Spatial Modelling to Optimize the Positioning of Air Defense Surveillance Radars with Minimal Shadow Zone

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Abstract — Indonesia’s strategic position between two continents and two oceans has resulted in an obligation for Indonesia to be involved in various international cooperation and international conflicts. The declaration of the development of the maritime sector to be the cornerstone of Indonesia’s main strength requires support from the air defense sector. The current condition of Indonesia’s air defense sector, especially the Air Surveillance Radar has not worked optimally resulting in an air defense operation that has not been maximized. The properties of high-frequency electromagnetic waves used in Doppler radar have a straight line of sight. Mountains, hills, and artificial objects/buildings can become obstacles, create blank areas (areas that cannot be covered by radar) behind them, and reduce the performance of the radar coverage. The use of sensing technology, in particular, the geographic information system to determine the position of air surveillance radar placing is an effective solution to optimize the coverage radars exist. The rectangular rule approach method combined with the land surveying technique is a combination of methods that can be used to measure the volume of air defense radar coverage. The level optimization of radar position planning point can be determined by processing the obstacle volume, land slope, earthquake and landslide vulnerability, and land cover conditions into the calculation of the fuzzy inference system technique. This study examines the concept of using Geographic Information Systems to measure the level of radar optimization when placed in a planned position. This research aims to produce a method review on optimizing the performance of air surveillance radar coverage by utilizing remote sensing technology to determine the radar placement position.

1. Introduction
Indonesia is the largest archipelago country in the world with an area of 7.7 million square km, covering a land area of 1.9 million square km, and an area of the water area of 5.8 million square km. Indonesia’s strategic position between two continents and two oceans has resulted in an obligation for Indonesia to be involved in various international cooperation and international conflicts. [1] The declaration of the development of the maritime sector to be the cornerstone of Indonesia’s main strength requires synergy between various sectors, including the air defense sector. Given the geographical conditions of Indonesia which are an archipelago. However, the current condition of Indonesia’s air defense sector has not been sufficient to support the government’s ideals. Air control is currently felt to be lacking. One effort that can be done to strengthen national defense is the addition and modernization of radar and its communication system so that the entire national airspace can be fully covered. In view of Indonesia’s
geographical conditions in the form of islands, and the nature of the high-frequency electromagnetic waves used on Doppler radar it has a straight line of sight, Mount; the hills; and artificial objects/buildings can become obstacles causing the radar coverage is not optimal (imperfect) and the area behind the obstacle becomes a blank area (areas that cannot be detected by radar). [2]

Among the 20 radar units currently available, several of them had suboptimal coverage, namely (1) 212 radar units. Some of the coverage was not optimal due to the obstacle in the form of Natuna Mountain, (2) the 224 Kwandang radar unit due to the obstacle in radial 180, (3) radar unit 226 Buraen presence of an obstacle on radial 300 and (4) radar unit 242 Tj. Warari as discussed above so that it can only detect optimally towards the Pacific Sea and cannot detect the maximum of air targets that fly from the west (Sorong). [3] Based on these data, it can be concluded that there is a need to improve radar performance by determining its optimal location/placement. Thus, the authors intend to create a Spatial Modeling concept that can be used to optimize the placement of an Air Surveillance Radar which results in the position of the air surveillance radar that has minimum Shadow Zone in the specified area. Researchers used a rectangular rule approach and land surveying technique to calculate the volume of radar coverage placed at certain planning positions. The level of optimization of the planned radar placement point can be determined by processing the obstacle volume, land slope, earthquake and landslide vulnerability, and land cover conditions into the calculation of the fuzzy inference system technique.

In this study examines the concept of using Geographic Information Systems to measure the level of radar optimization when placed in a planned position.

2. Literature Review
2.1. The Air Surveillance Radar
The main functions of an Air Surveillance Radar are monitoring, detecting, and directing. The monitoring function carried out by the radar is to monitor the entire airspace of Indonesia's sovereign territory by jurisdiction including monitoring the movement of aircraft and other air vehicles such as UAVs. [5] The Air Surveillance Radars in National Air Defense Operations are classified according to the specifications of their capabilities as follows [9]:

- Radar Early Warning (EW): serves to detect as early as possible the target that goes into the boundaries of the region. EW radars are required to have far-reaching coverage and overlap with other radars.
- Radar Ground Control Interception (GCI): additional radar specifications that can guide from the ground to an attack aircraft that will conduct pursuit and interception to targets that have been detected by Radar Early Warning.
- Gap Filler Radar and Airborne Radar: to cover the gap that has not been covered by EW and GCI radars

