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Analysis of Marine Traffic Feature for Safety Assessment at Southern Entrance of the Istanbul Strait-I

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Abstract : *The Istanbul Strait is one of the important waterways in the world. And its southern entrance has a highly congested local traffic. Till now there are several studies regarding how the Istanbul Strait is dangerous to navigate and how those dangers can be mitigated. But there is no study regarding local traffic which is posing great collision risk. In a certain traffic area, marine traffic safety assessment parameters are traffic volume, frequency of collision avoidance maneuver, traffic density, traffic flow and potential encounter. In this paper local traffic volume, traffic flow and potential encounter number of local traffic vessels and possibility of collision are investigated in order to find degree of danger at the southern entrance of the Istanbul Strait. Finally by utilizing those, risky areas are determined for southern entrance of the Istanbul Strait. Results have been compared to a previous study regarding risk analysis at congested areas of the Istanbul Strait (Aydogdu, 2006) and consistency of the results were presented.*

Key words : *The istanbul strait, Marine traffic engineering, Local marine traffic, Traffic volume, Traffic flow and potential encounter*

1. Introduction

The Istanbul Strait is a geological strait separating the European and the Asian continents, and it lies between the Black Sea and the Sea of Marmara. Historically, the Istanbul Strait has a strategic importance since it is the only sea route of the Black Sea states. The Istanbul Strait is a difficult water way to navigate due to its treacherous currents, twists and turns, it is one of the heaviest sea traffic regions in the World. The Istanbul Strait is the second strait in having the densest traffic and according to passing ratios, the volume of traffic in the Strait is 3 times greater than in the Suez Canal, 4 times greater than in the Panama Canal and 2 times greater than in the Kiel Canal (Ece, 2006). When the Montreux Convention was signed, which is the latest international treaty regarding status of Turkish Straits, annually 4,400 vessels were passing from the Istanbul Strait. Nowadays this number has reached up to 55,000 vessels. Despite the importance of the Istanbul Strait till now, there are only a few studies (Aydogdu, 2006; Yurtoren, 2004; Bas, 1999) regarding how the Istanbul Strait is dangerous to navigate and how that dangers can be mitigated. Also there are several studies regarding accident analysis and simulation method (Kum, 2006; Ece, 2006; Akten, 2004; Otay, 2003) at the Istanbul Strait. These studies indicated that southern entrance of the Istanbul Strait has a highly congested local traffic, but there is no study focusing on local traffic which is posing great collision risk. Thus in this paper local traffic volume, traffic flow and potential encounter number of local traffic vessel and possibility of collision are investigated in order to find degree of danger at the southern entrance of the Istanbul Strait. Finally by utilizing those, risky areas at southern entrance of the Istanbul Strait are determined. Results of this qualitative study are compared to previous quantitative study (Aydogdu, 2006) regarding risk analysis at congested areas of the Istanbul Strait by utilizing ship handling simulator and consistency of the results were presented.

2. General Characteristics of the Istanbul Strait

The Istanbul Strait is unique in many aspects. The very narrow and bending shape of the strait is similar to a river. The Istanbul Strait runs across Istanbul, the largest city of Turkey with a population of about 12 million. The Istanbul Strait has unique physical, oceanographic and hydrological

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characteristics. Also complicated navigational conditions prevail at the strait. Fog is most likely from September to April, visibility may drop below 1000 m for about 2 - 5 days per month during this period. It is the worst in the late night and early morning. Winds are variable particularly in fall and winter. The dominant wind directions are north-northeast and south-southwest. There are 4 different types of current flows in the Istanbul Strait which causes dangerous environment to navigate due to imbalanced and non-predictable character (Ece, 2006). Southern entrance of the Istanbul Strait where most of the local traffic is running, is highly affected by the current and other meteorological phenomena. In this area risk of collision has been increased significantly by the increase of vessel traffic in last decades.

