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Optimizing Maritime Security Decisions: Integrating Regret Theory, Expected Value, and Bayesian Probability for Risk Assessment

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Abstract:

Purpose: *Maritime freight transport operates in a multidimensional environment characterized by risks and/or threats that affect the entire supply chain, but also all components that make up the shipping industry (ports, floating platforms, etc.). For these reasons, optimization in decision-making in the process of implementing strategic and operational procedures for maritime security, is imperative to achieve high standards of it. The paper aims to approach this issue by applying quantitative methods of decision analysis, tools that can provide added value in the production/provision of maritime safety services.*
Design/Methodology/Approach: *The quantitative methods used under conditions of risk and uncertainty refer to: a) the theory of Regret Theory, which essentially highlights the opportunity cost in choosing a decision under conditions of threats and risks faced by international maritime transportation , b) the Expected Value Theory and c) using Bayes' theorem, a revision of the initial probabilities to a posteriori probabilities is made regarding the occurrence of maritime risks and threats.*
Findings: *The analysis on the one hand highlights the best decision chosen to deal with threats and risks such as piracy at sea, terrorist attack, armed robbery and crew kidnapping and on the other hand highlights the value of perfect information in order for decision-makers to subsequently develop the appropriate strategy for dealing with risks and or threats affecting maritime security, so that then, at operational and tactical level, the best possible results can be obtained.*
Practical implementation: *This work contributes to the international scientific literature in the application of quantitative methods in decision making, in the formulation of strategies and implementation of operations ensuring safe maritime transport conditions.*

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Originality/value: *This work is an original approach to decision-making in the process of strategic and operational tactics by competent bodies in order to achieve the best possible results in dealing with threats and risks at sea, with given resources and other constraints.*

Keywords: *Maritime Security, Decision Making , Regret Theory, Expected Value, Bayesean Theory, Risk Assessment*

JEL codes: *C11, C44, F59, R40.*

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1. Introduction

Maritime security and decision-making are critical aspects of global security, involving the protection of maritime interests, national security, trade, and environmental conservation. It is noted that maritime security, due to its nature, operates in a multidimensional environment characterized by risks and / or threats that affect international maritime trade and therefore the entire logistics supply chain, but also the crews of ships and generally all components that make up the shipping industry (ports, floating platforms etc.).

For the above-mentioned reasons, decision-making in the process of implementing maritime security strategies is an imperative task to achieve high standards of this. This paper approaches this issue by applying quantitative methods of decision analysis, tools that can provide added value to the production/supply of maritime security services.

These quantitative tools under risk circumstances refer to: a) Regret theory, which in essence is finding the opportunity cost in choosing a decision under conditions of threats and risks faced by international maritime trade, b) Expected Value theory and c) by using the Bayes Theorem, a revision of initial probabilities to a posteriori probabilities occurring.

Furthermore, the analysis gives on one hand the optimum decision that is chosen under the States of nature concerning threats and risks as Sea piracy, Terrorist Attack, Armed

Robbery and Crew Kidnapped and on the other hand it highlights the value of perfect information.

So, the following presentation attempts to clarify the above – mentioned points. First, we review the basic elements with attention focused on maritime security and risk. Second, we review the decision-making context to understand the rationale for implementing maritime security procedures. Third, we provide a numerical example to illustrate the important points concerning Regret theory, Expected Value theory and Bayes theorem to be revised from a priori probabilities to a posteriori ones.

The work in question contributes to the international scientific literature as far as the application of quantitative methods in decision-making in maritime security procedures and operations is concerned.

2. Literature Review- Conceptual Approaches

2.1 Maritime Security

Discussions of maritime security frequently do so by pointing to 'threats' that prevail in the maritime domain. They refer to threats such as maritime inter-state disputes, maritime terrorism, piracy, trafficking of narcotics, people and illicit goods, arms proliferation, illegal fishing, environmental crimes, or maritime accidents and disasters. The argument is then that maritime security should be defined as the absence of these threats[i]. (Klein, 2011; Kraska and Pedrozo, 2013; Roach, 2004). Also, King (2005)[ii] has pointed out that in the aftermath of 9/11 the wider international community has focused upon the need to strengthen security and prevent terrorism. Numerous measures have been introduced to this goal, many of them address the security of transportation in general and shipping in particular. This paper draws attention to the more significant of these measures and the circumstances surrounding their implementation.

Brooks and Button (2006), refer that "*…. Security, poses particular problems because, unlike safety where there is no conscious effort to cause harm, there is an inevitable gaming problem with potential perpetrators continually vying to circumvent security regimes. Added to this, security involves uncertainty that, unlike risk, has no real probability associated with it. These features necessitate a public as well as a private sector response. To develop public policy in these circumstances there is a need to tailor actions to the nature of the maritime market. A difficulty in doing this is that there is no single market; rather there are several overlapping markets. An added problem is that there is no consensus on the underlying structure of most of these markets. Their work fills some of the resultant voids by examining the extent to which actors in various market situations have internal incentives to ensure security and how they would react to external incentives such as regulations*"[iii].

