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Analysis of shipboard fire/explosion accidents occurred in the Turkish search and rescue area

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ABSTRACT

A shipboard fire/explosion may be occurred due to various causal factors such as actions, omissions, events or conditions. In this study, it is aimed to carry out an analysis focused on shipboard fire/explosion casualties. With this aim, the data on 127 shipboard fire/explosion casualties occurred in the Turkish Search and Rescue area, which were reported to the Main Search and Rescue Coordination Center between 2006-2015, have been analyzed. As a result of the statistical analysis (descriptive statistics), it has been observed that majority of the shipboard fire/explosion casualties were occurred on-board the Turkish flagged ships, on-board small passenger vessels/recreational vessels/private-commercial yachts among the classified ship types, in the regions of İstanbul, İzmir and Çanakkale, in the summer season, during the night-time, and in machinery spaces of the ships by described locations. It has been also observed that main events caused shipboard fires/explosion casualties were electricity contact/leakage, gas accumulation/leakage, cargo ignition, welding/hot works and other undescribed factors. Additionally, by examining the existing shipboard fire & explosion accident investigation reports of Transportation Safety Investigation Center between 2014-2020, it has been observed that the main possible causal/contributing factors for the shipboard fire/explosion casualties were related with the violations of the ISM-Safety Management System (SMS) requirements. Many previous studies in the relevant literature point out to the ISM/SMS-related causal/contributing factors as well. In conclusion, special attention should be paid to the effective implementation and continuous improvement of the ISM/SMS procedures related with shipboard fire safety for the prevention of shipboard fire/explosion casualties as well.

Keywords: Marine casualties, Shipboard fire/explosion, Maritime safety, Safety management, Accident analysis

Introduction

A fire, which is a chemical reaction, occurs when combustible substances combine with oxygen under sufficient heat. An explosion occurs when a substance flashes suddenly and turns into various gases, and its volume expands and forces its surroundings (MEB, 2016:5-7). According to the International Labour Organization (ILO), there are three basic requirements for a fire to be created and sustained (ILO, 2012:5).

a. The presence of fuel or flammable materials;

b. The presence of a source of ignition;

c. The presence of oxygen in the air to support the combustion.

The fuel/flammable materials may be any combustible substances or materials such as flammable liquids or gases, paper, rubber, wood or fabrics etc. The source of ignition, which is needed to preheat the fuel/flammable materials and keep the fire alight, may be open flames, hot surfaces, hot gases, sparks from mechanical or electrical equipment, static electricity, chemical reactions, lightning strike, electromagnetic radiation etc. Additionally, other sources of ignition (heat and spark sources) may also be oxy-acetylene flame, flames arising from ignition of leaks from flammable liquid and gas pipes, bare electricity cables, electric sparks, electrical heaters and devices, welding, grinding, metal cutting, scraper, steam/exhaust pipes, static electricity, and self-ignition that stored heat energy in substances starts to burn without any external effects (MEB, 2016:5-26).

The technical rules on construction-fire protection, fire detection and fire extinction of ships are basically established in Chapter II-2 of International Convention on Safety of Life at Sea (SOLAS) adopted by the International Maritime Organization (IMO). There are also many different international instruments on that issue. Instead of these instruments, marine casualties continue to be occurred due to human errors and/or technical failures. The IMO and its members attach a great importance to prevent marine casualties due to its negative effects on international shipping and trade. According to the IMO, *"marine casualty"* means an event, or a sequence of events, which has occurred directly in connection with the operations of a ship (IMO, 2020a). There have been different types of marine casualties such as collision, contact, grounding, capsizing, fire/explosion etc. that have negative consequences on human life, property and marine environment. The prevention of shipboard fire/explosion is also one of the most important issue in terms of maritime safety and environmental protection, as it may be resulted in severe damages and/or loss of life, loss of ships and pollution of marine environment (IMO, 2008). Table 1 includes some of very serious shipboard fire/explosion casualties in maritime history.

As also seen from the Table 1, a shipboard fire/explosion casualty may occur due to any internal causal factors, which include actions, omissions, events or conditions on a ship, or it may occur as a sequence of events such as collision, contact, grounding, and others (IMO, 2008). Determining the casual factors of a marine casualty is mostly possible with a very detailed investigation to be carried out by the Authorities such as flag States, costal States, port States etc. According to paragraph 7 of article 94 of United Nations Convention on the Law of the Sea (UNCLOS), regulation I/21 of SOLAS, articles 8 and 12 of MARPOL and article 23 of Load Lines Convention (LL 66), each Administration/State have responsibility to investigate serious and very serious marine casualties. The IMO adopted Resolution MSC.255(84) on "Casualty Investigation Code" in May 2008 in order to provide a standard approach to marine casualty and incident investigation (IMO, 2008). According to the IMO's Casualty Investigation Code, a very serious marine casualty means a marine casualty involving the total loss of the ship or a death or severe damage to the environment (IMO, 2008). A serious marine casualty was defined as a marine casualty other than very serious marine casualty that results in serious injury or substantial material damage that would render the ship unseaworthy according to the national "Deniz Kaza ve Olaylarını İnceleme Yönetmeliği/Regulation for Investigation of Marine Accidents and Incidents, 2019" of Turkey. According to the detailed definition of United Kingdom (UK) Merchant Shipping (Accident Reporting and Investigation) Regulations (2012), a serious marine casualty, which is an event or sequence of events that has occurred directly by or in connection with the operation of a ship but which does not qualify as a very serious marine casualty, that involves fire, explosion, collision, grounding, contact, heavy weather damage, ice damage, or a suspected hull defect, resulting in any of the immobilization of the main engines, extensive accommodation damage, severe structural damage including penetration of the hull under water rendering the ship unfit to proceed,

pollution or a breakdown that necessitates towage or shore assistance.

