



Hit Probability Bayesian Network for Sea Battles

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Abstrak

Bayesian Network is a method applied for probability analysis that considers the relationship of these influencing factors and is arranged in a Directed Acyclic Graph (DAG). Bayesian network structure is composed of initial information (prior probability) and the relationship between conditional probabilities at each node that have been determined based on expert knowledge or certain analysis. Such conditional probability is only valid for data analysis at the time of collection. In this study, a Bayesian network model for naval warfare, surface ships are involved was developed. The model is based on the results of a literature study and validation based on experienced professionals. The relationship between nodes shows five main influencing factors are fire control system, ammunition, personnel, movement of the target being shot, and environmental factors dominated by the marine environment.

Keywords: Naval warfare, Bayesian network, Hit probability.

1. INTRODUCTION

In naval warfare, surface ships are involved, on one side as an offensive ship and on the other as a defensive ship. Offensive side of the ship will try to immobilize defensive ships by shooting, which in this discussion uses artillery weapons. Meanwhile, the defensive side of the ship will try to avoid or even thwart the upcoming attack. As stated by Chircop (2018), determination of shooting requires 2 influential parameters, namely the likelihood of hitting the target (susceptibility) and the conditional probability of kill given a hit (vulnerability). In the discussion of likelihood of hitting, the objective function is the hit probability of shooting, not the chance to win warfare. Meanwhile, in the discussion of the conditional probability of kill given a hit, the objective function of the shooting is the level of damage caused if the shot hits the target. Hit probability is the probability of the targeted enemy's threat weapon at the enemy ship, how can it hit the target, and is calculated according to the characteristics and effectiveness of the threat weapon (Driels, 2004).

There are many factors that influence the shooting in naval warfare, which influencing each other, and can even reduce each other's factors in one system. The factors that influence the shooting can be compiled into a hit probability analysis model of a shooting with various methods, for example by using the Bayesian Network method which considers the relationship of the factors that influence each other and arranged in a Directed Acyclic Graph (DAG).



2. BAYESIAN NETWORK

Bayesian networks built from probabilistic theory and graph theory refers to a probability-based data modeling method which represents a set of variables and their conditional dependencies through a Directed Acyclic Graph (DAG). Probabilistic theory is directly related to data, while graph theory is directly related to the representation to be obtained (Heckerman, 1986). Probability is a way of expressing knowledge or belief that an event will occur or has already occurred. Meanwhile, Directed Acyclic Graph (DAG) is a directed graph structure without cycles. Bayesian network structure consists of nodes and edges. Nodes/nodes are filled with variables that represent the study objects, while edges describe relationships or associations between these nodes (Heckerman, 1995). Bayesian network applies a joint conditional probability distribution and a graph of a causal relationship model in the analysis process.

3. HIT PROBABILITY

In a naval warfare where the battlefield used is the sea, and warships are the main tools of the defense system used in combat which must be disabled so that they cannot work as they function, there will be many influential factors in the naval warfare. The factors that influence the shooting can be integrated into a hit probability analysis model of a shooting with various methods, where the value of this probability is $0 \leq f(x) \leq 1$. Based on several reviews about the influential factors of shooting in naval warfare, the discussion of hit probability refers to the factors that affect the shooting, which include fire control system (gun), ammunition used, environmental conditions at the time of the shooting the shooter, and the shooting target.

4. IDENTIFICATION OF FACTORS

Based on several reviews about the influential factors of shooting in naval warfare, the discussion of hit probability refers to the factors that affect the shooting, which include:

1. Fire control system (gun),
2. Ammunition used,
3. Environmental conditions at the time of the shooting/meteorology,
4. The shooter, and
5. The shooting target.

4.1 Fire control system

Fire control systems can use manual system or automatic systems. In general, fire control systems, both manual and automatic, have main components, namely tracking device, gun mount systems (vertical/horizontal thrust, recoil to launchers) and firing. In manual system, weapons operator personnel aim and fire weapons following target movement manually, while in automatic system, there is an integrated combat management system (CMS) which involves gun mounts, gun directors, range keepers, stable vertical/stable elements, and gun turrets, as well as support systems on board such as gyros, radar, navigation system, etc. The discussion of fire control systems in this study considers the similarities between the two systems and the earliest technology applied so that they can be approached in terms of changes due to these technological developments. Discussion regarding fire control system focuses on how to get targets (tracking), the weapon used (gun mount), and firing mechanism.