According to Bueger (2015)[iv],maritime security is one of the latest "buzzwords" of international relations. Major actors in maritime policy, ocean governance and international security have in the past decade started to include maritime security in their mandate or reframed their work in such terms. In 2014 the United Kingdom, the European Union[v] as well as the African Union (AU) have launched ambitious maritime security strategies.

2.2 The Notion of Risk

It is understood that the implementation of maritime security procedures takes place in order to minimize or even neutralize threats and risks and uncertainties that can cause damage to the operation of the shipping industry as a whole. Kaplan and Garrick (1981) provide a quantitative definition of risk based on the idea of a "set of triples". Specifically, risk is the set of triplets: Risk = $\{s_i, p_i, x_i\}$, i=1, 2,..N., where $\mathbf{s_i}$ is scenario identification, p_i is the probability of that scenario and $\mathbf{x_i}$ is the consequence or evaluation measure of that scenario, i.e., the measure of damage[vi]. Kaplan and Garrick define risk as the answers to three questions:

1. What can go wrong?
2. How likely is it going wrong?
3. If it does go wrong, what are the consequences?

However, Wall (2011)[vii], proposes a fourth question additional to the three questions of Kaplan and Garrick, underling that a concise quantitative meaning of the Risk requires such an extension. Wall points out that: "While *knowledge of Y (Y is the outcome of concern) and P_Y (probability of Y occurrence) is absolutely essential, risk cannot be assessed without knowledge of the decision maker's preference over the probable Y. We need to know how the decision maker values to the probable Y. Without preferences the decision maker doesn't care what happens – there is NO risk. Therefore, we ask a fourth question with reference to $P_{Y:}$ "How do you feel about it? How do you feel about the likely Y?"*[3]

Additionally to the authors Kaplan and Garrick, the definition of the risk is extended to include uncertainty and completeness and by using the Bayes' Theorem, is achieved the description of this connection and also the definition is used to be discussed the

[3]*Wall underlines that this question asks the decision maker to state preferences with respect to the likely Y. What outcomes do you most prefer to avoid? What outcomes do you most prefer to experience? The answer is the decision maker's payoff function, sometimes called the value, υ (Y). This function is NOT a utility function [see the extensive review in Schoemaker (1982) : " The Expected Utility Model : Its Variants, Purposes, Evidence and Limitations", Journal of Economic Literature, Vol. 20, pp. 529-563]. It is a prospect function as described in Kahneman and Tversky (1979), "Prospect Theory: An Analysis of Decision under Risk", Econometrica, Vol. 47, pp 263-291. The authors had introduced this theory as a descriptive theory, namely as a theory that refers how decisions are made in fact (and not how should be made) under uncertainty circumstances.*

notions of “relative risk”, “relativity of risk” and “acceptability of risk”.[viii] It’s interesting the fact that the above mentioned authors draw a distinction between the ideas of risk and hazard.

Thus, hazard exists as a source of danger and risk includes the likelihood of conversion of that source into actual delivery or loss, injury, or some form of damage[ix] and they express the above-mentioned idea symbolically in the form of an equation as follows: *risk = hazard/ safeguards.*[4] [x]

Rosa (1998; 2003) defines risk as an event where something of human value is at stake and where the outcome is uncertain[xi], while Renn (2005) defines the risk as an uncertain consequence of an event or an activity with respect to something that human value is at stake[xii].

Aven (2007) suggests the following definition of risk: “*By risk we understand the two -dimensional combinations of (i) events A and the consequences of these events C, and (ii) the associated uncertainties U (will A occurs and what value will C take”.* Furthermore, the author refers to this definition as (C, U) risk definition[xiii]. The same author Aven (2011) points out that Risk is an important concept in a number of scientific fields, yet there is no consensus on how it is to be defined and interpreted.

According to Avenn and Renn (2009), risk refers to uncertainty about and severity of the events and consequences or outcomes of any activity with respect to something that human value. The Risk Management Vocabulary provides a definition: Risk is a combination of the probability and scope of the consequences[xiv]. Campell (2005)[xv] underlines that risk equals expected damage, while Wilson and Crouch (1982)[xvi] consider that risk equals the product of probability and severity.

The estimation of a specific risk factor is done by calibration of both the probability and degree of damages as follows[xvii]:

Likelihood of Risk’s Occurence		*Damage Rating*	
Certain Risk	4	Fatal	4
High Possible	3	High Severe	3
Possible	2	Severe	2
Impossimple	1	Slight	1

Then the following Table is created:

[4] *The heading “safeguards” is the idea of simple awareness. That is awareness of risk reduces risk.*

Probabilities/ Damages	*Low*			*High*
	1	2	3	4
High 4				X risk max.
3				
2			X	
Low 1				

The highest degree of risk is 16, since it comes from the product of 4 (high probability) × 4 (fatal damage) = 16. If, for example, the damage is characterized as highly severe, i.e. with a degree of damage of 3 and its possible outcome, i.e. with a degree of 2, then the risk factor is 6 (3X2). So, 16/6 = 2.66 and calculated as a percentage is 100/2.66 = 37.6%.