In accordance with the international requirements, marine casualties occurred in the Turkish SAR area should be reported to the Turkish Main Search and Rescue Coordination Center (MSRCC)/Ana Arama ve Kurtarma Koordinasyon Merkezi (AAKKM). The serious/very serious ones of those can be investigated by the Transportation Safety Investigation Center (TSIC)/Ulaşım Emniyeti İnceleme Merkezi (UEİM) of the Ministry of Transport and Infrastructure (MoTI). Preparation of each investigation reports, which include possible causal factors and other information related with the casualty, can take a long time depending on scope of the casualty. A retrospective analysis of a set of marine casualties provides a holistic view of past events, as well as some clues on which issues should be focused on for more studies that are detailed in the future. In this context, it is expected that this study will also contribute to better understanding of shipboard fire/explosion casualties in the Turkish SAR area and provide a future perspective for more detailed studies on this issue.

Table 1. Some of very serious shipboard fire/explosion casualties (Ece, 2011; AA, 2014; EPA, 2020; Akten, 2006; Kozanhan, 2019; İstikbal, 2020).

Year	Name of Ship	Casualty	Location	Damages (to life, ships and/or marine environment)
1960	**World Harmony** **Peter Zoranic (Tanker)**	Fire due to collision of ships.	İstanbul Strait	18.000 tons of oil spilled.
1963	**Lakonia** (Passenger ship)	Fire in the hair salon.	North of Madeira in the Atlantic	A total of 128 people, including 95 passengers and 33 crew members, died. Only 53 of those died due to fire, while others died from falling and injuries due to panic.
1966	**Lutsk** (Tanker) **Kransky Oktiabr** (Genel Cargo)	Fire due to collision of ships.	İstanbul Strait	1.850 tons of oil spilled.
1973	**Golar Patricia** (Tanker)	Explosions, during the tank cleanings	130 miles off the Canary Islands, Spain	The ship sank, 10.000 tons of bunker oil spilled and 43 people died.
1975	**Jakob Maersk** (Tanker)	Fire/explosion due to grounding	Porto/Portugal	80.000 tons of crude oil spilled.
1979	**Independenta** (Tanker)	Fire due to collision with another ship.	İstanbul Strait	95.000 tons of oil spilled and 43 crew members died.
1994	**Nassia** (Tanker)	Fire/explosion due to collision with another ship.	İstanbul Strait	20.000 tons of oil spilled and 30 crew members died.
1987	**Dona Paz** (Passenger/ferry ship)	Fire due to collision with another ship (tanker).	Tablas Strait	4.375 passengers and 11 of 13 crew members died.
2010	**Deepwater Horizon** (Mobile Offshore Drilling Unit)	Fire/explosion	Gulf of Mexico	4 million barrels of oil spilled and 11 workers died.

Literature Review

In the literature, there are many studies regarding marine casualties with different aims and scopes. Some of those are related with analysis of marine casualties in the Turkish SAR area as well. The difference of this study from others is that this study has specifically focused on shipboard fire/explosion casualties among different types of marine casualties. Therefore, the relevant previous studies which particularly cover shipboard fire/explosion casualties have been reviewed in parallel with aim and scope of this study. For example;

Akten (2006) stated in his study on shipping accidents that groundings and shipboard fires were dominant types of shipping accidents worldwide.

Arslan & Turan (2009) examined factors, which affect marine casualties including shipboard fire/explosion casualties by using a combination of SWOT and AHP methods, and developed a strategic action plan for minimizing shipping casualties at the Strait of Istanbul.

Ellis (2011) analyzed marine casualties of ships carrying packaged or containerized dangerous goods between 1998–2008 and concluded that self-ignition or ignition of incorrectly declared dangerous goods were identified as a contributing factor for the fatal accidents.

Özkan et al. (2012) examined 18 of fire & explosion accident investigation reports between 1998-2010 in oil tankers and concluded that the main factors causing fire & explosion accidents are inappropriate equipment use, hot working, combustible gas accumulation and cargo leakage, respectively.

Ece (2012) analyzed ships accidents occurred in the Strait of İstanbul between 1982-2010 and stated that 7.6% of analyzed accidents (785) were shipboard fires.

Erol & Başar (2015) analyzed marine accidents occurred in the Turkish SAR area between 2001-2009 and concluded that many of ship accidents (60%) were resulted due to human errors.

You & Chung (2015) analyzed many cases of ship fires/explosions between 2009-2013 and concluded that majority of reasons for ship fires/explosions were lack of safety awareness.

Silva (2016) examined 20 of shipboard fire & explosion investigation reports and concluded that the main causal factors were lack of knowledge and inadequate operation & emergency procedures.

Park et al. (2016) analyzed marine casualties of fishing vessels in Korea and concluded that the causes of fires/explosions were mainly due to poor inspection and maintenance the electric cord.

Uğurlu (2016) examined fire & explosion events between 1999-2013 in tankers transporting and concluded that the most significant causes of accidents were hot work, electric arcs, static electricity, and combustible gas accumulation in the cargo tank. And, the main causative factors were the violation of work permits and a lack of risk analysis.

Krystosik-Gromadzińska (2016) examined engine room fire safety in his study and stated based on DNV that more than 50% of all engine room fires (excluding yard repairs) were caused due to the combination of oil leakage with a hot surface. This study also emphasized importance of cleanness of engine room and checkpoints in the engine room with care.

Yılmaz & İlhan (2018) analyzed marine accidents and incidents resulting in death, injury or loss of life occurred on or involving the Turkish flagged ships between 2002-2014 and stated that 4.4% of analyzed accidents and incidents (182) were shipboard fires/explosions.

Ece (2019) analyzed marine accidents in the Strait of İstanbul between 1982-2018 in her study and stated that 7.2% of analyzed accidents (857) were shipboard fires.

Rothblum (2020) stated in her study that human error contributes to 75% of fires & explosions and poor maintenance is a leading cause of fires and explosions.

İstikbal (2020) carried out a detailed analysis of three major accidents occurred in the Strait of İstanbul, some of which resulted with fire and explosion, and discussed the long-term proceedings of Left-hand side navigation in the Strait of Istanbul.

Çakır & Kamal (2020) analyzed 535 of marine accidents, 26 of which were shipboard fire/explosion casualties, occured in the Strait of İstanbul between 2001-2016.

