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Risk assessment of the Istanbul Strait by using Ports and Waterways Safety Assessment (PAWSA) method

Limanlar ve suyolları emniyet değerlendirmesi (LVSED) yöntemini kullanarak İstanbul Boğazı risk değerlendirmesi

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Abstract

Ports and Waterways Safety Assessment (PAWSA) is a comprehensive and sophisticated AHP-based Delphi method in which risk analysis and risk management are handled simultaneously. PAWSA has primarily developed for maritime domain, and there is a need to extend such risk analyses to the other fields. First aim of this study is to introduce PAWSA process and to add its methodology to existing academic literature. Significance of PAWSA is exhibited and innovative suggestions for further developments are given in this study. Secondly, PAWSA method is employed for Istanbul Strait to obtain the levels of navigational risks and to measure effectiveness of counter actions. It analyses risks of navigation situations, the conditions of vessels, traffic intensity and waterway characteristics. Ultimately, it is aimed to minimize the marine incidents and increase navigational safety by introducing new counter actions. The Istanbul Strait is one of the most difficult-to-navigate and the narrowest international waterway in the world. The Istanbul Strait has a dense traffic because of its geographical and strategic location. According to annual statistics, traffic density is two times more than the Suez Canal and three times more than the Panama Canal. Besides the heavy local traffic, the Strait is used by approximately 50.000 international vessels with a total gross tonnage of 600 million. 15 million people live in Istanbul and 300.000 people are transported daily from Asia to Europe using Istanbul Strait. A comprehensive risk analysis by a convenient method for the Istanbul Strait is therefore required for safe maritime transportation.

Keywords: Risk analysis, Istanbul strait, Risk management, Delphi method, PAWSA

Öz

Limanlar ve suyolları emniyet değerlendirmesi (LVSED), risk analizinin ve yönetiminin eş zamanlı olarak yapıldığı AHP tabanlı kapsamlı ve karmaşık bir Delfi yöntemdir. Öncelikle denizcilik alanı için geliştirilen LVSED'in, diğer alanlardaki risk analizi uygulamalarına da genişletilmesi gerekmektedir. Bu çalışmanın ilk amacı, LVSED sürecini tanıtmak ve metodolojisini akademik yazına kazandırmaktır. Bu çalışmada LVSED'in önemi gösterilmiş ve ileride geliştirilmesi için inovatif öneriler verilmiştir. İkinci olarak seyir risklerini elde etmek ve alınan tedbirlerin verimliliğini ölçmek için PAWSA metodu İstanbul Boğazı'na uygulanmıştır. Seyir durumları, gemi kondisyonları, trafik yoğunluğu ve suyolu karakteristiği risklerini analiz etmektedir. Son olarak, deniz kazalarını minimize etmek ve yeni karşı önlemler ortaya koyarak seyir emniyetini artırmak amaçlanmaktadır. İstanbul Boğazı, dünyada seyri en zorlarından biri ve dünyanın en dar kanalıdır. Stratejik ve coğrafik lokasyonundan dolayı İstanbul Boğazı yoğun bir trafiğe sahiptir. Yıllık istatistiklere göre, trafik yoğunluğu Süveyş Kanalı'ndan iki kat, Panama Kanalı'ndan üç kat daha fazladır. Yoğun yerel trafiğin yanında, Boğaz toplam tonajı 600 milyon olan yaklaşık olarak 50.000 uluslararası gemi tarafından kullanılmaktadır. Istanbul'da 15 milyon insan yaşamakta ve hergün 300.000 kişi İstanbul Boğazını kullanarak Asya'dan Avrupa'ya seyehat etmektedir. Dolayısıyla İstanbul Boğazı deniz taşımacılığı için güvenelir bir metot ile kapsamlı bir risk analizinin yapılması gerekmektedir.

Anahtar kelimeler: Risk analizi, İstanbul boğazı, Risk yönetimi, Delfi yöntemi, LVSED

1 Introduction

United Nations International Maritime Organization (IMO) Sub-Committee on Safety of Navigation NAV 52/17/2 describes the PAWSA method as follows: "The PAWSA risk assessment process is a disciplined approach to identify major waterway safety hazards, estimate risk levels, evaluate potential mitigation measures, and set the stage for implementation of selected measures to reduce risk" [1]. PAWSA was convened by National Dialogue Group (NDM) in 1998 under the support of the Marine Board of the National Research Council [2]-[4]. The United States Coast Guard (USCG) made PAWSA method permanent for its safety management tool kit [5],[6]. It was conducted for over 44 ports and waterways in the United States (Figure 1) [6].