Concluding this section, the essential importance of intelligence/information in the implementation of maritime security procedures is highlighted and this fact can be expressed through the formula[xviii]:

$$V = T * SM / SS$$

where V: Vulnerability, T: Threat, SM: Security Measures, SS: Sense of Security. It's pointed out that SS is created, on the one hand, by the understanding of information and its operational utilization, thus reducing both uncertainty and risk[5], and on the other hand, by the continuous training and retraining of the competent personnel. Thus, the higher the SS, the lower the quotient is, i.e. the result becomes smaller and therefore the degree of vulnerability to maritime targets is reduced.

The issue of handling sensitive security information and security-related communications is discussed in detail in the Directive of Section 9, Part A of the ISPS Code (International Ship Port Facility Security Code), considering the guidance provided in Part B of the Code (13.1.11)[xix].

Consequently, the risk is a multidimensional issue and cannot be addressed directly without previous investigation into objective, contexts, hazards, vulnerability, resilience and interested parties.[xx]

2.3 Decision-Making in Maritime Security

Decision-making in maritime security is a complex and critical process that involves assessing risks, managing resources, and coordinating with various stakeholders to protect maritime interests. It encompasses both strategic and operational decisions,

[5] *Uncertainty creates an environment called "decision making under risk" (Wall ,K., D., 2011).*

often under conditions of uncertainty and time pressure. Below are the key elements of decision-making in maritime security[xxi]:

- *Risk Assessment and Management[xxii]:*

- Threat Identification: The first step in decision-making is identifying potential threats, such as piracy, terrorism, smuggling, illegal fishing, and environmental hazards. Understanding these threats allows for targeted responses.
- Risk Analysis: Decision-makers must analyze the likelihood and impact of identified threats. Tools like risk matrices, statistical models, and scenarios analysis help assess vulnerabilities[6].
- Mitigation Strategies: Based on the risk assessment, decision-makers must decide on appropriate mitigation strategies, such as increased patrols, deployment of security forces, or the implementation of stricter regulatory measures.
- International Maritime Organization has adopted the FSA[xxiii] (Formal Safety Assessment) that is a structured and systematic methodology, aimed at enhancing maritime safety, including protection of life, health, the marine environment and property, by using risk analysis and cost benefit assessment. FSA can be used as a tool to help in the evaluation of new regulations for maritime safety[7] and protection of the marine environment or in making a comparison between existing and possibly improved regulations, with a view to achieving a balance between the various technical and operational issues, including the human element, and between maritime safety or protection of the marine environment and costs. FSA consists of five steps:

1. identification of hazards/risks (a list of all relevant accident scenarios with potential causes and outcomes).
2. assessment of risks (evaluation of risk factors);
3. risk control options (devising regulatory measures to control and reduce the identified risks);
4. cost benefit assessment (determining cost effectiveness of each risk control option); and
5. recommendations for decision-making (information about the hazards, their associated risks and the cost effectiveness of alternative risk control options is provided).

- *Coordination and Communication:*

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[6]*Analytical Hierarchical Process (AHP) combined with SWOT analysis could be a methodological tool.*

[7]*IMO refers the term safety. It involves a range of measures and regulations designed to prevent accidents and ensure safe operations at sea. One of the most important treaties is the International Convention for the Safety of Life at Sea (SOLAS), which sets safety standards for the construction, equipment, and operation of ships*. However, the FSA conditions apply for maritime security issues as well.

- Interagency Collaboration: Maritime security often requires coordination among different government agencies (e.g., coast guards, navies, customs), international organizations (e.g., International Maritime Organization), and private sector entities (e.g., shipping companies, port authorities). Effective communication channels are crucial for real-time information sharing and coordinated responses.
- International Cooperation: Given the global nature of maritime trade and security, decision-making frequently involves cross-border cooperation. International agreements, such as the United Nations Convention on the Law of the Sea (UNCLOS), provide frameworks for joint actions against maritime threats.

- *Strategic Decision-Making:*

- Long-Term Planning: Strategic decisions in maritime security involve long-term planning to ensure the safety of maritime routes and assets. This includes investments in infrastructure, technology, and personnel training.
- Policy Formulation: Government bodies and international organizations create policies that regulate maritime security practices. Decision-makers must balance security with the free flow of trade and the rights of nations and private entities.
- Military and Diplomatic Considerations: In cases of territorial disputes or regional conflicts, decision-makers must weigh military responses against diplomatic efforts to maintain stability in maritime zones.

- *Operational Decision-Making:*

- Real-Time Responses: Operational decisions involve immediate actions during incidents like pirate attacks, oil spills, or natural disasters. Quick and effective decision-making is critical to minimize damage and ensure the safety of vessels, crews, and marine environments.
- Use of Technology: Decision-makers rely on advanced technologies, including surveillance systems, satellite data, drones, and AI-driven analytics, to monitor maritime zones and make informed operational decisions.
- Resource Allocation: Deciding how to allocate resources, such as ships, aircraft, and personnel, is essential to maintaining a robust security presence while managing costs.