In the target tracking process, the manual weapon equipment relies on the eyes of the shooting personnel to get the object/target. There can be a limitation of target visibility and poor environmental visibility, as well as the height of the sea waves that interfere with the process of getting the target/object. After the target is obtained, the shooter follows the target movement to direct the gun barrel to the shooting position by moving the gun mount. Mechanical movement depends on the level of reliability of the system itself. The barrel on the gun mount that is not maintained can affect the muzzle velocity of the projectile as presented in Figure 1 below.

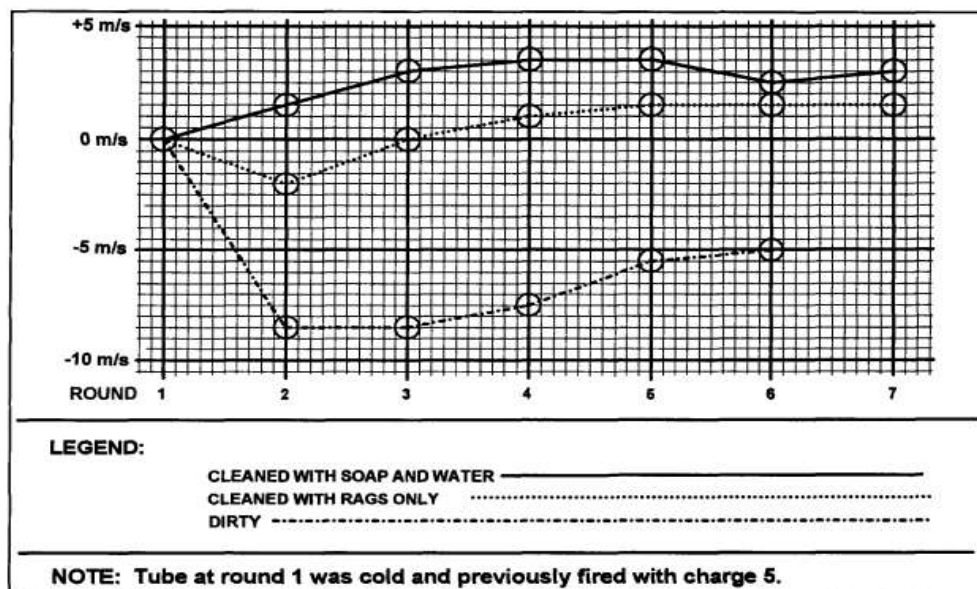


Figure 1. Muzzle velocity changes due to the fire of 105mm Howitzer with different gun barrel conditions (Department of The Army, 1999).

Furthermore, after getting the target and gun barrel is in a ready-to-fire position, the firing mechanism also affects the hit probability since each weapon has its own characteristics. Due to a strong recoil system, upon completion of the first firing, the gun mount position is no longer suitable with the initial condition at the time of shooting.

4.2 Ammunition

Further influential factor of a shooting in a naval warfare is the ammunition used. In general, ammunition consists of a projectile and a cartridge as shown in Figure 2 below.

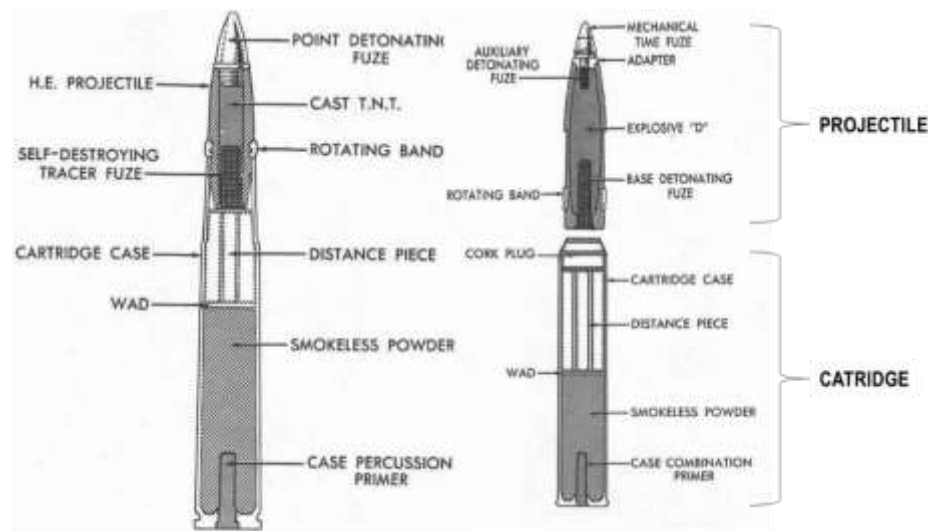


Figure 2. Parts of artillery gun ammunition, (Bureau of Naval Personnel, 1957).

