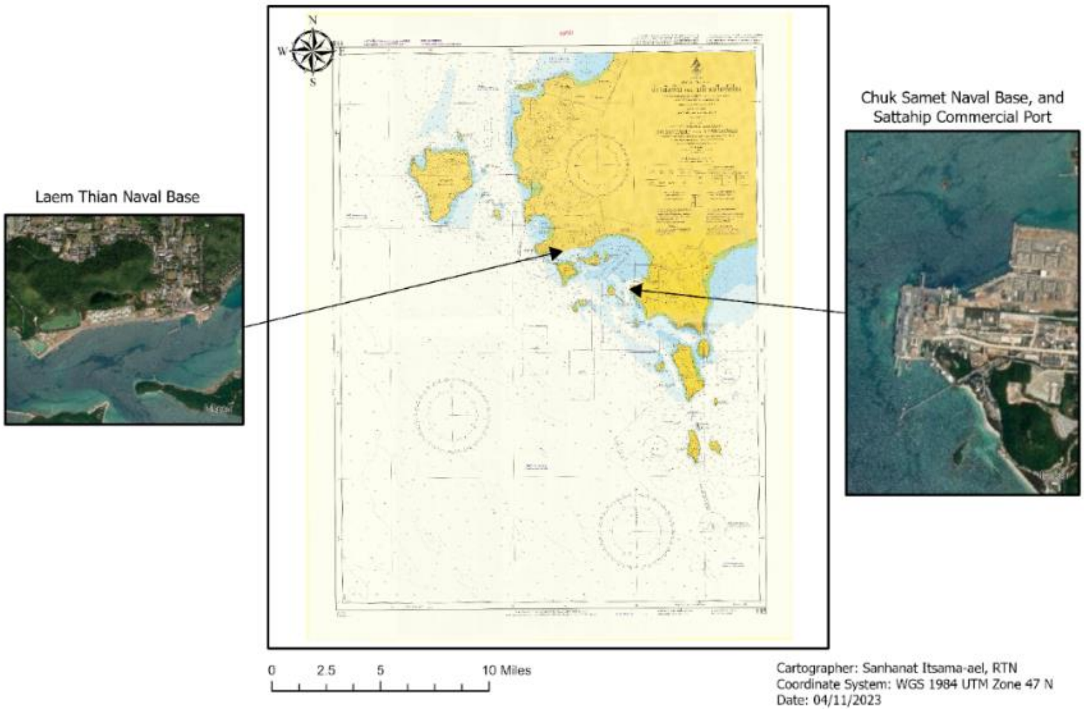


Figure 1 Overview of Sattahip Bay and Approaches, Thailand [1]

2. Literature Review

Fundamental and Considered Factors in Anchoring

Anchoring is a common task that seafarers do routinely. A ship drops an anchor to hold its position in the sea like parking a car. There are several circumstances that a ship has to anchor, for example, when they reach destinations a head of time, so anchoring is the best way to save fuel and rest their crews. Also, when they have technical issues, dropping an anchor to fix those problems is required. However, finding an appropriate site to anchor requires several factors to consider such as water depth, under-keel clearance, bottom types, current speed, weather forecast, traffic, clearance from dangerous objects, etc. [2]. Thus, it is necessary to consider those factors thoroughly before anchoring.

First of all, water depth and length of anchor chain are significantly related. Since water depth is a main parameter to compute the length of anchor chain to be released. There are official formulas that categorized by types of anchor chains that if the anchor chain is forged steel cable," the anchor chain length in shackles (1 shackle is 27.432 meters) will be released 1.5 times the square root of water depth in meters according to Equation (1) [3]. In case of “copper-based cable”, length of anchor chain in shackle is the square root of water depth in meters as presented in Equation (2) [3] However, a common equation that is practically used in Royal Thai Navy (RTN) is that the length of anchor chain is equal to 5 times of water depth,but if a ship anchors less than 24 hours, 3 times of water depth is used instead [4]. Therefore, 3 times of depth is reasonably used, because the typical reason that ships anchor in Sattahip Bay is to wait for berthing in ports, and it is usually less than a day. Consequently, if water depth is greater than 35 meters, it is not preferable for mariners, because 105-meter anchor chain must be released, and it takes a long time to operate.

$$L = 1.5\sqrt{d} \tag{1}$$

L = the length of anchor chain (shackle)
d = Water depth (meter)

$$L = \sqrt{d} \tag{2}$$

L = the length of anchor chain (shackle)
d = Water depth (meter)

In order to indicate a minimum water depth, a safety depth equation as shown in Equation (3) is broadly considered [5]. Firstly, average draft of ships that port-in/port-out in Sattahip Bay is lesser 7 meters, as such 7 meter is used as “Maximum Draft(static)”. Next, under-keen clearance (UKC) can be a fixed value, for example, 1 meter or a percentage of draft [6], so 1 meter is considerably used in this area. In term of squat parameter, squat is the phenomenal that is occurred when the draft increases with ship’s speed [7]. Also, the popular formula is “Squat = speed(knots) / 100 (meter)” (Barres’s Formula). However, squat does not affect an anchoring ship, so this variable can be eliminated. Finally, “Height of Tide” is out of scope, because the chart datum (vertical datum) of the Thai nautical chart is “Lowest Low Water” meaning no tide related. Therefore, safety depth = 7 + 1 = 8 meters and mariners do not normally drop anchors in the areas that shallower than 8 meters.

“Safety Depth = Maximum Draft(static) + UKC (Company’s Policy) + Squat (Maximum) – Height of Tide” (3)

As bottom types play a key role in a holding force, it is important to know characteristics of seafloor types. The holding force is efficiently high when seabed types are "clay, soft chalk, sand, sand/shingle and heavy mud," while an anchor is dragged in "softer seabed such as soft mud, shingle and shell" [3]. Hence, an anchor needs neither too soft nor too hard bottom types. Thus, it is obvious that sand and clay give proper holding force [8], while rocky seabed causes damage to anchor's metal parts [9]. In addition, the Coupled Eulerian-Lagrangian (CEL) was used to study anchor penetration in clay, the result showed that the anchor can penetrate deeper in clay more than loose sand [10],[11]. Therefore, it can be ranked the suitable bottom types from low to high levels as rock, shall, mud, sand, and clay.