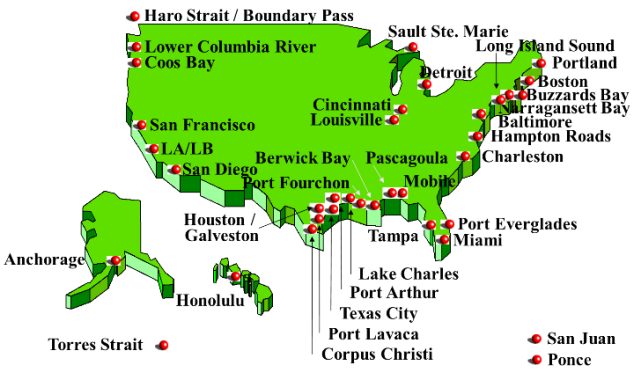

Figure 1: Previous PAWSA applications [6].

PAWSA is an extensive risk method in which risk analysis and risk management are dealt with concurrently. Figure 2 shows the PAWSA process. It has a multi-dimensional assessment process thanks to plurality, anonymity, group decision making, cross control, feedback mechanism and consensus-as we will explain below.

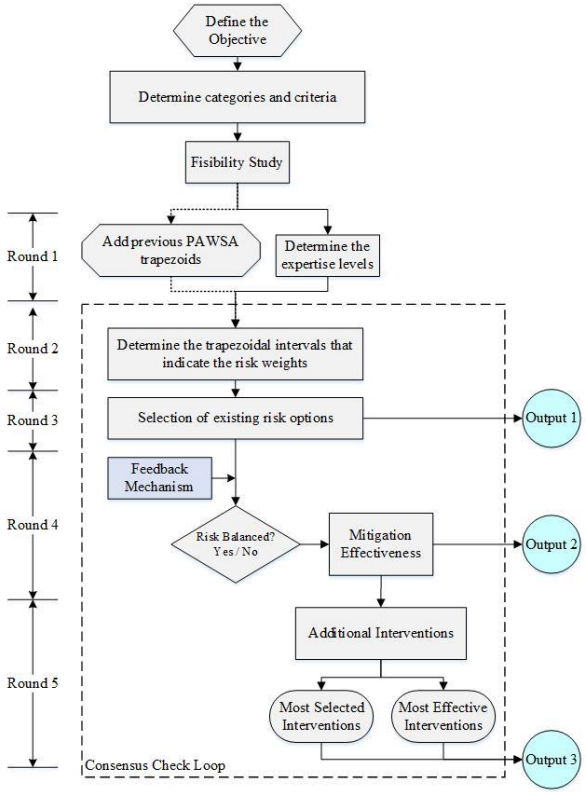

Figure 2: PAWSA procedure.

This sophisticated AHP based Delphi method can potentially be applied to other domains considering the above-mentioned merits [7]. However, in the literature there is only a limited number of application studies [8],[9], and no study gives the mathematical methodology underlying PAWSA. The authors wish to introduce its methodology and extend the applications of risk analyses to the other disciplines.

To the best of our knowledge, this is the first study that introduces the mathematical methodology of PAWSA method in the literature. The mathematical methodology of PAWSA will be presented. It is believed that future risk studies can be enriched by utilizing the outcomes of this study. To achieve this, PAWSA method is conducted for risk assessment of the Istanbul Strait. It is found that Istanbul Strait is highly risky in terms of the increasing volume of traffic, traffic mix and its unique characteristics.

The rest of this paper is organized as follows: Section 2 provides a literature review for the previous works of Delphi-based risk analysis and risk assessment of Istanbul Strait. Section 3 presents the PAWSA mathematical methodology in detail. Section 4 formally structures the content of risk criteria and their sub-criteria and demonstrate the successful PAWSA approach at Istanbul Strait. Section 5 provides the results of analysis, and provides a discussion on the method's advantages and strengths. Summary, conclusions, and directions for future research are presented in Section 6.

2 Literature review

2.1 Literature review on PAWSA methodology

Risk analysis has been studied extensively by several methods. However, many risk analysis methods are not supported by approved standards and guidelines [10]. PAWSA is a well-established method that includes consensus, feedback mechanism, scientific support, assessment, management, communication and operational aspects of the field.

In the literature, there exist several studies on diverse aspects of risk analysis [11]-[13]. Markmann et al. studied a Delphi-based risk analysis of identifying and assessing future challenges for supply chain security in a multi-stakeholder environment [14]. In their study, an application of the Delphi method is conducted for risk analysis in the subject of technology forecasting. Another application discusses effectiveness of community-based environmental protection policy by using a Delphi-fuzzy method [15]. Herrmann considers IT-related risk probabilities [16]. Moreover, another Delphi application is conducted by Karin et al. in a step-wise manner [17]. Flood damage analysis is done by Elmer by following the multi-step Delphi method [18]. Regarding construction projects in Yemen, Issa proposes a risk allocation model by the Delphi method [19]. Omran et al. presents a real-time Delphi method for food and water security [20]. Recently, the same method is developed for an ontology based real-time Delphi approach [21]. Clemen focuses on the combination of diverse experts' probability distributions in risk analysis [22]. Besides, there exist a vast amount reports of PAWSA as a risk analysis method at the USCG website [6]. All the above studies either explain the organization of the Delphi procedure, statistical approaches to the study or provide an extension for Delphi method.