The movement of the projectiles from the ammunition cannot be separated from the discussion about ballistics. Ballistics is the science which studies firing, projectile glides and the effects of projectile hit. The main thing in terms of ballistic control is the initial velocity of the ammunition (muzzle velocity), and projectile glides. The initial velocity is influenced by the thrust of the smokeless powder until the projectile exits from the end of the barrel (muzzle), while the projectile glide coupled with other external factors will affect the movement and trajectory of the projectile itself. Therefore, ballistics is very important in the ammunition design process. The design of the ammunition should consider the ballistic coefficient and range of the ammunition. Likewise with environmental conditions during warfare which should be considered. Cold environmental temperature will cause smokeless powder to cool so that the pressure during firing will also decrease. When the projectile glides in the air towards the target, and the projectile with mass (m) has an initial direction and velocity, then gravity will affect the projectile's motion, so that the projectile's trajectory will form a parabolic trajectory. Besides the effect of gravity, air resistance also

has a significant effect on projectiles that move at high speeds. When the projectile glides freely in the air (figure 3), due to the pressure of the projectile, the air in front of the projectile will move to follow the shape of the projectile, and it is as if the air movement opposes the movement and becomes a resistance towards the projectile glide.

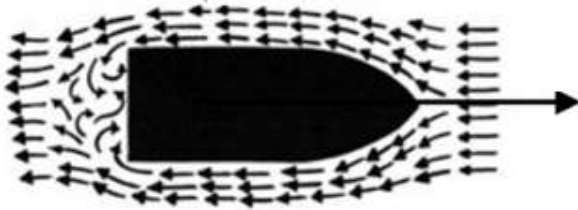


Figure 3. Fluid displacement due to projectile motion

The level of air resistance also depends on the dimensions of the projectile. Therefore, each projectile has a Ballistic Coefficient (BC) and a Drag Coefficient. Both can be seen in the following formula, where the situation applies to the standard condition environment.

$$BC = \frac{m}{Cd \cdot A} \quad (1)$$

$$Cd = \frac{2Fd}{\rho V^2 A} \quad (2)$$

Information:

BC : Ballistic Coefisien

Cd : Coefficient drag

m : Mass of the proyektil

Fd : Drag force

ρ : Air density

A : Projectile reference area

V : The velocity of the projectile towards the air

Wind speed and wind direction also affect the trajectory of a projectile, depending on the wind direction as shown in figure 4 below:

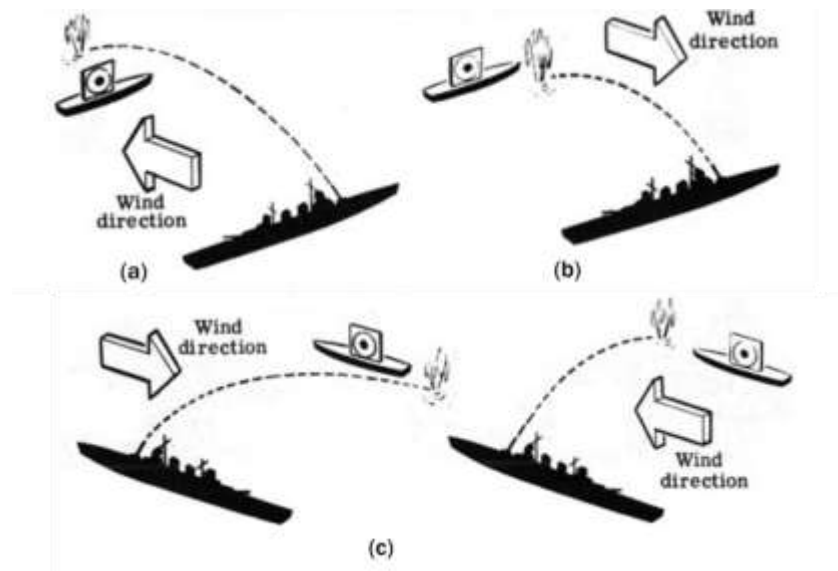


Figure 4. Effect of wind direction on the projectile trajectory (Bureau Of Naval Personnel, 1953).