Since the main forces that cause anchor dragging are current and wind speeds, those factors should be accounted. The maximum current and wind speeds that a ship can be held by an anchor are different based on ship's characteristics. If a ship anchors in harbored and shatter areas, 4.8 and 48 knots for current and wind speeds respectively are maximum, while in the opened sea 3 and 22 knots for current and wind speeds respectively are maximum acceptances [9]. According to basic understanding and fundamentals, it can be concluded that the lesser current and wind speeds, the better location for anchoring. Additionally, the clearance from dangerous objects is generally used in Royal Thai Navy is 700 - 1000 yards [4].

Communication is also another factor that is considered, because without the availability of telephone and internet services, a ship is isolated. Since line-of-sight propagation of communication wave can be blocked by topography such as hills that created a shadow zone [12]. In this case, the obstruction can be mountains and islands, so with digital elevation model (DEM), locations of communication towers on Google Map and visibility analysis tool in ArcGIS Pro, those shadow zones in the Sattahip Bay can be identified.

In term of statistical method, the logistic regression has been used to generate the model when a dependent variable is downgraded from a ratio scale and independent variables can be ratio, interval, ordinal, and nominal scales. A similar case of using logistic regression is the habitat of red squirrel in the Mt. Graham area [13], which is the same conditions with locating suitable anchoring sites.

Most previous research about anchoring focused on anchor penetration and environmental effects. For example, studying how anchor penetrates through seabed to reduce damages on submarine pipeline using models [14]. In case of environmental effects, research focused on scouring effects of anchoring to underwater environment [15]. However, it does not have a study on locating suitable sites for anchoring, so it is interesting to use the suitability index model technique in GIS and logistic regression model with factors above (e.g., water depth, bottom types, current speed, communication, clearance from dangerous objects) to implement the model.

3. Data and Methodology

3.1 Data and Pre-processes.

As 5 factors, which are water depth, seabed type, current speed, clearance from dangerous object, and the availability of communication signals were used to generate suitable anchoring location model, so water depth, seabed type, current speed, and clearance from dangerous object were obtained by Hydrographic Department of Royal Thai Navy (HDRTN). In case of the location of communication towers were derived from Google Map and digital elevation model (DEM) in Sattahip Bay was derived from Shuttle Radar Topography Mission (STRM), USGS for visibility analysis. Then, those raw data needed to be pre-processed to comply with GIS software in order to generate the model by using logistic regression.

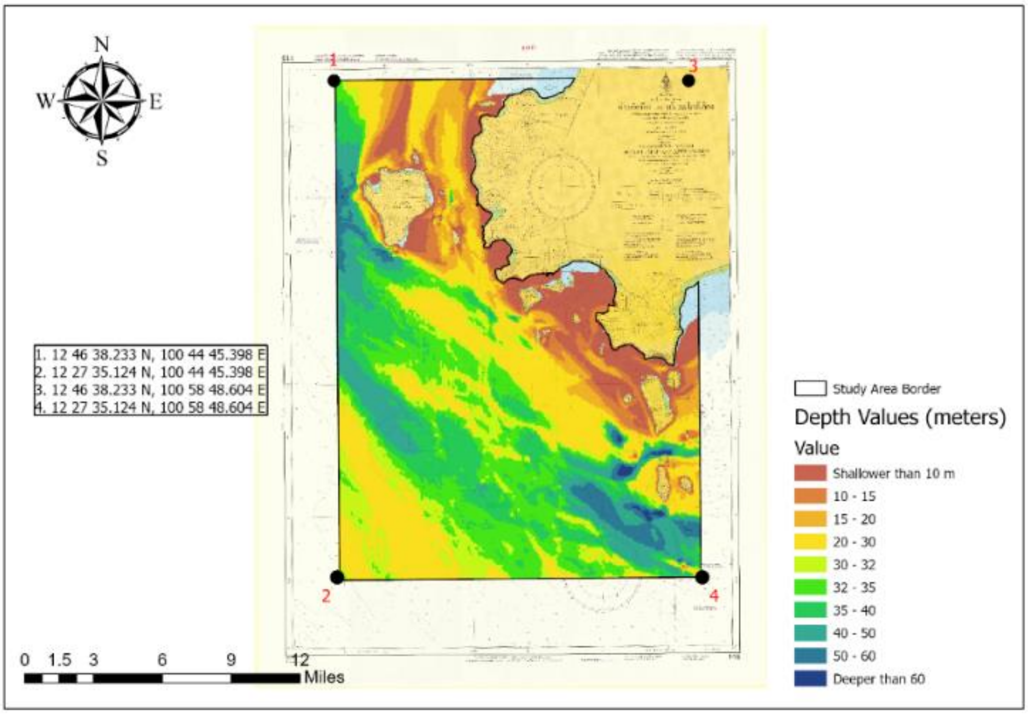


Figure 2 Study Area and Depth Values [1]

Firstly, the original format of water depth data was a point cloud format (in .XYZ with UTM Zone 47 N), but the model needed the raster format. Hence, the point cloud data was interpolated by using inverse distance weighted (IDW) to be a raster layer as shown in figure 2 [1].

Secondly, Thai nautical chart no.115, "Sattahip Bay, Thailand" was also derived from HDRTN in raster format with WGS 1984 UTM Zone 47 N. This was the source for other factors (seabed type, current speed, and clearance from dangerous object). In terms of current speed, there are current speed and direction shown on the map, so all those current symbols were digitized. After that, it is interpolated by using IDW to be a raster layer as shown in figure 3 [1]. In the same way, seafloor type can be seen on the map, so all those seabed symbols were digitized by ranking the seabed types based on unsuitability to suitability for anchoring as shown on the table 1. Then, it was interpolated by using IDW to be a raster layer as presented in figure 4 [1]. Finally, all dangerous objects that are land, islands, rocks, wrecks, etc. were digitized from the Thai nautical chart no.115.