- *Legal and Ethical Considerations:*

- Adherence to International Laws: Decisions must comply with international maritime laws, including the protection of human rights, environmental regulations, and the legal rights of sovereign states.
- Ethical Decision-Making: Ethical considerations, such as the use of force, the treatment of detained individuals, and the impact of security measures on local communities, are critical in maintaining legitimacy and trust.

- *Scenario Planning and Simulations:*

- Preparedness Exercises: Decision-makers often use scenario planning and simulations to prepare for various security threats. These exercises help test the effectiveness of response strategies and improve decision-making capabilities.
- Crisis Management: In the event of an incident, crisis management teams must quickly assess the situation, make decisions under pressure, and coordinate responses across multiple agencies and jurisdictions.

- *Continuous Learning and Adaptation:*

- Post-Incident Analysis: After a security incident, decision-makers conduct thorough reviews to understand what went right or wrong. This analysis informs future decisions and helps improve protocols.
- Adaptive Strategies: As new threats emerge, decision-makers must continuously adapt strategies and policies to address evolving security challenges.

3. Regret Theory -Minimax Regret (Savage Criterion) and Maritime Security

3.1 Theoretical Approach

The theory of regret states that decision-making includes the desire of the decision maker to avoid unpleasant emotions because of a decision that turns out to be wrong. In other words, it is a criterion by which the decision maker avoids complete optimism or complete pessimism and is therefore interested in minimizing the degree of regret by not implementing the most favorable situations possible for a decision. [xxiv]When the outcome of a choice between alternative decisions taken under conditions of uncertainty and/or risk becomes known, the decision-maker will compare the outcome of that decision with the outcome that would have occurred if another alternative decision had been taken.

Thus, this comparison inevitably leads to emotions, either regret, if the other alternative decision that was ultimately not chosen, would have led to a better outcome than the one that resulted from the one finally taken, or satisfaction since the decision finally taken led to a better outcome than the alternative if it had been taken and which was ultimately not taken[xxv]. In other words, there is a possibility, if the result is not the best, that some regret may occur. This regret can be measured by the difference between the two results.

The basic assumption of the theory of regret lies in the fact that it is expressed as an ascending function R_{ij} of the difference between the degree of outcome that has taken place and the maximum profit-benefit from making another alternative decision-choice. The regret function is a curve with a concave shape with respect to this difference.

This is how the degree of regret R_{ij} is initially calculated, as follows[xxvi] [4]:

$$R_{ij}= \max V(X_{ij}) - V(X_{ij}) \quad (1)$$

where: R_{ij} is the tender for the decision D_i and the state S_j,, max$V(\Theta_{ij})$ is the maximum possible benefit/gain for the state S_j and $V(\Theta_{ij})$ is the profit/benefit from the decision D_i and the state S_j.[8]. Next, we determine the maximum degree of repentance R_i^+ for each alternative D_i decision as below:

$$R_i^+= \max R_{ij} \quad (2)$$

and chosen as the best decision D_i is that decision D_i giving the minimum of the maximum degrees of tender, for which the relationship applies:

$$\min R_i^+= \min\max R_{ij} \quad (3)$$

This criterion applies in a similar way to minimisation issues. So in this case the degree of Regret, Rij is calculated according to the relation:

$$R_{ij}= V(X_{ij}) - \min V(X_{ij}) \quad (4)$$

3.2 Implementation in Maritime Security procedure

Numerical Example:

The Structure of the problem:

a. We consider the following conditions state of nature Sj that constitute threats and risks for the unhindered operation of maritime freight transport, with the respective probabilities of occurrence of these threats and risk in a concrete sea region e.g. Southeast Asia:
   S_1: Sea Piracy, with an occurrence probability of 45% (p_1)
   S_2: Terrorist attack, with a probability of occurrence of 25% (p_2)
   S_3: Armed Robbery, with a 25% probability of occurrence (p_3)
   S_4: Kidnaped Crew, with a 5% probability of occurrence (p_4)

b. We also consider the following alternative decisions D_i, one of which should be taken by the decisions maker who is involved in Maritime Security issues, considering from one hand the above-mentioned states of nature (threats and risks) related to the perspective occurrence probabilities and on the other hand the benefits or /and loses data (for example in monetary units) illustrated in a payoff matrix (*Table 1*):

[8]*In other words, to find the degree of regret Rij, in each column of the table of results, we subtract each element from the maximum element of the column.*

D_1: Deployment of armed security personnel on board ship.
D_2: Physical barriers[9].and Safe muster points and/or citadels.[10]
D_3: Watch keeping and enhanced vigilance.
D_4: Naval Forces escorting.