2.1 Marine Traffic Condition

Marine traffic flow in southern entrance of the Istanbul Strait consists of south-north bound transit traffic and east-west bound local traffic. Number of vessels passing through the Istanbul Strait has been increasing continuously in last decade due to commencement of Russian and Caspian oil exportation, therefore the amount of dangerous cargo passing through Istanbul increased relatively. 3,653 vessels over 200 meter long, 7,204 tankers and a total number of 56,606 vessels passed through the Istanbul Strait in 2007 (Coastal Safety, 2008) On the other hand around 2100 local traffic vessels navigate at the southern entrance of the Istanbul Strait in a day, besides various types of private boats, recreation boats and fishing vessels.

Kum and Yurtoren divided the Istanbul Strait into areas according to the environmental and traffic conditions as Fig.1. Southern entrance of the Istanbul Strait was defined as Area-A by Kum and Area-1 by Yurtoren.

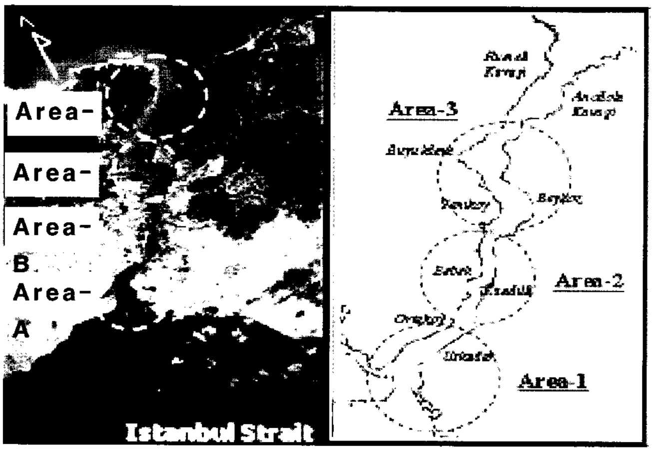

Fig. 1 Division of Istanbul Strait areas

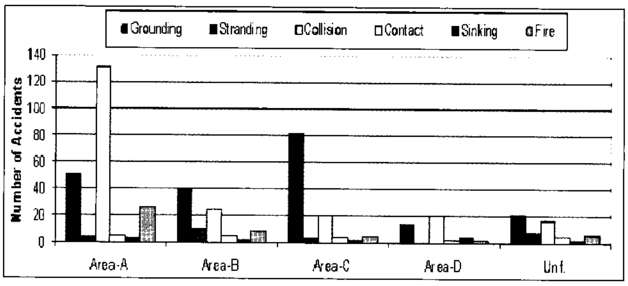

Fig. 2 The most dangerous area for collision type accident

Yurtoren indicated Area-1 as the most difficult area to operate a ship in the strait due to enormous traffic congestion in his simulator study. Kum described Area-A as most dangerous area for risk of collision as seen in Fig.2, due to accident statistics of the strait. Therefore in this paper, the area of 7.5 miles lying between the line connecting Moda Burnu to Bakirkoy (located at southern entrance of the Istanbul Strait) and Bogazici Bridge is chosen as research area, where 95% of the local traffic runs. There are two critical turning points for the transit vessels in the research area. Local traffic in the research area mainly consist of scheduled, Fast Ferries, Sea Buses (Jet Foils), Conventional Vehicle Ferries, Conventional Passenger Boats and Passenger Boats and unscheduled, fishing and recreation boats. Fast Ferries, Sea Buses (Jet Foils), Conventional Vehicle Ferries, Conventional Passenger Boats belong to Istanbul Municipality and operated by IDO (Istanbul Sea Bus LTD.), serving with a total number of 82 vessels(IDO, 2008) Passenger boats belong to private owner and managed by two boat owners cooperative, Dentur Avrasya and Turyol which are operating their registered vessel in different locations of Istanbul. 4 different types and total 39 vessels are registered to Dentur Avrasya (DenturAvrasya, 2008) and 5 different type, total 62 vessels are registered to Turyol (Turyol, 2008). According to statistics between 1991 and 2005 taken from Istanbul Harbor Master, 73.4% of the collisions occurred in the southern entrance of the Istanbul Strait (Aydogdu, 2006). Also according to statistics between 1994 and 2000 in the Istanbul harbor limit, 59.5% of the accidents was collision. Moreover the percentage of collisions to all accident types reach up to 90% in the research area (Yurtoren, 2004). Therefore, it is obvious that there is a high risk of collision between vessels running in the research area. Not only actual collisions, but also potential collision such as close situation to collision, could cause loss of life due to possible panic of passengers, i.e. drowning, crushing and etc. All those factors indicate necessity of local traffic management in order to control and to minimize danger at southern part of the Istanbul Strait.