Table 1 Seabed Type Ranks

Seabed types	Mud and Gravel	Mud and Gravel	Sand and Gravel	Sand and Shell	Clay and Sand
Rank	1	2	3	4	5

In terms of the availability of communication signal, five communication stations in point vector format as well as its attribute table were generated as shown in figure 5 [1].

To implement the logistic regression model, the reference data is required to be the dependent variable that is dichotomous in this case presence means it is suitable for anchoring and absence means unsuitable for anchoring. Thus, 32 historical anchoring locations from 4 ships, which is H.T.M.S. Phraruehatsabodi, H.T.M.S. Suk, H.T.M.S. Suriya, and H.T.M.S. Janthara, were supported by HDRTN, which are presence locations. Also, the other 32 locations are randomly generated to be absence locations by using GIS, so the total is 64 locations as can be seen on the figure 6 [1].

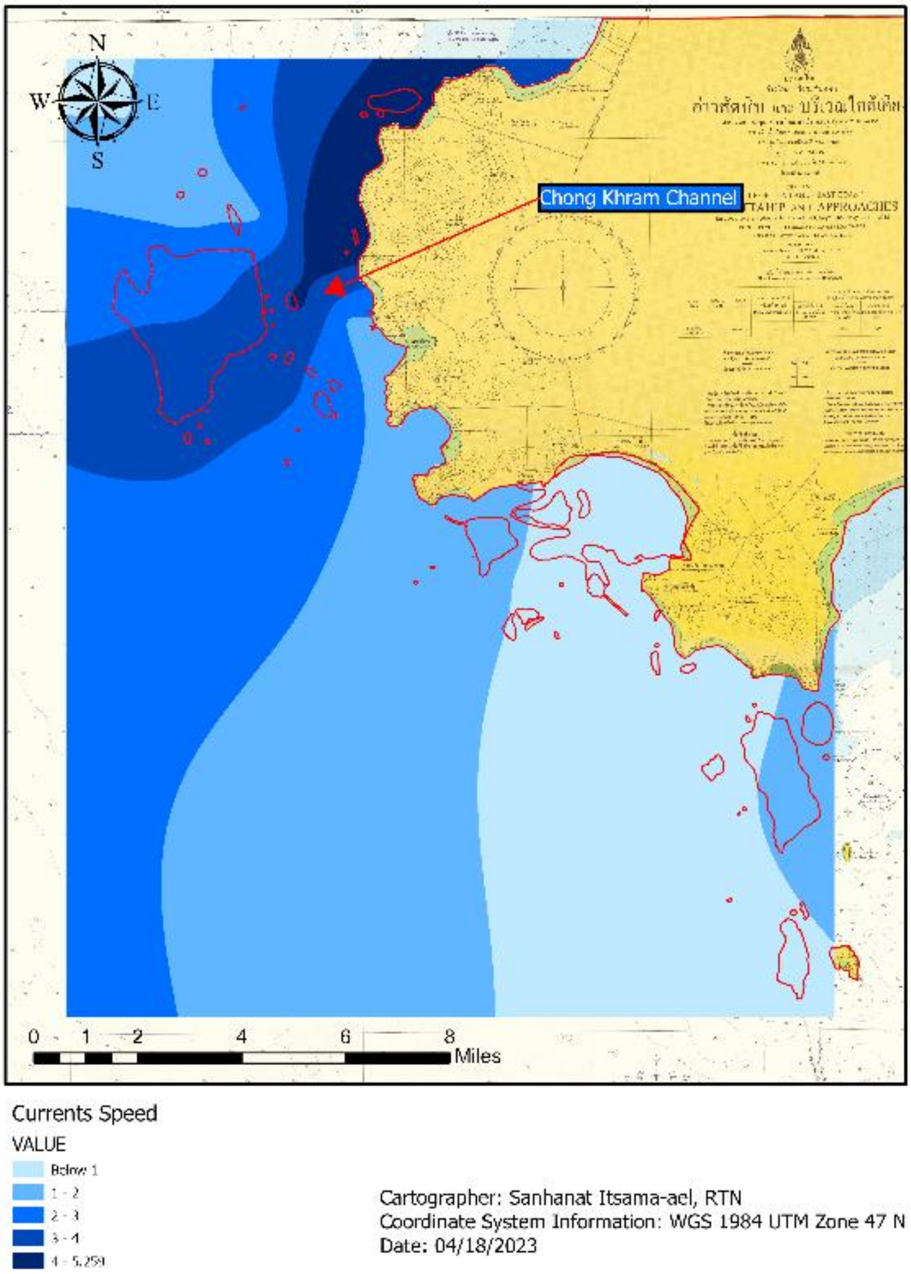


Figure 3 Current Speed (knots) [1]

3.2 Processes

After all data were pre – processed, the availability and shadow zones of communication signals had to be done first, because it is one of the 4 variables (water depth, seabed type, current speed, and communication signal), so it must be implemented before generating the logistic regression model. The main reason that clearance from dangerous object was not included in the model at the beginning is because the complication of topography in Sattahip Bay and approaches that resulting low accuracy of the overall model, so it was applied later. This is the challenge for the further research. In order to do that, the visibility analysis tool in GIS was used to create those zones with the 5 locations of communication towers, which are 80-meter height. The reason 80 meters was chosen is that the common height of a communication tower is 40, 60, and 80 meter [16], so in the future research, the exact height of each pole should be measured.