Keceli and Arslan [23] compares the failure analysis/risk assessment methods considering several factors such as comprehensiveness, user friendliness, quantification considerations, closeness to human thinking style, reasonableness, depth of analysis, etc. When comparing all criteria given in their study, PAWSA method has several advantages over other given methods (Table 1). For instance, (1) PAWSA method does not only deal with the risk analysis but also risk management, (2) crisp, fuzzy or grey values can be used in lieu of probabilities, (3) it is open to further development.

In this paper, the authors present a mathematical structure for PAWSA in order to contribute the literature and introduce this method to academia. The objective is to apply the methodology not only to ports and waterways but also to all other fields. In addition, the authors consider how this method can be further developed. One of the subjects of this study, the AHP-based risk analysis, differs considerably from that of other studies as this work explicitly incorporates Delphi rationale and also accounts for its applicability for other disciplines.

2.2 Literature review on Istanbul strait

There exist various studies regarding maritime risk analysis for Istanbul Strait in order to identify and reduce hazards and to keep risks under permissible level. These studies are conducted by several methods based on different risk factors and data sources. Some researchers use simulation models [24]-[27], whereas some utilize statistics-based methods [28]-[31].

Table 1: Comparison of PAWSA and other methods.

	Does it provide quantitative results?	Does it explore reasonable causes?	Does it pinpoint specific root causes?	Does it focus on solution generation?	Does it generate corrective/preventive action?	Does it use a standard form?	Does it determine priorities for the reasons and strategies?	Does it reflect the working of human mind in evaluation results?	Does it identify shareholders responsible in implementing corrective actions?	Does it have an easy to grasp and applicable structure?	Does it address soft issues?	Does it adopt atomistic approach?	Does it have a theoritical tool?	Does it obtain a systematic process?	Does it resolve ill structured problem?	Is it easy to understand?
PAWSA	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
5 WHYs	-	+	+	+	-	-	-	-	-	+	-	+	+	+	-	+
CED	-	+	-	+	-	-	-	-	-	+	+	+	+	+	-	+
FTA	+	+	+	+	-	-	-	-	-	+	-	+	+	+	-	+
ETA	+	+	-	+	-	-	-	-	-	+	-	+	+	+	-	+
PARETO	+	+	+	+	-	-	-	-	-	+	-	+	+	+	-	+
STEP	-	+	+	+	-	-	-	-	-	+	-	+	+	+	-	+
FMEA	+	+	+	+	-	-	-	-	-	+	-	+	+	+	-	+
STORYTELLING	-	+	-	-	-	-	-	-	-	+	-	-	-	-	-	+
CHANGE	-	+	+	+	-	-	-	-	-	+	+	+	+	+	-	+
BARRIER ANALYSIS	-	+	+	+	-	-	-	-	-	+	-	+	+	+	-	+
BOW-TIE	-	+	+	+	-	-	-	-	-	+	+	+	+	+	-	+
K-T	-	+	+	-	-	-	-	-	-	+	-	+	+	+	-	+
CRT	-	+	+	+	-	-	-	-	-	+	-	+	+	+	-	+
ARCA	-	+	+	+	-	-	-	-	-	+	-	+	+	+	-	+
ID	+	+	+	+	-	-	-	-	-	+	-	+	+	+	-	+
CAT-WOE	-	+	+	-	-	-	-	-	-	+	+	+	+	+	+	+
TRIZ	-	+	+	+	-	-	-	-	-	+	-	+	+	+	+	+
RPR	+	+	+	+	-	-	-	-	-	+	-	+	+	+	-	+
BAYESIAN INFERENCE	+	+	-	+	-	-	-	-	-	-	-	+	+	+	-	-
MORT	-	+	-	+	-	-	-	-	-	+	+	+	+	+	-	+

Simulation models are studied for analysing the risks by simulating the impact of various factors in marine traffic. Sarioz et al. (1999) carried out a survey on investigating the maneuvering performance of large tankers in the Istanbul Strait by using a real-time simulation [24]. This study considered realistic environmental conditions and pointed out safely limitation on the number of vessels navigating within the traffic separation lane. Also, Otay and Ozkan (2003) developed a stochastic prediction to simulate random transit maritime traffic through the Istanbul Strait [25]. In their study, the model computes probability distributions of vessel positions within the Strait and introduces a risk map which indicates expected number of accidents in different parts of the Strait. Moreover, by using a ship handling simulator with environmental stress model, navigational risks from local traffic were investigated by Yurtoren and Aydogdu (2009) and, the type of hazards exposed by the local traffic and the most dangerous spots in the Istanbul Strait were identified [26]-[28]. Kose et al. (2003) examined the effects of probable increase in marine traffic due to new oil pipelines via simulation. In the result of this study, it was claimed that new pipelines of Russia will increase the traffic at the Turkish Straits significantly [26],[29].