Material and Methods

This study is specifically focused on shipboard fire/explosion casualties occurred in the Turkish SAR area. It is expected that it will contribute to better understanding what is general

profile of shipboard fire/explosion casualties occurred in the Turkish SAR area, and to determine what further measures can be taken for the future. With this aim, the data on 127 fire/explosion casualties occurred on-board ships in the Turkish SAR area between 2006 and 2015, which include ship flag, ship type, ship tonnage, casualty season, casualty time, casualty region, location of fire/explosion on board ship, event caused fire/explosion on board ship, have been provided from "accident/event statistics" database published on web site (https://aakkm.uab.gov.tr/kaza-olay-istatistikleri) of the MSRCC/AAKKM which is open to public access (MSRCC/AAKKM, 2020). Then, the data provided have been properly classified and descriptive statistics/frequency tables have been prepared by using a software. The maritime literature has been considered during the classification of ships' technical particulars such as ship type, ship tonnage. The same definition of the "night-time" on the national legislation "Gemiadamları ve Kılavuz Kaptanlar Yönetmeliği/Regulation for Seafarers and Pilots (2018)" of Turkey has been used. The MSRCC/AAKKM's own data have been considered during the classification of events caused shipboard fires/explosions. The locations of fires/explosions onboard ships have been generically classifed according to explanations in the accident/event statistics database of the MSRCC/AAKKM. Yearly statistics of the shipboard fire/explosion casualties occured in the Turkish SAR area between 2006-2015 are shown in Table 2.

As seen from the Table 1 and Figure 1, 789 people were recovered, 35 people were injured, and 7 people were died due to 127 fire/explosion casualties occurred on ships in the Turkish SAR area between 2006-2015.

In addition to the statistical analysis, the existing marine accident investigation reports related with very serious shipboard fire/explosion casualties (TSIC/UEİM, 2020a; 2020b; 2018; 2015; 2014) prepared by the TSIC/UEİM, which are open to public access from web site (https://ulasimemniyeti.uab.gov.tr/deniz) of the TSIC/UEİM, have been also examined and summarized in the Appendix – Table 1.

Table 2. Shipboard fire/explosion casualties in the Turkish SAR area (MSRCC/AAKKM, 2020).

Year	Number of Shipboard Fire/Explosion Casualties	Number of People Recovered	Number of People Injured	Number of People Died
2015	7	8	19	-
2014	13	63	9	1
2013	12	279	-	3
2012	15	92	-	-
2011	13	73	-	-
2010	10	40	7	1
2009	11	57	-	1
2008	19	64	-	1
2007	13	84	-	-
2006	14	29	-	-
Total	127	789	35	7

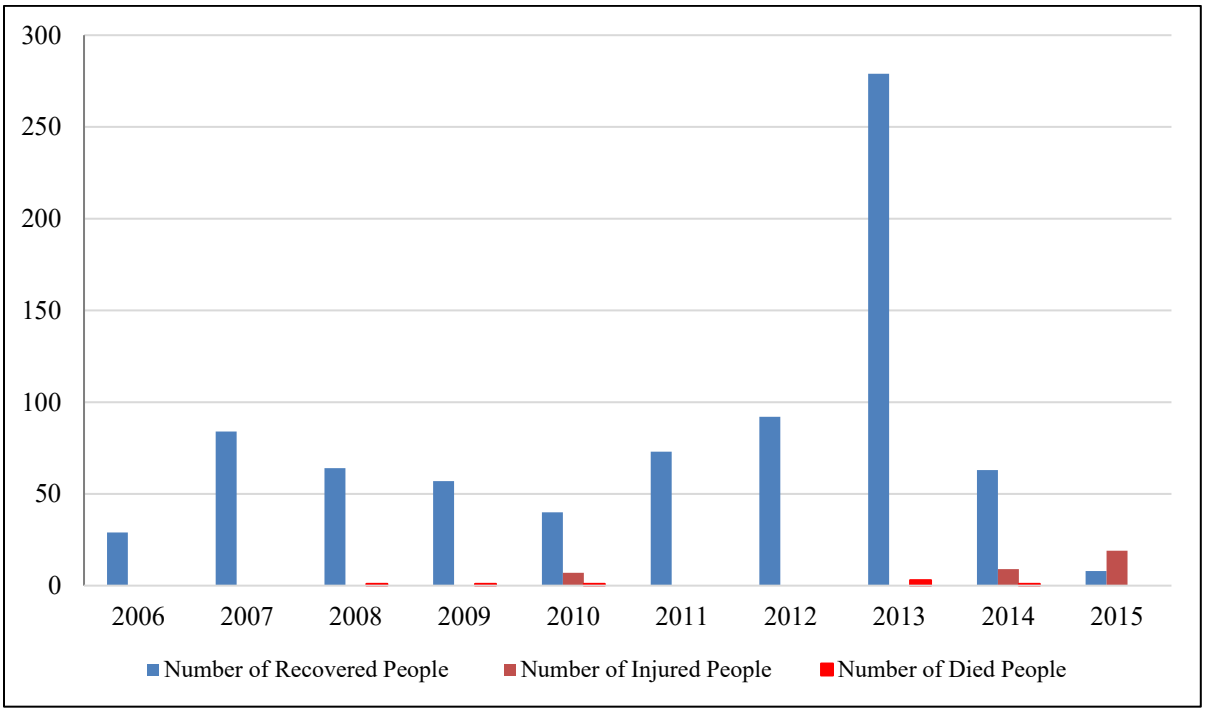

Figure 1. Number of people recovered, injured and died due to shipboard fires/explosions

Results and Discussion

Descriptive Statistics

As seen from Table 3, most of ships involved fire/explosion casualties between 2006-2015 were "Turkish flagged" with a share of 72.44% and "Foreign flagged" with 25.98%. The "Flag" data of some ships were undescribed or not described properly with 1.57%.

