The Placement of Sonobuoy and Sound Surveillance Systems in Strategic Straits to Support Underwater Defense Systems in the Archipelagic State of Indonesia

Nanang Hery S[1], Yohannes Enggar R[2], Hikmat Zakky Almubaroq[3]

[1]*Defense Management, Republic Indonesia Defense University, Indonesia*
[2]*Naval Hydrographic-Oceanography Center, Indonesia*
[3]*Defense Management, Republic Indonesia Defense University, Indonesia*

***Abstract*: ALKI waters as strategic straits are Indonesian seawaters that have complex characteristics and are prone to infiltration by foreign ships. Currently, the Indonesian Navy is still focusing on security at sea level, while with current technological advances, many foreign submarines are using the underwater area to commit transnational crimes. The area under the water surface that is used is the shadow zone, which has the potential as a hiding place for submarines. The shadow zone is a safe zone where the temperature and salinity of the layer reflect the propagation of incoming sound waves so that submarines can avoid detection by Sonar. This paper aims to provide an alternative solution to the use of acoustic tomography technology by installing the Sonobuoy and Sound Surveillance System (SOSUS) to monitor the movement of foreign submarines entering Indonesian territory, especially through strategic straits. This study uses mixed methods, to process quantitative data from the questionnaires from the respondents regarding the criteria and alternatives to determine the coordinates of the Sonobuoy placement with the Analytic Network Process (ANP) and the detection probability theory approach. To process the quantitative data (shadow zone and submarine detection), the researchers simulated and modeled sound wave propagation from SOSUS using the parabolic equation method which was processed using MATLAB and the Act up v.2.2L toolbox, and processing qualitative data from interviews with experts would be analyzed to complete the quantitative data. The results of the research showed that the optimal placement priority and number of Sonobuoys were obtain. From the optimization of the sound wave propagation simulation by paying attention to hydro-oceanographic data in the form of temperature, salinity, and speed of sound. It is also obtaining the placement position and number of SOSUS with the concept of fixed sonar array operation, which is expect to be able to know the shadow zone and detect foreign submarines to support the underwater defense system in the Indonesian archipelago**

***Keywords*: ALKI, Shadow Zone, Sonobuoy, SOSUS, Underwater Defense System**

I. INTRODUCTION

As an archipelagic country where two-thirds of Indonesia's area is the sea, logically the potential threats to national defense are in and or from the sea (Marsetio, 2014). The potential threat is getting higher because Indonesia's strategic geographical position is at the crossroads of the world, and has the Indonesian Archipelagic Sea Lane (ALKI) as a shipping lane of strategic value. From a defense perspective, this condition opens up opportunities for threats from various directions, especially from strategic funnels. The threat in question is that foreign submarines that infiltrate Indonesia's maritime territory through ALKI have not been monitoring optimally (Tasdik, 2009). This is because the submarine surveillance capabilities carried out by the Republic of Indonesia Warship (KRI) equipped with sonar are still limited. On the other hand, countries in the region have adopted "Acoustic Tomography" technology by installing a Sound Surveillance System network on the seabed and Sonobuoy on the sea surface as an underwater defense system.

Currently, the Indonesian Navy does not yet have an adequate subsurface defense system. Therefore, the challenge is how to monitor the movement of foreign submarines that infiltrate Indonesian waters, when faced with a vast sea territory, and the limitations of presenting KRI and Aircraft. This has resulted in the weakening of national defense because it has not been able to identify, detect and provide a deterrent effect to the dangers of submarine threats.

So far, the development of the Navy's strength in anti-submarine warfare (AKS) is still stuck in the modernization of the submarine itself (Dickry, 2017). Meanwhile, other aspects have not been explored comprehensively, integrally, and sustainably, namely the use of acoustic tomography technology. Until now, the Indonesian Navy does not have an underwater defense system using this technology as an ideal underwater defense concept for Indonesia through the placement of a sonar network system on the seabed and Sonobuoy on the sea surface. This system, apart from being able to know the direction of the submarine's movement, size, speed, and position can also be monitoring from the Command-and-Control Center (U.S Naval, 1965). Therefore, with the use of this technology, it has hoped that the response to the threat of foreign submarines in ALKI waters can be overcome more quickly, and the supervision and security operations will be more effective and efficient. So, it’s supported the underwater defense system in the Indonesian archipelago

Acoustic tomography technology is strategic because the characteristics of seawater media are very complex to be modeling mathematically so the level of difficulty in the application of this technology is also high. Only countries that master the science and technology of Underwater Acoustic have the advantage. Meanwhile, the ability of the Indonesian Navy in mastering this technology is still very limited. The use of acoustic tomography technology for submarine surveillance requires accurate and up-to-date hydro-oceanographic data (Dian, 2008). In addition, the Indonesian Navy does not yet have detection equipment and the organization that workers the equipment. However, the Indonesian Navy always carries out its duties in guarding all waters of national jurisdiction, especially ALKI, but is only limited to securing sea levels and has not been able to detect shadow zones and even the presence of foreign submarines in ALKI. (Hilda, 2015).

In general, the submarine detection and search system along with technological developments underwent several technical innovations and modifications. According to the ATP 28 Allied Anti-Submarine Warfare Manual (1980), several developments in submarine detection system, include Active and Passive Sonar, Periscopes, Variable Depth Sonar (VDS), Radar, Sonobuoy, Magnetic Anomaly Detector (MAD), and Sound Surveillance System (SOSUS). The various submarine detection sensors, and with all their limitations, SOSUS and Sonobuoy are the submarine detection sensors that have the most effective detection capabilities at sea, where there is the least amount of mechanical noise interference.

Table1.1 Use of Best Sensor in Operations and Threats

NO.	OPERATION	THREAT	SENSOR	OBSERVATION
1.	Area operations and remote support	Diesel electric submarine	SOSUS Sonobuoy	Sea state < 3
		Diesel electric submarine	SOSUS Sonobuoy	Both sensors are activated to maximize detection
		Diesel-electric and nuclear ships passing or patrol	SOSUS Sonobuoy	Passive/active sonar on the seabed and bui sonar on the sea surface
		No intelligence data on threats	SOSUS Sonobuoy	Passive/active sonar on the seabed and bui sonar on the sea surface
2.	Area operations and close-range support	Diesel electric submarine moving in attack position	SOSUS/ Sonobuoy Radar	Narrow area and both sensors activated
		Nuclear submarine moving in attack position	SOSUS Sonobuoy	Sonar Barrier (Blokade)

(Source: ATP 28 Allied Anti-Submarine Warfare Manual, 1980)

Due to the increasing size of the potential threat, the development of Indonesia's defense including the concept and strategy as well as the procurement of defense equipment must have serious attention from the government. The underwater defense system should have priority, considering that Indonesia as an archipelagic country is very vulnerable to threats, due to the limited submarine fleet of the Indonesian Navy. TNI-AL's proposal to procure 12 modern submarines is a strategic step in responding to these challenges. Besides procuring submarines for defense, we also need to strengthen the mastery of anti-submarine monitoring technology. This paper provides an alternative solution for using remote sensing technology, namely acoustic tomography to monitor the movement of foreign submarines entering Indonesian territory, especially through the main strait in ALKI.

For infiltration, submarines generally move using a "shadow zone" of sound wave transmission. This area is a safe zone where the temperature and salinity of the sea in this layer reflect the propagation of incoming sound so that submarines can avoid detection from sonar. In addition, technological advances have been able to make submarine materials have a minimum reflectance effect and an electronic defense system that can disrupt and damage the opposing party's active sonar system (jamming). Therefore, another effort is need to track the presence of foreign submarines using acoustic tomography technology (Syamsudin F, 2003).

The priority of placing Sonobuoy in ALKI in this study uses a calculation process using the Analytic Network Process (ANP) method and Probability Theory. ANP is use to determine the priority value of the Sonobuoy placement area from some existing ALKI entrance funnels, considering that in determining the area that is capable of being an intercept point for submarine threat detection, it has various dynamic, interconnected, disproportionate, and even contradictory criteria. On the other hand, the most important thing in determining the placement of Sonobuoy is to determine the coordinates of the placement points at each ALKI entrance funnel, whereas in this study the determination of the coordinates of the Sonobuoy placement using the Probability Theory approach. This step needs to been carried out because according to probability theory, the measure of success in detecting targets is if we can determine how big the level of probability of success and probability of failure is. So, knowing the measurement of the success of the detection will be the basis for making the best decision. By knowing the detection probability level, the optimal number of Sonobuoys can be determined which is the basis for determining the coordinates for placing Sonobuoys at the entrance funnels in ALKI.

By optimizing the sound wave emission simulation modeling using the parabolic equation method and paying attention to hydro-oceanographic conditions in the form of salinity, temperature, and speed of sound, the depth position for the placement and number of SOSUS can detect the shadow zone area and even foreign submarines in all ALKI waters. So that it has expected to make a positive contribution to increasing the supervision of foreign submarines to support national defense at sea.

Problem Statement

a. How to determine the priority areas for placing Sonobuoy and SOSUS at alternative ALKI entrances in detecting the threat of foreign submarines?

b. How to determine the coordinates of the Sonobuoy location and the depth of SOSUS as the optimal submarine detector in each detection area?
c. How to determine the number of Sonobuoy and SOSUS needs for optimal submarine threat detection in each detection area at the entrance of ALKI?

II. THEORETICAL DEVELOPMENT

Analytic Network Process

The Analytic Network Process (ANP) is a method that produces a framework for overcoming the problems of decision-makers without involving the assumptions, which are relation to the independence between higher and lower-level elements, and the independence of elements at one level. Like the Analytic Hierarchy Process (AHP), ANP involves hierarchical relationships but this hierarchical control does not require a standard structure as in AHP so that it can handle complex relationships between decision levels and attributes. Of ANP models a system with feedback where one level may dominate or be dominating, directly or indirectly by another level. In ANP, pairwise comparisons such as AHP are also used. This pairwise comparison process uses a number/scale that reflects the level of importance/preference of a decision element with other decision elements in the same hierarchical level. This helps decision-makers in comparing each element of the decision because each pairwise comparison only concentrates on two of them (Saaty, 1993).

The advantage of ANP over AHP is that it frees up the need to arrange components in a straight chain such as a hierarchy. ANP allows structures to develop more naturally, so it is a better way of describing what is going on.ANP is more objective and more likely to capture what is happening in the real world with dependencies, feedback, and cycles of influence on the super matrix. The important thing in building the ANP model is the existence of choices and selection criteria. By incorporating the Expert's assessment, through pairwise comparisons on a scale of importance 1-9 into the model, the priority of choice is obtaining (Saaty, 1993).

Table 3.1 Pairwise Comparison Scale

Level of Interest	Definition
1	Both elements are equally important
3	One element is slightly more important than the others
5	One element is actually more important than the other elements
7	One element is clearly more important than the other elements
9	One element is absolutely more important than the other elements
2, 4, 6, 8	The middle value between two adjoining ratings

(Source: Saaty, 1993)

Probability Theory

The target of the detection is as an early warning so that anticipation can be make against the enemy so that it does not become a threat or reduce the degree of the threat. The existence of threats in certain areas allows it to be known or, not so all detection activities must be carried out as much as possible and evaluated continuously.

The presence of a threat can been predicted, but the calculation of the probability of successful detection of the threat is very important to do. The measure of detection success is the magnitude of the probability of success, where the success of detecting a threat is expression by the certainty value of its success or failure. Ideally, the probability of successful detection of the target is when the probability of successful detection is close to one (Naval Operation Analysis, 1999).

Detection Theory

a. *The determinants factors of successful detection based on Naval Operation Analysis (1999) are as follows:*

- *Target type*

The targets can be in the form of surface ships, submarines, sea mines, torpedoes, missiles, or aircraft that can be a potential threat to the Republic of Indonesia. In a peaceful situation, the operations of elements of the Indonesian Navy tend to be limited to detection. However, in a war situation where operations have carried out for the action of detecting, searching, reducing, and eliminating an opponent's combat capability.

- *Surrounding sea conditions*

The parameters of the surrounding sea conditions including sea state, pressure, temperature, and salinity, as well as the condition of the seabed in the form of rocks, weather, light, and cloud formation, must also be considering.

- *Sensor equipment condition*

The type, characteristics, and capabilities of the detection sensor equipment play an important role in the success of the detection. Technological capabilities, reliability, and feasibility at a high level of effectiveness and efficiency further increase the success of detection, in addition to the level of professionalism of the crew of the sensor equipment.

- *The methods and tactics used*

Target detection tactics are focused on discussing the analysis of the detection methods used, and evaluations have always carried out on the level of effectiveness and efficiency.

b. *Lateral Distance*

In general, the target passes in a straight line through or across the possible detection zone of the sensor. The closest distance measured from the detection vessel to the target is the closest point defined as the Lateral Distance (X). Meanwhile, the detection probability area located in the circle of the detection tool has a radius that is the maximum possible detection distance (Rm) in Figure 3.1 (Naval Operation Analysis Chapter 6: 111, 1999).

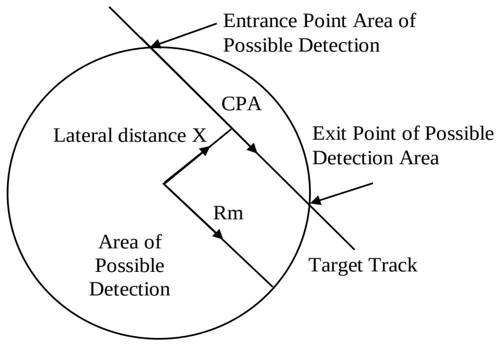

Figure 3.1 Lateral Distance

Where:

CPA= Closest Point Approach
Rm = Radius of the maximum range of the detector

c. Lateral Distance Curve

The probability of detecting a target that is entering and crossing the detection zone from the sensor of the detection equipment at a lateral distance (X) can be determined by calculating the cumulative probability P(x). Where the cumulative probability P (x) is, define as the accumulation of the probability of detecting the target when the target begins to enter the zone detection until the target is out of the detection zone. The following is a lateral distance curve as shown in Figure 3.2.