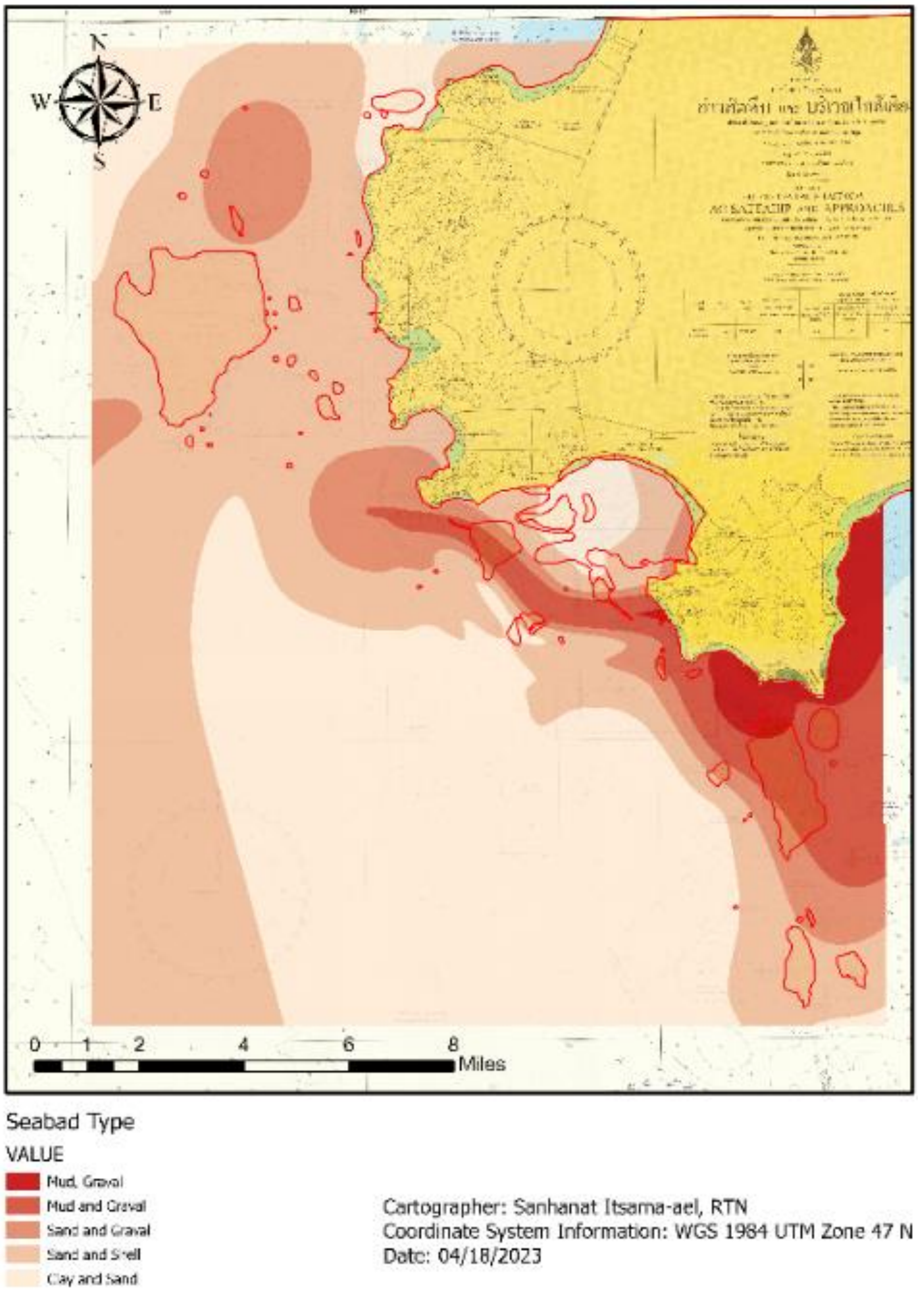


Figure 4 Seabed Types [1]

As 4 factor layers were already prepared, so 64 reference data were used to extracted values from each raster layer by using extract value to point tool in GIS. In this way,the 64 reference locations had all raster values from each layer.

Next step was to generate the logistic regression model from 4 factors (water depth, seabed type, current speed, and communication signal) in this case all factors were ratio scale except the communication signal that was a dummy variable. In order to build the logistic regression model, the generalized Linear Regression tool in GIS was used with those 4 factors as explanatory variables and the presence/absence historical anchoring locations as dependent variable. Then each slope for all independent variables as well as intercept were obtained according to Equation (4), so the model was already generated. Then, the model was applied in raster calculator tool in GIS to obtain the Y value layer. Finally, the probability of suitable anchoring location was received from applying logistic regression equation as shown in Equation (5) in raster calculator tool again.

$$Y = \beta_0 + \beta_1 \times \text{water depth} + \beta_2 \times \text{seabed type} + \beta_3 \times \text{current speed} + \beta_4 \times \text{communication} \quad (4)$$

$$P(Y) = \frac{1}{1+e^{Y}} \quad (5)$$

From this point, the raster layer of the popularity of suitable anchoring location P(Y) was obtained, but the suitable and unsuitable anchoring sites were not categorized yet. Therefore, the raster layer of the popularity of suitable anchoring location P(Y) needed to be reclassified with 0.5 as a threshold (P(Y) < 0.5 is unsuitable, P(Y) >= 0.5 is suitable).

The last step was to create buffers surrounding all dangerous objects with 1000 yards. Finally, the suitable anchoring areas layer from the model was clipped with the dangerous object buffers to be the final result.

4. Result and Discussion

The first result of the process is the availability of communication signal in Sattahip Bay and approaches that is shown in figure 5 [1]. It is obvious that the communication is organized for serving the users on the land, because there are many shadow zones on the sea. For instance, the north part of the bay (zone number 1) is the largest shadow zone, because the line-of-sight propagation from the communication stations are blocked by the mountains along the western coastline. Furthermore, Ko Khram Island also obstructs the line-of-sight propagation, if any ship selects to anchor surround the Ko Khram Island especially on the western side, the probability of receiving the communication signals is very low. In zone number 2, most locations can receive communication signals, because no high mountain or hill on the shoreline obstructs the line-of-sight propagation. However, some shadow zones are occurred, because some islands blocked the propagation, so anchoring too close to the islands may cause losing communication. In the third zone, since mountains and islands limit the line-of-sight propagation, only the eastern part can access the signals.