Table 3. Flags of ships involved fire/explosion casualties

Flag of Ship	Frequency (f)	Percentage (%)
Turkish	92	72.44
Foreign	33	25.98
Undescribed / Not described properly	2	1.57
Total	127	100.00

As seen from Table 4, most of ships involved fire/explosion casualties were "Recreational Vessels/Private-Commercial Yachts" with 33.07% and "Dry Bulk Cargo Ships" with 25.20%, respectively. The "Passenger Vessels/Ferries" with 17.32%, "Other types" with 7.87%, "Tankers (Oil, chemical etc.)" with 5.51%, "Fishing Vessels" with 5.51% and "Ro-Ro/Ro-Pax" with 3.94% were also involved in shipboard fire/explosion casualties, respectively. The "Type of Ship" data of some ships were undescribed or not described properly with 1.57%.

Table 4. Types of ships involving fire/explosion casualties

Type of ship	(f)	%
Passenger Vessels / Ferries	22	17.32
Recreational Vessels / Private-Commercial Yachts	42	33.07
Ro-Ro / Ro-Pax	5	3.94
Dry Bulk Cargo Ships	32	25.20
Fishing Vessels	7	5.51
Tankers (Oil, chemical etc.)	7	5.51
Other type of ships above	10	7.87
Undescribed / Not described properly	2	1.57
Total	127	100.00

As seen from Table 5, most of ships involved fire/explosion casualties were "less than 500 GRT" with a share of 47.24%. The ships between "500 – 2,999 GRT" with 18.11%, ships between "3,000 – 9,999 GRT" with 16.54%, ships "more than 10,000 GRT" with 7.87% were also involved in fire/explosion casualties, respectively. The "GRT" data of some ships were undescribed or not described properly with 10.24%.

Table 5. Grosstonnages (GRT) of ships involving fire/explosion casualties

GRT of ship	(f)	%
Less than 500	60	47.24
500 – 2,999	23	18.11
3,000 – 9,999	21	16.54
More than 10,000	10	7.87
Undescribed / Not described properly	13	10.24
Total	127	100.00

As seen from Table 6, most of shipboard fires/explosions were occurred in the region of "İstanbul" with 38.58%, in "İzmir" with 22.05% and in "Çanakkale" with 17.32%, respectively. Others were also occurred in "Antalya" with 9.45%, in "International Waters" with 4.72%, in "Mersin" with 3.15%, in "Samsun" with 2.36%, in "Trabzon" with 1.57%, respectively. The "Region" data of some shipboard fire/explosion casualties were undescribed or not described properly with 0.79%.

Table 6. Regions where shipboard fire/explosion casualties occurred

Region	(f)	%
Antalya	12	9.45
Çanakkale	22	17.32
İstanbul	49	38.58
İzmir	28	22.05
Mersin	4	3.15
Samsun	3	2.36
Trabzon	2	1.57
International Waters	6	4.72
Undescribed / Not described properly	1	0.79
Total	127	100.00

As seen from Table 7, most of shipboard fires/explosions were occured in the "Summer" season with 33.86%. Others were also occured in "Autumn" with 25.20%, in "Spring" with 23.62% and in "Winter" with 17.32%, respectively.

Table 7. Seasons of fire/explosion casualties

Season	(f)	%
March-April-May (Spring)	30	23.62
June-July-August (Summer)	43	33.86
September-October-November (Autumn)	32	25.20
December-January-February (Winter)	22	17.32
Total	127	100.00

As seen from Table 8, shipboard fires/explosions were occured during the "Nigthtime (20:00-06:00)" with 51.18% and "Daytime (06:01- 19:59)", respectively.

Table 8. Time of fire/explosion casualties

Time	(f)	%
20:00- 06:00 (Night-time)	65	51.18
06:01- 19:59 (Day-time)	62	48.82
Total	127	100.00

As seen from Table 9, the locations where fires/explosions were occurred on-board ships were mostly undescribed or not described properly with a share of 51.18%. According to described locations, most of shipboard fires/explosions were mostly occurred in "Machinery Spaces" of ships with 25.20%. Others were also occurred in "Accommodation / Passenger Spaces" with 11.02%, in "Tanks / Enclosed Spaces" with 6.30% and in "Cargo Spaces" with 6.30%, respectively.

Table 9. Locations of fires/explosions on-board ships

Location of fire/explosion	(f)	%
Machinery Spaces	32	25.20
Undescribed / Not described properly	65	51.18
Accommodation / Passenger Spaces (Crew cabins, passenger longest, kitchens, bridges, etc.)	14	11.02
Tanks / Enclosed Spaces	8	6.30
Cargo Spaces	8	6.30
Total	127	100.00

As seen from Table 10, events caused shipboard fires/explosions were mostly undescribed or not described properly with 70.08%. According to described events, events caused shipboard fires/explosions were mostly related with "Electricity Contact/Leakage" with 18.11%. Others were related with "Gas Leakage/Accumulation" with 4.72%, "Cargo Ignition" with 4.72% and "Welding/Hot Works" with 2.36%, respectively.

The shipboard fire/explosion casualties may be resulted with loss of life, loss of ships and pollution of marine environment. Very serious shipboard fire/explosion casualties occurred in the maritime history, which are included in the Table 1, supports this view.

Table 10. Events caused shipboard fires/explosions

Event caused fire/explosion	(f)	%
Electricity Contact/Leakage	23	18.11
Gas Leakage/Accumulation	6	4.72
Cargo Ignition	6	4.72
Welding/Hot Works	3	2.36
Undescribed / Not described properly	89	70.08
Total	127	100.00

According to the retrospective analysis carried out in this study, 127 shipboard fire/explosion casualties occurred in the Turkish SAR area between 2006-2015 were mostly occurred:

- on-board "Turkish flagged ships"
- on-board "Recreational Vessels/Private-Commercial Yachts" and "Passenger Vessels"
- in the regions of "İstanbul", "İzmir" and "Çanakkale"
- in the "Summer" season
- during the "Night-time (20:00-06:00)"
- in "Machinery Spaces" of the ships (according to described locations)
- caused from "Electricity Contact/Leakage" (according to described events)

According to the statistical analysis, majority of the shipboard fire/explosion casualties in the Turkish SAR area were occurred on-board the Turkish flagged ships. On the other hand, Table 11 shows that total number of Turkish flagged cargo ship visits and total number of foreign-flagged cargo ship visits at Turkish ports are approximate.