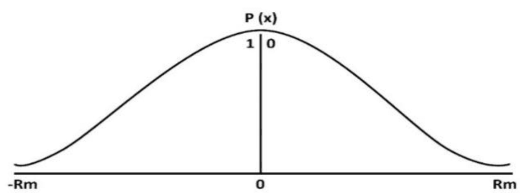

Figure 3.2 Lateral Distance Curve

Where:

P(x) = Probability of target detection
X = Lateral distance

d. The sweeping width

The physical sweep width indicates the effective width of the detection zone of the detection equipment sensor. The sweep width (W) is a measure of the capability of the detection equipment and is a measure of the magnitude of the detection probability.

$$W = \int_{-Rm}^{Rm} P(x)\,dx \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

e. Random Search Method

If the target is in a certain marine area with an area of A, due to lack of information, the position of the target is considered to be randomly distributed. A is divided into N equal parts. Suppose a target can be detection in one part, of a where the chance of detecting this is the same as if the target is in another part. Where B is the situation where the target is in an area with length (L/N) and width (2Rm), so that there is a chance of detection, and assume if C is the situation that the target has detected. Then the probability of detection is:

$$P(B) = \frac{2Rm(L/N)}{A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

$$P(C|B) = \frac{1}{2Rm}\int_{-Rm}^{Rm} P(x)\,dx \ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

$$P(det) = P(B).P(C|B) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.4)$$

$$P(det) = \frac{2Rm(L/N)}{A} x \frac{1}{2Rm}\int_{-Rm}^{Rm} P(x)\,dx \ldots\ldots\ldots (3.5)$$

For detection in the first part:

$$P(det) = \frac{L}{NA}\int_{-Rm}^{Rm} P(x)\,dx = \frac{WL}{NA} \ldots\ldots\ldots\ldots (3.6)$$

$$P(det) = \prod_{i=1}^{N}\left(1 - \frac{WL}{NA}\right) = \left(1 - \frac{WL}{NA}\right)^{N} \ldots\ldots\ldots (3.7)$$

The lower limit of the probability of detection:

$$P(det) = 1 - \left(1 - \frac{WL}{NA}\right)^{N} \ldots\ldots\ldots\ldots\ldots\ldots (3.8)$$

$$\text{For } \frac{WL}{NA} = \text{Small} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.9)$$

$$\ln\left(1 - \frac{WL}{NA}\right) \cong -\frac{WL}{NA} \ldots\ldots\ldots\ldots\ldots\ldots (3.10)$$

$$\left(1-\frac{WL}{NA}\right)^N = e^{N\ln\left(1-\frac{WL}{NA}\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.11)$$

$$\left(1-\frac{WL}{NA}\right)^N = e^{-WL/A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.12)$$

$$P(det) = 1-\left(1-\frac{WL}{NA}\right)^N = 1-e^{N\ln\left(1-\frac{WL}{NA}\right)} \ldots\ldots (3.13)$$

$$P(det) = 1-\left(1-\frac{WL}{NA}\right)^N = 1-e^{-WL/A} \ldots\ldots\ldots (3.14)$$

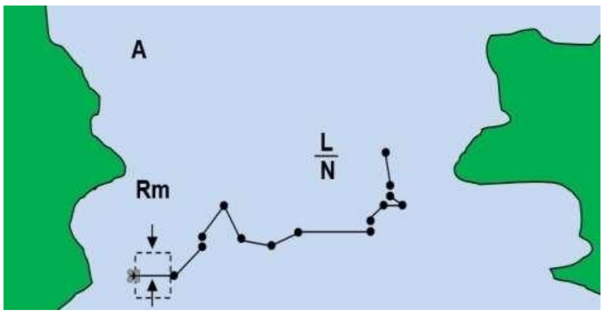

Figure 3.3 Random Search

Where:

W = Sonar sweeping width
L = Patrol path length
A = Sea area where the enemy is located
E = Euler's constancy
P = Detection Probability

Bottoming of Submarine Method

This method of operating submarine positions is use for the task of destroying enemy sea forces in areas near bases, channels, straits, and enemy lines of defense, protecting friendly forces, and reconnaissance tasks. Submarines are placing in a predetermined area, namely the Waiting Area (DT), which should not have abandoned.

a. *Strengths*

1) Easier to operate the submarine.
2) Easy command and control.
3) The data of the area can be collection.
4) High effectiveness.
5) Easy to include other units because the position of the submarine is known.

b. *Weaknesses*

1) Difficult to determine DT if the enemy route is uncertain.
2) The capability of one submarine in the face of strong AKS resistance.
3) Must add or replace the submarine for continuous surveillance, if the area is in enemy territory.
4) Not free to maneuver and passive in carrying out tasks (cannot take the initiative).
5) Possibility of enemy naval forces avoiding or not passing through the area.
6) Requires a special battery charging area outside the surveillance area if the DT is in the enemy's AKS defense area.

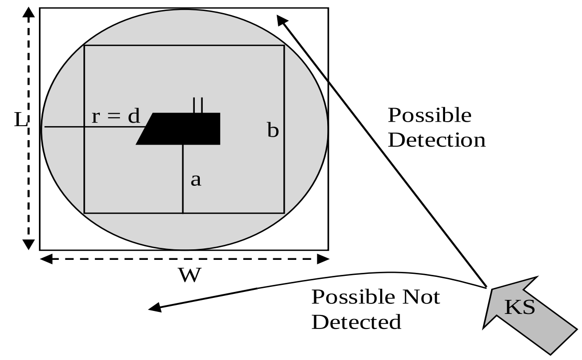

Figure 3.4 Submarine Operation Bottoming Method

(Source: Bujukpur Peperangan Kapal Selam, Mabesal, 2012)

Where:

L = Length of waiting area sector
W = Width of waiting area sector
d = Effective range of passive sonar detection
KS = Submarine Sonar

Since, L and W have the same length and are square, then:

$$a = {}^{1}/_{2}\, d\sqrt{2} = 0{,}7d \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.15)$$

$$b = d\sqrt{2} = 1{,}4\, d \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.16)$$

$$L = W = 2d \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.17)$$

Underwater Defense Concept

Far into the future, the threat to the existence of a country will still exist. The essence of this threat applies to every nation in the world, including Indonesia. Therefore, even though they love peace, the Indonesian people must always be ready to face threats that want to undermine the integrity and integrity of the Unitary State of the Republic of Indonesia. One way to anticipate these threats is to build military strength and defense systems. The power that is build will not only be use for war in the truest sense, but the most important thing is that it can provide a deterrent effect on all parties who want to interfere. However, efforts to build Indonesia's military strength will always be hamper by the limited capacity of the state's resources. Therefore, a breakthrough is needed that can avoid these limitations to obtain effective and efficient results. For this purpose, Indonesia must formulate a war strategy and defense system that can take advantage of the geographical conditions and constellation of Indonesia as an archipelagic country, where the strategy is direct at achieving the country's defense capability at sea while increasing deterrence, even in the face of larger opposing forces. The strategy that puts forward Indonesia's geographical condition as archipelagic country is Archipelagic Warfare.

This strategy can be used both in the concept of war over water and underwater warfare to close the gap in the quantity and quality aspects of the main weapon system, for example by taking advantage of the existence of islands that are close to each other, with limited depth. In several Indonesian waters, water mass dynamics and hydro-oceanographic conditions (Kowaas, 2004). Thus, hydro-oceanography plays an important role in providing dynamic marine information, in the form of data that meets the requirements of current Ness and accuracy, so that it can provide solutions to optimize this strategy. In addition to hydro-oceanographic data, mastery of acoustic tomography remote sensing technology can provide an alternative solution for monitoring the movement of foreign submarines into Indonesian territory, especially through the main straits in ALKI. The application of this technology with the design of installing sonar networks on the seabed and Sonobuoys on the sea surface is fix in strategic straits to complement SIONAL as an attack station in the concept of archipelagic warfare.

This sonar system is also integration with the Tactical Command Control Station, so that the data and information that is obtained from Sonobuoy and SOSUS can be used for naval warfare, especially in detecting and providing information about the direction, speed, and type of the opposing ship continuously with a good level of precision. This system is also be connected to a coastal torpedo launch system where information from this detection system is used to control the launch of the torpedo towards a selected target or opponent. In addition, this system can also be integration with elements of anti-submarine patrol units in identifying targets/objects/submarines both in anti-submarine activities and as a means of monitoring the movement of submarines while in the ALKI and surrounding waters. This concept is equivalent to the Naval Guerilla tactics in basic seated method submarine operations, which occupy a waiting position by sitting at the bottom or at a considerable distance from the coast to await enemy elements.

In this study, the Sonobuoy and SOSUS deployment areas has assumed the same as the waiting area, which is an area for submarines to wait for the enemy to be attack, usually in the form of an area as large as the ship's sonar detection capability. However, the waiting position for this submarine must be accessible to friendly anti-air weapons from the KRI or from land near the coast, which can protect in the event of an enemy air attack. The criteria for the waiting area (Muhammad Ali, 2002: 12) are:

a. In the form of an area, that naturally has advantageous tactical value in terms of geography, hydro-oceanography, and intelligence.

b. Must have alternative routes for evasion after carrying out the attack

c. Must be achievable in a condition half times its ability to operate at sea, and be kept secret

d. Must has known by friendly elements, to ensure that only enemy or neutral elements pass through the area.

In the waiting area, the submarine can perform ship operations and reconnaissance methods depending on the environmental conditions of the waiting area. The environmental conditions of the submarine operating area can have seen in Table 3.2 below.

Table 3.2 Operating Methods and Operating Environment Requirements

No	Submarine Operation Method	Environmental Requirements			
		Depth	Seabed Type	Seabed Topography	Sea Wave
1	Bottoming	Min : 50 m Max: 250 m	• Sand • Mud Sand • Sand Gravel	Relatively flat with a slope not exceeding 5'	Relatively small, not exceeding 2 knots

(Source: Naval Operation Analysis, 1999)

This reconnaissance area can also use as a waiting area for submarines, to calculate the need for submarines in supervising a water area by using the maximum length of the waiting area, namely the length of the reconnaissance area. To calculate the ideal submarine needs, the following formula is used:

$$JDT = \frac{LP}{L} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.18)$$

Where:

JDT = Number of waiting areas
LP = Width of water with a depth of more than 50 m
L = Length of the waiting area

From the calculation of the number of submarine needs, it can be determined the number of waiting areas according to the number of ships. So that in the discussion later the formula for calculating the need for submarines is used to calculate the number of waiting areas which are the placement of Sonobuoy and SOSUS or submarine detection intercept areas at the entrances of strategic straits as a concept of underwater defense in supporting archipelagic warfare in Indonesian sea areas.

Underwater Acoustic

Underwater acoustics is based on the transmission of sound waves with water as the propagation medium, so the physical properties of the water greatly affect the speed and direction of the sound wave transmission, as well as the weakening of its emitting power. The speed of sound determines much of the behavior of sound transmission at sea. The speed of sound varies with depth, season, and geographic location. There are 3 (three) main parameters that determine the speed of sound, namely temperature, salinity, and depth. The sound velocity profile (SVP) is the variation of the speed of sound with depth. This variation causes the bending of sound waves in certain water columns (Barmawi, 1994).

The key to success in underwater warfare is early detection while the main equipment used is sonar (Urick, Robert. J, 1983). In its propagation in the sea, sound waves emitted from the sonar system will experience a weakening of the transmit power (Transmission Loss/TL) due to the influence of frequency characteristics which are strongly influenced by variables of physics, dynamics, seawater chemistry, and seabed topography which are referred to as conditions hydro-oceanography. The two things that have the most influence on sound wave propagation are SVP and TL (Horton, J.W, 1959). Therefore, to get a picture and model of sound wave propagation that is close to the actual condition, the influence of both must has taken into account.

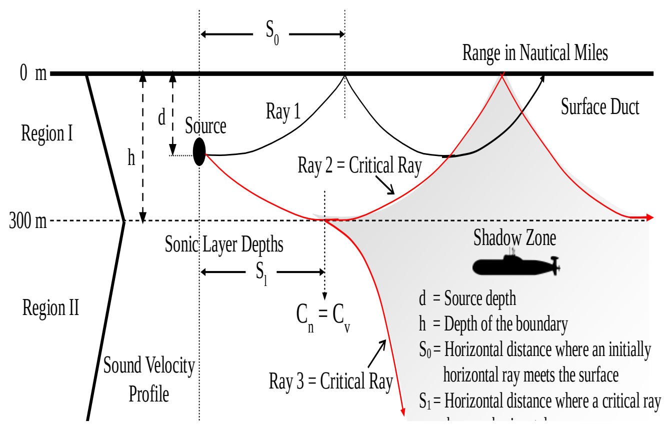

Figure 3.5 Illustration of Sound Wave Propagation

(Source: Urick, R.J., 1983)

Sound wave transmission can be modeling using several methods, namely ray tracing, normal mode, and parabolic equations. In the parabolic equation method, the propagation of sound waves is described in terms of a characteristic function called parabolic which is an additive combination to meet the desired boundary and source conditions. The parabolic equation method can be use at any frequency but is more suitable for low-frequency wave propagation in long-distance ocean wave guidance.

Long beam distances can be obtained on a positive gradient that occurs near the surface, where sound propagation will be refracted onto the surface and after reaching the surface will be reflected so that it will form a surface duct (see Figure 3.5). In these conditions, it would be very good to carry out detection of submarines at periscope depth, but cannot detect or find it difficult to detect deep-diving submarines. This occurs when there is a positive sound velocity gradient on the surface (Region I), where the sound path will have deflected upwards to the surface, if the surface is relatively calm, and then the sound propagation has been reflected down. If this process is repeat it will, form a sound tunnel called a surface duct. In the surface duct, the sound will only propagate in it; so that a target that is outside the sound tunnel cannot be detection, (this area is calling the shadow zone). This shadow zone can be use by submarines to approach surface contact without being detection by sonar. In general, the surface duct will be shallower (the shadow zone is getting bigger) when the velocity gradient is steeper because a negative gradient will bend the sound path towards areas of lower sound velocity. On a negative gradient, the sound path will have bent downwards (Region II), so the sound path will reach the critical angle faster and be reflection first.