3. Research Process

Local traffic management can be describe by defining dangers and necessary precautions taken to minimize risks in a certain marine traffic area. Therefore, in order to carry out local traffic management it is necessary to find degree of danger in the research area. For this purpose marine traffic safety assessment parameters which are traffic volume, frequency of collision avoidance maneuver, traffic density, traffic flow and potential encounter need to be investigated(Park, 2005). In this paper local traffic volume, traffic flow and potential encounter number of local traffic vessels and possibility of collision are investigated in order to find degree of danger at southern entrance of the Istanbul Strait. Finally by utilizing those, most risky area are determined at southern entrance of the Istanbul Strait.

3.1 Possibility of Collision

As given in formula (1), possibility of collision can be calculated by dividing number of collisions in a certain time interval by number of navigating vessel in a certain area.

$$P_C = \frac{C_N}{S_A} \tag{1}$$

where

P_C : Probability of Collision
C_N : Number of Collisions
S_A : Amount of Ship Movement

By using this formula, probability of collision has been computed for several waterways as given in Table 1. In this table data of Korean waterways from 1999 to 2004 were utilized (MOMAF, 2005). And the research area were compared with Korean waterways in order to illustrate the degree of danger in the research area. When comparing data from 1999 to 2004 for the research area similar collision probability exist for Busan, Ulsan and Incheon, however by the effect of fore-mentioned traffic volume increase in the Istanbul Strait, probability of collision become almost two times higher than Korean waterways in last 5 year.

3.2 Traffic Flow and Probability of Collision

Table 1 Probability of collisions for various Waterways

Area	Collision Probability
Busan	11.68×10^{6}
Ulsan	10.63×10^{6}
Incheon	11.18×10^{6}
Yeosu	1.94×10^{6}
Research Area	14.29×10^{6}
Research Area last 5 years	23.31×10^{6}
Research Area last 13 years	17.78×10^{6}

Local traffic vessels which are running in the research area has been investigated and determinated. After determination of local traffic running in the research area, timetable, origin-destination and voyage duration of each have been examined through internet and information centers. Hence, traffic flow and detailed ship movement in the research area determined which were given by separate timetable for weekdays, Saturdays and Sundays. Finally weekly, monthly and yearly amounts of ship movement were calculated in the research area. After calculating the amount of ship movement in the research area, Istanbul Harbour Local Traffic Guide and the study of Yurtoren has been utilized in order to define main traffic flow in research area. Istanbul Harbour Local Traffic Guide gives recommended course to local traffic navigator and Yurtoren indicated traffic flow by carrying out a traffic survey in the research area.

