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Evaluation of Tugboat Response Time as an Accident Prevention Measure in the Strait of Istanbul

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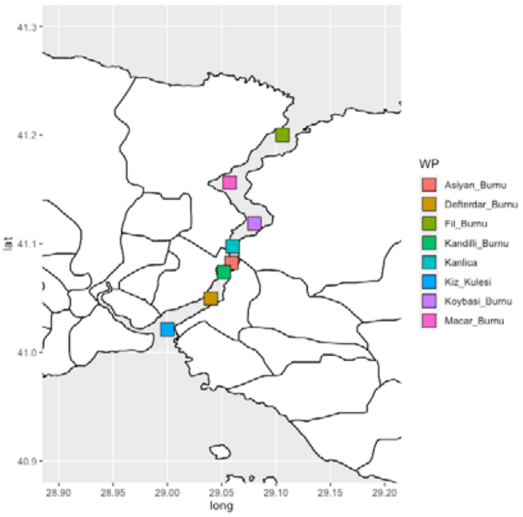
ABSTRACT: The Strait of Istanbul, 17 nautical miles long, is one of the main routes of international maritime trade. Connecting the Black Sea countries with other countries of the world, the Strait is the second busiest waterway in the world in terms of international ship traffic. In addition to busy sea traffic, limited geographical conditions also make it difficult to navigational safety. The Strait of Istanbul is the only chokepoint that stands out with the risk of maritime accidents on the primary routes of world maritime trade. This situation poses a risk for both the transiting ships and the city of Istanbul, which has a dense population around it. Some of the accidents that took place in the recent history have caused worldwide concern due to the environmental pollution they cause. Considering the advantages provided by the developing shipbuilding technology and today load capacity of the ships, a disaster that will occur in a possible accident today will cause much greater destruction than in the past. In this direction, it has become a necessity to examine the accident profile in the strait in order to develop effective accident prevention measures and to strengthen the level of navigational safety in the region. In this study, maritime accidents that occurred in the Strait of Istanbul over a 16-year period were discussed in terms of their types and the response time of tugboats to a possible accident was examined.

1 INTRODUCTION

Maritime accidents have emerged in different ways and their effects were different. The most common types of maritime accidents were collision, allision, contact, capsizing, flooding, foundering, breaking up, grounding, stranding, breakdown of the ship underway, and fire or explosion [1],[8]. Some of these terms are quite simple, for example, grounding and stranding are probably the most common maritime incidents. However, most terms are often used incorrectly. In fact, a ship is aground when she strikes to the sea floor, while a ship is stranded when the ship has been staying for a while. Similarly, flooding means taking on excessive water in one or more of the spaces of a ship such as the engine room, while foundering is fundamental taking on water to the point where the ship becomes unstable and begins to sink or capsize. Another example that causes confusion is collision vs allision and these accident types constitute the two basic variables of this study. These terms are generally used interchangeably, but technically, the collision is the crashing of two ships, while allision is used when a ship crashes to a fixed object, such as a bridge or dock [19]. In other words, the allision is defines an accident in which only one of the objects moves, while the collision defines two moving objects that collide with each other [4]. All these accident types have different dynamics by their nature and they have the potential to be prevented with different intervention options. Literature review has shown that maritime accidents occur most frequently at chokepoints [6]. Maritime chokepoints classified as primary routes that act as bridges between major economies and secondary routes that connect smaller markets. According to this classification, Strait of Malacca, Strait of Istanbul, Hormuz, Bab El-Mandeb, Gibraltar, Panama and Suez channels are the primary chokepoints. Compared to other primary chokepoints, the Strait of Istanbul is the only waterway that stands out with its maritime accident risk. In addition, the Strait of Istanbul is the world's busiest waterway after the Strait of Malacca, with an average of 50,000 ships passing annually [23]. The Strait of Istanbul was chosen as the study area, both because it is the only waterway between the Black Sea countries and other countries of the world, and because it constitutes the riskiest area in terms of navigation on the global maritime transport routes.