III. METHODOLOGY

This research used a mixed-methods approach. Mixed methods involve combining or unifying research between qualitative and quantitative data in research (Creswell, J. W, 2016). This method has chosen because mixed methods have the power to describe qualitative and quantitative research and minimize the limitations of the two approaches. At the procedural level, mixed methods are a useful strategy to gain a more complete understanding of the problem formulation. The sources of data collection used in this study consisted of primary and secondary data sources. Primary data sources were obtaining through questionnaires and interviews, the agencies involved as primary data sources were the Submarine Unit and the Naval Hydro-Oceanography Center (Pushidrosal).

The primary data used in this study has divided into two, namely primary data, which is quantitative and qualitative. The quantitative primary data used in this study is the result of a questionnaire from the respondents' assessments related to the criteria and alternatives for placing Sonobuoy. These data are process using the ANP method to determine the priority of the submarine detection area using Sonobuoy in the ALKI, while the determination of the optimal placement coordinates and number of Sonobuoys at the entrance of the ALKI is calculate using a detection probability approach using the basic sitting position method.

The secondary data used in this study are divide into two, namely quantitative and qualitative. The secondary quantitative data used in this study are temperature, salinity, and depth data in 2021 as measured by the CTD instrument, obtained from Balitbang-KP, Research Center, Development of Marine and Coastal Resources, and Pushidrosal. The data are from CTD measurements at the entrances to strategic straits in ALKI. Data processing carried out in this study;

namely quantitative data processed by the parabolic equation method. Using MATLAB R2008b software equipped with the Ac TUP V 2.2L toolbox to determine temperature, salinity, and sound velocity profiles concerning depth, and to model sound wave propagation patterns from SOSUS and the optimal number of SOSUS so that the shadow zone is known that has the potential to be a hiding place for submarines. After processing the data, then data analysis has carried out. This data analysis has clarified by qualitative data from interviews. Qualitative data analysis is been carried out through data reduction (organizing data, sorting into data units that can be processed, and compiling into patterns), presenting data, and drawing conclusions to produce interpretations that are used as information to determine the depth of SOSUS placement, verify, and validate the number of needs. SOSUS is optimal to be placing in the submarine detection intercept areas at the entrance of strategic straits.

Data Collection

Data collection was been carried out using the methods, namely questionnaires, interviews, and literature studies. These data include data on criteria that affect the prioritization of the degree to which a submarine threat is likely to been passed. Primary data was obtaining from the results of data collection through questionnaires and interviews with respondents who are experts in the field of submarine operations. Secondary data is obtaining from the results of literature studies or reference books related to criteria and alternatives. This data is need for mapping potential underwater threats or submarines, and calculating the level of possibility of submarine threats, where in this study it is assume that underwater threats originate from neighboring countries bordering the sea with Indonesia and countries with an interest in Indonesian seas. Figure 4.1 is a map of Indonesia that is use as the basis for determining the priority of placing Sonobuoy and SOSUS at the entrance area of ALKI waters.

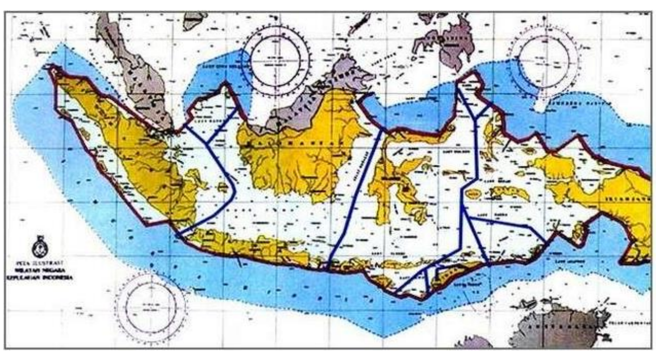

Figure 4.1 Map of ALKI

(Source: PPRI Nomor 37 Tahun 2002)

ALKI which has been established through PP no. 37 of 2002 consists of three lines, namely ALKI I, ALKI II, and ALKI III, the concept of ALKI has been submitted by the Government of the Republic of Indonesia to the International Maritime Organization (IMO) on May 18, 1998, namely:

a. ALKI I: Routes for shipping from the South China Sea through the Natuna Sea, South Karimata, Java Sea, and South Sunda to the Indian Ocean.
b. ALKI Branch IA: Route for shipping from South Singapore across Natuna Sea, South Karimata, Java Sea, and Sunda Strait to the Indian Ocean, or across Natuna Sea, to the South China Sea.
c. ALKI II: Route for shipping from Sulawesi across Makassar Strait, the Flores Sea, and Lombok Strait to the Indian Ocean.
d. ALKI IIIA: Route for shipping from the Pacific Ocean across Maluku Sea, Seram Sea, Banda Sea, Ombai Strait, and Sawu Sea west of Sawu Island to the Indian Ocean.
e. ALKI Branch IIIB: Route for shipping from the Pacific Ocean across Maluku Sea, Seram Sea, Banda Sea and Leti Sea to the Timor Sea.
f. ALKI Branch IIIC: Routes for shipping from the Pacific Ocean across Maluku Sea, Seram Sea, and the Banda Sea to the Arafura Sea.
g. ALKI Branch IIID: Routes for shipping from the Pacific Ocean across Maluku Sea, Seram Sea and the Banda Sea, Ombai Strait and Sawu Sea east of Sawu Island to the Indian Ocean.
h. ALKI Branch IIIC: Routes for shipping from Sulawesi across Maluku Sea, Seram Sea, Banda Sea, Ombai Sea, and Sawu Sea west of Sawu Island or Sawu Sea east of Sawu Island to the Indian Ocean. Or across Maluku Sea, Seram Sea, Banda Sea, Leti Strait, and the Timor Sea to the Indian Ocean, or the Seram Sea and the Banda Sea to the Arafura Sea.

Determination of Submarine Shipping to Operation Area

a. *Stage I*

1) Sailing through areas that are continuously protect from their units.
2) Sailing can be done on the surface of the water, diving, or snorkeling.

b. *Stage II*

1) Sailing in open sea areas that cannot been permanently controlled by the units themselves.
2) There is a chance of encountering the enemy's AKS air force.
3) Sailing during the day diving, at night carrying out snorkeling.

c. *Stage III*

1) Sailing in areas where enemy AKS obstacles are known or suspected.
2) The cruise has done by diving deep enough at an economical speed.
3) Before entering an area that is suspect to be very dangerous, the submarine must have fully charged the

battery.

d. Stage IV

1) A voyage in the open sea carried out under the surface of the water after passing through enemy AKS obstacles.
2) Submarine voyages ware carried out by diving or snorkeling by considering security against enemy detection.

e. Stage V

1) The cruise is approaching the operating area.
2) It is a very important and dangerous stage.
3) Enemy actions against submarines can occur at any time, especially if the area of operation is near the coast.
4) Confidentiality is absolute.
5) The approach to the destination point must be by diving and arriving in the dark/night.
6) This stage must be reachable within 24 hours.

Determination of Criteria and Alternatives

The ideal defense concept for a country must be able to exploit the physical and non-physical conditions of the country so that it can give rise to advantages that can be used to weaken and defeat the enemy. The diversity and differences in geographical characteristics in the territorial waters of the Indonesian archipelago are national assets that must been utilized for the national interest. In the context of national defense, the use of constellations and characteristics of the archipelagic state is manifest in the form of archipelagic warfare. Based on geographical conditions, especially the hydro-oceanographic aspect, the concept of Indonesian sea defense is very relevant if it leads to the "concept of underwater warfare".

The right underwater warfare strategy is to optimally utilized Indonesia's geographical and hydro-oceanographic conditions as well as submarine tactics through increasing submarine capability development, submarine strength development, submarine title patterns, and placing Sonobuoy and SOSUS in strategic funnels to achieve warfare capabilities. The optimal underwater in the waters of the Indonesian archipelago.

The underwater warfare strategy aims to achieve the capability of war in Indonesian archipelagic waters from all forms of military threats. This strategy must be able to become a guide in carrying out the construction, use of submarines, and be able to integrate with acoustic tomography technology, which functions as early detection of threats and underwater communications.

Referring to the concept of an underwater defense system in the Indonesian archipelagic waters, plus brainstorming with experts in the field of Submarine Operations, the criteria and sub-criteria used in determining the priority areas prone to threats from foreign submarines in this study are operational criteria and criteria geographical conditions.

Table 4.1 Criteria for Determining Threat Weights

No.	Criteria	Assessment Parameters
1	Operation	Operational requirements are related to the strategic value of submarines in determining the stage of shipping to the area of operation
2	Geographical Condition	Technical requirements related to geographical conditions in determining the operation trajectory

Table 4.2 Sub-criteria in Operational Criteria

No.	Operational Sub-criteria	Assessment Parameters
1	Potential Area of Deception	Operational requirements are related to the strategic value of submarines in determining the stage of shipping to the area of operation
2	Don't Meet Another Submarine	Technical requirements related to geographical conditions in determining the operation trajectory
3	Other Countries' Submarine Capability	The strength of the number and deployment of other countries' submarines
4	Not GPLL area	This area is an area that is directly related to the opponent's area

Table 4.3 Sub-criteria in Operational Criteria

No.	Geographical Condition Sub-criteria	Assessment Parameters
1	Deep sea	Deep depth conditions are a safe area for submarines to navigate especially to avoid detection
2	Soft Seabed	Soft or not hard seabed types are able to absorb acoustic waves so that it can reduce the possibility of being detected
3	Funnel Wide	The approach funnel is a threat entry point, making it easier for submarines to navigate underwater, thereby reducing the chance of being detected.
4	Nearest Route	The selection of shipping stages to certain destinations with the closest possible route option will be chosen for operational cost savings
5	No Obstacle	The situation of the channel that does not have obstacles in the form of winding island clusters or other navigational obstacles will narrow the submarine's movement

The alternative used to determine the weight of vulnerability to submarine threats at each ALKI entrance were obtained from a map published by Pushidrosal and used as a Sonobuoy placement area. Based on this map plus the results of interviews and brainstorming with experts and literature studies, several alternative Sonobuoy placement areas can be determined. By using the Campers Electronic Chart System software, the ALKI entrance water area is an alternative for Sonobuoy placement to minimize the threat of foreign submarines infiltrating the waters of Indonesian jurisdiction as shown in Table 4.4

Table 4.4 Alternative Placement of Sonobuoy

No.	Area	Location	Range (Nm)	Depth (m)	Seabed Type
1.	ALKI IA-1 Natuna Sea	P. Bintan - P. Mangkai	118	10-100	Sand Mud
2.	ALKI I-1 Natuna Sea	Tj. Pianadang - P. Subi Kecil	49	20-200	Sand Mud
3.	ALKI II-1 Makassar Strait	Tj. Mangkaliat - P. Tuguan	55	400-3.000	Mud
4.	ALKI IIIE-2 Sulawesi Sea	Tj. Toade - Beng Laut	62	100-3.200	Sand Mud
5.	ALKI IIIA-1 Maluku Sea	Tj. Damau - P. Sedeng	95	100-2.500	Sand Mud
6.	ALKI IIIC-2 Arafuru Sea	Tj. Waamgalier – P. Atnebar	61	30-1.600	Sand Mud
7.	ALKI IIIB-2 Leti Strait	Tj. Mahin - Tj. Sio	23	600-2.800	Mud
8.	ALKI IIID-1 Sawu Sea	P. Dao Besar - Tj. Lie Geta	41,8	60-1.000	Sand Mud, Coral
9.	ALKI IIIA-13 Sawu Sea	Tj. Wuimahi - Tj. Undu	51,5	70-1.600	Sand Mud, Coral
10.	ALKI II-8 Lombok Strait	P. Nusa Penida - Tj. Bebera	11,4	70-900	Sand, Coral
11.	ALKI I-15 Sunda Strait	Ujung Cukuredak - Tj. Waton	46	20-350	Sand Mud, Coral

Sonobuoy Deployment Priority Model with ANP

Figure 4.2 shows that there is an influence, where the base of the arrow means the cluster that affects, while the direction of the arrow means the cluster that is affected. For example, on elements in the operational cluster that affect the alternative cluster. While the two-way arrows indicate the interplay between the two clusters or the target element (feedback). For the two-way arrow on the operational and geographical condition, it shows that the operational cluster has an influence on the geographical condition cluster and vice versa, the geographical condition cluster influences the operational cluster.

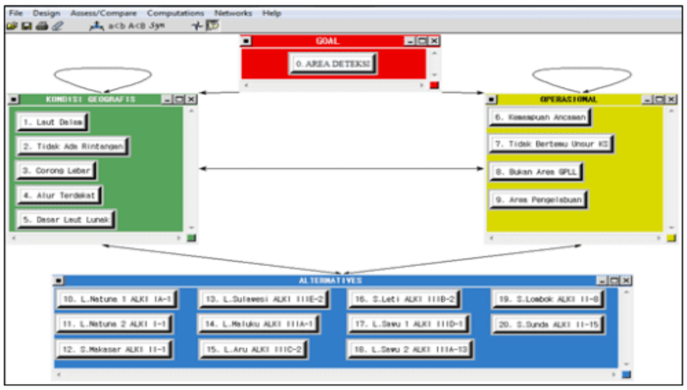

Figure 4.2 Sonobuoy Placement Priority Network Model

The ANP model above consists of an inner and outer dependency relationship that occurs in the entire cluster and the elements in it. The relationship that occurs is the result of brainstorming according to the experience and judgment of the experts. The following is an explanation of the Inner-dependence relationship for each criterion cluster, and the Outer-dependence relationship between clusters in the ANP method as follows:

Table 4.5 Inner dependence on Geographical Conditions Cluster

No.	Inner dependence	Understanding / Assessment Parameters
1	Deep sea – No obstacle	With deep water conditions, it reduces obstacles to the submarine in navigating
2	Wide Funnel – No obstacles	The wide groove entrance will reduce obstacles in navigating the submarine

Table 4.6 Inner dependence on Operational Cluster

No.	Inner dependence	Understanding / Assessment Parameters
1	Areas of potential phishing – Do not encounter enemy submarines	By taking advantage of the deception area, the chances of meeting the enemy's submarine are getting smaller
2	Wide Funnel – No obstacles	The GPLL area is one area that is very vulnerable to threats so that patrol elements are always in the area, so the possibility of meeting submarine elements in the GPLL area is very large

Table 4.7 Outer dependence Relationship between Clusters

No.	Outer dependence	Assessment Parameters
1	Geographical Condition – Operation	Sub-criteria on Geographical Conditions will affect the operation of the submarine in determining the stage of the operation trajectory. And vice versa, where the Sub-criteria in Operations are very dependent on Geographical Conditions so that in determining the priority of the submarine intercept area it will be more selective.