Table 11. Total number of cargo ship visits at Turkish ports (DGM, 2020).

Year	Turkish flagged	(%)	Foreign flagged	(%)	Total
2019	20,991	38.0	34,311	62.0	55,302
2018	38,219	52.8	34,141	47.2	72,360
2017	38,263	52.2	35,043	47.8	73,306
2016	37,644	52.9	33,576	47.1	71,220
2015	38,397	52.1	35,288	47.9	73,685
2014	38,685	51.7	36,081	48.3	74,766
2013	39,835	52.3	36,295	47.7	76,130
2012	38,333	50.5	37,542	49.5	75,875
2011	37,234	49.6	37,900	50.4	75,134

The fact that approximately half (47%) of the total shipboard fire/explosion casualties were occurred on-board ships below than 500 GT points out that those were domestic small passenger/recreational vessels and private-commercial yachts which are mostly not subject to the international rules, in the Cabotage. Because other types of ships are generally more than 500 GT. Besides one third of the total shipboard fire/explosion, casualties were occurred on such ships. Therefore, it may be more beneficial to conduct further studies primarily in order to improve the fire safety of such ships. For example; as stated on the relevant marine accident investigation report (TSIC/UEİM, 2015), further studies can be conducted on the following issues:

- Effective inspection for marine type approval of portable electrical devices & equipment using on-board such vessels which are not under supervision of classification societies,
- Fixed fire pumps to be driven remotely,
- Control of periodical emergency drills.

Even though the summer season seems to be a little more prominent, seasonal changes did not make a significant difference for occurrence of shipboard fire/explosion casualties. The shipboard fire/explosion casualties were occurred at daytime or nigh time, irregardless of time.

Causal/Contributing Factors of Shipboard Fires/ Explosions

The causal factors of shipboard fire/explosion casualties are a combination of various factors such as actions, omissions, events or conditions. The fuel, oil, oily bilge water, sludge, oil absorbed materials, hot surfaces, damaged parts, heat-generating works, and self-igniting substances in the *engine rooms* of ships may cause a fire. The flammable liquids, heated oils for frying, hot surfaces, ovens, heated pans, damaged electrical installations in the *kitchens* of ships may cause a fire. The combustible materials, drapes, curtains, personal electrical devices, matches, cigarettes, electrical contacts, papers in the garbage in the *accommodation spaces* of ships may cause a fire. The self-heating cargo, oxidizable cargo, cargo that may spark by friction, organic substances, and accumulated/compressed gases in tanks/enclosed spaces, flares; explosives in the *cargo spaces* of ships may cause a fire. The shipboard fires usually occur due to human errors such as lack of knowledge, lack of care, lack of experience etc. (MEB, 2016:5-26)

According to the statistical analysis carried out in this study, electricity contact/leakage, gas accumulation/leakage, cargo ignition, welding/hot works and other factors undescribed/not described properly were main events caused shipboard fires/explosions. Of course, fuel/oil leakage is one of very important factors of shipboard fires/explosion casualties in general but there is no data on that issue in the "accident/event statistics" database of the MSRCC/AAKKM. Since the accident/event statistics between 2016-2020 had not been published on the web site of the MSRCC/AAKKM, this study was designed to cover a 10-year period from 2006 to 2015. Descriptive (frequency) analysis was possible but any correlation or root-cause analysis could not be carried out, as more than 70% of the data on "events caused fire/explosion casualties on board ships" had been undescribed or not described properly in the accident/event statistics of the MSRCC/AAKKM.

In order to better understand the main reasons and the advance of shipboard fires/explosions, the existing marine accident investigation reports of the very serious shipboard fire/explosion casualties (TSIC/UEİM, 2020a; 2020b; 2018; 2015; 2014) prepared by the TSIC/UEİM between 2014 – 2020 have been examined and summarized in the Appendix – Table 1 as well. By examining the results and recommendations stated on the reports, it has been observed that the possible causal/contributing factors of the shipboard fire/explosions were mostly related with some violations of the ISM-Safety Management System (SMS), such as improper cargo operation, improper supply operation, improper gas-free operation, improper hot work operation, insufficient procedure, insufficient audit/inspection, etc. Some reports also point out to the insufficient shipboard familiarization & awareness trainings about cargo operations, insufficient ship safety culture, and ineffectiveness of emergency fire and abandon ship drills on-board ships. Figure 2 contains a visual representation of those factors.