2.2. Legal Basis for Conventional Air Radar Placement
Based on the Decree of the Director-General of Civil Aviation Number: SKEP/ 113/ VI/ 2002 regarding the Criteria for Placement of Aviation Electronics and Electrical Facilities as follows:

- The height of the building around the ATC Radar antenna does not become an obstacle for the radiant wave.
- The area of land needed to be able to accommodate radar equipment shelters, radar antenna towers, and other supporting facilities is at least 100m x 100m.
- The height of the building which is around the antenna tower up to a distance of 500m from the antenna midpoint does not exceed the height of the antenna tower base elevation.
- High voltage electrical networks are not permitted up to a distance of 1000m from the center of the radar antenna.
- Land for laying VHF Omnidirectional Range (VOR) is chosen such that the surface of the building seen from VOR equipment has a minimum azimuth. And the elevation angle is less than 1.2 degrees.
2.3. Classification of Obstacle
To classify whether there is an obstacle in the radar coverage area by comparing the height of the radar location point coordinates \((x, y)\) consider point A with the height of the next point coordinates \((x + 1, y + 1)\) consider point B. If the difference between the height of the radar location point \((A)\) to the height of the next point \((B)\) is positive so it is concluded that there is no obstacle up to that point B. Conversely, if the difference between the height of the radar location point \((A)\) and the next point \((B)\) is negative, it is concluded that there is an obstacle at that point B. Formula classifying obstacle:

\[
O_b = H_n - H_{(n+1)}
\]

If \(O_b > 0\), not an obstacle
If \(O_b < 0\), there is an obstacle

Explanation:

\(O_b\) = Difference between the height of the radar location point \((A)\) and the height of the next point \((B)\).

\(H_n\) = Radar point height.

\(H_{(n+1)}\) = next point height.

2.4. Altitude Value Correction on Topographic Maps
The height of the topographic map before entering the obstacle classification process is first corrected by considering the earth's curvature. This is done because the elevation value on the topographic map is the height on a flat plane that does not take into account the earth's curvature at a certain distance from the radar location. Height correction is done using the following formula: [11]

\[
\text{Earth's curvature factor} = \frac{d^2}{2kR}
\]

Explanation:

\(d\) = Distance of \(T\) point with \(T'\) point.

\(R\) = The radius of the Earth 6470 km

\(k\) = Earth's refraction coefficient = 4/3

To get the value of the height of \(h\) that has been corrected, that is:

\[
h_{after} = h_{before} - \frac{d^2}{2kR}
\]

2.5. Geographic Information System (GIS)
Geographic Information System (GIS) can be defined from three points of view: toolboxes, databases, and organizations. [10] Thus, GIS is a spatial data management system that is reliable (powerful) and at the same time as a decision support system (decision support system). In this context, it is implied that GIS cannot be seen from just one perspective, for example as a system, but GIS has two essences,
namely in terms of structure and function. In terms of structure, GIS consists of components that include hardware, software, data collection, data management systems, and the organization where GIS is implemented. While its functions cover what can be done, how GIS performs work, who is served, and for what GIS is used. One of the prominent functions of GIS, and at the same time what distinguishes it from computer cartography, is a reliable analysis and manipulation function, both graphically (spatial) and tabular (table-based data). [4]

2.6. Fuzzy System Model

The fuzzy model system is a system based on rules or knowledge [8]. Several components are forming a fuzzy system. The first is the fuzzifier, which is a component for conducting the fuzzification process. The second is the rule base, the component containing the rules, and finally the defuzzifier, the component for defuzzification. [7]

![Fuzzy System Model](image)

Figure 3. Fuzzy System Model

3. Research Methods

3.1. Calculation of Radar Coverage Volume

The technique of calculating radar coverage volume without the shadow zone used is a combination of the rectangular (rectangular rule) method with soil geometry. The following are the steps that must be done to calculate the radar coverage of air surveillance:

- Determination of radar specifications to be calculated the volume of the cover. In this study, it was discussed to discuss the Doppler type radar specifications with the Helical scanning type.
- Calculation of the overall radar coverage volume in ideal conditions free of obstacles. Radar coverage volume in ideal condition free from obstacle with helical scanning type ($V_{cr_{brutto}}$) is calculated using the half ball volume approach with the following formula:

$$V_{cr_{brutto}} = \frac{4}{3} \pi R_{radar}^3$$  \hspace{1cm} (3.1)

Explanation:

$V_{cr_{brutto}}$ : overall radar coverage volume in ideal obstacle-free conditions.