The arrangement of the questionnaire uses a reference network model that has been forming. The questionnaire has made based on the relationship between the criteria elements, both inner and outer dependence, and the preference relationship between the criteria and the goal through pairwise comparisons between clusters and between cluster elements.

This questionnaire aims to find out how big the relationship is based on the assessment of the respondents. The respondents are experts, in Submarine Operations. The reason for choosing different respondents to fill out this questionnaire is in the hope that there will be stakeholder representation in providing assessments with different perspectives and can reduce the element of subjectivity in the selection so that it can approach the actual conditions. This questionnaire leads to assessment objectives for weighting in determining alternative priorities for submarine detection intercept areas using Sonobuoy in ALKI.

Underwater Sound Speed Profile

The hydro-oceanographic conditions of Indonesian waters, which have a tropical climate, greatly affect the underwater sound propagation system. This is very beneficial for submarines because it will be difficult to detect their existence. Conditions in tropical waters have high salinity, a greater afternoon effect, more marine organisms and biota, and the influence of various seabed contours, making sonar detection capabilities relatively poor.

Indonesian marine waters also have variations in-depth, from shallow waters to deep waters, both around narrow waters such as straits or bays as well as wide waters such as the seas between large islands. Due to the difference in depth and seasonality, namely in the west and east monsoons, there are various layers of temperature (thermo-layer), salinity, and pressure differences that affect the speed of sound, thus forming areas that are difficult for sound waves to penetrate. By knowing the characteristics or profile of the speed of sound in certain waters, especially the depth of the layer (shadow zone), we can detect the presence of submarines.

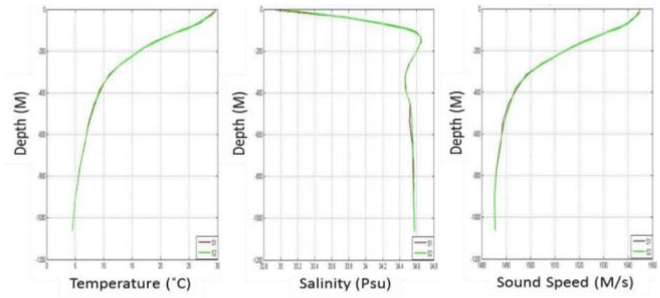

Figure 4.3 Profile Samples of Temperature, Salinity, and Speed of Sound against Depth in the West Season in the Lombok Strait

Figure 4.3 shows that the oceanographic conditions in the west monsoon in the Lombok Strait, namely the vertical temperature profile at a depth of up to 1000 m. The average temperature distribution in Indonesian waters are 22.06°C. The salinity profile shows that the salinity value on the surface is relatively small, namely 32.93 psu. The highest salinity value is at a depth of 100-150 m, which is 34.65 psu; and the profile of the speed of sound in the west monsoon shows that the image is relatively uniform with an average value of the speed of sound, which is 1527.24 m/s.

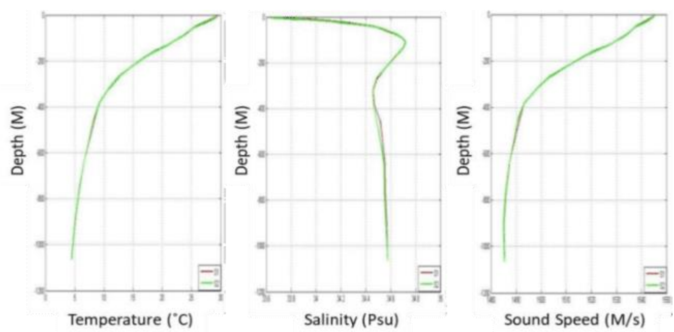

Figure 4.4 Profile Samples of Temperature, Salinity, and Speed of Sound Against Depth in the West Season in the Lombok Strait

Figure 4.4 shows oceanographic conditions in the east monsoon in the Lombok Strait, namely the distribution of the average temperature in this season, which is 21.45 °C; the value of 33.67 psu, and the maximum salinity is at a depth of 100-150 m with a value of 34.72; the speed of sound in the east monsoon has an average value of 1526.24 m/s. In the west monsoon, the temperature is higher than in the east monsoon. This is because, in the east monsoon, the wind blowing from the Australian continent brings cooler air masses to the Asian continent (K. Wyrtki, 1961), resulting in low humidity (colder water masses), vertical mixing, and flowing water masses. to an area that has little influence of radiation that causes a decrease in temperature. (A. G. Ilahude, 1970).

Besides Lombok Strait, several straits in the Indonesian archipelago that have strategic value are Malacca Strait, Sunda Strait, and Makassar Strait, especially with the implementation of ALKI. In times of war or peace, the territory of the Indonesian state must be protected from all kinds of possible threats to the territory of the Republic of Indonesia. One of the ideas that can be developed is to permanently install an acoustic sensor network (SOSUS) on the seabed in straits that have potential as an entry point for threats, especially submarines. Until now, SOSUS is still considered the most appropriate tool for detecting the phenomenon of sound wave transmission from underwater objects. The use of an approach model by looking for the relationship between the position of the source, the velocity profile of sound (based on data of temperature, salinity, and depth), the sound waves propagation pattern, and the attenuation of the emitting power of SOSUS is an advantage in underwater warfare.

IV. RESULTS AND DISCUSSION

The Priority Sonobuoy Placement Area

The geographical location of the territory of the Indonesian state is at a cross position between two continents and two oceans, making Indonesian waters an important shipping traffic lane for countries in the regional and international regions. In addition, it also increases the possibility of foreign country threats, both surface ships and submarines, which come through ALKI approaches such as straits that have strategic value (Strategic Straits). The changing pattern and strategy of warfare from deep-water warfare to littoral warfare have further increased the possibility of the entry of opposing forces supported by technology to carry out increasingly sophisticated inland warfare into the territory of the Archipelagic State of Indonesia.

Referring to the above conditions, efforts are needed that are strongly influenced by the development of the strategic environment, namely the rapid development of submarine technology. So, to keep pace with these technological developments, it can be done through the selection of the Sonobuoy placement area to increase the supervision of the presence of foreign submarine threats in ALKI using the ANP method. From Figure 4.2, which is the Sonobuoy placement priority model, then the questionnaire data processing is carried out.

The geometric mean is the midpoint between two or more opinions in different decision-making. In this study, before determining the geometric mean, the results of each respondent's questionnaire were tested for consistency first. This test was carried out on the results of the expert questionnaire regarding pairwise comparisons between criteria and elements. If the inconsistency index shows a number below 0.1, then the choice is consistent and deserves to be combined with the opinions of other decision-makers whose consistency has been tested. For example, the largest inconsistency value from the results of pairwise comparisons between criteria and elements, namely Deep Sea – Nearest Route and Funnel Wide – Soft Seabed with a value of 0.07283, then this value is still below 0.1 which means consistent.

Table 5.1 Inconsistency Index

Rank	Row	Colom	Current Val	Best Val	Old In consist	New In consist	% Improvement
1	Nearest Route	Soft Seabed	3,00000	1,00000	0,07389	0,04006	45,79%
2	Funnel Wide	Nearest Route	5,00000	1,83543	0,07389	0,04808	34,92%
3	Deep Sea	Soft Seabed	5,00000	12,6637	0,07389	0,04808	34,92%
4	Deep Sea	Funnel Wide	3,00000	1,58083	0,07389	0,06244	15,49%
5	Deep Sea	No Obstacle	2,00000	1,20233	0,07389	0,06564	11,16%
6	No Obstacle	Funnel Wide	2,00000	1,09271	0,07389	0,06564	11,16%
7	No Obstacle	Soft Seabed	5,00000	6,62229	0,07389	0,07048	4,61%
8	No Obstacle	Nearest Route	5,00000	3,23901	0,07389	0,07048	4,61%
9	Deep Sea	Nearest Route	5,00000	5,88671	0,07389	0,07283	1,44%
10	Funnel Wide	Soft Seabed	5,00000	3,99742	0,07389	0,07283	1,44%

The results of the ranking of criteria can be seen by looking at the weight value of the limiting super-matrix calculation. For example, "no barriers" is the sub-criteria with the highest ranking. This is because the condition of the channel without obstacles greatly facilitates the submarine's operating strategy. The order of the ranking of the sub-criteria based on the magnitude of the weight values as in table 5.2.

Table 5.2 Criteria Weight Value

Rank	Criteria	Normalized by Cluster	Limiting	Weight
1	No Obstacle	0,32362	0,14986	0,11913
2	Don't Meet Another Submarine	0,45455	0,15487	0,11101
3	Deep Sea	0,22700	0,10512	0,08959
4	Nearest Route	0,24887	0,11524	0,08258
5	Not GPLL Area	0,24831	0,08461	0,06538
6	Threat Ability	0,10880	0,03707	0,06295
7	Potential Area of Deception	0,18834	0,06417	0,05475
8	Funnel Wide	0,12551	0,05812	0,05352
9	Soft Seabed	0,07500	0,03473	0,03236

The results of data processing with Super Decisions software are known as alternative priorities by looking at the weight value of each alternative obtained from the Limiting Super matrix calculation. The order of alternative priorities is based on the magnitude of the weight values as in Table 5.3.

Table 5.3 Alternative Weight Value

Priority	Area	Location	Weight
1	ALKI IIIA-13 Sawu Sea	Tanjung Wuimahi – Tanjung Undu	0,12839
2	ALKI IIID-1 Sawu Sea	Great Dao Island – Tanjung Lie Geta	0,10911
3	ALKI IIIB-2 Leti Strait	Tanjung Mahin – Tanjung Sio	0,10564
4	ALKI IIIC-2 Arafuru Sea	Tanjung Waarngalier – Atnebar Island	0,09132
5	ALKI II-1 Makassar Strait	Tanjung Mangkaliat – Tuguan Island	0,09097
6	ALKI IIIE-2 Sulawesi Sea	Tanjung Toade – Beng Laut	0,08145
7	ALKI IA-1 Natuna Sea	Bintan Island – Mangkai Island	0,08139
8	ALKI IIIA-1 Maluku Sea	Tanjung Damau – Sedeng Island	0,08056
9	ALKI II-8 Lombok Strait	Nusa Penida Island – Tanjung Bebera	0,07658
10	ALKI I-1 Natuna Sea	Tanjung Pianadang – Small Subi Island	0,07253
11	ALKI I-15 Sunda Strait	Ujung Cukuredak – Tanjung Waton	0,07088

The Coordinates Determination and Number of Sonobuoy

After knowing the priority weights of placing Sonobuoy in strategic straits which become the entry point for submarine threats as shown in Table 5.3, then another important thing to carry out is to determine the optimal Sonobuoy placement coordinates.

In this research, the determination of the coordinates of the Sonobuoy placement using a probability theory approach to the equation math 3.14. Based on area (A) determined from the funnel width distance (L) and the width sweep (W), the midpoint is the receiving source of the sound wave propagation beam from the detection area for each Sonobuoy is the coordinates of the location of the Sonobuoy. With modeling optimization detection probability using probability theory and the help of Electronic Chart System software Cmapecs, as well as by taking into account the geographical conditions and the operation of the submarine, the position coordinates for Sonobuoy placement which has optimal detection coverage area, where no gap does not have an intersection between the reception range and Sonobuoy is a source of receiving wave sounds. Thus, the determination of the optimal number required is based on the optimal level of detection probability. The probability of detection is said to be optimal if every addition of 1 Sonobuoy unit will increase detection to the target of 10%. On the other hand, if each addition of 1 Sonobuoy unit increases the probability is 10% which means not significant. The results of determining the placement coordinates and calculating the optimal number of Sonobuoy detection area in ALKI is as follows:

a. Priority 1 in ALKI IIID-1 (Sawu Sea) requires Sonobuoy Fix 3 units with a probability detection of 91.6%, and the optimal location of the coordinates, namely the Sonobuoy coordinates first: 10° 35,291' S-122° 05,580' T; second Sonobuoy coordinates: 10° 40,457' S-122° 18,701' E; third Sonobuoy coordinates: 10° 45.621' S-122° 31.857' E.
b. Priority 2 in ALKI IIIA-13 (Sawu Sea) requires Sonobuoy Fix 3 units with a probability detection of 85.4%, and the optimal location of the coordinates, namely the Sonobuoy coordinates first: 10° 10,692' S-120° 57,356' E; second Sonobuoy coordinates: 10° 21.595' S-121° 10,839' E; third Sonobuoy coordinates: 10° 32.491' S-121° 24,323' E.
c. Priority 3 in ALKI IIIB-2 (Leti Strait) requires Sonobuoy Fix 2 units with a probability detection of 96.2%, and the optimal location of coordinates, namely the first Sonobuoy coordinates: 8°07.752'S-127° 19.494'T; second Sonobuoy coordinates: 8°11,226'S-127°30,571'E.
d. Priority 4 in ALKI IIIC-2 (Arafuru Sea) requires Sonobuoy Fix 3 units with a probability detection of 89.1%, and the optimal location of the coordinates, namely the Sonobuoy coordinates first: 6° 11,471' S-132° 21,907' E; second Sonobuoy coordinates: 6° 30.009' S-132° 13,647' E; third Sonobuoy coordinates: 6° 48.647' S-132° 05.134' E.
e. Priority 5 in ALKI II-1 (Makassar Strait) requires Sonobuoy Fix 3 units with a probability detection of 88.3%, and the optimal location of the coordinates,

namely the Sonobuoy coordinates first: 0° 39,093' N-119° 39,672' E; second Sonobuoy coordinates: 0° 47,420' N-119° 23,278' E; third Sonobuoy coordinates: 0° 55.268' N-119° 06.751' E.