After the available communication zone was created, four raster layers (water depth, seabed type, current speed, and communication signal) were used to generate the logistic regression model. The result of model with 4 factors and the Y value are shown in figure 6 [1] and Equation (6), respectively. As can be seen from figure 6 [1], the suitable anchoring areas are mostly located on the depth range from 10 – 35 meters if compared with figure 2 [1]. This complies with the real situation that mariners do not anchor their ships in too deep or too shallow water depth. However, there are some sites that water depth is lesser than 8 meters, but they are classified as suitable anchoring areas. This is because the dangerous object factor is not included in the model. Nevertheless, those will be eliminated by clipping with dangerous object buffer in the last step.

$$Y = -15.689652 + 0.192456 \times \text{water depth} - 2.480281 \times \text{seabed type} + 8.490783 \times \text{current speed} - 3.946946 \times \text{communication} \quad (6)$$

In terms of seafloor type, the model result with 4 factors was overlayed with the seabed type layer as shown in figure 7 [1], it can be noticed that the suitable anchoring areas are mostly the combination between clay and sand that gives the most appropriate holding force. However, some locations that are the mixing of sand and shell also indicated as suitable sites, but sand and shell also give a proper holding force even lesser than clay and sand. Therefore, the initial result from the model is reasonable with the theory that clay and sand give the most suitable holding force [8]

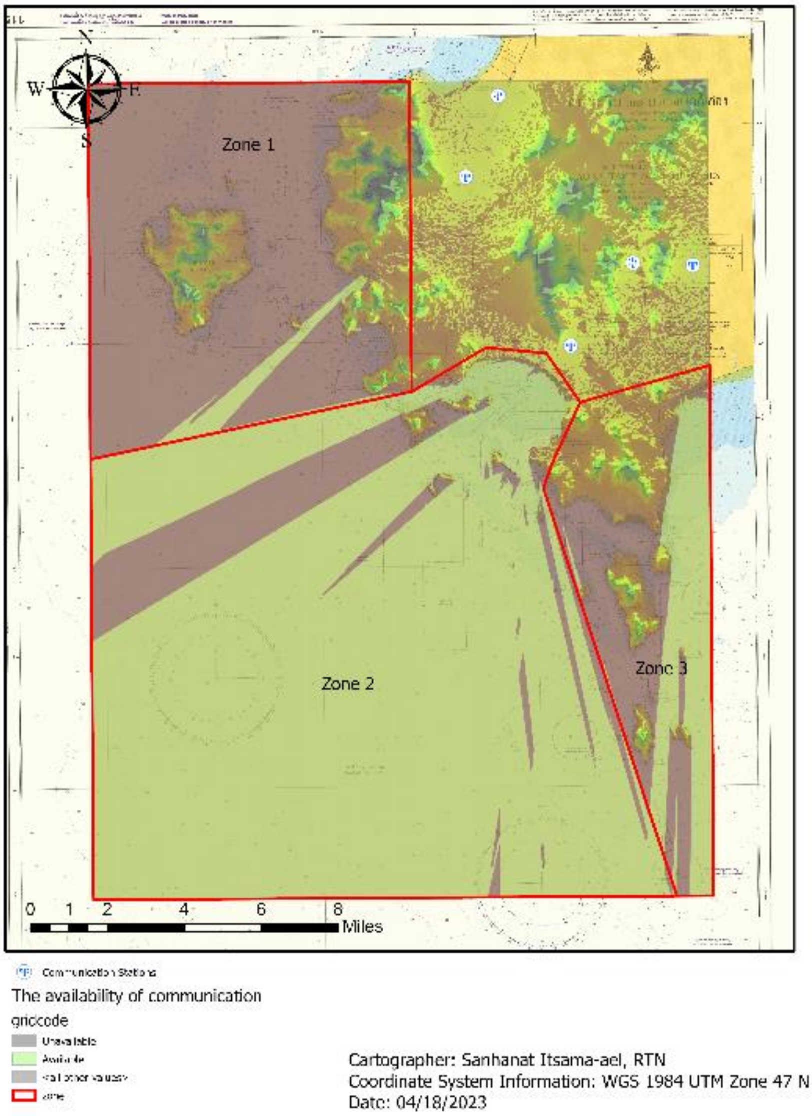
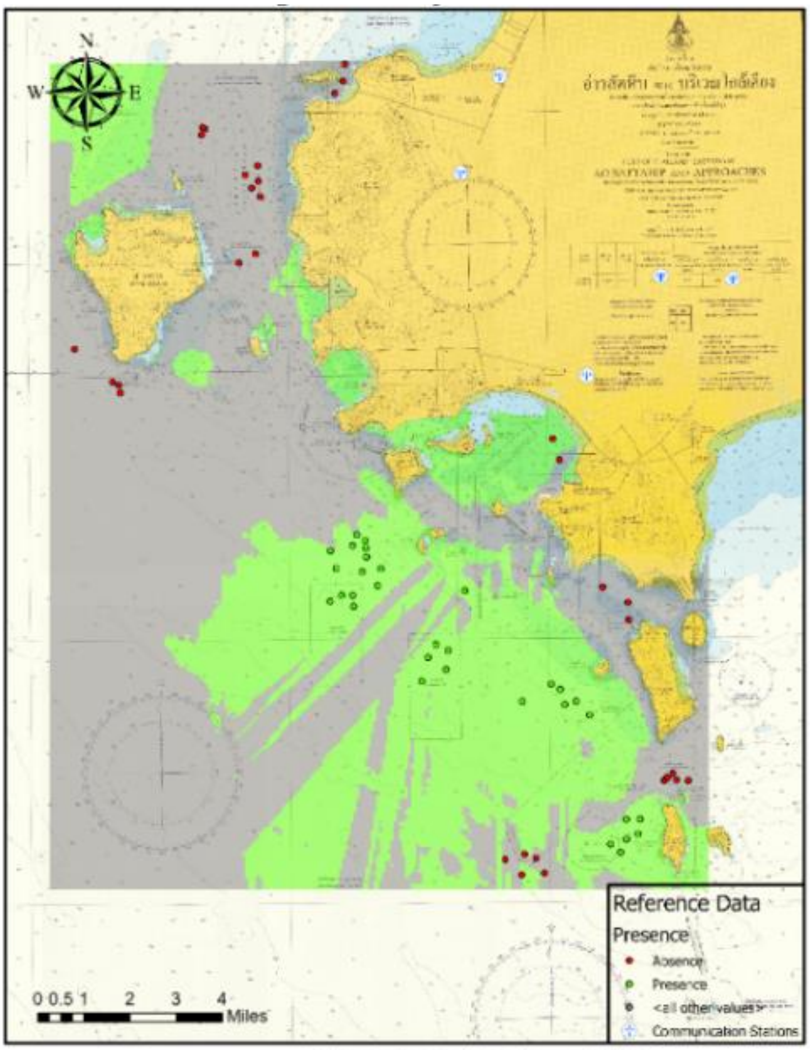