***Table 1**. Payoff matrix*

Alternative Decisions	*States of Nature* Sea Piracy S_1 p_1: 45%	Terrorist Attack S_2 p_2: 25%	Armed Robbery S_3 p_3: 25%	Kidnaped Crew S_4 p_4: 5%
D_1: Deployment of armed security personnel on board ship.	70	120	150	-30
D_2: Physical barriers and Safe muster points and/or citadels	-30	140	190	70
D_3: Watch keeping and enhanced vigilance	-80	70	250	100
D_4: Naval Forces escorting	90	280	-50	130

***Source:** Own study.*

***Table 2.** The profit/benefit or loses from the decision D_i and the state S_j*

Alternative Decisions	*States of Nature* Sea Piracy S_1 p_1: 45%	Terrorist Attack S_2 p_2: 25%	Armed Robbery S_3 p_3: 25%	Kidnaped Crew S_4 p_4: 5%
D_1: Deployment of armed security personnel on board ship.	70 (0.45) = 31.5	120 (0.25) =30	150 (0.25) =37.5	-30(0.05) = -1.5
D_2: Physical barriers and Safe muster	-30(0.45) =-13.5	140(0.25) =35	190(0.25) =47.5	70(0.05) =3.5

[9]Physical barriers are intended to make it as difficult as possible for attackers to gain access to ships by increasing the difficulty of the climb for those trying to illegally board. When planning the placement of barriers special consideration should be given to ships with sunken poop decks.
[10]A safe muster point is a designated area chosen to provide maximum physical protection to the crew and will be identified during the planning process. A citadel is a designated area where, in the event of imminent boarding, all crew may seek protection. A citadel is designed and constructed to resist forced entry. The use of a citadel cannot guarantee a military or law enforcement response.

points and/or citadels				
D_3: Watch keeping and enhanced vigilance	-80(0.45) = -36	70(0.25) = 17.5	250 (0.25) =62.5	100 (0.05) =5
D_4: Naval Forces escorting	90 (0.45) = 40.5	280 (0.25) = 70	-50 (0.25) = -12.5	130 (0.05) = 6.5

Source: *Own study.*

Table 3. *Savage criterion results due to profits/benefits score*

Alternative Decisions	*States of Nature* Sea Piracy S_1 p_1: 45%	Terrorist Attack S_2 p_2: 25%	Armed Robbery S_3 p_3: 25%	Kidnaped Crew S_4 p_4: 5%	R_i^+
D_1	40.5- 31.5= 9	70-30= 40	62.5-37.5 = 25	6.5- (-1.5) = 8	40: D^*
D_2	40.5- (-13.5) = 54	70-35 = 35	62.5-47.5 = 15	6.5-3.5= 3	54
D_3	40.5- (-36) = 76.5	70- 17.5 = 52.5	62.5- 62.5= 0	6.5-5= 1.5	76,5
D_4	40.5 -40,5 =0	70 – 70 = 0	62.5-(-12.5)= 75	6.5-6.5 =0	75

Source: *Own study.*

Table 3 shows that the best decision is $D_1 = D^*$, i.e. the adoption of Deployment of armed security personnel on board ship, since this gives the minimum of maximum degrees of regret. Especially in the first step and given the states of nature, we can determine the maximum possible benefit/gain which are 40.5, 70, 62.5 and 6.5. Using the formula (1), each element of the payoff matrix derives the perspective degree of regret. Then for each alternative decision, the maximum degree of regret Ri+ is chosen according to formula (2) and finally using the formula (3) the optimum decision is $D_1 = D^*$ which is being chosen.

Table 4. *Savage criterion results due to loses score*

Alternative Decisions	*States of Nature* Sea Piracy S_1 p_1: 45%	Terrorist Attack S_2 p_2: 25%	Armed Robbery S_3 p_3: 25%	Kidnaped Crew S_4 p_4: 5%	R_i^+
D_1	31.5- (-13.5) = 45	30-17.5 = 12.5	37.5- (-12.5) = 50	-1.5 – (-1.5) = 0	50: D^*
D_2	-13.5- (-13.5) = 0	35- 17.5 = 17.5	47.5 – (-12.5) = 60	3.5- (-1.5) = 5	60

D_3	-36-(-13.5) = -22.5	17.5-17.5= 0	62.5- (-12.5) = 75	5- (-1.5) = 6.5	75
D_4	40.5- (-13.5) = 54	70- 17.5 = 52.5	-12.5- (-12.5) = 0	6.5 – (-1.5) = 8	54

Source: *Own study.*

The above-mentioned *Table 4* shows the results from minimax regret criterion, considering the data of payoff matrix (*Table 1*) as cost elements. Especially in the first step and given the states of nature, we can determine the minimum possible loss/cost which are -13.5, 17.5, -12.5, -1.5. Using the (4) formula, each element of the payoff matrix derives the perspective degree of regret. Then for each alternative decision, the maximum degree of regret Ri+ is selected according to formula (2) and finally using formula (3) the best decision is $D_1 = D^*$ which is being chosen, namely: Deployment of armed security personnel on board ship. This decision gives the minimum of maximum degrees of regret.