f. Priority 6 in ALKI IIIE-2 (Sulawesi Sea) requires Sonobuoy Fix 3 units with a probability detection of 84.2%, and the optimal location of the coordinates, namely the Sonobuoy coordinates first: 3° 33,900' N-125° 52.827' E; second Sonobuoy coordinates: 3° 43,860' N-126° 10,619' E; third Sonobuoy coordinates: 3° 53,893' N-126° 28,298' E.
g. Priority 7 in ALKI IA-1 (Natuna Sea) requires Sonobuoy Fix 4 units with a probability detection of 81.3%, and the optimal location of the coordinates, namely the Sonobuoy coordinates first: 2° 37.697' N-105° 35.352' E; second Sonobuoy coordinates: 2° 12.842' N-105° 17.910' E; third Sonobuoy coordinates: 1° 48.878' N-105° 00,592' E; fourth Sonobuoy coordinates: 1° 24,760' N-104° 43,497' T.
h. Priority 8 in ALKI IIIA-1 (Maluku Sea) requires Sonobuoy Fix 4 units with a probability detection of 89.2%, and the location of the optimal coordinates, namely the Sonobuoy coordinates which first: 2° 26,234' N-127° 37,487'E second Sonobuoy coordinates: 2° 47.311' N-127° 24,179' E; third Sonobuoy coordinates: 3° 07.683' N-127° 10,760' E; fourth Sonobuoy coordinates: 3° 28,197' N-126° 57,778' E.
i. Priority 9 in ALKI II-8 (Lombok Strait) requires Sonobuoy Fix 1 unit with a probability detection is 96.4%, and the optimal coordinates are: 8° 45,889' S-115° 43,483' T.
j. Priority 10 in ALKI I-1 (Natuna Sea) requires Sonobuoy Fix 3 units with a probability detection of 87%, and the optimal location of the coordinates, namely the first Sonobuoy coordinates: 3° 09.287' N-108° 45.252' E; second Sonobuoy coordinates: 3° 21,643' N-108° 34,460' E; coordinate third Sonobuoy: 3° 33.996' N-108° 23,667' E.
k. Priority 11 in ALKI II-15 (Sunda Strait) requires Sonobuoy Fix 2 units with a probability detection of 88.9%, and the optimal location of the coordinates, namely the Sonobuoy coordinates first: 6° 23,891' N-105° 03.525' E; second Sonobuoy coordinates: 6° 04.961' N-104° 50.315' E.

The Depth Determination and Amount of SOSUS

Determination of the depth of SOSUS is carried out through optimization of sound wave propagation simulations that aim to determine the optimal placement of SOSUS at the entrance to the strategic straits in ALKI with the concept of operating a Fix Sonar Array on the seabed that can transmit and receive sound waves from the target, namely the submarine. The discussed underwater sound velocity profile in the previous subchapter 4.5 serves to determine the acoustic characteristics underwater. Speed sound is one of the important variables in underwater sound transmission to determine the shadow zone and detect submarines.

Lombok Strait has a length of about 60 km with a width of 30 km to the north and 18 km to the north-south. The depth of the northern part of the Lombok Strait is more than 1000 m and becomes 700 m in the area threshold in the south. The conception of using SOSUS technology in the context of securing ALKI, especially the Lombok strait, was carried out by simulating the propagation of sound waves. Environmental restrictions in the same distance of 20 km, water depth of 650 m, with different positions of the sound source and recipient. The source is at a depth of 25 m, 110 m, and 300 m and the receiver is at the depths of 30 m, 115 m, and 310 m. This depth is based on the three depths used by a submarine while sailing towards the area of operation. This propagation modeling is carried out with several settings, including entering configure environment data and setting the observed frequency 100 - 500 Hz, and the TL used is <= 80 dB.

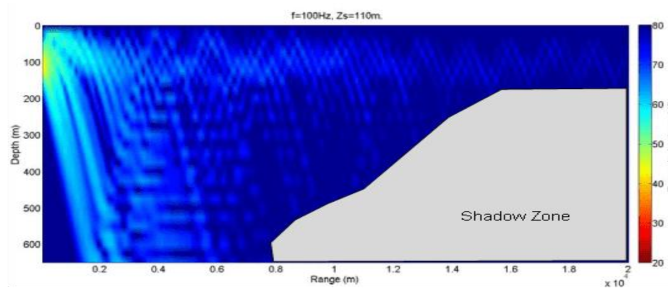

Figure 5.1 Simulation of Lost Sound Wave Transmission Energy in Lombok Strait with a Transmitter Depth of 110 m and Receiver of 115 m

This detection models the propagation of sound waves using the parabolic equation method, code propagation is called the RamGeo model. The author performs a computer simulation of wave propagation sound between acoustic stations on Nusa Penida Island and West Lombok Island for location identification shadow zone and detects the presence of submarines passing through the Lombok Strait. In this simulation, the position of the transmitter is placed at a depth of 110 m on the island of Nusa Penida and the sound waves propagate along the seawater column toward the receiver (hydrophone/receiver placed at a depth of 115 m) in the western part of Lombok Island (see figure 5.1).

For Lombok Strait, the loss of sound wave transmission energy in the range of 50-60 dB occurs almost evenly in all water columns, except at 8-20 KM from Nusa Penida Island with a range of 70-80 dB (gray color in Figure 5.1) covers the surface area to a depth of 60 m. this location has the potential as a shadow zone, so it is a conducive place for submarines to enter the area of Indonesia. From the results of this simulation, we can see how easy it is for foreign submarines to enter the Indonesian territory which is only by infiltrating a few tens of meters below the surface. So, the shadow zone is located at a depth of below 200 m at 8-20 KM from Nusa Penida Island to West Lombok island as shown in Figure 5.1 below.

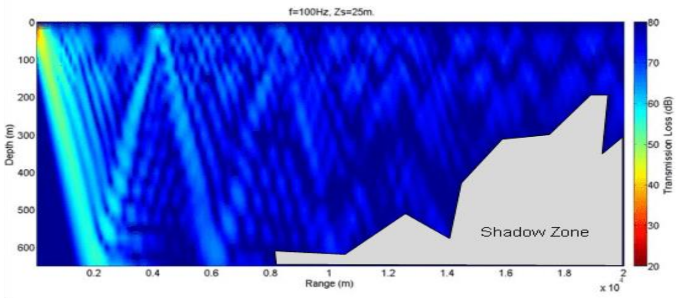

Figure 5.2 Simulation of Lost Sound Wave Transmission Energy in Lombok Strait with a Transmitter Depth of 25 m and Receiver of 30 m

To penetrate the sound, wave propagation through the area (shadow zone), it is necessary to add two more SOSUS, namely the position of the transmitter is placed at a depth of 25 m and the receiver is at depth of 30 m (see Figure 5.2), and the position of the transmitter placed at a depth of 300 m and receiver at a depth of 310 m (see Figure 5.3).

By looking at the characteristics and geographical constellation between Bali Island - Nusa Penida Island - Lombok Island, the design of the SOSUS network placement is laying the depth of both transmitter and receiver between the island of Bali - Nusa Penida island and also Bali Island - Lombok Island refers to the simulation results of sound wave propagation that propagates along the seawater column from Nusa Penida Island to Lombok Island.

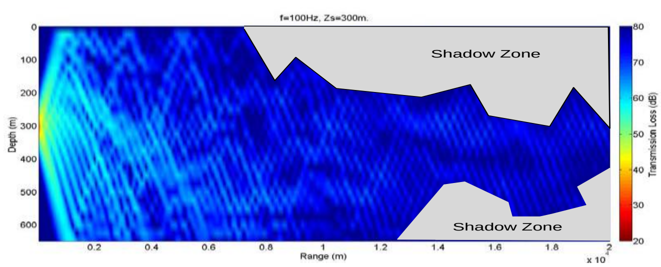

Figure 5.3 Simulation of Lost Sound Wave Transmission Energy in Lombok Strait with a Transmitter Depth of 300 m and Receiver of 310 m

The placement of three SOSUS units at three depths used by submarines in operation is a minimum requirement to know the shadow zone and detect the presence of submarines. These three depths respectively represent the depth of the submarine when it is at depth periscope, cruising depth of the submarine, and the maximum depth of the submarine. This is in line with Syamsudin, (2003) who states that the placement of three acoustic stations is a requirement minimally for monitoring all physical processes, such as current conditions, temperature fields, and tides, as well as foreign submarines in the water column of Lombok Strait.

The optimal placement of SOSUS as an effort to increase the ability to secure its sea lines and the ability to control the sea lines used by the opponent is the main factor of success for sea control. To ensure control optimally, a pattern and degree of operation using SOSUS technology are needed to be able to overcome all existing limitations to ensure the use of the sea for its interests and close opportunities for opponents. For this purpose, the Indonesian Navy must formulate strategies that can take advantage of the geographical conditions of Indonesia as an archipelagic country, where strategies directed at achieving the country's defense capability at sea, as well as increasing the deterrence against foreign submarine threats. The strategy that prioritizes geographical conditions in Indonesia as an archipelagic country to deal with these threats is an optimal placement strategy for SOSUS.

From the results of optimization modeling simulation of sound wave emission using the parabolic equation method by paying attention to hydro-oceanographic data in the form of temperature, salinity, and speed of sound, then the depth position is obtained for the placement of SOSUS which is expected to be able to find out the shadow zone even detects foreign submarines throughout the waters of ALKI entrance. It aims to develop the concept of underwater defense in the Indonesian Archipelago can provide a strong deterrence effect and protect the integrity of the Indonesian archipelago and sovereignty throughout the territory of the Republic of Indonesia.

The concept of the archipelago's sea defense is based on deep defense, where every terrain is laid out in layers of defense. Between these layers of defense is the terrain resistance which is the third layer of defense area which is the area of resistance located in the territorial sea, archipelagic waters, and the air layer above it in the face of every form of threat to the safety of the nation and state.

Considerations for placing SOSUS on ALKI waters, because ALKI is a potential area that becomes the entrance and foreign submarines infiltration, is because: First, ALKI is located in the territorial sea and archipelagic waters as a battlefield. Second, ALKI is geographically the mouthpiece of a strategic approach, and one of the controls of the sea. Third, ALKI is a blockade strategy that can create an alternative deterrence that is effective and efficient. Fourth, ALKI is face to face with international shipping lanes so that the enemy has the opportunity to invade and sabotage.

Table 5.4 Comparison of Operational Risks of Sonar Stations and Submarines according to Geographical Conditions in the Archipelagic State of Indonesia

NO	Risk Comparison	Sonar Station		Submarine	
		D	P	D	P
1.	Wind influence	3	2	3	3
2.	Effect of ocean waves	3	2	3	3
3.	Effect of background noise	2	1	4	4
4.	Detection time	5	1	5	3
5.	Use depth	5	1	5	3
6.	Operating costs	1	2	4	3
7.	Maintenance costs	2	2	4	3
8.	Design costs	2	2	4	4
9.	Lack of personnel	3	2	4	3
10.	Personnel accident risk	2	2	4	3
11.	Risk of material damage	4	3	4	3
12.	Energy use	3	2	4	3
13.	Threat level risk	1	1	5	3

Along with the development of the strategic environment, in this case, the rapid development of ship technology diving in the world, due to the impact of the Revolution in Military Affairs (RMA). This military innovation concept leads to revolution and innovation in military technology. RMA has an impact on military technology progress, operational concepts, war doctrine and military strategy, and restructuring of the yudha system (Order of Battle), and increased battle performance through the evaluation of Yudha's title (Military Employment) and organizing. On the other hand, increasing awareness of Maritime Domain Awareness (MDA) will also affect changes in strategic policies in the region. This requires the Indonesian Navy to take strategic steps in overcoming the threat of foreign submarines faced the spectrum of the Indonesian Navy's duties is increasing, from law enforcement and maritime security to maritime security to defend the sovereignty and territorial integrity of the territorial waters of Indonesia's national jurisdiction from all form of threats, but still pay attention to all the risks that exist. These risks can be analyzed based on the results of filling out the questionnaire from the experts in Table 5.4.

From the results of the questionnaire in Table 5.4 with predetermined criteria and calculations by using the Risk Assessment method, the characteristics of the Risk Assessment are obtained from the use of acoustic tomography technology through the placement of Sonobouy and SOSUS on the approach funnel which forms the basis of this research include: (1) On the detection of submarines by using the operation of a submarine, generally in quadrant 4 which means it has high enough risk to very high risk, and (2) In the detection of submarines by using Sonar Station (Sonobouy and SOSUS placement), generally located in quadrant 2 which means it has a low to moderately low risk as shown in Figure 5.4.

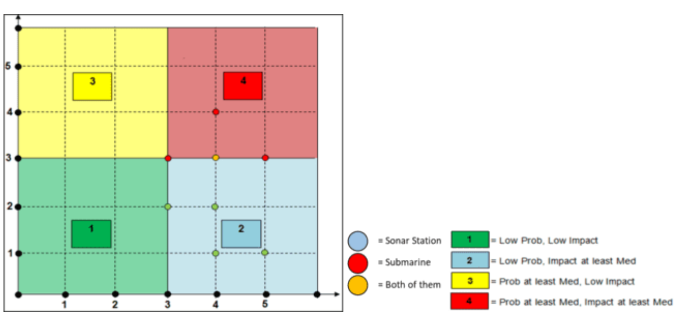

Figure 5.4 Comparison Diagram of Sonar Station and Submarine Operational Risks

Thus, it can be ascertained that the detection of submarines in the approach funnels strategic and ALKI by using Sonar Stations (Sonobouy and SOSUS) which are placed at a point with a fixed sonar array operating concept both placed on the surface of the water and at the sea bottom, has a lower level of risk compared to submarines. This is the basis of the background of this research, given the limited number of submarines owned. So, detection area design in the Indonesian archipelago that has geographical characteristics and conditions complex hydro-oceanography will focus on optimizing the detection of foreign submarines through the placement of SOSUS at the entrance of ALKI to support deterrence and blockade strategy with the aim of early detection. From the SOSUS placement area itself in territorial waters, then the need for optimal SOSUS results from the optimization of wave emission simulation modeling sound using the parabolic equation method as in Table 5.5.