Table 2 Determined main traffic flow and defined OD

No	OD Name	OD in detail
1	AB	kadikoy-haydarpasa-karakoy kadikoy-eminonu
2	BC	eminonu-uskudar
3	AD	besiktas-kadikoy kabatas-kadikoy-adalar
4	CD	uskudar-besiktas
5	CE	uskudar-kabatas
6	FG	sirkeci-harem
7	AH	kadikoy-yenikapi
8	BD	karakoy-besiktas-cayirbasi

Yurtoren utilized a berthed passenger vessel radar for 2 days during peak times of marine traffic. Thus, main traffic flow of the local vessels running in the research area have been determined as given in Table 2. The research area is highly influenced area by current and wind, therefore local traffic navigators can not navigate easily. Also local vessel navigators need to consider requirements of passengers about their tight time schedule. They should also give the way to transit vessel according to COLREG Rule 10 which gives another handling difficulty and time delays for local navigators. All these factors are main causes of variations in characteristics of local traffic flow. And that makes it difficult to determine the traffic flow in the research area. Main local traffic flow were defined according to origin-destination locations of local vessels. After determination of main traffic flow, data of maritime accidents in the Istanbul Strait obtained from various sources was utilized in order to find collision locations in the research area. By using those collision locations for each OD, annual collision numbers were divided by previously determined amount of ship movement to determine probability of collision, as given in Table 3.

Table 3 Collision probability for each main local traffic flow line

Years	Collision Probability of Each OD							
	AB	BC	AD	CD	CE	FG	AH	BD
1995	11.9×10^{-6}	5.2×10^{-6}	6.9×10^{-6}	0	0	3.5×10^{-6}	18.9×10^{-6}	1.8×10^{-6}
1996	17.6×10^{-6}	15.5×10^{-6}	12.0×10^{-6}	5.2×10^{-6}	2.6×10^{-6}	0	14.0×10^{-6}	9.2×10^{-6}
1997	14.7×10^{-6}	7.7×10^{-6}	3.4×10^{-6}	0	0	6.9×10^{-6}	9.3×10^{-6}	1.8×10^{-6}
1998	2.9×10^{-6}	7.8×10^{-6}	5.2×10^{-6}	10.4×10^{-6}	7.7×10^{-6}	0	0	7.3×10^{-6}
1999	8.9×10^{-6}	5.2×10^{-6}	5.2×10^{-6}	2.6×10^{-6}	0	3.5×10^{-6}	4.71×10^{-6}	1.8×10^{-6}
2000	8.9×10^{-6}	7.8×10^{-6}	1.7×10^{-6}	2.6×10^{-6}	2.6×10^{-6}	7.0×10^{-6}	4.7×10^{-6}	0
2001	3.0×10^{-6}	2.6×10^{-6}	1.7×10^{-6}	2.6×10^{-6}	2.6×10^{-6}	0	4.8×10^{-6}	0
2002	3.0×10^{-6}	2.6×10^{-6}	1.7×10^{-6}	0	2.6×10^{-6}	0	4.7×10^{-6}	3.7×10^{-6}
2003	8.9×10^{-6}	7.8×10^{-6}	1.7×10^{-6}	2.6×10^{-6}	2.6×10^{-6}	3.5×10^{-6}	4.7×10^{-6}	1.8×10^{-6}
2004	8.7×10^{-6}	0	6.8×10^{-6}	2.6×10^{-6}	0	0	13.7×10^{-6}	1.8×10^{-6}
2005	8.7×10^{-6}	7.7×10^{-6}	5.1×10^{-6}	0	0	0	0	0
2006	0	0	0	0	0	0	0	0
2007	8.6×10^{-6}	7.6×10^{-6}	5.1×10^{-6}	0	0	3.4×10^{-6}	4.5×10^{-6}	1.8×10^{-6}

After annual collision probabilities were calculated, it was difficult to realize the degree of danger of each traffic flow line (OD). For this reason average values of last 5 and 10 years have been taken and average values of collision probability of main traffic flow lines were determined, as given in Fig. 3.