Figure 5 The Availability of Communication Signal in Sattahip Bay and Approaches, Thailand [1]

The overlay between the initial result and the current speed layer also implies that the most suitable anchoring sites are low current speed, ranging from below 1 to 2 knots as shown in figure 8 [1]. Only a few areas that have current speed higher than 2 knots are predicted as suitable anchoring sites. Hence, this model highly complies with the practical instruction that strong current speed is not appropriate for anchoring After deriving the model from 4 factors (water depth, seabed type, current speed, and communication signal), the last factor that is the clearance from dangerous objects with 1000- yard buffer was used to clip the result from the logistic regression model. The result is shown in figure 9 [1]. As can be seen from the result, all shallow areas (less than 8 meters) that were classified as suitable anchoring locations were eliminated. Similarly, the suitable areas surrounding the dangerous objects were clipped as well.

This led to a more reasonable result. However, there are some locations in the northern part of the bay that are predicted to be suitable anchoring areas, but it is enclosed with dangerous objects, this is because that area meets almost all criteria with combination between clay and sand, locating in approximately 10-meter depth, and low speed current location. In this case, it may be fixed by adding the clearance from dangerous objects in the model at the first place, so it is an interesting point to develop this model in the next phase. Also, the north-west corner location is also located to be a suitable area, but it does not have communication signals in that area. The reason thar such a location is predicted to be a suitable area is that it is also clay and sand seafloor and current speed is lower than 1 knot as well as the water depth is ranging between 10 – 30 meters. Consequently, such an area meets most criteria.



Cartographer: Sanhanat Itsama-ael, RTN
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Figure 6 The Suitable Anchoring Location Without the Dangerous Object Factor [1]

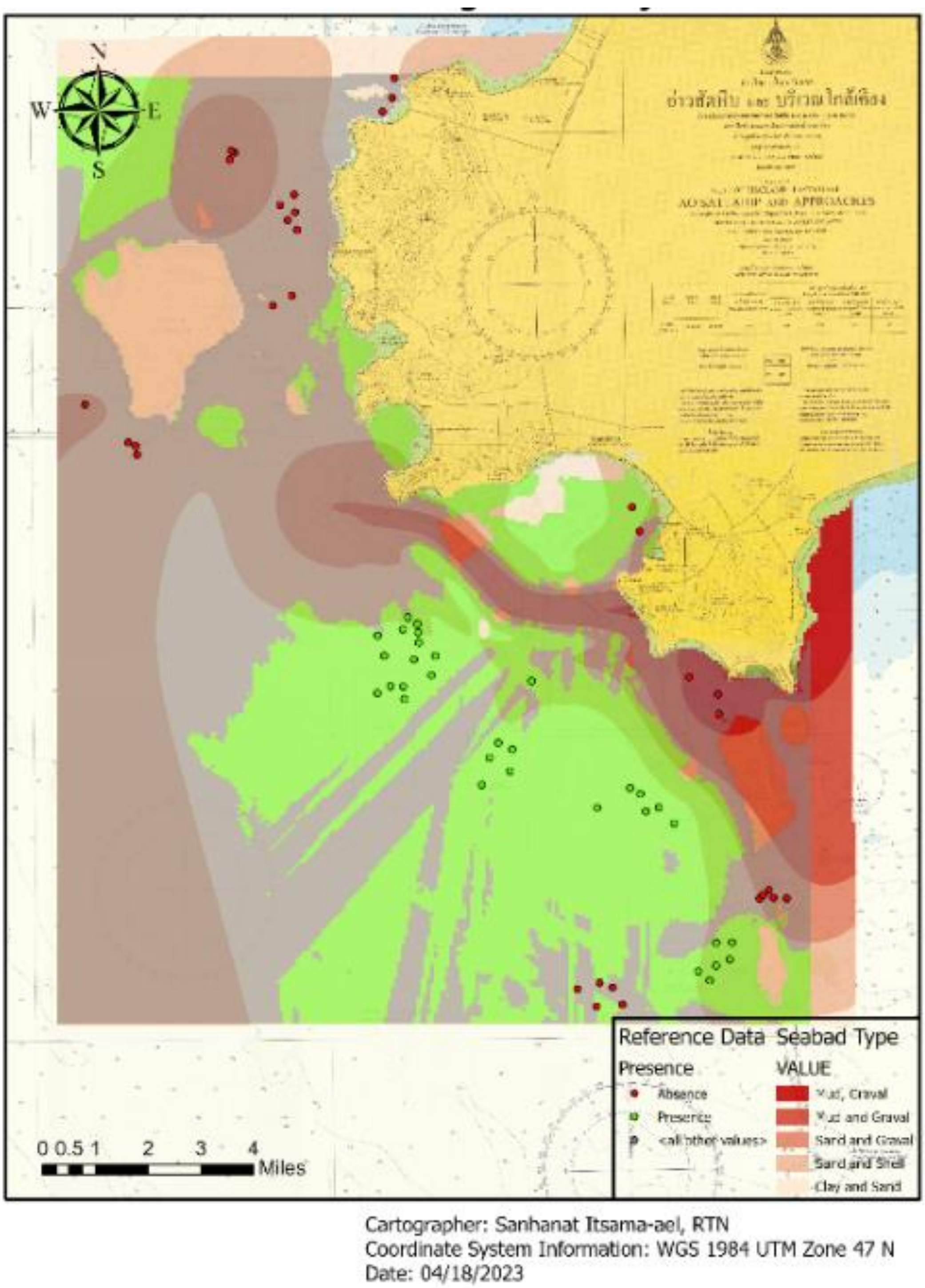

Figure 7 The Overlaying Between the Initial Result and Seabed Type Layers [1]