Referring to the results of this study, the Indonesian Navy needs to take strategic steps in overcoming the limited number of KRI equipped with sonar, both surface ships and submarines are faced with how wide Indonesia's territorial waters are but are still able to carry out their duties optimally. Because KRI and Aircraft cannot always be on standby at a fixed choke point. However, KRI and the aircraft must always carry out maritime security patrols in a very wide area. In addition, KRI and Aircraft each have limited operational durability.

Of course, this will cause the choke point to be very vulnerable to the threat of infiltration either ships on water or submarines because they cannot be guarded all the time. One of the strategic steps to anticipate this threat is the placement of Sonobouy at sea level referring to the optimal placement concept and design (see Appendix I), and SOSUS placement with the optimal operation concept of the sonar array on the seabed at the depths referred to in table 5.5. Strategic funnels such as ALKI are expected to make a positive contribution to improving surveillance of foreign submarine threats and achieving maritime control. Indonesia's national jurisdiction is an ideal underwater defense system concept in Indonesia as an archipelagic state.

Table 5.5 Number of SOSUS Needs on Alternatives

No.	Area	Location	Source Depth (m)	Receiver Depth (m)	Total
1.	ALKI IA-1 Natuna Sea	Bintan Island – Mangkai Island	10; 30	15; 35	2 Unit
2.	ALKI I-1 Natuna Sea	Tanjung Pianadang – Small Subi Island	10; 30	15; 35	2 Unit
3.	ALKI II-1 Makassar Strait	Tanjung Mangkaliat – Tuguan Island	30; 200; 400; 750;1000	35; 210; 410; 765;1050	5 Unit
4.	ALKI IIIE-2 Sulawesi Sea	Tanjung Toade – Beng Laut	30; 200; 400; 750;1000	35; 210; 410; 765;1050	5 Unit
5.	ALKI IIIA-1 Maluku Sea	Tanjung Damau – Sedeng Island	15; 150; 300; 750	20; 155; 310; 755	4 Unit
6.	ALKI IIIC-2 Arafuru Sea	Tanjung Waarngalier – Atnebar Island	30; 90; 300; 750;1000	35; 95; 310; 755;1050	5 Unit
7.	ALKI IIIB-2 Leti Strait	Tanjung Mahin – Tanjung Sio	25; 110; 300; 1000	30; 115; 310; 1050	4 Unit
8.	ALKI IIID-1 Sawu Sea	Great Dao Island – Tanjung Lie Geta	20; 150; 400; 950	25; 155; 410; 965	4 Unit
9.	ALKI IIIA-13 Sawu Sea	Tanjung Wuimahi – Tanjung Undu	20; 150; 400; 950	25; 155; 410; 965	4 Unit
10.	ALKI II-8 Lombok Strait	a. Nusa Penida Island – Lombok Island	25; 110; 300; 700	30; 115; 310; 715	4 Unit
		b. Nusa Penida Island – Bali Island	25; 110; 300	30; 115; 310	3 Unit
11.	ALKI I-15 Sunda Strait	Ujung Cukuredak – Tanjung Waton	20; 50; 100	25; 55; 110	3 Unit

Indonesian Navy is also expected to carry out an operational analysis (naval operation analysis) by optimizing its limited resources. Operational analysis is one of a series of naval research and development activities that are always carried out to achieve the optimal use of equipment and weapons, especially the optimization of the use of the Sonar detection system in marine operations (Garret et al., 1969). To support the strategic placement of Sonobouy and SOSUS optimally, it is necessary to be equipped with a fixed underwater detection station on the funnel strategic as an attack station in the concept of archipelagic warfare so that it is hoped can improve deterrence strategies and blockade strategies against foreign submarine threats that infiltrate the territorial waters of the Indonesian sea.

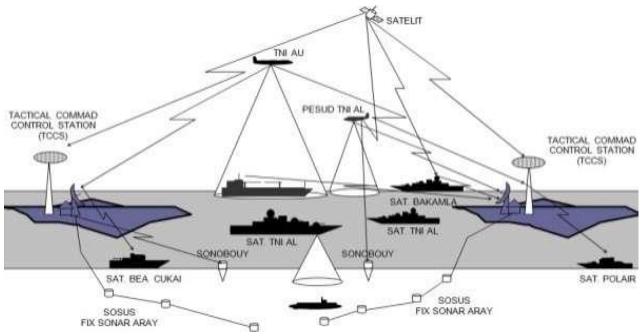

Figure 5.5 Concept of Integrated and Coordinated ALKI Security Operations Using Detection Systems

This station is a tactical command control station (TCCS) station that serves as the center of control and coordination of the tactical and operational aspects of security activities in the strategic straits and ALKI according to the determination of the area that is the responsibility of the control center. TCCS will receive data and information from ALKI security elements consisting of the Navy, Air Force, Bea Cukai, Bakamla and Polair, as well as all detection sensors, both water surface detection sensors and underwater detection sensors in their area, especially Sonobouy and SOSUS. Data and information obtained from the integrated surveillance system can be used for the benefit of naval warfare tactics especially in detecting and providing data and information about the direction, speed, and type of the enemy ships continuously with a very good level of precision.

Then continuously analyze all information, especially aspects of sovereignty and law enforcement at sea. Data and information obtained from the integrated surveillance system can be used for the benefit of naval warfare tactics especially in detecting and providing data and information about the direction, speed, and type of the enemy ships continuously with a very good level of precision. Then continuously analyze all information, especially aspects of sovereignty and law enforcement at sea. Analyzed results forwarded to the Central Command Control Station (CCCS) located at Mako Koarmada I, II, and III. This will become a pattern of marine security operations in the integrated archipelago of Indonesia through the placement of Sonobouy and SOSUS, as well as supporting an underwater defense system as shown in Figure 5.5 below

In addition, with the existence of this TCCS Station, it is no longer necessary to operate the KRI element as well as aircraft in ALKI or other choke points to carry out deep underwater surveillance permanent degree, because the TCCS Station is capable of being operated continuously to maintain the choke point of the threat of foreign submarines entering Indonesian waters illegally. With no need for the operation of the KRI and Aircraft in a permanent degree at the choke point to oversee the presence of foreign submarines can reduce operational costs. The operational costs can be used for other important activities so that the use of the current defense budget can be done more effectively and efficiently.

In every action of taking action against security disturbances or providing assistance in the event of an incident and calls for emergency assistance, the TCCS Station can immediately order the security elements needed is being assisted in the area that is his responsibility to immediately provide assistance and respond by taking action quickly to the scene guided from the station TCCS and then report to the CCCS Puskodal, especially regarding the deployment of units additional assistance both from elements of the Indonesian Navy and Air Force and other relevant stakeholders as a response to an action.

To deal with threats in the form of infiltration efforts and territorial violations and the threat to territorial sovereignty and national security, then the control of elements of security in the field will be taken over by the CCCS Puskodal, as well as taking decisions and the deployment of forces according to the escalation of the threat.

In this condition, the TCCS Station works as the data controller and necessary tactical information as well as target identification according to the detection results it receives and distributes to the CCCS Puskodal. By operating this station, and the integrated ALKI security operation pattern using an underwater detection system that is integrated between Sonobouy and SOSUS, then the concept of the title of TNI AL strength in security operations ALKI from underwater threats consisting of KRI, Pesud, and base are arranged in an action which is focused on selective vulnerable areas that are expected to be the axis of the threat. While the permanent title is carried out by deploying TCCS Stations located in strategic straits or ALKI, to improve anti-access strategies or countermeasures against the threat of foreign submarines entering Indonesian waters, and also supporting the blockade strategy in islands warfare.

The deployment of this station can continuously monitor underwater activities. This station is also can provide online data both to elements who are carrying out patrols in the area of operation as well as to the CCCS Puskodal. The data and information are forwarded to the controlling City which will later send KRI and Airplanes as elements of the prosecution to continue to detect the underwater threats and take action. The data was also sent to the KRI which currently patrolling the waters so that the response in detection and action is more accurate and faster. A permanent form of a TCCS Station that is integrated with the elements of the KRI and Aircraft, increases the capability of the Indonesian Navy in securing ALKI and the ability of the Navy in anti-submarine warfare.

Then the holding of the title of prosecution and permanent title by the Indonesian Navy in securing ALKI can be carried out throughout the year continuously to prevent threats, control the sea and of course, ensure the security of ALKI so that the sea of Indonesia's national jurisdiction is safe to use for users and free from threats on the activities of using or exploiting the sea.

From the concept of the title of TNI AL strength and ALKI security operations in an integrated and coordinated through the placement of Sonobouy and SOSUS as described above, of course, can improve the ability of the Navy in securing ALKI which is the line of control of the sea lines used by the opposing party so that the control of the sea can be realized, and can support the implementation of the underwater defense system water level in the Indonesian archipelago. This is under the theory of A.T. Mahan in his book entitled "The Influence of Sea Power Upon Story". In addition, it can increase the capabilities and the role of the Indonesian Navy which consists of military aspects, law enforcement aspects, and diplomatic aspects under Ken Booth's theory is as follows:

a. Capable in the military function on the implementation of a pattern of building the ability of Navy elements which will increase the overall capability. The capabilities in question include sensing capabilities, mobility, firepower, and C4ISR.
b. Capable in the constant function to ensure the safety of the sea so that the sea is free from threats to marine use or utilization activities.
c. Capable in the diplomatic function is the realization of increasing the diplomacy of the Navy in particular related to maritime security cooperation with countries in the region.

V. CONCLUSIONS

The geographical shape of Indonesia in the form of a group of islands gives certain characters and characteristics under existing hydro-oceanographic conditions. With many straits and the intermediate sea, the depths of the sea (Bathymetry) that varies will influence the parameters of water characteristics oceans such as temperature, salinity, surface currents, tides, coastal currents, density, transparency, and the color of the seawater, and the characteristics of the seabed, besides that it will also influence the meteorological conditions. This very complex geographical condition will affect the speed profile sound and sound wave propagation pattern of the Sonar detection system so that in the end forms areas that are difficult to penetrate by sound waves (shadow zone). This area is a safe zone where the temperature and salinity of the sea in the layer reflect the propagation of incoming sound so that the submarine avoided Sonar detection.

By referring to these conditions, Indonesia can take advantage of them in the system of National Defense. The physical form of Indonesia as an archipelagic country will provide good benefits in strategic, operational, and tactical and the utilization of constellations and characteristics of the archipelago country manifested in the form of the concept of archipelagic sea warfare.

Concept implementation requires an adequate subsurface defense system through a placement strategy sonar detection network system in the form of placing Sonobouy on the surface of the water and placing SOSUS on the seabed in strategic funnels such as ALKI which is the entry point for threats both threats above the water surface and underwater threats (submarine and underwater drones). Where this sonar detection network system is integrated with TCCS as an attack station which is also equipped with Coastal Torpedo Launch and CCCS as Puskodal for the deployment of additional aid units both from elements of the Indonesian Navy and Air Force and other relevant stakeholders as a response to prosecution, as well as elements of the KRI and Aircraft.

This research uses mixed methods to process quantitative data from the questionnaire results, the respondents regarding the criteria and alternatives to determine the coordinates of placement and quantity of optimal Sonobuoy with ANP method and probability theory approach, as well as quantitative data (detection of shadow zones and submarines) in the form of temperature, salinity, bathymetry and speed of sound to determine the optimal placement depth and number of SOSUS, as well as qualitative data from the results of interviews with experts who will be analyzed to complete quantitative data so that produce an interpretation that can be used as additional information. Ranking results Sonobouy placement criteria and alternatives with ANP found that "No Obstacles" is sub-criteria with the highest-ranking weight value, namely 0.11913, and ALKI III-13 Sawu Sea is the alternative priority with the highest-ranking weight value, amounting to 0.12839. With optimization detection probability modeling using probability theory and the help of Electronic Chart software of the Cmapecs system, and by taking into account the geographical conditions and the operation of the submarine, the coordinates position for Sonobuoy placement which has optimal detection coverage area, where no gap does not have an intersection between the reception range and Sonobuoy as a source of sound wave reception (see Table 5.3). To find out the shadow zone and detect the presence of foreign submarines by simulating and modeling wave propagation of the sound of SOSUS with the parabolic equation method. From optimization of sound wave propagation simulation which pays attention to hydro-oceanographic data in the form of temperature, salinity, and speed of sound, it is found that optimal positioning depth of placement and number of SOSUS with Fix Sonar Array operating concept which can detect shadow zones and detect foreign submarines (see Table 5.5) to support Indonesian maritime defense strategy.

The optimal placement of Sonobouy and SOSUS is part of the archipelago's maritime defense strategy which includes (1) Deterrence strategies aimed at preventing the intentions of the opposing party or parties who want to threaten the integrity and sovereignty of the Unitary Republic of Indonesia and Indonesia's national interests, (2) Strategy layered defense or carried out to eliminate or destroy external threats through the title of combined sea and air force in the buffer defense field, defense field main areas, and especially in the area of resistance in the strategic approach funnels (ALKI), (3) Strategy control of the sea directed at ensuring the use of the sea for its power and preventing its use by the opposing force, and (4) a blockade strategy to block the opponent from the ability to move freely and lead to the desired area. Thus, this will produce a pattern of operations for securing marine waters in the archipelagic state of Indonesia in an integrated and coordination with relevant stakeholders, and support the implementation of the defense system underwater in archipelagic sea warfare to increase the capability and the role of the Navy from the military aspect, law enforcement aspect and diplomatic aspect.