$R_{radar}$ : The capability of the furthest range of air surveillance radar used.

1. Calculation of the obstacle + shadow zone volume on the radar air surveillance radar. In this process consists of several stages, including Divide $V_{cr_{brutto}}$ into several slices, from each slice the area is then calculated. The radar coverage area calculation technique is performed using the rectangle rule method. Suppose that the area bounded by a function $f(x)$ in the interval $[a, b]$, if the interval $[a, b]$ is divided into $n$ pieces, then one section of the slice can be seen in the following figure:
The area of one slice of the slice can be determined by the formula of the area of a rectangle $L = p \times l$ where the length is represented by $h = x_1 - x_0$ and the width is represented by $f(x_1)$ which is the right-hand side, so that the area of one slice is $L = h \times f(x_1)$, but there are still blank areas that are counted as an area called gatel (error). If the width is represented by $f(x_0)$ which is the left side, then the area is shown as in the following figure:

$$L = h \times f(x_0), \quad L = h \times f(x_1)$$

2

$$2L = h \times f(x_1) + h \times f(x_0)$$

From the formula of the width of one piece, it is obtained the formula of irregular area under the curve $f(x)$, i.e.:

$$L = \int_{x_0}^{X_1} f(x)dx = \frac{h}{2} \left( f(x_0) + f(x_1) \right)$$

After the area of each slice is calculated, the next step is to calculate the volume by adding the leftmost slice area ($P_0$) with the area of the next slice $P_{0+1}$ then multiplied with $p$ (where $p$ is the distance between slices) the volume of the first slice field is found. The next step is to calculate the volume of the next slice area as before, but the calculation starts from the area of the slice section $P_{0+1}$ with the area of the slice section $P_{0+2}$, and so on until the entire volume of the incision plane is calculated. The total amount of the total volume of the incision is the obstacle volume and the shadow zone radar.
3.2. Data Processing Techniques
Data processing techniques that can be used to calculate the optimal level of radar coverage is to use the Mamdani fuzzy inference system based on Geodetic, Topographic, and disaster vulnerability parameters.

3.3. Data Analysis Techniques
Data analysis techniques in this study were carried out with several stages including data preparation, preprocessing, and fuzzy model implementation. [9] In general, the stages can be seen in the following figure:

- Dataset
  The data used in this study are the spatial data of height and distance parameters obtained through DEMNAS data, as well as the data on Earthquake Disaster and Landslide Disasters.
- Preprocessing
Preprocessing is a clustering process carried out on the area of radar-free obstacle coverage, distance, slope of the land, land cover, earthquake and landslide vulnerability in the specified area.

- **Fuzzy Model**
  Stages of the analysis of determining the strategic location of the radar placement with the fuzzy model, as shown in Figure 9:

![Figure 9. Stages of Analysis of the Fuzzy Model](image)

The Radar Location Variable Value, Obstacle Height, Obstacle Distance, Land Slope, Earthquake Vulnerability, Landslide Disaster, and Land Cover must be converted into fuzzy numbers. Fuzzy numbers are used as input to the Fuzzy Inference System (FIZ) process. The FIZ process itself is carried out following the stages in Figure 9. The end of the fuzzy model is the location of the strategic location of the air surveillance radar in the classification appropriate, less appropriate, and not appropriate.

4. **Conclusion**

The Spatial Model that has been developed in this research can be used as a reference for the military in the process of meeting the needs of Indonesia’s air surveillance radar following the MEF requirements. In the spatial model that has been built in this research, the accuracy of the value of the radar coverage area is determined by how many intervals \([a, b]\) is divided into \(n\) parts in the calculation of each region in the calculation process using rectangular rules. The greater the number of \(n\) used in calculations will produce a smaller radar coverage volume measurement error value. For further research, the researcher recommends considering other non-technical aspects in determining the strategic position of the radar such as the ease of access to the location, and the availability of electricity networks.

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**Acknowledgment**

This research was supported by the Capacity Building Program of the Faculty of Defense Technology, Indonesia Defense University.