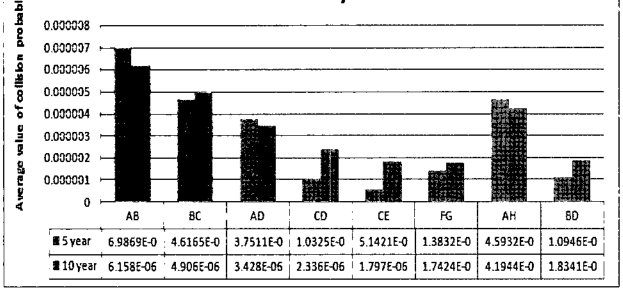

Fig. 3 Collision Probability for each OD

3.3 Probability of near miss

After computing the probability of collision for each main local traffic flow line, probability of near misses were calculated for each OD in the research area by utilizing Heinrich's principle. According to Heinrich's principle if an accident occurs, there is a probability of 300 near misses (Park, 2007). Probability of near misses calculated for last 5 and 10 years' average probability of collision values are given in Fig. 4.

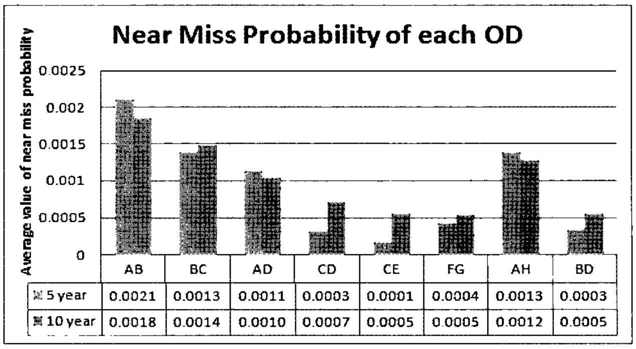

Fig. 4 Probability of near miss for each OD

Main traffic flow AB is found as most dangerous line by 2.1% near miss probability for last 5 years average figure followed by main traffic flow line BC by 1.3% near miss probability for last 5 years average figure, main traffic flow line AH by 1.3% near miss probability for last 5 years average figure and main traffic flow line AD by 1.1% near miss probability for last 5 years average figure, respectively. AB, BC, AH and AD lines have higher probability values because Eminonu-Karakoy and Kadikoy, which can be called as two major city centers of Istanbul, fall into these lines. 816 local vessels visit Kadikoy and 1,212 local vessels visit Eminonu-Karakoy per day. Total 1,356 local vessels run in a day at both areas and that causes such a high near miss and collision probabilities on those OD.

And also as seen in Fig.5, AB, BC and AD lines intersect with each other. On the other hand the local vessels on AH line may be encountered with transit vessels in various possible locations due to being at entrance and exit of the strait, which causes high number of encounters.

3.4 Potential encounter locations & numbers

After defining main traffic flow, the research area has been divided into three sectors as given in Fig. 5, namely Sector A1, Sector A2 and Sector A3 according to close passing/encounter locations of local traffic flow in order to

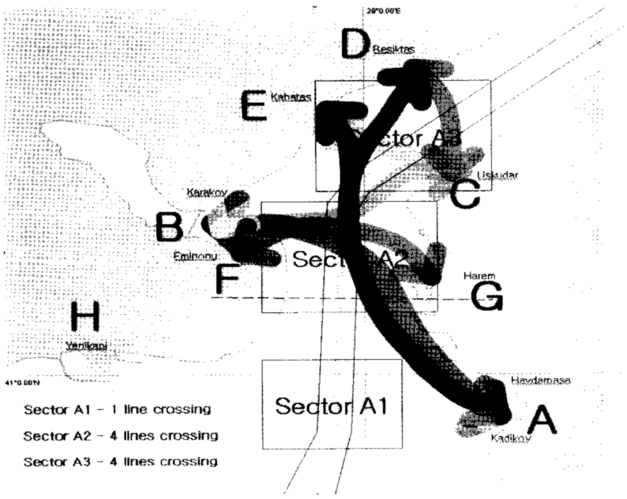

Fig. 5 General traffic flow and sectors in the research area

find traffic volume. It has been observed that AH line intersect with transit vessel flow in Sector A1, 4 main local traffic flow lines (AB, BC, AD and FG) intersect with each other and transit traffic flow at different locations in Sector A2 and 4 main local traffic flow lines (BC, AD, CE and BD) intersect with each other and transit traffic flow at different locations in Sector A3.