VI. LIMITATIONS AND FUTURE RESEARCH

Acoustic tomography technology for the open ocean has advanced and is used to monitor temperature fluctuations and ocean currents (Munk et al., 1995). Acoustic tomography method of measuring the speed of sound and current field using the difference in travel time of the acoustic signal sent between observation stations in the waters.

This adult acoustic tomography development has successfully mapped the transverse structure of currents, temperatures, and other physical processes occurring in the entire water column (Park and Kaneko, 2000).

In case of submarines passing through straits with complex geographical conditions, then wakes due to submarine maneuvers can be tracked. Speeding (1997) shows the repulsions that arise due to the movement of the submarine have a stable pattern in the form of regular changes in vertical vortex trails on the back of the tail and occur for a long duration.

Internal natural processes stable wave (waves propagate in layers between different densities) cannot produce patterns similar to a submarine, because it has a much smaller wave phase velocity, around 1m/s, when compared to a submarine's minimum speed of 4 m/s.

Further research can consider the internal wave factor, considering that Indonesia consists of many straits, complicated coastal morphology and bathymetry make this region rich with phenomena (Syamsudin et al., 2004). At the location where the internal wave range is in the order close to the minimum speed of the submarine, then the interference effect of the two sources of interference may occur, but it can be minimized by applying a high-frequency transmitter so that the coherent effect can be suppressed and the submarine pulse signal can be detected.

The key to success in underwater warfare is early detection, while the main equipment used is sonar. As it propagates in the sea, sound waves emit from sonar with a certain frequency and voltage characteristics are strongly influenced by physical variables, dynamics, seawater chemistry, and seabed topography. To get a picture of wave propagation the sound from the sonar system is close to the actual condition, further research needs to be done about the attenuation of the acoustic emission power to obtain more accurate information regarding detection distance and effective communication distance. More intensive research on underwater acoustic propagation and oceanography in all Indonesian waters needs to be done. This can be useful for increasing marine resource exploration and national defense activities. Besides, the numerical modeling of the parabolic equation method should be developed by taking into account the following factors: (1) The transmission energy loss factor due to absorption caused by the effect of viscosity, relaxation of boric acid, and relaxation of magnesium sulfate, (2) Consequence factors imperfect reflection both on the sea surface and on the seabed, (3) Leakage factor (leakage) and field anomalies, and (4) Use of the bottom boundary under bathymetry map of measurement and observation locations. Thus, the simulation results will be obtained by modeling the sound wave propagation of the approaching sonar detection system, and according to actual environmental conditions in the detection area.

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Appendix I

Sonobouy Placement Design on Alternative

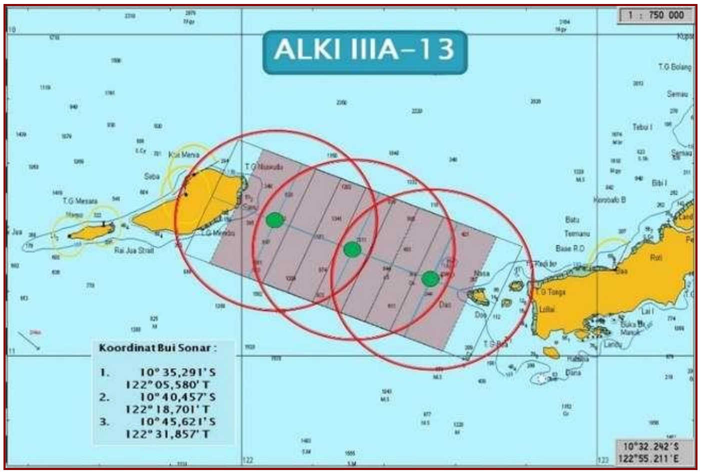


Figure 1. Placement of Sonobouy on the First Priority

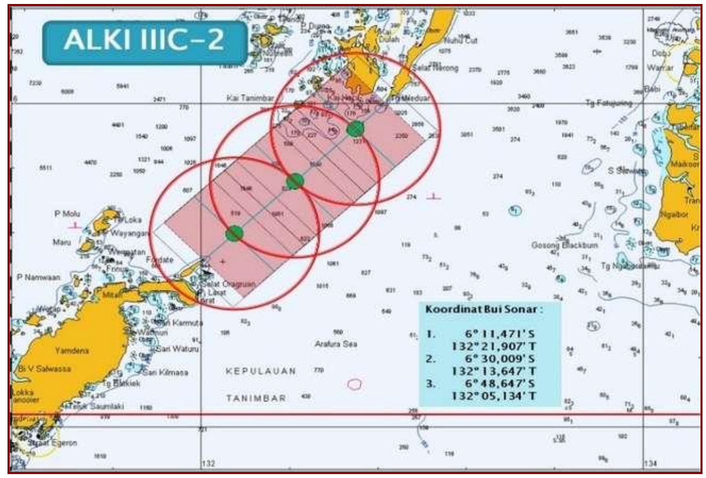


Figure 4. Placement of Sonobouy on the Fourth Priority

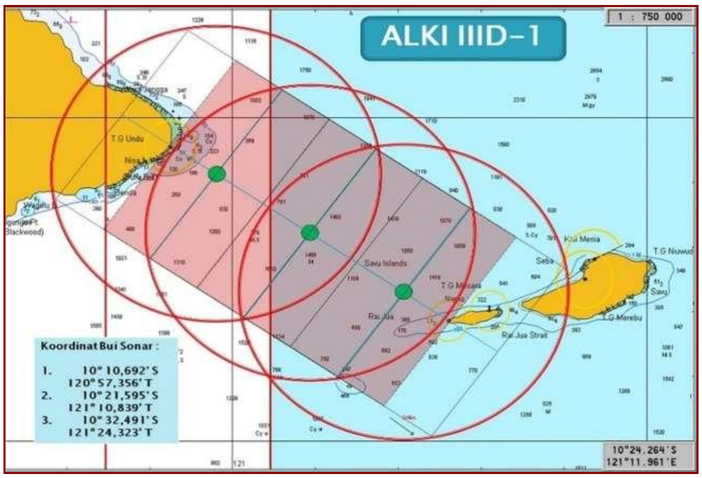


Figure 2. Placement of Sonobouy on the Second Priority

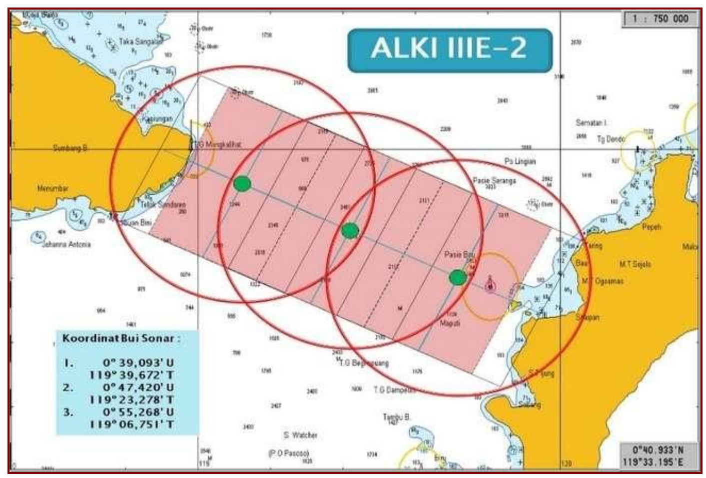


Figure 5. Placement of Sonobouy on the Fifth Priority

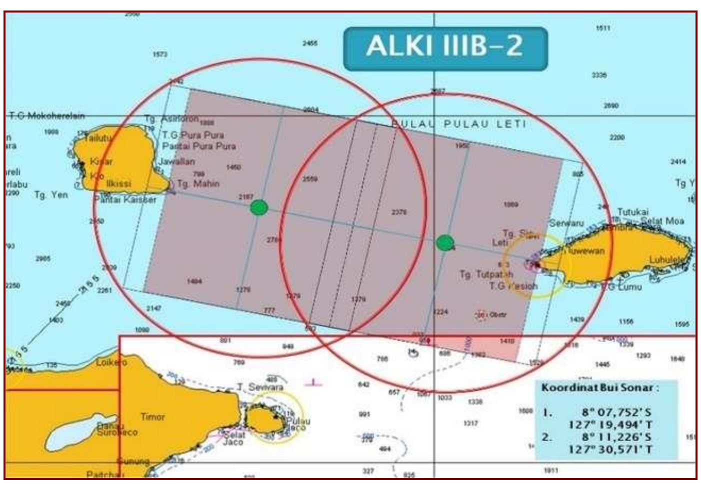


Figure 3. Placement of Sonobouy on the Third Priority

Figure 6. Placement of Sonobouy on the Sixth Priority

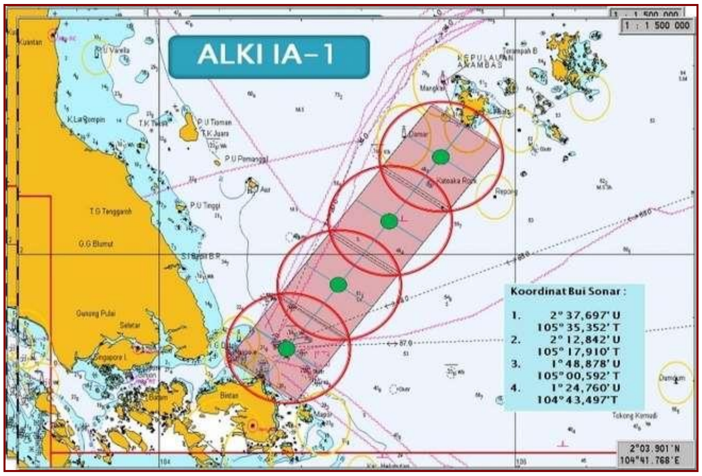


Figure 7. Placement of Sonobouy on Seventh Priority

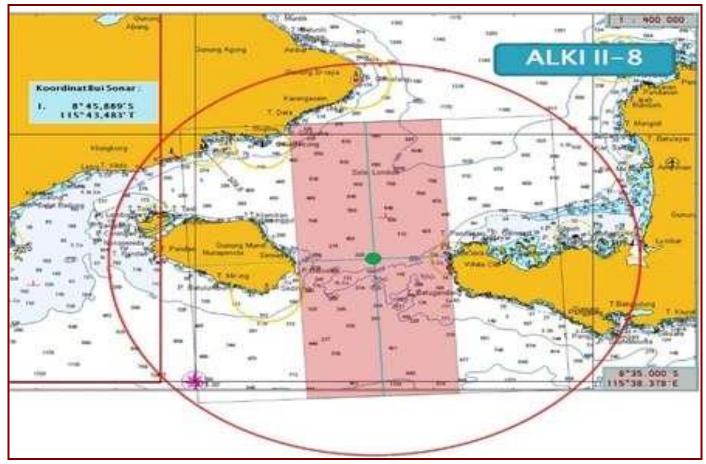


Figure 9. Placement of Sonobouy on the Ninth Priority

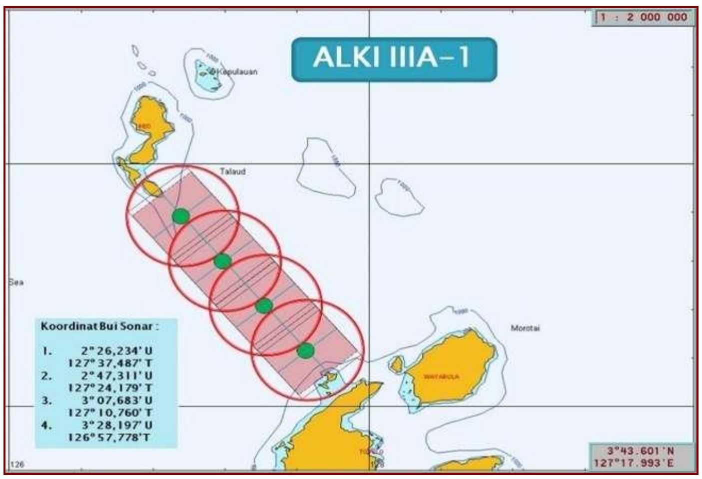


Figure 8. Placement of Sonobouy on the Eighth Priority

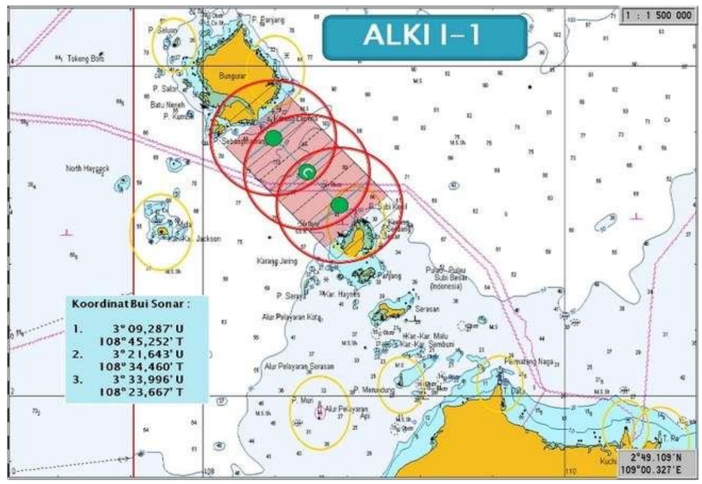


Figure 10. Placement of Sonobouy on the Tenth Priority

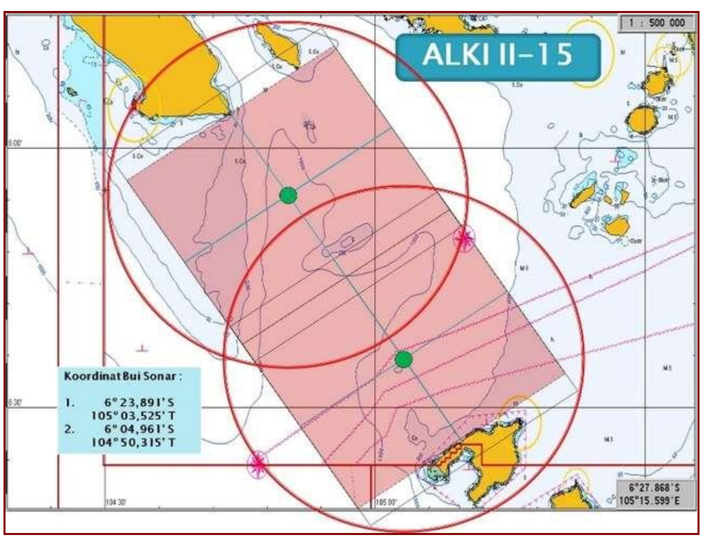
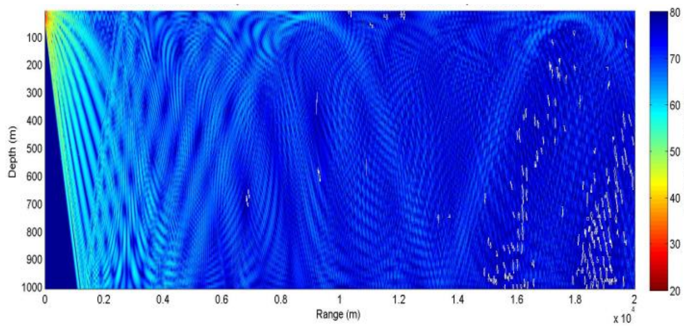