In addition to the factors mentioned regarding the ballistic aspects above, what characterizes naval warfare is ammunition logistics. Without ammunition, the warship cannot take offensive action, which means that the warship's basic function has been lost. Strategy and tactics provide the pattern for conducting military operations, while logistics provide the means (Eceles, 1959). The other factor besides the ballistic factors where guidance for the weapons so as to increase the hit probability in naval warfare.

4.3 Shooting target

Not only ballistic factors that may affect the hit probability, but also the conditions of the firing ship as well the target, which include:

- Target distance. By knowing the ability of the ammunition to be used to shoot the target, the maximum distance and effective distance in shooting will be obtained. The Coriolis effect of the earth's rotation will also affect the hit probability towards the target.
- Target movement. In naval warfare where the warship is the target of fire, the targeted ship can move freely, either moving closer or away, crossing left or right, at different speeds or while stopping. All target moves will have their own level of difficulty. The target's diagonal movement (oblique target) also affects the shooting of the target. Such movement has a unique problem. If the target moves diagonally, either moving closer or away, even though the target is moving at a constant speed and in the same direction, the target seems to be slowing down.

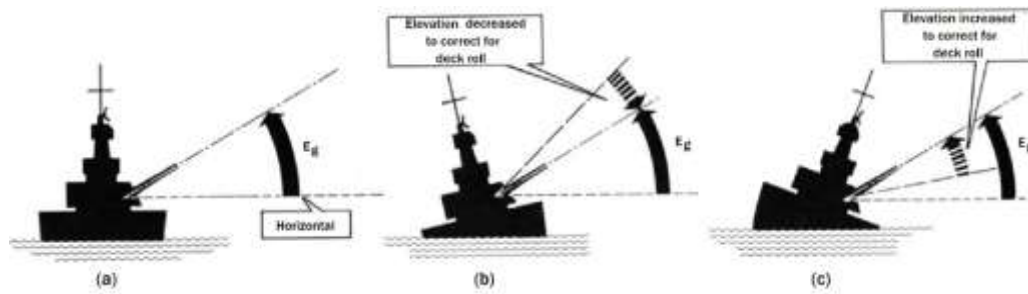


Figure 5. The effect of the rolling motion of the ship due to sea waves on the angle of shooting (Bureau Of Naval Personnel, 1953)

- Waves of sea water (sea state) will affect the angle of shooting and the position of the shooting target (figure 5). Several ship movements due to the influence of waves include heaving, pitching, rolling, swaying, surging and yawing, which have an effect on hit probability.
- Limited exposure/spread of targets, warships with transverse hulls (figure 6), so that part of the ship from the bow to the stern is visible. Of course it will be easier to become a target of fire than ships that are only visible from the stern or bow side.
- The ability to avoid shooting. Warships may have anti-missile defenses, but sometimes there is a lack in the ability of personnel to be able to control the ship which is not supported by the smooth ship's motion when carrying out evasion from an attack. Thus, the ship movement needs to be considered in terms of personnel capabilities and the capabilities of the ship itself. For example, a ship that has one thruster will be more difficult to maneuver in terms of carrying out evasion from attacks.



Figure 6. Target area of the hull (Bureau Of Naval Personnel, 1953).

4.4 Shooter

In naval warfare, humans are equipment operators, and of course they must have certain conditions in order to be able to operate the armament. Not only the number of crew members that must be met, but also the ability of each armament personnel. The quality of human resources is generally measured by the level of



education, competence, and expertise possessed, so that the readiness of personnel needs to be considered as a determining factor. There are various systems and equipment subsystems inside the warship also that are interrelated with one another, so that appropriate communication lines within the ship are required. During naval warfare, which require precise timing analysis, as well as command lines that are integrated with the communication system, it is necessary to consider that the communication system on the warship ensures that there is no delay in information or wrong commands.