4. Value of Perfect Information and Effectiveness in the Implementation of Maritime Security Procedures

Using the criterion of expected value and after calculations according to formula

$$E(V_i) = =\sum_{j=1}^{m} p_j V(X_{ij}) \quad (5)$$

the conclusion is that the optimum decision between the four alternatives is $D_4=D^*$, i.e Naval Forces escorting with a score of 104.5 monetary units (Table 4.1). This is the expected value without perfect information, and which is determined based on a priori probabilities.

Table 5. *Results through Expected Value Criterion*

Alternative Decisions	*States of Nature* Sea Piracy S_1 (a priori probabilities) p_1: 45%	Terrorist Attack S_2 p_2: 25%	Armed Robbery S_3 p_3: 25%	Kidnaped Crew S_4 p_4: 5%	*Expected Value* $E(V_i) = =\sum_{j=1}^{m} p_j V(X_{ij})$
D_1: Deployment of armed security personnel on board ship.	70 (0.45) = 31.5	120 (0.25) =30	150 (0.25) =37.5	-30(0.05) = -1.5	67.5
D_2: Physical barriers and Safe muster points	-30(0.45) =-13.5	140(0.25) =35	190(0.25) =47.5	70(0.05) =3.5	72.5

and/or citadels					
D_3: Watch keeping and enhanced vigilance	-80(0.45) = -36	70(0.25) = 17.5	250 (0.25) =62.5	100 (0.05) =5	49
D_4: Naval Forces escorting	90 (0.45) = 40.5	280 (0.25) = 70	-50 (0.25) = -12.5	130 (0.05) = 6.5	104.5 EV max $D_4=D^*$

Source: *Own study.*

The concept of expected value calculated is that if this D_4 decision were repeated consistently e.g. every year (period set by the maritime security executive competent personnel of a maritime company, as the period within which security parameters and costs are reviewed and updated), then in the long run the average benefit would be 104.5 monetary units. This means profit/ benefit would accrue if we added up the financial results over a long period of time during which sometimes there would be a loss of 12.5 monetary units and other gains of 40.5, 70 and 6.5 monetary units.
If it is assumed that the competent intelligence services dealing with threats and risks in shipping, know exactly which form of threat will take place (state of nature), then and according to the data in *Table 1*, if the S_1 situation occurs, the decision D_4 that gives the greatest benefit equal to 90 monetary units will be chosen. If S_2 occurs, decision D_4 will be chosen that gives the greatest benefit equal to 280 monetary units, while if S_3 occurs, decision D_3 that gives the greatest benefit equal to 250 monetary units will be chosen. Finally, if the S_4 situation occurs, the D_4 decision that gives the greatest benefit equal to 130 monetary units will be chosen.

Therefore, the Expected Value of Perfect Information (EVPI) is:
$$90\ (0.45) + 280\ (0.25) + 250\ (0.25) + 130\ (0.05) = 40.5+ 70+ 62.5 +6.5 = 179.5 \quad (5)$$

So, the value of perfect information is EVPI – EVmax= 179.5- 104.5 = 75. (6)

This means that if a particular shipping company or law enforcement agency ensuring maritime security conditions could obtain additional information about states of nature (Sea Piracy, Terrorist Attack, Armed Robbery, Kidnaped Crew), it will consider spending less than 75 units of money to obtain this proper information.

Regarding the calculation of the Efficiency Ratio, it is first pointed out that the state of perfect information is an ideal case, but it is a marginal case and is not always achieved. In any case, however, the result of a decision-making process in the shipping industry and international organizations to address threats and risks in maritime transport is improved by leveraging more information.

The effectiveness of the information available in decision-making is measured using the efficiency ratio which is defined as the quotient of EVmax to EVPI i.e.:

EVmax/EVPI (7)

In this case, the coefficient of effectiveness of decision-making based on state of nature data is 104.5/ 179.5 = 0.5821 or 58.21%

The above coefficient shows the limits for improvement in a decision-making process. A value close to 100% indicates that there is a small limit for improvement, and therefore the cost of seeking additional information to improve the quality of the decision may exceed the potential benefit.

Conversely, a low efficiency ratio suggests that there are significant limits for improving decision quality that can be achieved by obtaining additional information (Ipsilantis P., 2015)[xxvii]. Therefore, the specific value of the efficiency ratio, 58.21%, indicates that there is a margin to improve the quality of decision by obtaining more and more qualitative information.

5. Sensitivity Analysis

After the solution of the problem and the selection of the best decision, sensivity analysis is applied to investigate whether the optimal choice changes. In this case, it is examined whether changes in a priori probabilities affect or alter the proposed decision.

Thus, in section (a) of Table 6 the a priori probabilities change to 30%, 20%, 30% and 20% for States of Nature. Similarly, in section (b) of the same table, the a priori probabilities vary to 25%, 30%, 17% and 28% for S_1, S_2, S_3 and S_4, states of nature respectively. It is found that in both cases of changing the a priori probabilities, the optimal decision is again D_4 (Naval Forces escorting). This does not mean, however, that it is always the case that the optimal decision remains the same after the initial probabilities change.