The length of the Strait of Istanbul is 17 nautical miles. The curved geomorphology and the resulting geometric constraints force passing ships into wide-angle turns. A ship non stopover passage through the Strait must change course at least 8 times during this route [7]. These turns and route changes to be made during these turns are shown in Figure 1.



Primary Turns

Fil Burnu	13°
Macar Burnu	73°
Koybaşı Burnu	82°
Kanlıca	46°
Aşiyan Burnu	39°
Kandilli Burnu	21°
Deftardar Burnu	36°
Kız Kulesi	51°

Figure 1. Large angular turns in the Strait of Istanbul

The Strait of Istanbul has been the subject of many scientific studies until today due to the difficult navigational conditions and the risk of marine accidents. Effect of ship length as a factor in safe navigation in the Strait of Istanbul has examined using by AHP method. Obtained results have shown that ships over lengths of 151 - 200 m has a risk on navigational safety [11]. An artificial neural network model was created to estimate maritime accidents in the Strait of Istanbul. Study results have indicated that vessels larger than 58.000 GRT caused accidents when they did not receive piloting service [16]. In order to mitigation of risks of the maritime traffic in the Strait of Istanbul comprehensive scenario analysis has been made [20].

It has been pointed out that the factors affecting the safety of navigation in the Strait of Istanbul differ according to the types of accidents [7]. Collision-type accidents were investigated and a maritime traffic modelling based on Automatic Identification System [3]. It has been highlighted that collision and grounding type accidents in the Strait of Istanbul are generally made by general cargo ships and these accidents tend to increase especially at night [26]. Maritime accidents in the Strait of Istanbul have spatially analyzed the using the GIS method. Obtained results have shown that the accidents were concentrated in the waiting areas [21]. It has been investigated the reducing the probability for the collision of ships by changing the passage schedule in Strait of Istanbul [15]. The Strait of Istanbul has been evaluated in terms of ship passages, ship hydrodynamics and blockage effect [5],[25]. Effect of maritime traffic in the Strait on the number of accidents was investigated using regression analysis. The results obtained showed that the number of passing ships had an explanatory power of 51% on the accidents. Within the scope of the study, the accident rate per ship was calculated and the results showed that 76 out of every 10.000 ships passing through were involved in the accident. The results of the study also showed that the measures taken as a result of the accidents and especially the VTS, which became operational in 2003, have a reducing effect on the accidents [12]. Due to one-way planning of traffic with the Marmaray project that started in 2005, it has been observed a noticeable reducing effect on maritime accidents [13]. However, the Vita Spirit accident in 2017 brought forward a well-known vulnerability: in the case of an engine breakdown and rudder failure on the ship while passing through these narrow areas, all the measures taken may remain useless. VTS with all it's services remains ineffective. In Vita Spirit case, there was only 7 minutes between the engine breakdown and ship crashed into house. Options that can be initiated in order to prevent such an accident in these 7 minutes are very limited. At this point, it has been suggested that if there was a patrol tug near the ship and pushed ship directing her back in the channel could be a solution [14]. This solution highlighted to all related parties to place patrol tugs in certain areas in the Strait of İstanbul and monitor the ships passing through very risky areas and take action in the case of any wrong going. For this reason, the need to investigate tugboat response time as an accident prevention measure in narrow channels has arisen and this has been the motivation of this study.

Reducing the risk of accidents for large commercial vessels, both in port berthing and take-off maneuvers and when navigating in restricted waters, requires the help of specialized vessels that are well aware of the region-specific features [17], [10], [22], [9]. These vessels, called escort tugs, are specially designed to produce the rudder and braking force necessary to control the escorted vessel [17], [2]. In the literature, there are various studies on tugboat intervention in terms of navigational safety. When the factors affecting collision type accidents are examined, the importance of the arrival time of the tugboat for emergency response draws attention [29]. Examining the tugboat response time in the range of 15/30/45 minutes for emergency response on the Yangtze River showed that the arrival time of the tugboat was critical due to the limited response time [28]. There is a size limit in terms of navigational safety for ships that can maneuver even in the absence of wind, current and wave in the Strait of Istanbul. Because under unfavorable navigational conditions, it is not possible for ships above certain limits to maintain their position within the traffic lanes [24]. MSRCC records have shown that 32 near-miss events occurred between 2001-2016, which were caused by rudder and engine failures and were prevented by tugboat intervention before the accident occurred. This number also means that about 2 accidents per year can be prevented by tugboats. In this study, the temporal and spatial profile of accident types in the Strait of Istanbul was investigated, and the response time of tugboats to a possible accident was examined. It is thought that the results obtained will form an infrastructure for policy makers to develop accident-specific measures.