4.5 Environment

Land warfare and naval warfare have several differences, including human involvement in combat, equipment and technology used, the environment of the combat area, and so on. In naval battles, there will be many factors to consider. Naval warfare with environmental influences are dominated by (3) weather, time of warfare (day/night) and sea water conditions. In sea water condition, waves or wave height (sea state) originate from the wind that moves over the sea surface, and is influenced by the gravitational force of the moon and sun. This sea state will affect the movement of the ship from both the defensive and offensive sides, so that it will affect the tracking process when determining the target. The wind will also affect the movement of the ship and the glide of the projectile when the projectile is in the air. The time of the warfare, whether day or night has different levels of difficulty. When warfare occurs at night, the level of visibility will decrease, so the tracking process will also be affected. During the day where the air temperature is generally higher than at night, there will be differences in air density and humidity. Such condition will greatly affect the state of the smokeless powder when fired and affect the projectile's glide when it reaches the target. Projectile trajectory/glide will be affected by altitude and temperature according to the level/layer of the earth's atmosphere through the atmospheric pressure as (3) in the following formula (U.S. Standard Atmosphere, 1976):

$$p = p_i \left[\frac{T_i}{T_i + \lambda_i(h - h_i)} \right]^{\frac{g_o}{R\lambda_i}}$$

For condition where $\lambda = 0$ and $T = T_i = \text{constant}$, the isothermal state applies as shown in the following formula:

$$p = p_i \exp \left[\frac{g_o}{RT_i} (h - h_i) \right] \quad (4)$$

Information

- p = Atmospheric pressure
- p_i = Atmospheric pressure at the height of layer i .
- λ_i = Change in temperature with altitude (Laps rate) on layer i (K/km).
- T_i = Standard temperature on layer i (K).
- h = Altitude (km).
- h_i = Altitude on layer i (km).
- g_o = Earth's gravity at altitude 0 above sea level. (9.8067 m/sec²)
- R = Universal gas constant (8.31432 J/mole·K).

Meanwhile, relative humidity can be calculated using formulas (5) and (6) below, so that the relationship between air density, air temperature and humidity can be seen in the following graphic (7)

$$\rho_{humid} = \frac{Pd.M_d + Pv.M_v}{R.T} \quad (5)$$

$$RH = P_v/P_{sat} \quad (6)$$

Information:

ρ_{humid} = Air density of moist air (kg/m³)

Pd = Partial air pressure (Pa)

Pv = Water vapor pressure (Pa)

M_d = Molar mass of dry air (0.0289652 kg/mol)

M_v = Molar mass of water vapor (0.018016 kg/mol)

R = Universal gas constant (8.31446 J/(K · mol))

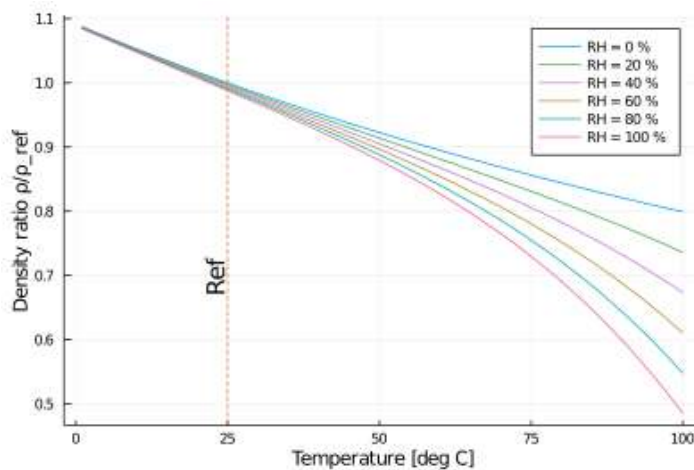


Figure 7. Graph of the effect of air on temperature, pressure and humidity

In rainy warfare conditions with a limited visibility, the target tracking process will also be difficult. Rainy condition will also lead to an increase in the level of humidity and a decrease in environmental temperature.

STUDY METHODS

In this study, the authors collected the influential factors and compiled a Direct Acyclic Graph model based on expert opinions, literature sources, and compiled the model using the GeNie Academic Version software. In echelon 1, the factors that affect the hit probability, namely the fire control system, ammunition, shooting personnel, shooting targets and environmental factors, were obtained from expert opinions or interviews.



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