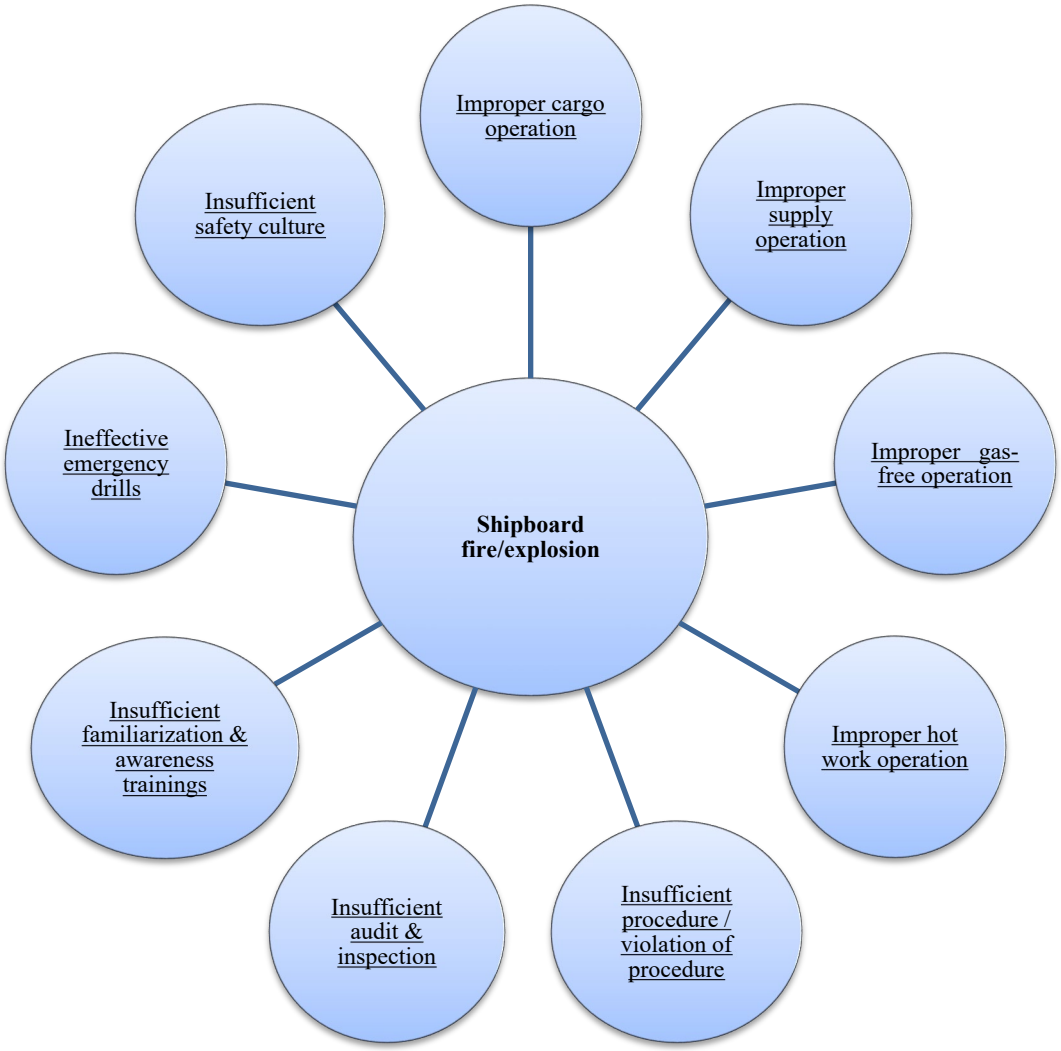

Figure 2. Possible causal/contributing factors of the shipboard fire/explosions according to the TSIC/UEİM's investigation reports examined in this study.

Those are the topics mostly related with the implementation of the ISM-Safety Management System (SMS). As seen from Table 12, many previous studies in the relevant literature also point out to some ISM/SMS-related causal/contributing factors of the shipboard fires and explosions.

Accordingly, the effective implementation and continuous improvement of the ISM/SMS are very important topics for the prevention of shipboard fire/explosion casualties as well. The International Management Code for the Safe Operation of Ships and for Pollution Prevention (International Safety Management (ISM) Code), which aims to provide the safe management and operation of ships and the protection of the marine environment, is based on general principles and objectives, which include assessment of all identified risks to one Company's ships, personnel and establishment of appropriate safeguards (IMO, 2020b). The Company should develop instructions and procedures to ensure safe operation of ships. The Company should periodically review and evaluate the effectiveness of the SMS in accordance with procedures established by the Company. Further, it is one of the master's responsibilities to review periodically the SMS and to report its deficiencies to the Company. Companies should carry out periodical internal shore-based and shipboard audits to verify whether shore-based and shipboard activities comply with the SMS. The Company should also continuously improve safety

management skills of personnel ashore and on-board ships, including emergency preparedness, and ensure that all personnel have the qualifications, training and experience that may be required in support of the SMS. Master is responsible for implementing the safety and environmental-protection policy of the Company and motivating the crew in the observation of that policy. Master is also responsible for periodically reviewing the SMS and reporting its deficiencies to the Company (ISM Code, 2010; MEPC.7/Circ.8, 2013).

Table 12. Causal/contributing factors of shipboard fires/explosions in the literature

Causal/contributing factors	References
• Cleanness of engine room; fuel leakages in pumps, piping, generators, main engines • Electrical failures originating from the generators or switchboards	(Krystosik-Gromadzińska, 2016) (Lindgren & Sosnowski, 2009) (Silva, 2016)
• Violation of work permits • Lack of risk analysis • Hot working • Electric arcs, static electricity • Combustible gas accumulation in cargo tanks • Inappropriate equipment use	(Uğurlu, 2016) (Uğurlu, Başar & Köse, 2012)
• Poor inspection and maintenance the electrical installations/devices	(Park at al., 2016)
• Self-ignition or ignition of incorrectly declared dangerous goods	(Ellis, 2011)
• Lack of safety awareness • Crew's lack of knowledge • Inadequate operation • Inadequate emergency procedures/check lists	(You & Chung, 2015) (Silva, 2016)

Meanwhile, domestic recreational vessels/commercial yachts are subject to neither the SOLAS Chapter IX / ISM Code requirements nor the national technical rules, as such ships are mostly navigating in the Cabotage and less than 500 GT. On the other hand, some ISM Code requirements are being partly applied to the passenger ferries navigating in the Cabotage and their companies according to the national "Uluslararası Emniyet Yönetimi Kodunun Türk Bayraklı Gemilere ve İşletmecilerine Uygulanmasına Dair Yönetmelik/National Regulation on the Application of the ISM Code to Turkish Flagged Ships and Operators, 2009" of Turkey.

Globally, the training and certification of the seafarers are being conducted according to the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW 78/95). The Turkish seafarers are also being trained and certified in accordance with the national legislation "Regulation for Seafarers and Pilots (2018)" in line with the STCW 78/95. Of course, effectiveness of on-shore trainings is a very important topic but on the other hand, effectiveness of shipboard familiarization & awareness trainings of the seafarers to be carried out in scope of the SOLAS Chapter IX / ISM Code is also another important topic for providing the sustainability of the safety of ships and occupational safety of seafarers. Additionally, Regulation 4.3 of the Maritime Labour Convention (MLC, 2006) also requires that seafarers should be trained on-board ship in terms of health and safety protection and accident prevention. The Port State Control (PSC) provides the effective implementation of international maritime rules, together with flag State, Class and P&I inspections.