2 MATERIALS AND METHOD

The data used in this paper, is gathered by Republic of Turkey Ministry of Transportation and Infrastructure and it contains maritime casualty records between 2001 and 2016. In order to avoid confusion, maritime accidents were categorized according to their own characteristics. In this context, accident types that are the categories of data set has determined as collision, allision, contact, grounding, capsizing, drifting, fire, engine breakdown, listing, person overboard and other. The incidents outside of the main accident types such as flooding, foundering, breaking up, stranding, breakdown of the ship underway, water ingress are mentioned under the heading "Other".

Maritime traffic in the Strait of Istanbul operates on 3 VTS sector areas. These are Kadıköy, Kandilli and Türkeli sector areas, from south to north, respectively, as shown in Figure 2. The study area has been filtered within the VTS sectors in the Strait of Istanbul in order to observe the spatial profile of the accidents in higher resolution and to identify the high-risk points.

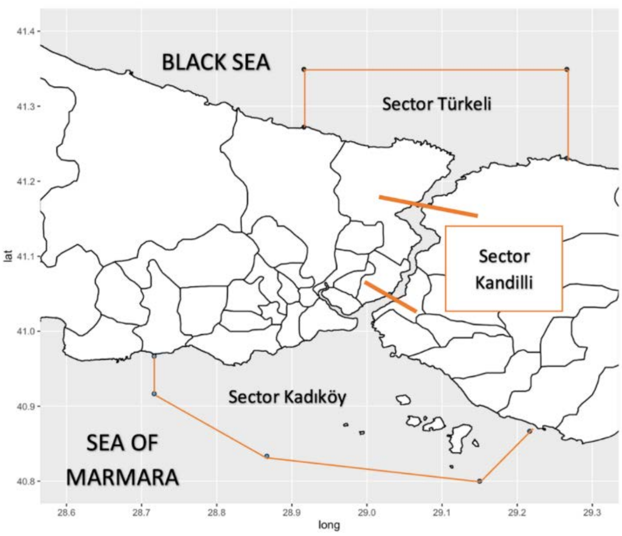


Figure 2. The area and sectors of Istanbul Vessel Traffic Services [27]

In the scope of this study, a data set was created by separating 590 accidents within the VTS sector areas from all the accidents that occurred between 2001 and 2016, and these accidents were classified according to both their types and the sector area in which they occurred. Thus, it has become possible to see the spatial profile of the accidents and it has been revealed which accident type is concentrated in which region. After the creation of the data set, the classification of the accident types and the spatial profile of the accidents, the time-dependent variation of the accident types was investigated. The last part of the study was devoted to the examination of tugboat efficiency as accident preventive measure in the Strait of Istanbul and the tugboat response time was calculated in line with the geometric constraints of the region. The process followed within the scope of the study is shown in the flow chart in Figure 3.