In addition, there are two recommended anchoring locations on the Thai nautical chart no. 115. Clearly, most of the suitable anchoring locations from the model cover the recommended anchoring locations on the map. Only some parts are considered unsuitable because those areas are in the shadow zone of communication signals. This implied that the recommended anchoring locations might not be created with consideration of a communication factor

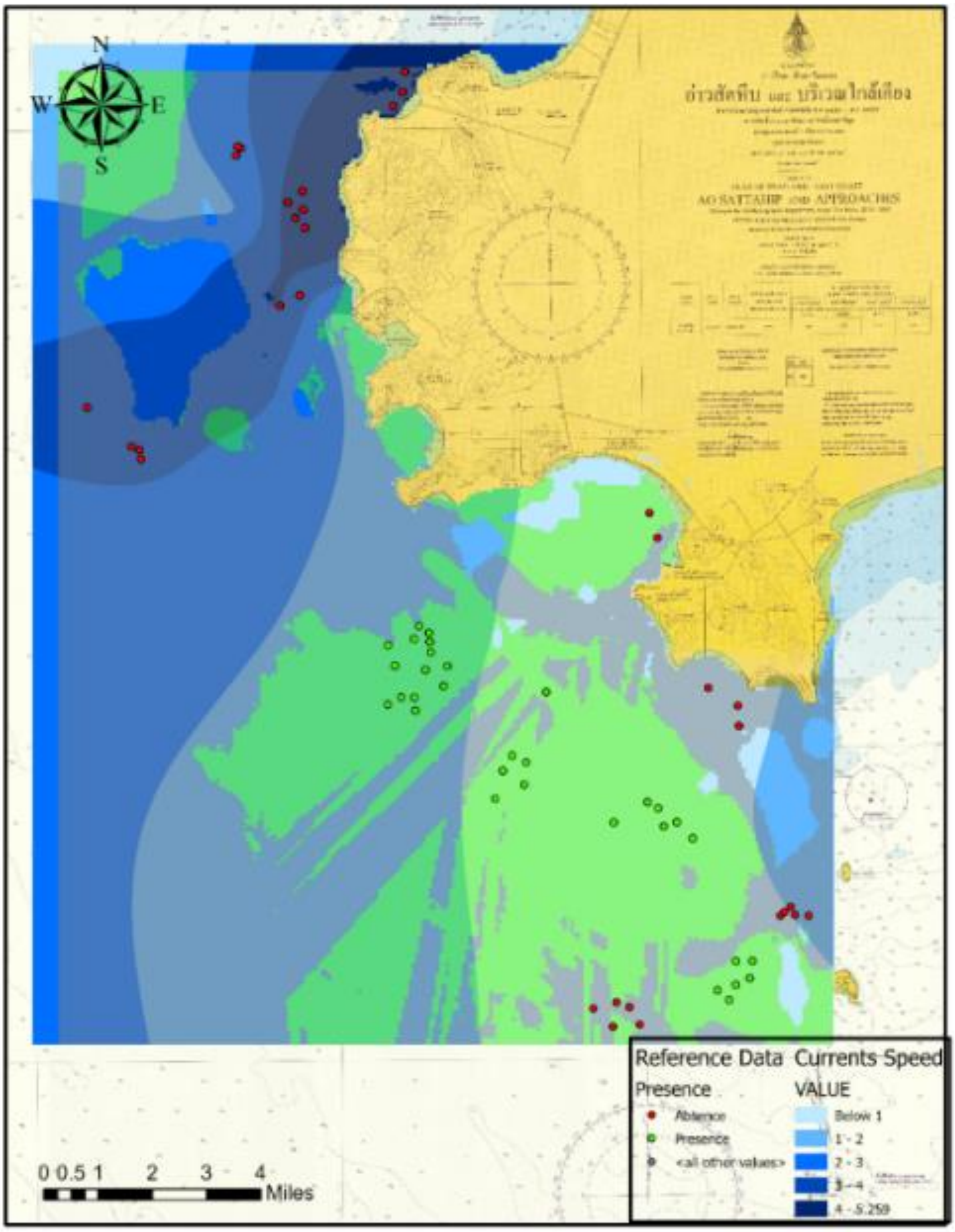

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Figure 8 The Overlaying Between the Result and Current Speed [1]

From the summary of generalized linear regression (GLR) result as shown in table 2, all variance inflation factors (VIF) are about to 1, meaning that no significantly perfect multicollinearity among independent variables. In the same way, all p-values are lesser than significant value (α = 0.05), except the seabed type factor that has 0.058622 for p-value. However, seabed type is well known to be significant for anchoring, so it was still forced to be a variable in the model. To validate the model, confusion matrix and overall accuracy are implemented, which is displayed in table 3. Therefore, the overall accuracy is ((32 + 29)/64) x 100 = 95.3125 %.