Fire Safety of Ship Engine Room

According to the statistical analysis carried out in this study, it has been observed that most of shipboard fires/explosions were occurred in the "machinery spaces" of the ships. According to Krystosik-Gromadzińska (2016), 50% of all engine room fires are due to the combination of oil leakage with a hot surface. Figure 3 also shows causes of engine room fires according to Krystosik-Gromadzińska (2016).

Lindgren & Sosnowski (2009) carried out a safety risk assessment for oil tankers and container vessels focused on fire & explosion in the machinery space and concluded that generators and leaking fuel pumps were the most critical components with respect to fires whereas boilers initiated the most explosions. In general electrical failures (usually originating from the generators or switchboards) and fuel, leakages in pumps, piping and the main combustion machinery (the generators and the main engine) were the most common sources of fire. Table 13 includes the most common sources of ignition and sources of oil leakages in the machinery spaces of

the ships according to another study carried out by the United States of Coast Guards (USCG).

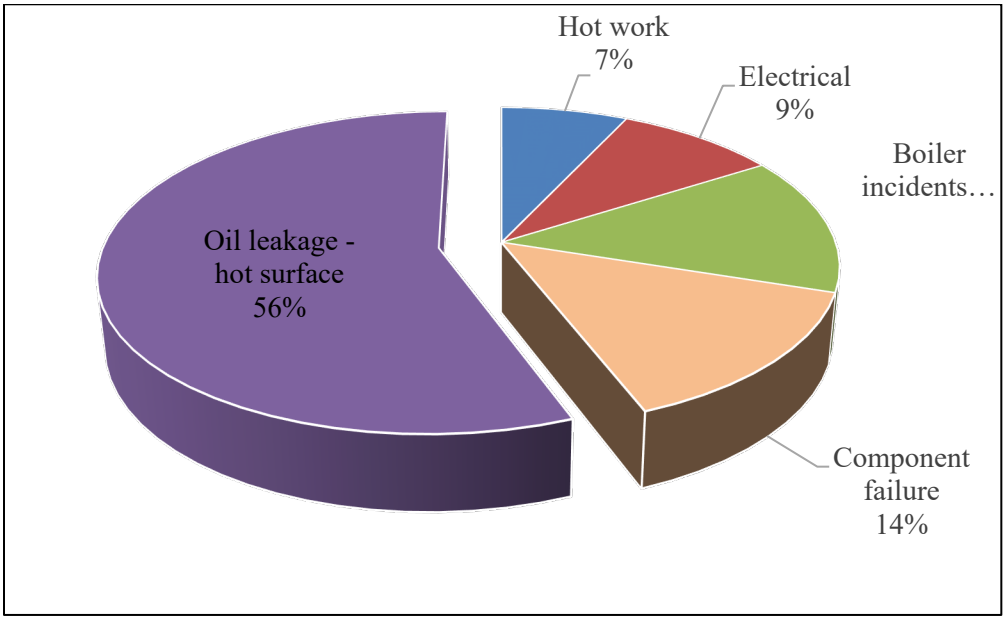

Figure 3. Causes of engine room fires (Krystosik-Gromadzińska, 2016)

Table 13. The most common sources of ignition and sources of oil leakage in the machinery spaces (USCG Research and Development Center, 1998; Lindgren & Sosnowski, 2009).

Source of ignition (component)	(%)	Source of oil leakage (component)	(%)
Boiler	0.7	Main engine	4.0
Explosion (other)	2.1	Pums	4.0
Hot surface (other)	52.5	Separator/purifier	1.1
Open flame	4.9	Turbocharger	1.7
Spark	1.4	Vents/pipes	61.7
Steam line	2.8	Other	17.7
Turbocharger	9.1	Onknown	9.7
Other/unknown	26.6		
Total	100.0	Total	100.0

As seen from the Table 13, the most common sources of ignition in the machinery spaces are hot surfaces (other), turbochargers, open flames, steam lines, sparks and boilers, respectively. The most common sources of oil leakage in the machinery spaces are related with some components such as vents/pipes, pumps, main engines, turbochargers and separators/purifiers, respectively.

Therefore, fire safety of engine room is very important issue. Figure 4 shows some major components of engine room fire safety that should be considered.