On the other hand, statistical calculations were conducted to predict probable risks in different cases. Uluscu et al. (2009) developed a mathematical risk model based on historical data of various situations, various accidents, the related consequences and. In their study, it was indicated that schedule changes to induce more vessel passage will increase risks to extreme levels, whereas scheduling policy based on reducing risks may cause increases in average vessel waiting times [26],[30]. Besides, another survey was conducted by Özbaş et al. (2013) to analyse the influence of several factors on safety risks and accordingly the impact of each factor in terms of vessel passages and waiting times for both entrances of the Istanbul Strait [26],[31]. They suggest risk mitigation procedures that could reduce both risk and waiting times. Also, Akten (2004) analysed some factors which cause shipping casualties in the Istanbul Strait by using statistical data [26],[32]. This study showed that the major casualty types were grounding and stranding. Or and Kahraman (2002) conducted a survey in the Strait to elicit probable factors contributing to accidents by using Bayesian analysis and simulation modelling [26],[33],[34]. They indicated that there were remarkable increases in the number of accidents for higher transit traffic rates, denser local traffic conditions, higher percentage of longer ships and/or adverse weather conditions [35].

Taking all risk analyses on Istanbul Strait into account, there has been various research on the Istanbul Strait. Regrettably, one of the most prestigious methods, PAWSA, has not yet been applied for this region.

3 Methodology

PAWSA is an open-source formal risk-assessment tool for waterways and ports posted at the website of United States Coast Guard, Navigation Center [6]. PAWSA methodology is an AHP-based risk analysis procedure based on the Delphi technique. Risk assessment and risk management are realized simultaneously by analyzing qualitative and quantitative expressions of the experts. Numerical inputs of the expert responses are entered into the PAWSA software during the several rounds. After each round, the aggregated results are re-assessed by the experts. In PAWSA, there are five logical rounds. Consensus alerts provide an opportunity for experts to review the results, discuss and revise the answers. In the first round, an "expertise level" is computed for each category and the weight of these expertise levels impacts the expert judgments for all subsequent rounds. The second round deals with a measurement scale of the risk factors. Pairwise comparisons are conducted for each risk-factor rating scale. Baseline risk levels for each intended waterway are determined on the developed scale by the experts in the third round. The fourth and fifth round are concerned with risk management.

The purpose of the fourth round is twofold: Firstly, effectiveness of the existing risk mitigation strategies are discussed. Second, the experts are asked if the current risk mitigation strategies are sufficient to balance the various risk levels. The fifth round enables experts to offer additional interventions by considering the results of the fourth round. In this round, the most effective intervention categories are identified for each risk factor.

There are six risk categories in PAWSA and each category includes four risk criteria. These six categories are:

1. The *Vessel Conditions* risk category indicates all risks arising from the quality of the vessels and their personnel, machine/steering/equipment failures, and deficiency of equipment. It unveils register flags, educational sufficiency of personnel and their age, inspection records, survey and maintenance records, flag/language impediments and lack of knowledge about local area,
2. The *Traffic Conditions* risk category covers all risks which are related to the density, diversity, congestion and confusion of traffic in the risky areas,
3. The *Navigational Conditions* risk category includes all risks which can affect safety of navigation and maneuverability. These risks depend typically on meteorological, oceanographic and environmental conditions,
4. *The category of waterway conditions* represents all natural risks arising from the characteristics and properties of the risk area,
5. *Immediate Consequences* is the immediate impacts of a waterway and vessel casualties to the people, environment and the transportation systems,
6. *Subsequent Consequences* is the subsequent effects of waterway and vessel casualty to society, environment and the transportation systems.

The diagram (Figure 3) shows the final form of the six risk categories and corresponding risk factors in the Waterway Risk Model.

The theory underlying the PAWSA process is the Delphi method which converts expert opinions into quantified results during several rounds. Conventional PAWSA has the above mentioned six categories and under each category are four criteria.

3.1 Round 1. expertise level

For each category, expertise levels c are determined by assigning a 1, 2 or 3 rating, Or

$$\forall c \in \{1,2,3\} \tag{1}$$

Define c_k^i as the expertise level of category i by decision maker (DM) k where $k = 1,2,...,15$.

Let λ_k^i represents an expertise weight of category i for DM k as follows:

$$\lambda_k^i = \frac{c_k^i}{\sum_{k=1}^{15} c_k^i} \tag{2}$$

where $i = 1,2,...,6$.

3.2 Round 2. risk factor rating scale

Each risk criteria consist of four options that point out the current risk situation. These options are placed in a hierarchical sequence from the best case to the worst. Three pairwise comparisons are conducted for four consecutive options on a 1-9 scale. Trapezoidal intervals are constructed for each criterion by obtaining weights for the options. Updated trapezoidal intervals are then generated by embedding trapezoidal intervals obtained from previous PAWSA studies to the current study.

In order to calculate trapezoidal intervals in 1-9 scale, the following formulas are applied for each criteria.