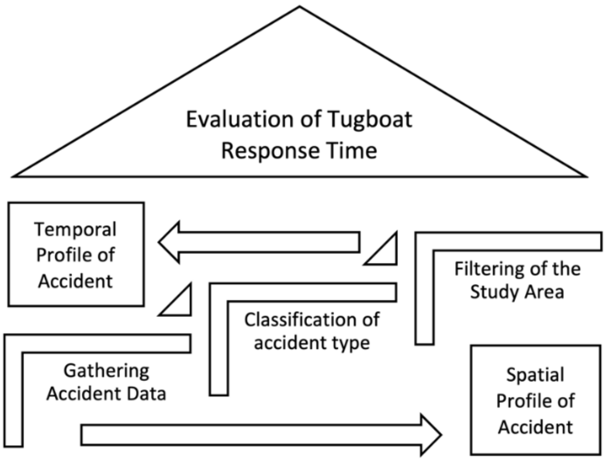


Figure 3. Workflow of the study

3 RESULT AND DISCUSSIONS

The distribution of the accidents that occurred in the Strait of Istanbul for 16 years according to their types is given in Figure 4. As can be clearly seen from the pie chart, the major accident type in the strait is collision. The second type of accident that occurs commonly is grounding. Other accidents that except for the 10 defined accident types, take the 3rd place among the most common accident types that have occurred during the 16 years.

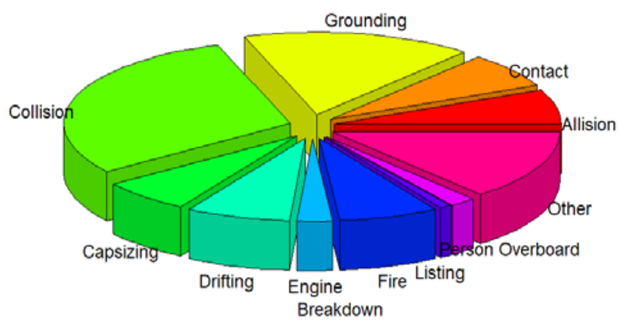


Figure 4. Distribution of accidents by types in the Strait of Istanbul (2001-2016)

This was followed by drifting, fire, contact, allision, capsizing, engine breakdown, person overboard and listing, respectively. When the maritime accidents in the Strait are analyzed according to their types, it is seen that the accidents that can be prevented by tugboat intervention have an important place in the total accidents.

Table 1. Annual percentages by types of marine accidents in the Strait of Istanbul

Years	Collision	Allision	Contact	Grounding	Capsizing	Drifting	Engine Breakdown	Fire	Listing	PoB	Other	Total
2001	0,300	0,000	0,067	0,333	0,100	0,000	0,033	0,033	0,00	0,00	0,133	1
2002	0,161	0,000	0,032	0,226	0,129	0,000	0,000	0,097	0,00	0,00	0,355	1
2003	0,214	0,071	0,000	0,286	0,071	0,000	0,000	0,179	0,04	0,00	0,143	1
2004	0,231	0,077	0,058	0,250	0,154	0,000	0,000	0,077	0,00	0,00	0,154	1
2005	0,255	0,137	0,059	0,137	0,098	0,000	0,000	0,078	0,00	0,00	0,235	1
2006	0,170	0,085	0,191	0,170	0,043	0,000	0,000	0,106	0,00	0,00	0,234	1
2007	0,314	0,057	0,257	0,200	0,029	0,000	0,029	0,029	0,00	0,00	0,086	1
2008	0,381	0,063	0,111	0,175	0,016	0,111	0,032	0,016	0,00	0,00	0,095	1
2009	0,442	0,019	0,096	0,115	0,038	0,058	0,000	0,077	0,00	0,00	0,154	1
2010	0,424	0,015	0,000	0,106	0,061	0,167	0,076	0,030	0,02	0,00	0,106	1
2011	0,400	0,057	0,000	0,086	0,057	0,200	0,029	0,057	0,00	0,06	0,057	1
2012	0,235	0,059	0,000	0,088	0,029	0,265	0,059	0,088	0,00	0,15	0,029	1
2013	0,241	0,207	0,034	0,138	0,000	0,138	0,069	0,138	0,00	0,03	0,000	1
2014	0,133	0,067	0,000	0,000	0,133	0,067	0,000	0,200	0,13	0,13	0,133	1
2015	0,063	0,250	0,000	0,188	0,063	0,125	0,063	0,000	0,06	0,06	0,125	1
2016	0,833	0,000	0,167	0,000	0,000	0,000	0,000	0,000	0,00	0,00	0,000	1