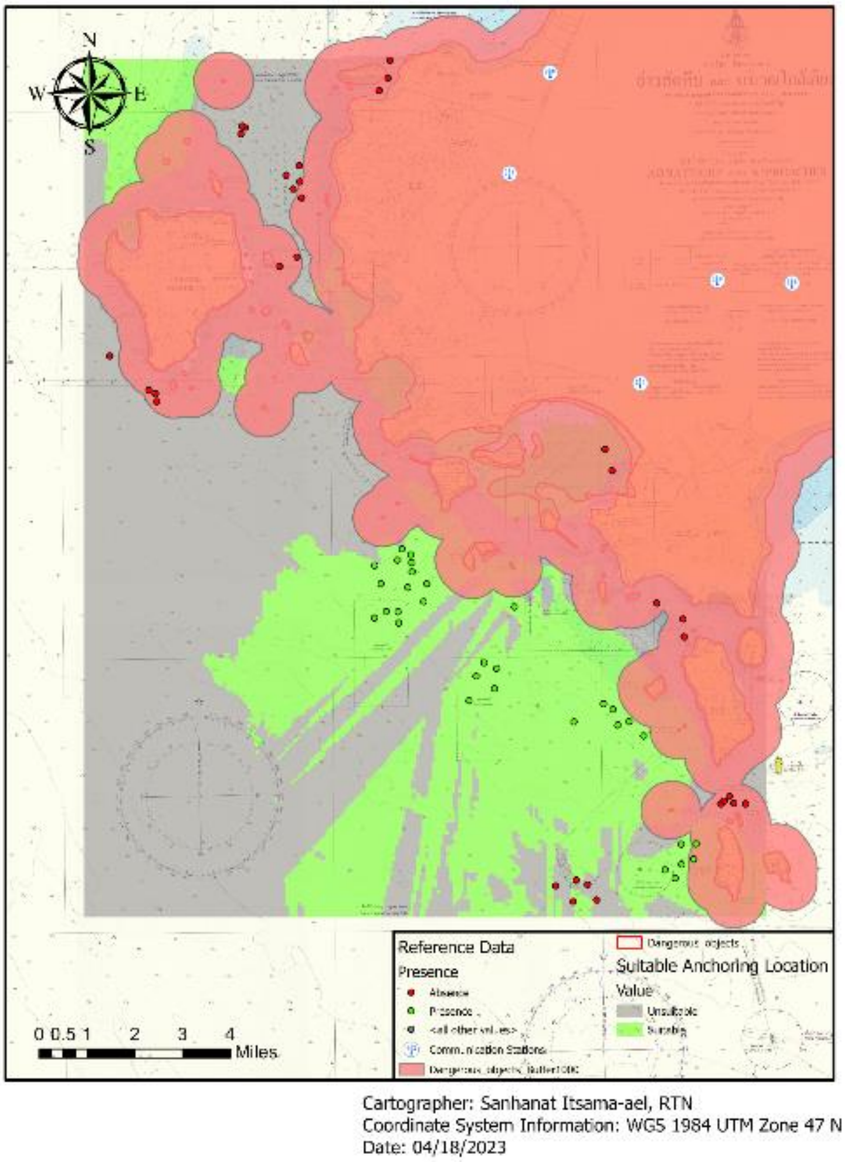

Figure 9 The Suitable Anchoring Locations in Sattahip Bay, Thailand (Final Result) [1]

Table 2 Summary of GLR Results

Variable	Coefficient	StdError	z-Statistic	Probability	Odds Ratio	Wald's Low (95%)	Wald's High (95%)	VIF
Intercept	-15.689652	11.393336	-1.37709	0.168484	0	0	766.079384	0
Depth	0.192456	0.078621	2.447893	0.014369	1.212223	1.039104	1.414184	1.067152
Current	-2.480281	0.841986	-2.94575	0.003222	0.08372	0.016074	0.436054	1.095323
Seabed Type	8.490783	4.490058	1.891019	0.058622	4869.67898	0.733645	32323221.97	1.063304
Communication	-3.946946	1.933742	-2.04109	0.041242	0.019314	0.000436	0.854865	1.095241

Table 3 Confusion Matrix

		Modeled			
		Presence	Absence	total	accuracy
Truth	Presence	32	0	32	1
	Absence	3	29	32	0.90625
				64	

In conclusion, based on the result, the middle part of Sattahip Bay is the most suitable location for anchoring, because the water depth is between 10 – 35 meters, so ships are safe from getting ground as well as no need to release too long anchor chains. Moreover, most of the locations in the middle of the bay are clay and sand that yield a proper holding force. Also, there is low current speed (lower than 1 to 2 knots) in that location, because it is far enough from the Chong Khram Channel, which is the bottle neck that creates strong current. In the same way, there is no dangerous object found in the middle bay as well. However, the only problem is about a communication signal since some parts of the middle bay are in the shadow zone of communication. Although the accuracy of this model is high, some misclassification is still available. Hence, it is not recommended to only rely on the result of the model for selecting an anchoring location, but the model can be used as a cross check tool with human decision. In this way, unexpected incidents during anchoring can be reduced.

5. Conclusion

As Sattahip Bay, Thailand is one of the dense maritime regions, because 3 main harbors, which are Laem Thian Naval Base, Chuk Samet Naval Base, and Sattahip Commercial Port, are existed. When ships reach their destinations ahead of time, they can save fuel and rest their crews by anchoring their ships. However, selecting a right place to anchor is not an easy task since unsuitable anchoring locations led to unexpected incidents, for example, getting ground on the rock, because did not keep enough clearance from dangerous objects and did not have enough a holding force from the seafloor during the strong current. Furthermore, communication between ships and land is also important. Hence, it is important to locate suitable anchoring locations in Sattahip Bay, Thailand by using GIS and logistic regression model with 5 factors that are water depth, seabed type, current speed, clearance from dangerous object, and the availability of communication signal.

The result from the model shows that the middle part of Sattahip Bay and approaches is the most suitable area for anchoring, because all criteria is met such as not too deep and too shallow water depth (10 – 35 meters), suitable holding force with sand and clay, low current speed, no dangerous object, but only some parts of the central of Sattahip Bay are lack of line-of-sight communication propagation, because some islands block those signals. However, there are some parts of the bay that are not suitable, but they are classified as proper locations for anchoring, so it is necessary to always use human decision with the result from the model. Therefore, this model is useful for being a cross check tool to mitigate man errors in selecting the wrong location to drop an anchor.

For further research, some contexts in the model can be developed to make this model to be more accurate. For example, the exact height of communication towers should be measured, so the visibility analysis result will be more precise. Some interesting factors should be added such as weather based on seasons and monsoons, which require physical models and weather dataset. Finally, maritime traffic routes ought to be imported to the model since anchoring a ship on a traffic route led to ship collision that need more data and dynamic model.

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