In order to determine potential encounter in defined local sectors, actual data of departure time, destination, traffic flow were utilized and voyage durations were assumed according to the study of Aydogdu. Then, as given in Fig.6, daily number of potential encounters were determined by 10 minute time intervals.

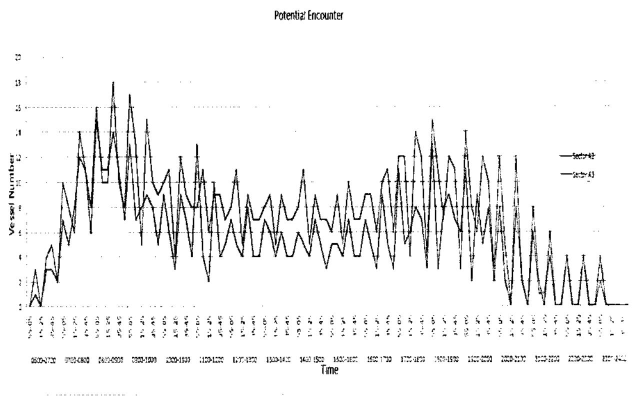

Fig. 6 Number of Potential Encounter in the Sector A2 and in the Sector A3 by 10 minutes time interval in a weekday

Also, traffic volume, maximum and minimum number of potential encounters were determined per hour, as given in Table 4. According to the results, there are 73 different vessels running in a single hour during peak times, with a maximum of 18, and a minimum of 8 vessel being in close

Table 4 Traffic volume and maximum/minimum possible encountering vessel number in a hour

Time	Sector	A1	A2	A3
Peak Time	Number of vessel running in a hour	4	73	67
	Max/Min number of potential encounter	2/2	18/8	11/7
Off-Peak Time	Number of vessel running in a hour	4	59	47
	Max/Min number of potential encounter	2/2	11/5	9/4

location or encountering in Sector A2. In case of off-peak times, the total number of vessels running in the area is 59, with a maximum of 11, and a minimum of 5 vessels being in close location or encountering. The results are similar for Sector A3. 67 vessels run in a single hour, with a maximum of 11, and a minimum of 7 vessels being in close location or encountering during peak times, and a total number of 47 vessels run in a single hour with a maximum of 9, and a minimum of 4 vessels being in close location or encountering during off-peak times. On the other hand the encounters in Sector A1 are mainly with transit vessels, thus encounters among local vessels are negligible when compared to the other sectors.

Probability of collision in each defined sector is calculated as given in Fig. 7. In this figure first column represents probability of collision, second column represents number of OD intersect in the sector, third column represents number of running vessel in a single peak time hour and fourth column represents maximum number of potential encounter number in a single peak time hour.