The index j indicates the sequence of comparisons between hierarchical options. The metric $a_{j,k}$ represents a selected comparison value on the 1-9 scale between the hierarchical options. Risks are defined as a fuzzy trapezoidal number as shown on the Figure 4, where the risk levels A, B, C, and D for the x^{th} criterion are defined in Equation (3), starting with a risk level of unity for A and ending with the highest risk level of 9 for D.

$$A = 1,$$

$$B = 1 + \frac{\sum_{k=1}^{15} a_{1,k} \cdot \lambda_k^i}{\sum_{j=1}^{3}\sum_{k=1}^{15} a_{j,n} \cdot \lambda_k^i} \cdot 8, \qquad C = B + \frac{\sum_{k=1}^{15} a_{2,k} \cdot \lambda_k^i}{\sum_{j=1}^{3}\sum_{k=1}^{15} a_{j,n} \cdot \lambda_k^i} \cdot 8, \tag{3}$$

$$D = C + \frac{\sum_{k=1}^{15} a_{3,k} \cdot \lambda_k^i}{\sum_{j=1}^{3}\sum_{k=1}^{15} a_{j,n} \cdot \lambda_k^i} \cdot 8 = 9$$

Vessel Conditions	Traffic Conditions	Navigational Conditions	Waterway Conditions	Immediate Consequences	Subsequent Consequences
Deep Draft Vessel Quality	Volume of Commercial Traffic	Winds	Visibility Impediments	Personnel Injuries	Health and Safety
Shallow Draft Vessel Quality	Volume of Small Craft Traffic	Water Movement	Dimensions	Petroleum Discharge	Environmental
Commercial Fishing Vessel Quality	Traffic Mix	Visibility Restrictions	Bottom Type	Hazardous Materials Release	Aquatic Resources
Small Craft Quality	Congestion	Obstructions	Configuration	Mobility	Economic

Figure 3: Risk model for the Istanbul strait.

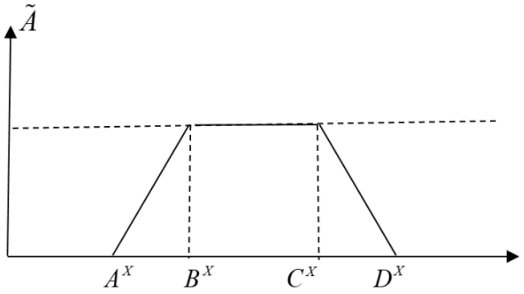

Figure 4: Trapezoidal intervals.

3.3 Round 3. baseline risk level

Notice that the proper option under each criterion is selected by the experts. This illustrates the current risk situation for intended risk area. At the end of this round, numerical values of options are found from the trapezoidal intervals and a risk map is generated for that risk area.

Let y be the sequence of selected risk situation where $y=1,2,3,4$.

$$R^x=\begin{cases}A^x, & if \quad y=1\\ B^x, & if \quad y=2\\ C^x, & if \quad y=3\\ D^x, & if \quad y=4\end{cases} \tag{4}$$

Here, R^X is the updated trapezoidal interval for each criterion. The total baseline risk level is now shown as a composite of the 15 experts that participate in the Delphi procedure:

$$R_T^x=\sum_{k=1}^{15}R_k^x \tag{5}$$

3.4 Round 4. mitigation effectiveness

In this round, the possible lowest risk values on a 1-9 scale are obtained by the assumption of employing current risk mitigation efficiently. In a second step, a cross check is realized by asking whether current risk mitigation circumstances are in fact utilized efficiently. At the end of this round, a result about the sufficiency of the current risk mitigation measures are obtained and assessed.

3.4.1 Step 1

In Equation (6) below, S^x shows that the lowest possible risk level if all existing risk mitigation systems for the x^{th} criteria are used effectively.

Z_k^x represents the risk level reduction if all existing risk mitigation systems for the x^{th} criteria are used effectively based on the evaluation of the k^{th} expert.

$$S^x=\sum_{k=1}^{15}Z_k^x\cdot\lambda_k^i \tag{6}$$

3.4.2 Step 2: risk balanced? yes/no agreement

This step computes whether existing risk mitigation systems provide a "balance" to the risk value.

The answer "Yes" ($\overset{+}{\lambda}{}_k^i$) represents "Balanced".

The answer "No" ($\overset{-}{\lambda}{}_k^i$) represents "Not-balanced".

Accordingly, an "Expertise sum" for all the experts is arrived at for normalization purposes:

$$\sum\overset{+}{\lambda}{}_k^i+\sum\overset{-}{\lambda}{}_k^i=1 \tag{7}$$

3.4.3 Mitigation effectiveness results

For each criterion, the following effectiveness ratings are obtained:

If $S^x>R^x$, or the risk level is below the safest level, we rate the criterion as "Rising", meaning that an improvement is underway;

else if $\sum\overset{+}{\lambda}{}_k^i>0.66$, or that the experts judged that positive steps were taken for safety to meet a threshold, we rate the criterion as "Balanced";

else if $\sum\overset{-}{\lambda}{}_k^i>0.66$, or the experts judged that no positive steps were taken to result in violating a threshold of safety, we rate the criterion as "No";

Otherwise "Maybe" is used to indicate a fuzzy outcome of the evaluation.