When the percentage of accidents occurring within a year is examined separately for each year, the percentage increase in the annual total of collision and contact type accidents draws attention. Collision type accidents accounted for only 30% of total accidents in 2001, while this rate increased to 83% in 2016. Similarly, while the share of contact type accidents in total accidents was 0.06% in 2001, this rate reached 16% in 2016. A common feature of these two accident types, the frequency of which has increased dramatically, is that both types of accidents are accident types that can be prevented by tugboat intervention. At this point, the individual profile of accident types gains importance. In order to observe the time-dependent change, time series plots were created following the 16-year movement of each accident type. Obtained results are given in Figure 5.

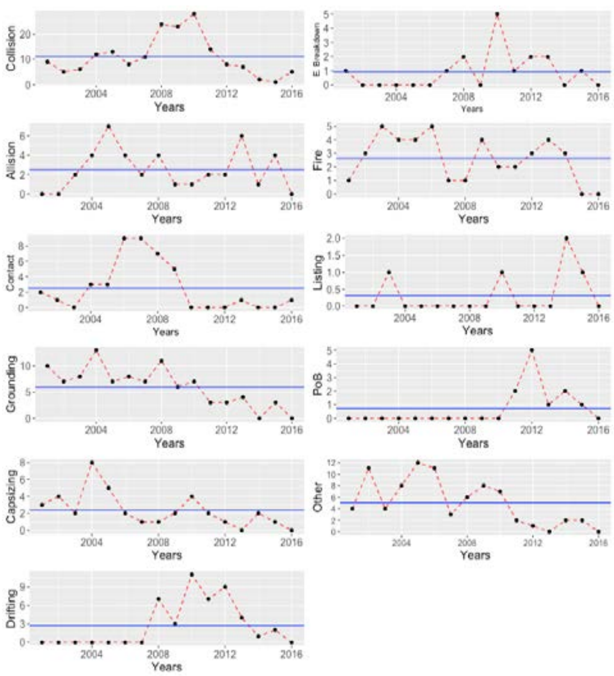


Figure 5. Time-dependent variation of maritime accident types in the Strait of Istanbul

Figure 5 show the time-dependent change of each accident type over 16 years. The vertical axis of the graphs shows the number of accidents in the relevant accident type, and the horizontal axis shows the years. The blue line shows the 16-year average for the relevant accident type. Accordingly, the findings from Figure 5 mainly pointed out the following results for each accident type.

- The average of collision type accidents is 11. The number of collision type accidents, which reached its peak in 2010, followed a steady downward trend until 2015. The annual number of accidents over the 16-year period is generally below the average. Collision type accidents are the types of accidents that can be prevented by tugboat intervention when the time factor is used effectively.
- Allision type accidents have shown a zig-zag behavior over the 16-year period. Accidents reached their maximum value in 2005. The annual number of accidents is generally below the 16-year average. Allision type accidents are among the types of accidents that can be prevented by tugboat intervention within the reaction time.
- Contact type accidents peaked in 2006 and 2007 and then showed a steady decline until 2010. Annual accident frequency is generally below the average. Contact type accidents are among the types of accidents that can be prevented by tugboat intervention within the response time.
- Grounding type accidents have not shown a steady increase or decrease over the years. The annual number of accidents is generally above the average. Grounding type accidents are among the types of accidents that can be prevented by tugboat intervention within the response time.
- Drifting and engine breakdown accidents are the types of accidents that reached their maximum value in 2010. The annual number of accidents in both types of accidents is generally below the average. Both two types of accidents can be prevented by tugboat intervention within the response time.
- Fire, listing, personal overboard and other types of accidents have followed a fluctuating profile over a 16-year period. All four types of accidents are not accident types that can be prevented by tugboat intervention in terms of navigational safety.

The Strait of Istanbul has its own dynamics in terms of environmental factors affecting maritime traffic. Features such as its curving geomorphology and current system make different areas of the strait defenseless for different types of accidents. At this point, the spatial distribution of accident types is important. Figure 6 shows the distribution of accidents in the strait by VTS sector areas.