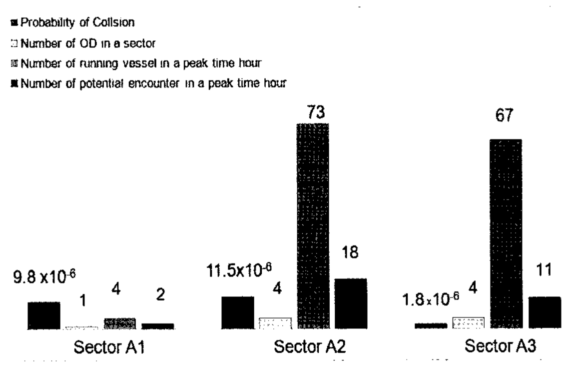

Fig. 7 Summary of result for each sector

3.5 Comparison of Results

When compared this qualitative study result with quantitative study of Aydogdu regarding risk analysis at congested areas of the Istanbul Strait by utilizing SHS(ship handling simulator), it can be found that both result show similarity (Fig.8). In that study, how much stress a ship navigator feels due to local traffic while passing through southern entrance of the Istanbul Strait has been investigated by utilizing SHS and Environmental Stress Model (Inoue, 2000). 225 meter tanker ship passage simulation conducted during peak times and off-peak times of local traffic through southern entrance of the Istanbul Strait. In both studies, sector A2 is determined as most risky area due to high traffic volume. Also Sector A1 is determined as second risky area in both studies. Sector A1 has been found dangerous in spite of lowest traffic volume and potential encounter due to being entrance and exit point of strait. Transit vessels navigating mainly at similar courses in TSS(traffic separation scheme) during passage of the strait but navigating at different locations out of TSS, therefore sector A1 is determined dangerous in both studies. The study of Yurtoren also found that the research area in this paper is most difficult area to navigate due to congestion.

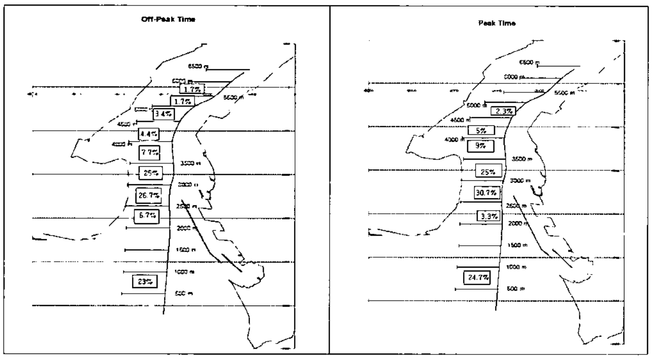

Fig. 8 Previous quantitative study determined risky area for a transit vessel navigator while passing strait

4. Conclusion

This research attempted to determine traffic volume, traffic flow and potential encounter in order to find degree of danger due to local traffic at southern entrance of the Istanbul Strait. Probability of collision is calculated for several waterways and the research area shows almost two times higher probability than those of Busan, Ulsan and Incheon.

Traffic flow is investigated in the research area, 8 main origin-destination (OD) are defined and the probability of collision and the probability of near miss are calculated for each OD. AB line (between Eminonu-Karakoy and Kadikoy) is assessed as most dangerous OD and followed by BC line (between Eminonu-Karakoy and Uskudar), AH line (between Kadikoy and Yenikapi) and AD line (between Kadikoy and Besiktas-Kabatas). The research area is divided into 3 sectors as given in Fig.5, namely Sector A1 (area lies between Kadikoy and Yenikapi at southern entrance of Istanbul strait), Sector A2 (area lies between Sirkeci-Harem) and Sector A3 (area lies between Besiktas-Kabatas and Uskudar) according to close passing/encounter locations of the traffic flow in order to find traffic flow and potential encounter. There is only one OD in the Sector A1 which intersect with transit vessel flow, although 4 OD intersect with each other and transit vessel flow in Sector A2 and Sector A3. Number of vessels running in a single peak time hour is 4 in Sector A1, 73 in Sector A2 and 67 in Sector A3. And maximum number of potential encounter/being in close location in a single peak time hour is 2 in Sector A1, 18 in Sector A2 and 11 in Sector A3. As given in Fig.8, results for defined sectors were compared in order to determine most dangerous sector and Sector A2 were determined as most dangerous sector. Results were compared with a previous quantitative study, and Sector A2 were determined as most dangerous area in both studies. Results showed that local traffic vessel departure times should be re-arranged in Sector A2 and A3 due to high traffic volume and potential encounters. Also necessary safety precautions should be taken such as more intensive VTS surveillance for both local and transit vessels in Sector A1 in order to minimize existing encounter risks.

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