6. Revised a Priori Probabilities to a Posteriori Probabilities by Bayesian Theorem

The calculation of a posteriori probabilities, bearing in mind the initial probabilities of the outcome of the situations, i.e.:

S1: Sea Piracy, with an occurrence probability of 45% (p1)
S2: Terrorist attack, with a probability of occurrence of 25% (p2)
S3: Armed Robbery, with a 25% probability of occurrence (p3)
S4: Kidnaped Crew, with a 5% probability of occurrence (p4),

requires competent Maritime Security Intelligence Services to design scenarios e.g. A, B, C as well as determine conditional probabilities/bound probabilities for each possible state of nature. This can be done by using Bayes' theorem

Table 6. *Sensitivity Analysis*

		S1	S3	S3	S4	Expected Value
		SENSITIVITY ANALYSIS				
	D1	70	120	150	-30	84
	D2	-30	140	190	70	90
(a)	D3	-80	70	250	100	85
	D4*	90	280	-50	130	94
	Probabilities	30%	20%	30%	20%	

		S1	S3	S3	S4	Expected Value
	D1	70	120	150	-30	55
(b)	D2	-30	140	190	70	86,4
	D3	-80	70	250	100	123,5
	D4*	90	280	-50	130	134,4
	Probabilities	25%	30%	17%	28%	

Therefore, the above-mentioned can be expressed as follows:

- *Scenario A: Threats and Risks reducing*
- *Scenario B: Unchanged Threats and Risks Level*
- *Scenario C: Escalation of Illegal and Hostile's Actions*

The conditional probabilities for the four states of nature, P(A/Sj), P(B/Sj) and P(C/Sj), j=1,2,3,4, are illustrated in the below Table 6.1. Based on these, the following a posteriori probabilities P(Sj/A), P(Sj/B) and P(Sj/C), by using Bayes Theorem,[11] are calculated by following four steps. The first Step is presented in *Table 7*:

Table 7. *The conditional probabilities for the four states of nature, P(A/Sj), P(B/Sj) and P(C/Sj)*

1st Step

Scenarios	S_1	S_2	S_3	S_4
A	$P(A/S_1)$ 60%	$P(A/S_2)$ 30%	$P(A/S_3)$ 10%	$P(A/S_4)$ 7%
B	$P(B/S_1)$ 30%	$P(B/S_2)$ 40%	$P(B/S_3)$ 20%	$P(B/S_4)$ 85%
C	$P(C/S_1)$ 10%	$P(C/S_2)$ 30%	$P(C/S_3)$ 70%	$P(C/S_4)$ 8%
a priori probabilities	45%	25%	25%	5%

Table 8.

2nd Step

Scenarios	S_1	S_2	S_3	S_4
A	0.27	0.075	0.025	0.0035
B	0.135	0.1	0.05	0.0425
C	0.045	0.075	0.175	0.004
a priori probabilities	45%	25%	25%	5%

In Step 2, the elements in *Table 8* are obtained if each element in the column of *Table 7* is multiplied by the corresponding a priori probability. For example, 60% X 45% = 0.27, 40%X25%= 0.1, 70X25%= 0.175, 85X5%= 0.0425, etc.

In Step 3, *Table 8,* by adding the elements of each row, the probabilities of each scenario's occurrence are found. For example:

0.27+0.075+0.025+0.0035= 0.3735: **37.35% P(A),**
0.135+0.1+0.05+0.0425=0.3275: **32.75% P(B),**
0.045+0.075+0.175+0.004=0.299: **29.9% P(C)**

Table 8.

3rd Step

Scenarios	S_1	S_2	S_3	S_4	P(A) P(B) P(C)
A	0.27	0.075	0.025	0.0035	37.35%

[11] *For example, for Scenario A:* $P(Sj/A) = \frac{P(Sj \cap A)}{P(A)} = \frac{P(A/Sj)P(Sj)}{\sum_{j=1}^{m} P(A/Sj)P(Sj)}$

B	0.135	0.1	0.05	0.0425	32.75%
C	0.045	0.075	0.175	0.004	29.9%
a priori probabilities	45%	25%	25%	5%	

Table 9.

4th Step

Scenarios	S_1	S_2	S_3	S_4	P(A) P(B) P(C)
	p_1^* a posteriori probabilities	p_2^*	p_3^*	p_4^*	
A	0.72289 72.28%	0.2008 20.08%	0.06693 6.69%	0.00937 0.937%	37.35%
B	0.4122 41.22%	0.3053 30.53%	0.1526 15.26%	0.1297 12.97%	32.75%
C	0.15050 15.05%	0.25083 25.08%	0.5852 58.52%	0.01337 1.33%	29.9%
a priori probabilities	45%	25%	25%	5%	

In Step 4 (*Table 9*), the a posteriori probabilities (p_1^*,p_2^*,p_3^*,p_4^***),** are calculated, dividing the elements of each row by the corresponding total probability of each row, i.e.:

1st line: 0.27/0.3735=0.72289:72.28%,
0.075/0.3735=0.2008:20.08%,
0.025/0.3735=0.06693:6.69%,
0.0035/0.3735=0.00937:0.937% and so on for 2nd and 3rd rows.