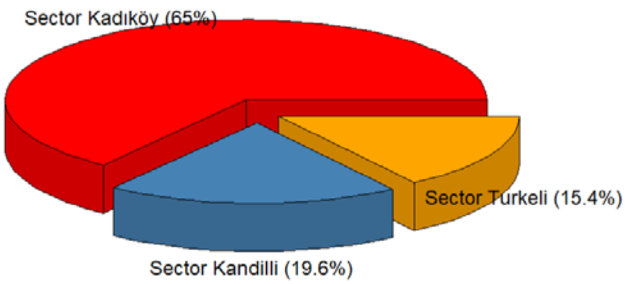


Figure 6. Spatial profile of maritime accident types in the Strait of Istanbul

As can be clearly seen from the pie chart, the accidents occur overwhelmingly within the boundaries of Sector Kadıköy. So much so that the accidents occurring in the Sector Kadıköy region constitute 65% of the total number of accidents in 16 years. It is followed by Sector Kandilli with 19.6% and Sector Türkeli with 15.4%, respectively. Another result given by Figure 6 is that the accidents in the Strait of Istanbul increase from south to north. In other words, when the spatial profile of the accidents in the strait is examined, it is observed that the accidents increase from south to north.

Table 2. Distribution of accident types by regions in the Strait of Istanbul

Sectoral Area	Kadıköy	Kandilli	Türkeli	Total
Collision	144	17	15	176
Allision	24	12	4	40
Contact	37	3	1	41
Grounding	44	32	21	97
Capsizing	24	4	10	38
Drifting	23	13	8	44
Engine Breakdown	7	7	1	15
Fire	30	6	6	42
Listing	3	0	2	5
Person overboard	8	1	2	11
Other	39	21	21	81
Total	383	116	91	590

Table 2 shows that collision type accidents in the Strait of Istanbul are overwhelmingly concentrated in the Sector Kadıköy region. At this point, it has become a requirement to develop special measures for collision type accidents within the boundaries of Kadıköy sectoral area in order to prevent collision type accidents. To prevent this situation, tugboats patrolling the Strait of Istanbul have been suggested as a solution in the literature [14].

Wide of the Strait of İstanbul in most areas changes between 0.5 and 1 nautical mile. This geometric constraint creates a major difficulty in terms of navigation. Typical ship speed on the ground varies between 8 to 12 knots, it roughly means that the response window for the tug intervention could be as little as 1 minute (half the strait width) and 30 minutes the most. On the other hand, maximum speed of a typical tug at low sea conditions is about 14 knots. In other words, if the tugboat is at a distance of 0.25 nautical miles from the ship, it will take approximately 2 minutes to reach the ship [7]. In this direction, considering the geometrical constraints of the Strait, the response time of the tugboat for a possible accident was calculated as follows.

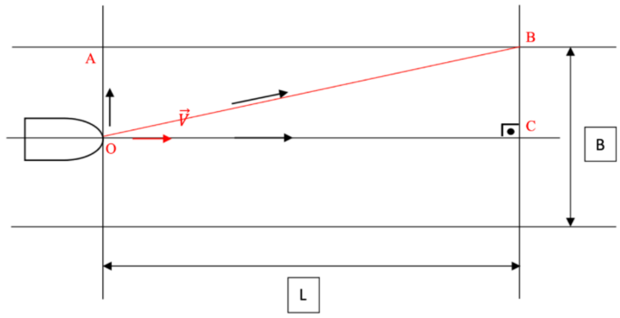


Figure 7. Route alternatives for tugboat.

In Figure 7, L represents the straight area channel length and B represents the channel width.
$B1 = B_{min} = 0.5$ nm.
$L1 = L_{min} = 3$ nm.
V1 = 8 knots.
$B2 = B_{max} = 1{,}0$ nm.
$L2 = L_{max} = 4$ nm.
V2 = 12 knots.