3.5 Round 4. mitigation effectiveness

In this round, additional interventions are presented to experts. Experts select the proper interventions which will reduce the current risk level. Then, the effects of the selected interventions over the current risk level are determined at the end of this round.

The expression $x_k^m\lambda_k^i$ symbolizes weighted values of the m^{th} additional interventions as judged by expert *k* for risk category i and criterion *x*.

$\sum\lambda^*$ is the sum of experts whom they agree on employment of additional interventions. Weighted scores are obtained for each of the 9 risk option scales:

$$WS=\sum\frac{x_k^m\lambda_k^i}{\sum\lambda^*} \tag{8}$$

For each criterion *x*, a table of scores are recorded:

WS	Mitigated Risk Level	Intervention Effectiveness
WS_1	S^x	S^x-WS_1
WS_2	S^x	S^x-WS_2
$\vdots$	$\vdots$	$\vdots$
WS_9	S^x	S^x-WS_9

The most effective additional intervention is identified by $\max(S^x-\mathrm{WS})$ for each criteria.

The selected intervention is preferred as if $s(\max(S^x-\mathrm{WS}))>1$ for each criterion *x*. In other words, if the maximum intervention-effectiveness scale exceeds 1

3.5.1 Consensus

Consensus for each rounds is judged by using standard deviation as

$$S = \sqrt{\frac{1}{14}\sum_{k=1}^{15}(y_i - \bar{y})} \quad (9)$$

Where a low S value indicates consensus, and a high S indicates otherwise.

4 Application

In this study, expert judgments are obtained via face to face meetings and online communications. 15 experts are asked for the risk assessment of Istanbul Strait. Distribution of expertise is provided in Table 2.

Table 2: Distribution of expertise.

Risk Category	Top 1/3	Mid 1/3	Lower 1/3
Vessel Conditions	67%	27%	7%
Traffic Conditions	93%	7%	
Navigational Conditions	87%	13%	
Waterway Conditions	80%	20%	
Immediate Consequences	73%	27%	
Subsequent Consequences	53%	47%	
All Categories Average	76%	23%	1%

The experts determined the baseline risk levels of Istanbul Strait as given in Figure 5. On the 1-9 scale, 1.0 represents the low risk which is the desired case, the risk increases accordingly until 9.0 which is the worst case (or the highest risk).

Vessel Conditions	Traffic Conditions	Navigational Conditions	Waterway Conditions	Immediate Consequences	Subsequent Consequences
Deep Draft Vessel Quality	Volume of Commercial Traffic	Winds	Visibility Impediments	Personnel Injuries	Health and Safety
7,3	8,0	4,1	3,2	8,2	7,5
Shallow Draft Vessel Quality	Volume of Small Craft Traffic	Water Movement	Dimensions	Petroleum Discharge	Environmental
5,5	7,3	8,7	7,3	8,8	8,4
Commercial Fishing Vessel Quality	Traffic Mix	Visibility Restrictions	Bottom Type	Hazardous Materials Release	Aquatic Resources
6,5	7,9	4,4	4,2	7,1	5,8
Small Craft Quality	Congestion	Obstructions	Configuration	Mobility	Economic
7,8	6,9	1,5	5,2	8,0	8,7

Figure 5: Risk model for the Istanbul Strait.

The experts consider the effectiveness of the risk mitigations based on all risk factors. Figure 6 expresses baseline risk levels on the left side and risk level considering the existing mitigations. The consensus shows that 18 out of the 24 risk factors are well balanced by existing mitigations. There is no consensus for the remaining 6 risk factors on whether the existing mitigations adequately reduced risks. In other words, the experts agree with a 3/4 consensus.

The experts recommend some actions in order to reduce the risks if needed in the last round. Figure 7 shows the relevant interventions, risk improvements and the consensus on those risk factors. In this Figure, the type of "Intervention" is indicated by way of a strategy that the most of the participants has selected. By default, "Caution" represents there is no consensus on that intervention.

This study analyses (1) current risk levels for pre-defined 24 risk factors, (2) possible mitigated risk levels in case of efficient usage of existing risk mitigation systems and (3) additional interventions and their effects for the Istanbul Strait. The highest risk factors are examined below.

Vessel Conditions	Traffic Conditions	Navigational Conditions	Waterway Conditions	Immediate Consequences	Subsequent Consequences
Deep Draft Vessel Quality	Volume of Commercial Traffic	Winds	Visibility Impediments	Personnel Injuries	Health and Safety
7,3 6,0	8,0 7,3	4,1 4,1	3,2 3,1	8,2 6,4	7,5 6,9
Maybe	Maybe	Balanced	Balanced	Maybe	Maybe
Shallow Draft Vessel Quality	Volume of Small Craft Traffic	Water Movement	Dimensions	Petroleum Discharge	Environmental
5,5 4,8	7,3 5,3	8,7 5,7	7,3 6,6	8,8 7,6	8,4 7,5
Balanced	Maybe	Maybe	Balanced	Maybe	Maybe
Commercial Fishing Vessel Quality	Traffic Mix	Visibility Restrictions	Bottom Type	Hazardous Materials Release	Aquatic Resources
6,5 5,4	7,9 6,0	4,4 4,4	4,2 3,1	7,1 6,8	5,8 5,7
Balanced	Maybe	Balanced	Balanced	Maybe	Balanced
Small Craft Quality	Congestion	Obstructions	Configuration	Mobility	Economic
7,8 6,2	6,9 5,9	1,5 1,5	5,2 4,1	8,0 7,0	8,7 7,3
Maybe	Balanced	Balanced	Balanced	Maybe	Maybe

Figure 6: Mitigation effectiveness.