Table 10 *Expected Values by a posteriori probabilities*

(A) <u>SCENARIO A</u>

EXPECTED VALUES

S3

S1 S2 S4

A POSTERIORI PROPABILITIES

p_1^* p_2^* p_3^* p_4^*

72.28% 20.08% 6.69% 0.937% EV

D1

70 120 150 -30 84,4459

D2

-30 140 190 70 19,7949

D3 -80 70 250 100 -26,106

D4 90 280 -50 130 119,149 D^* optimum

(B) SCENARIO B

EXPECTED VALUES

A POSTERIORI PROPABILITIES

	S1	S2	S3	S4	
	p_1^*	p_2^*	p_3^*	p_4^*	
	41.22%	30.53%	15.26%	12.97%	EV
D1	70	120	150	-30	84,489
D2	-30	140	190	70	68,449
D3	-80	70	250	100	39,515
D4	90	280	-50	130	131,813 D^* optimum

(C) SCENARIO C

EXPECTED VALUES

A POSTERIORI PROPABILITIES

	S1	S2	S3	S4	
	p_1^*	p_2^*	p_3^*	p_4^*	
	15.05%	25.08%	58.52%	1.33%	EV
D1	70	120	150	-30	128,014
D2	-30	140	190	70	142,725
D3	-80	70	250	100	153,155 D^* optimum
D4	90	280	-50	130	56,255

Then, using the calculated a priori probabilities, the expected values are calculated for each scenario separately, as shown in *Table 10*. The calculation shows that for scenario A, the optimal decision is D_4, as in the case of a priori probabilities. The same applies to scenario B, while for scenario C, the optimal decision is D_3.

Using the data in *Table 11*, which summarizes the results from all the previous analysis, it is possible to calculate the Long Run Expected Value* according to the following formula (8). This calculation is useful if decision-makers consider that the occurrence of this maritime security issue is repetitive. In other words, the total probability of realization of all three scenarios is holistically taken into account, as well as the optimum expect values for each scenario separately, which have been calculated based on a posteriori probabilities.

Table 11

Scenarios A, B, C Total Probabilities A, B, C	a posteriori probabilities	OPTIMUM EXPECTED VALUES

						FOR EACH SCENARIO
A 37.35%	72.28%	20.08%	6.69%	0.937%		119,149
B 32.75%	41.22%	30.53%	15.26%	12.97%		131,813
C 29.9%	15.05%	25.08%	58.52%	1.33%		153,155
a priori probabilities	45%	25%	25%	5%		104.5 EV max

LREV* (long Run Expected Value) * =
= 0.3735*119,49+0.3275*131,813+0.299*153,155=133.6 (8)

A value of 133.6 suggests that using scenarios that certainly require the collection and use of further intelligence significantly improved the Expected value almost by 28%., which was initially 104.5. Thus, calculating the Long Run Expected Benefit, formula (9), which is 29.1, it follows that if shipping companies or competent services and institutions engaged in ensuring high standards of maritime security, they decide to obtain more intelligence, then they will be willing to spend up to 29.1 units of money.

LREB (Long Run Expected Benefit): LREV*- EVmax=133.6 – 104.5= 29.1 (9)

Finally calculating the Efficiency Ratio by formula (10), taking into account the holistic consideration concerning scenarios A,B,C, it is concluded that the efficiency of obtaining more information has a satisfactory output, but also there are some improvements possibilities aiming at goals achievements.

Efficiency Ratio: LREV*/EVPI[12]: 133.6/ 179.5=0.74428 = 74.43% (10)

7. Concluding Remarks

Maritime security and decision-making are interconnected processes vital for ensuring the security and efficiency of maritime operations. This involves protecting sea-based activities from a range of threats, including piracy, terrorism, smuggling, illegal fishing, and environmental disasters. Decision-making in this context is complex due to the dynamic and vast nature of the maritime domain, requiring coordination across

[12] *See formula (5)*

multiple stakeholders, including governments, international organizations, and private entities.

Decision-making in maritime security requires a comprehensive approach that integrates various disciplines and actors. The Theory of Decision-Making offers tools that can be used for stakeholders and decision-makers to implement them in order to ensure high standards of maritime security and therefore the uninterrupted operation of maritime freight flows. This paper used some of the quantitative decision-making methods in maritime security processes, highlighting their usefulness in this field of the maritime industry at a practical level.

In addition to the conclusions that emerge from the use of the theory of regret, which in essence is finding the opportunity cost in choosing a decision under conditions of threats and risks faced by international maritime trade, with the analysis through decisions in risk conditions using probabilities, the value of perfect information in the whole process is highlighted precisely measured. Even more, the revision of a priori probabilities by using the Bayes Theorem enables further holistic investigation of the issue, since on the one hand various scenarios are designed under the conditions of threats and risks, and on the other hand having in mind these scenarios and by exploiting a posteriori probabilities the long-term expected value can be calculated, the long-term expected benefit as well as the efficiency ratio. We consider that these measurements create further added value in the whole process of production/supply of the maritime security product.

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