The route alternatives that the ship with a rudder or engine failure can make from the 0 point (origin) at the entrance of the straight channel and on the middle axis are $\overline{OA}$, $\overline{OB}$ and $\overline{OC}$.

$$\overline{OB} > \overline{OC} > \overline{OA}, \quad \overline{OB} = \sqrt{\overline{OC}^2 + \overline{OA}^2}$$

(Pythagorean theorem)

$$Time = \frac{Distance}{Speed}$$

$$1\ knot = \frac{1\,nautical\ mile}{1\,hour} \cong \frac{1852\,m}{3600\,s} \cong 0{,}5144\ m/s.,$$

Table 3. Tugboat response time

Alternatives	B (nm)	L (nm)	V (kn)	Route OA (nm)	OB (nm)	OC (nm)	t (minute)
1	0,5	-	8,0	0,25	-	-	1,875
2	0,5	-	12,0	0,25	-	-	1,250
3	1,0	-	8,0	0,50	-	-	3,750
4	1,0	-	12,0	0,50	-	-	2,500
5	0,5	3,0	8,0	0,25	3,010	3,0	22,600
6	0,5	4,0	8,0	0,25	4,008	4,0	30,600
7	1,0	3,0	8,0	0,50	3,041	3,0	22,800
8	1,0	4,0	8,0	0,50	4,031	4,0	30,230
9	0,5	3,0	12,0	0,25	3,010	3,0	15,050
10	0,5	4,0	12,0	0,25	4,008	4,0	20,040
11	1,0	3,0	12,0	0,50	3,041	3,0	15,210
12	1,0	4,0	12,0	0,50	4,031	4,0	20,160
13	-	3,0	8,0	-	-	3,0	22,500
14	-	3,0	12,0	-	-	3,0	15,000
15	-	4,0	8,0	-	-	4,0	30,000
16	-	4,0	12,0	-	-	4,0	20,000

a) Time to hit the channel edges: (Alternative 1-4)

minimum = 1,25 minutes, maximum = 3,75 minutes (Route ($\overline{OA}$))

b) Hitting the channel edge for the diagonal route (($\overline{OB}$)): (Alternative 5 -12)

minimum = 15,05 minute, maximum 30,23 minutes

c) End of straight channel for straight course ($(\overline{OC})$) in midline:

minimum = 15 minutes, maximum = 30 minutes (Alternatives 13 - 16)

Within the framework of the above calculations, the response time for tugboat intervention can be change between a minimum of 1.25 minutes and a maximum of 30 minutes. This rate can be expressed as approximately 1 to 30 minutes.

4 CONCLUSION

As a result of the study, the following conclusions have been reached.

- It has been observed that the main accident types in the Strait of Istanbul are collision and grounding, respectively. These accidents were followed by drifting, fire, contact, allision, capsizing, engine breakdown, person overboard and listing respectively.
- Main accident groups except by "other" are the types of accidents that can be prevented by tugboat intervention within the response time.
- When the spatial profile of the accidents is investigated, it is observed that the accidents are concentrated in the Sector Kadıköy area.
- Maritime accidents in the Strait of Istanbul increase from north to south.
- The temporal profile of the accidents did not show a stable trend on the basis of accident type, but it revealed that the measures introduced recently had an effect on increasing the safety of navigation.
- The establishing of VTS and the one-way planning of the traffic in line with the Marmaray Project led to a sharp decline, especially in Collision and contact type accidents, after 2010.
- In line with the accident profile obtained, it has been concluded that tugboats will contribute to the safety of navigation as an accident preventive measure. In other words, it has emerged that tugboats can intervene in accidents before they occur with the effective use of the time factor. In this direction, the response time of a tugboat was calculated considering the geometrical constraints of the Strait of Istanbul. Obtained results showed that tugboat response time varied between 1.25 and 30 minutes. In this direction, it is critical for policy makers to develop measures that will highlight tugboat intervention.
- The results of the study supported the judgment that especially patrolling tugboats would play an active role in preventing accidents within the response time.
- In this concept, tugboats using Kort – nozzle propeller, Voith – Schneider propeller and Schoettel propeller are recommended.

ACKNOWLEDGEMENT

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