Vessel Conditions	Traffic Conditions	Navigational Conditions	Waterway Conditions	Immediate Consequences	Subsequent Consequences
Deep Draft Vessel Quality	Volume of Commercial Traffic	Winds	Visibility Impediments	Personnel Injuries	Health and Safety
Rules & Procedures	Enforcement	Balanced	Balanced	Enforcement	Coordination / Planning
2,6	2,1			0,9	1,1
Shallow Draft Vessel Quality	Volume of Small Craft Traffic	Water Movement	Dimensions	Petroleum Discharge	Environmental
Enforcement	Enforcement	Rules & Procedures	Balanced	Coordination / Planning	Coordination / Planning
1,0	0,2	0,5		1,6	1,0
Commercial Fishing Vessel Quality	Traffic Mix	Visibility Restrictions	Bottom Type	Hazardous Materials Release	Aquatic Resources
Balanced	Rules & Procedures	Balanced	Balanced	Coordination / Planning	Balanced
	1,0			1,0	
Small Craft Quality	Congestion	Obstructions	Configuration	Mobility	Economic
Enforcement	Balanced	Balanced	Balanced	Coordination / Planning	Coordination / Planning
1,4				0,9	0,7

Figure 7: Additional interventions.

Systems and technologies efficiently. Although, risk level can be mitigated further to 6.0 thanks to coordination / planning (new politics, technical regulations etc.). However, it is still quite high.

The Istanbul Strait has a unique set of environmental characteristics and a strong water movement. Risk level of water movement is excessively high with 8.7 on the 1-9 scale. Fortunately, experts believe that the risk level of water movement can be reduced to the level of 5.7 by judicious pilotage service. However, getting the pilot in the Istanbul Strait is not compulsory owing to Montreux Convention. Therefore, the awareness of the need for a pilot should be raised. Besides, this study represents that new rules and procedures as an additional intervention can mitigate risk level to as low as 5.2.

Turkish Straits (Canakkale and Istanbul Straits), almost the narrowest and crowded waterways in the world, are the only gates for international transportation for the Black Sea countries. When Istanbul Strait is closed, these countries get economically stranded. This could raise the risk level of economy to 8.7. If existing risk mitigation systems are utilized efficiently, it could be mitigated to 7.3. Going further, experts claim that new coordination/planning can also mitigate the risk

level to as low as 6.6. Moreover, if the Strait closes, the mobility of the Black.

Sea bordering states and local traffic would stumble. This study indicates that the risk level for mobility is 8.0 which is quite high on the 1-9 scale. However, risk level of mobility can be mitigated to 7.0 considering the efficient usage of existing risk mitigation systems. For risk management, this study recommends better coordination/planning with a mitigation impact of 0.9, further reducing the risk level.

The risk level for the criterion of environment is 8.4. Due to fact that the Istanbul Strait is an inland sea, oil pollution is always possible in case of a marine accident. A reduced risk level of 7.5 is attainable by using existing risk mitigation procedures efficiently. The risk level can also be further mitigated to 6.5 via coordination/planning.

The Istanbul Strait sea area is the potential danger for personnel injures because of its environmental characteristics and high population. This study presents a risk level of personnel injures as 8.2 out of 9. By implementing existing risk mitigation procedures efficiently, the risk level might be reduced to 6.4 for the crucial aspect of the Strait. The risk level of personnel injures can be further reduced to 5.5 with enforcements that raise standards of maintenance and inspection, and operates new compulsive navigation procedures and rules.

The risk levels of commercial traffic volume traffic mix and small craft quality are 8.0, 7.9 and 7.8 respectively. These risk levels can be mitigated to 7.3, 6.0 and 6.2. International commercial traffic caused by the deep draft vessels in the Istanbul Strait is the remaining major risk factor and it is urgent to solve these traffic problems. The risk level of deep draft vessel is as high as 7.3. The quality, inspection and maintenance standards of vessels are to be balanced, which are under the control of international rules. This criterion consists of risks of deep draft vessels due to human error. However, most of these vessels are foreign-flagged and the characteristics of the Istanbul Strait are not well-known to these vessels. The lack of knowledge on the Istanbul Strait increases the risk level. Experts recommend using pilotage services to mitigate risk level of deep draft vessel.