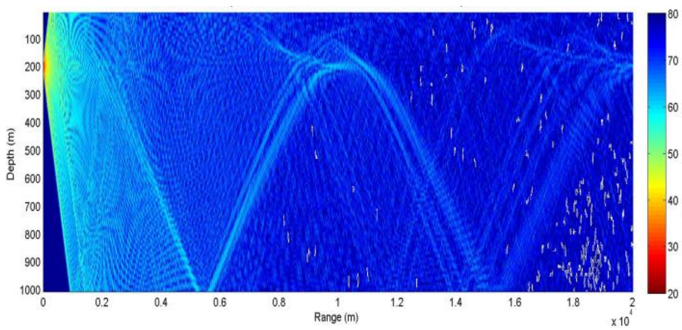
Figure 11. Placement of Sonobouy on the Eleventh Priority

Appendix II

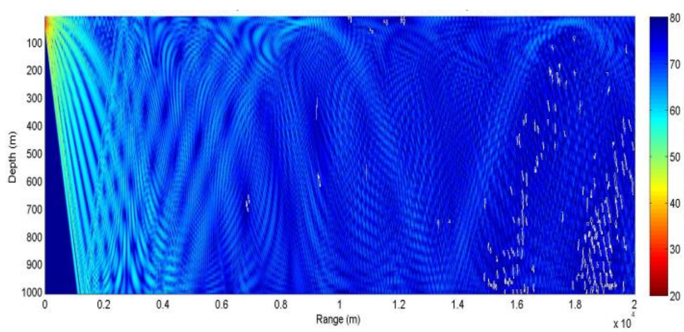
Sound Wave Transmission Energy Simulation from SOSUS



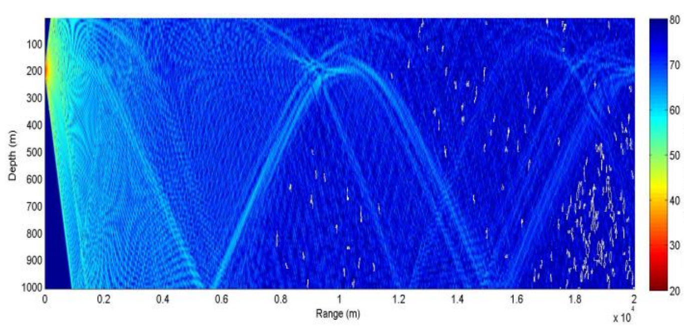
Simulation results of lost sound wave transmission energy in the Makassar Strait with a transmitter depth of 30 m and a receiver depth of 35 m receiver



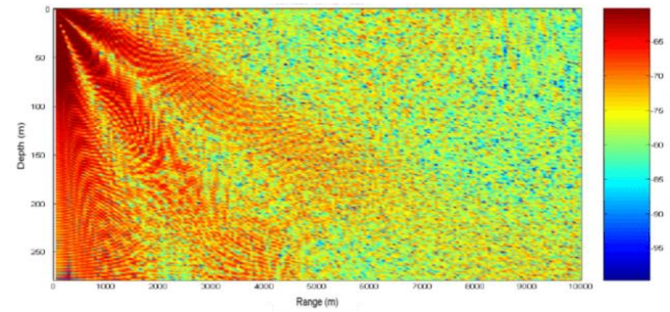
Simulation results of lost sound wave transmission energy in the Makassar Strait with a transmitter depth of 200 m and a receiver depth of 210 m



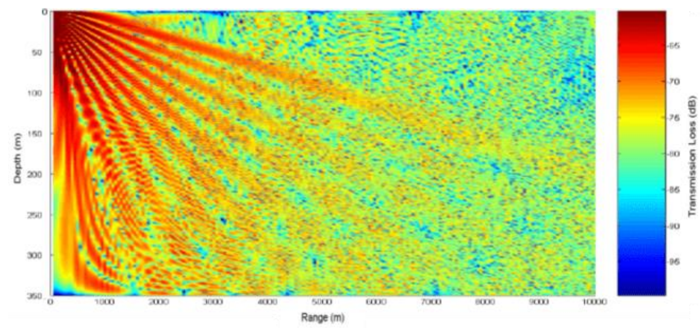
Simulation results of lost sound wave transmission energy in the Sulawesi Sea with a transmitter depth of 30 m and a receiver depth of 35 m



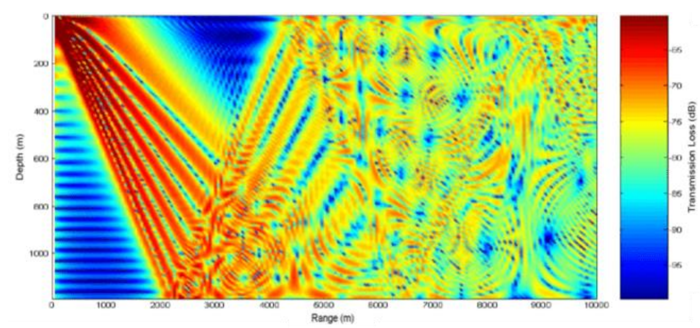
Simulation results of lost sound wave transmission energy in the Sulawesi Sea with a transmitter depth of 200 m and a receiver depth of 210 m



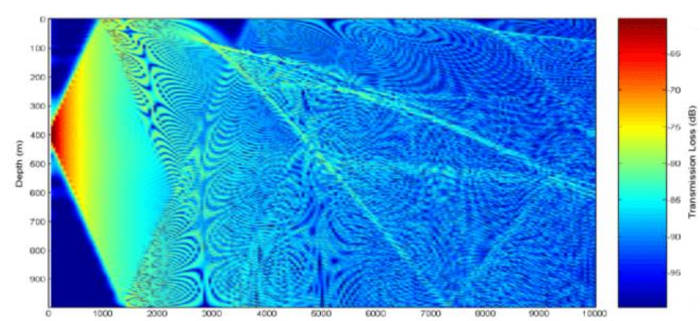
Simulation results of lost sound wave transmission energy in the Natuna Sea with a transmitter depth of 10 m and a receiver depth of 15 m



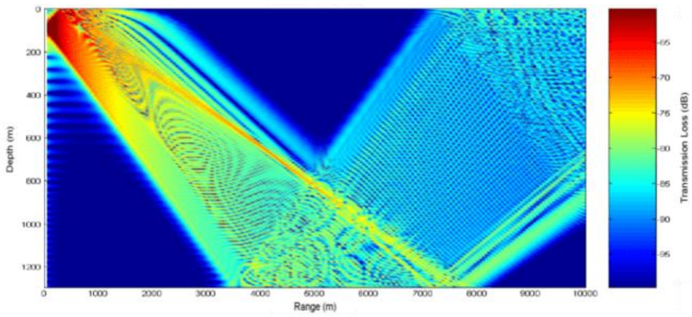
Simulation results of lost sound wave transmission energy in the Natuna Sea with a transmitter depth of 20 m and a receiver depth of 25 m



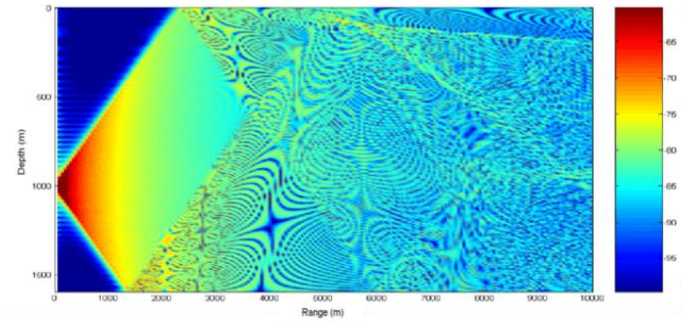
Simulation results of lost sound wave transmission energy in the Sawu Sea with a transmitter depth of 20 m and a receiver depth of 25 m



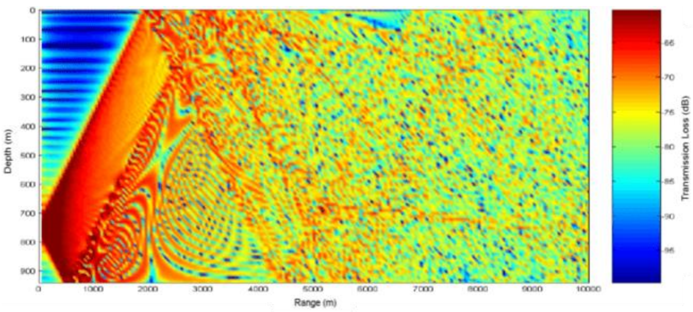
Simulation results of lost sound wave transmission energy in the Sawu Sea with a transmitter depth of 400 m and a receiver depth of 410 m



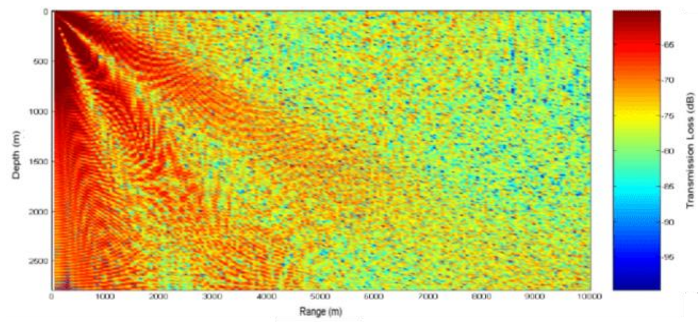
Simulation results of lost sound wave transmission energy in the Arafura Sea with a transmitter depth of 90 m and a receiver depth of 100 m



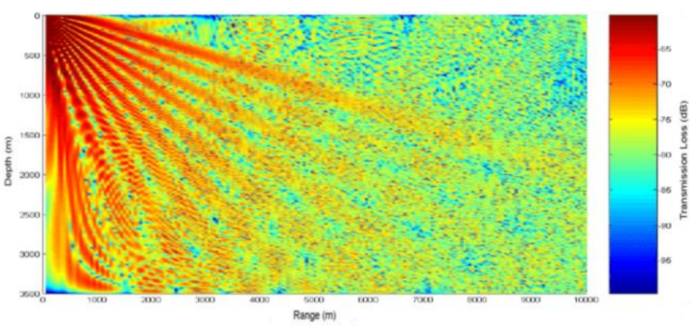
Simulation results of lost sound wave transmission energy in the Leti Strait with a transmitter depth of 1000 m and a receiver depth of 1025 m



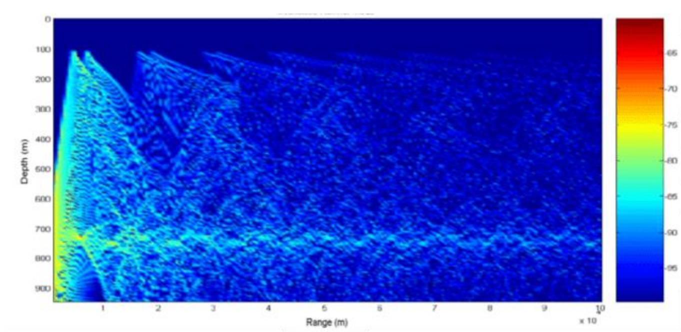
Simulation results of lost sound wave transmission energy in the Arafura Sea with a transmitter depth of 750 m and a receiver depth of 755 m



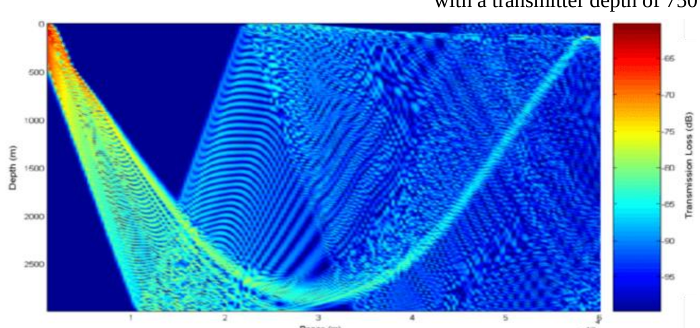
Simulation results of lost sound wave transmission energy in the Maluku Sea with a transmitter depth of 15 m and a receiver depth of 20 m



Simulation results of lost sound wave transmission energy in the Leti Strait with a transmitter depth of 25 m and a receiver depth of 30 m



Simulation results of lost sound wave transmission energy in the Maluku Sea with a transmitter depth of 750 m and a receiver depth of 755 m



Simulation results of lost sound wave transmission energy in the Maluku Sea with a transmitter depth of 150 m and a receiver depth of 155 m