In 2003, The Turkish Straits Vessel Traffic Service (TSVTS) is established by the Turkish authorities to increase the safety of navigation, improve the protection of environment and life by utilizing developed technological systems. VTS is a beneficial navigation control system providing recommendations and warnings to vessels which use the Turkish Strait. It arranges the passages of the vessels and gives information about current traffic. However, it is not sufficient only to improve safety of the Istanbul Strait, it is also necessary to introduce new regulations by Turkish authorities. The Montreux Convention hinders Turkish authorities in taking precaution against maritime risks in the Turkish Straits. While high volume of commercial vessel traffic is the main reason for all these risks in the Istanbul Strait, Turkish authorities cannot delimit passages of the vessels. At the same time, it is not compulsory to board a pilot through the Turkish Straits according to the Montreux Convention.

The general risk map exhibits that the Istanbul Strait is an extremely risky sea area. The traffic volume of the Istanbul Strait increases consistently, parallel to development in global transportation. The Istanbul Strait will be riskier in the future considering the increasing total tonnage and number of tankers. It is possible to mitigate possible risks in the Istanbul Strait if only if the Turkish authorities can delimit the vessel passages and mandate pilot usage. In order to provide more safety and avoid environmental pollution, sanction power of Turkish authorities should be increased over the Turkish Straits. The IMO should also support the policies of Turkey authorities on the safety of the Turkish Straits.

PAWSA is a AHP-based risk analysis method that combines consensus, plurality and feedback mechanism. Also, it has cross checks to analyze the brainstorming results after each round in preparation for the next round.

Considering the use of “expertise level” is one of the strongest aspects of the PAWSA process. Expert categorization would make PAWSA even more a reliable procedure. Currently, PAWSA demands experts to assign their own expertise level. It might be possible to engage a moderator who would refer to some pre-defined standards.

As mentioned, pairwise comparison is conducted at the second round. A trapezoidal interval is generated for each criterion. Then, results of previous PAWSA studies are embedded to the current pairwise comparisons by employing their average. These pairwise comparisons are independent of the locations applied, due to the fact that these pairwise comparisons solely depend on the criteria themselves. This makes the PAWSA procedure even more attractive. From our experience, using “crisp” numbers during the pairwise comparison process is quite difficult. We support usage of fuzzy numbers instead of crisp values.

At the third round, current risk situation selected by experts corresponding the numerical expression is derived from the previous trapezoidal interval scale. This systematic procedure provides reliable baseline risk levels on a 1-9 scale based on our experience.

The fourth round provides a multi-dimensional risk assessment to the moderator. First of all, the probable mitigated risk level by using the existing sources is obtained. Secondly, it reveals whether or not existing systems and technologies are effectively utilized. This assessment is significant in terms of risk management. This round forces experts to consider existing risk mitigation sources. The brainstorming supports fifth round and enables more reliable results for additional interventions.

Additional interventions and their impacts on mitigating risk for the selected criteria are determined at the fifth round. The effect of interventions is assessed by comparing with the mitigated risk levels of previous round. Both the most effective and the most selected interventions are considered together. It shows, once again, that PAWSA has a multidimensional perspective.

5 Conclusions

PAWSA is a comprehensive Delphi-based risk assessment method that includes risk analysis and risk management together. Aside from marine and waterways navigation PAWSA has not been applied to other fields so far. This study contributes to academic literature by presenting its mathematical methodology. Moreover, strengths and weaknesses are analyzed and discussed here in the conclusion section below. Very clearly, this study points out that PAWSA is open for new applications in diverse fields as well as improvements and enhancements for further studies.

A very comprehensive research and an accurate method that includes consensus, large majority, consistency, expertise, equality, plurality and feedback mechanism are the requirements of risk analysis for marine accidents. In this study, PAWSA as a comprehensive risks analysis method is conducted. Numerical values of each risk criteria which have effects over the maritime causalities on the Istanbul Strait are obtained. The Istanbul Strait has an increasing importance for the international maritime transportation. This significance makes it as one of the most intensive waterway in the entire world. Outcomes of this study will help authorities as well as academicians to understand minimizing the risks in this region.

While the PAWSA methodology has a track record of success in waterborne navigation, it can be further improved, similar to any other mathematical models. First, the existing AHP framework of the procedure can be tightened up. Instead of using a standard deviation to assess consensus, as shown in Equation (9), the *consistency index* of AHP can be used. This requires tightening up the pairwise comparison procedure currently employed to follow more closely the hierarchical structure of AHP (in regards to the *categories* in the upper level and the *criteria* at the lower level). Following AHP, a ratio/ordinal scale can be employed in lieu of the prevailing reliance on weights under the Delphi instrument in the existing PAWSA. Notice that the iterative procedure of the Delphi method is consistent with the requirement to refine multiple, sequential AHP surveys in order to provide the best consistency indices. Also, the fuzzy metric for evaluation can still be employed. The advantage of leaning more toward AHP (rather than the Delphi) is that there is a structured body of knowledge that has been accumulated on AHP, not the least of which is its formal relationship to *multiattribute utility theory*-a widely disseminated technique for assessing and ranking alternatives.

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