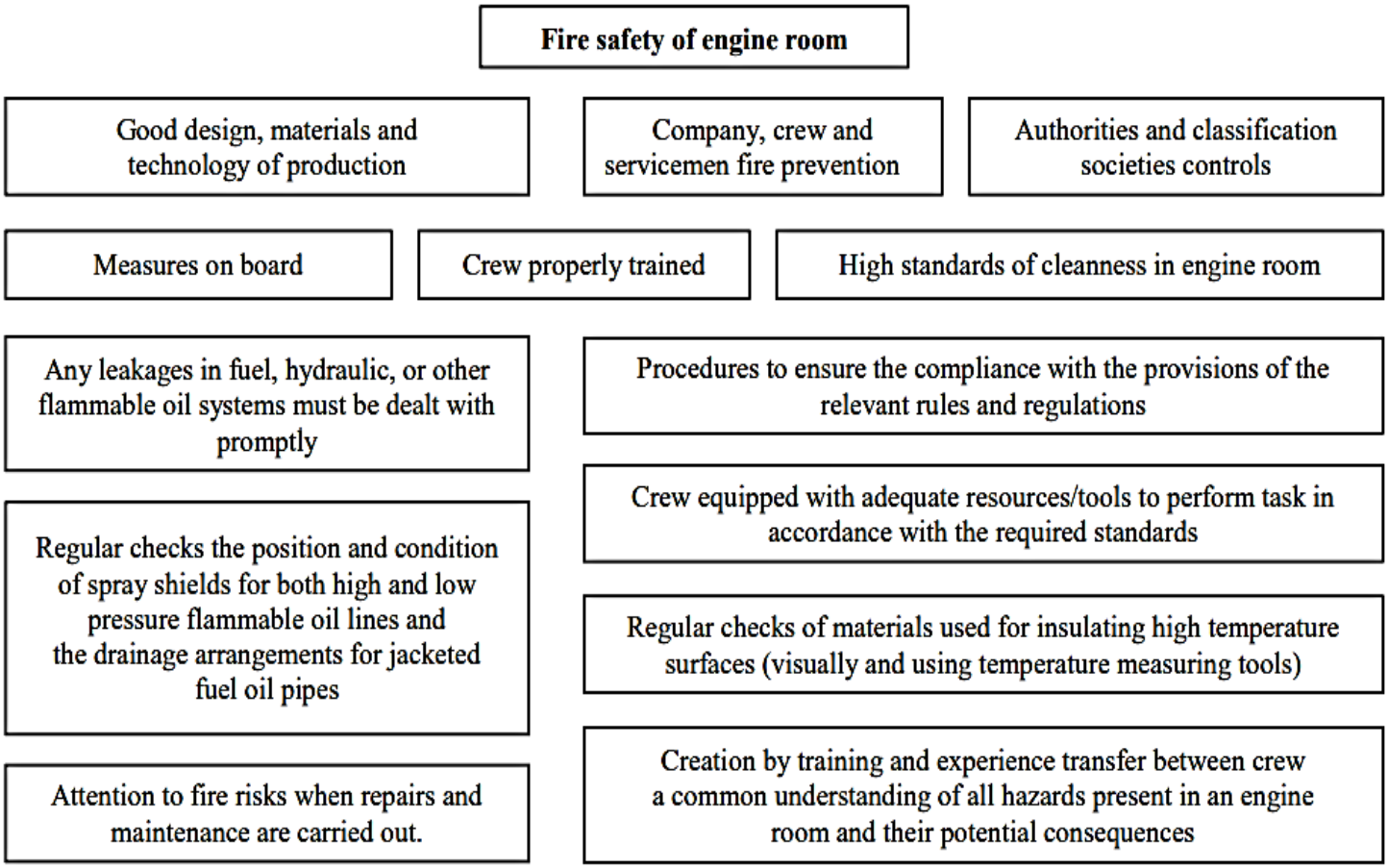

Figure 4. Components of engine room fire safety (Krystosik-Gromadzińska, 2016)

Fire safety of engine rooms starts from a good design, materials and technology of production. Accordingly, naval architects have also important roles and responsibilities for the proper design and construction of ship engine rooms in terms of fire safety. Company and ship crewmembers should have awareness of fire prevention. The inspections carrying out by authorities and classification societies provide the sustainability of fire safety of ships. The cleanness of an engine room is very important for prevention of shipboard fires/explosions. All fuel/oil leakages in the engine rooms should be monitored and checked regularly in accordance with ship's safety management procedures. Any violations of work permits should be avoided. The personal protective equipment should be provided by company to crewmembers and be used by crewmembers. The attention to fire risks, when repairs and maintenance are carried out, should be paid. A common understanding of all hazards and their consequences should be created by training and experience transfer between crewmembers. Experienced engine officers and ratings are also important to ensure the safe machinery operations.

In this study, an analysis focused on shipboard fire/explosion casualties occurred in the Turkish search and rescue (SAR) area has been carried out. Some descriptive statistics and possible causal/contributing factors of shipboard fires & explosions have been presented and discussed with previous studies in the section of "Results and Discussion" of the study.

As a result of the statistical analysis (descriptive statistics) of the shipboard fire/explosion casualties reported to the MSRCC/AAKKM between 2006-2015, it has been observed that majority of the shipboard fire/explosion casualties were occurred on-board the Turkish flagged ships, on-board small passenger vessels/recreational vessels/private-commercial

yachts among the classified ship types, in the regions of İstanbul, İzmir and Çanakkale, in the summer season, during the night-time, and in machinery spaces of the ships by described locations. It has been also observed that main events caused shipboard fires/explosion casualties were electricity contact/leakage, gas accumulation/leakage, cargo ignition, welding/hot works and other undescribed factors.

By examining the existing shipboard fire & explosion accident investigation reports of the TSIC/UEİM between 2014-2020, it has been observed that the main possible causal/contributing factors for the shipboard fire/explosion casualties were related with the violations of the ISM-Safety Management System (SMS) requirements, such as improper cargo operation, improper supply operation, improper gas-free operation, improper hot work operation, insufficient procedure, insufficient audit/inspection, insufficient shipboard familiarization & awareness trainings about cargo operations, insufficient ship safety culture and ineffectiveness of emergency fire and abandon ship drills on-board ships, etc. Many previous studies in the relevant literature also point out to some SMS-related causal/contributing factors of the shipboard fires/explosion casualties.

Recommendations to Avoid from Shipboard Fire / Explosion Casualties

An effective fire safety management is very important issue for all ships. The technical rules on construction-fire protection, fire detection and fire extinction of ships engaged in international voyages are basically established in Chapter II-2 of SOLAS. As a recommendation, special attention should be paid for the fire safety measures and the effective implementation of the relevant ISM-SMS procedures of international cargo ships during the flag State and port State inspections as well as during the P&I and class inspections. Additionally, shipboard trainings of seafarers to be carried out in accordance with STCW 78/95, SOLAS Chapter IX / ISM Code and MLC 2006, emergency drills and audits should also be carefully inspected as well.

Of course, Companies should also fulfil their duties without waiting for the flag State, port State, P&I or class inspections. The Companies should also effectively inspect their ships in a close cooperation with the shipmasters. The Companies are primarily responsible to provide a ship safety culture to seafarers on their ships and effectively implement the ISM Code requirements. In this study context, whether the shipboard safety awareness trainings of seafarers, emergency drills and audits related with fire safety management are effectively performed or not should be carefully monitored and necessary corrective actions should be taken by the Companies. Special attention should be paid on cleanness of engine room, fuel leakages in pumps, piping, generators, main engines, electrical failures originating from the generators or switchboards, work permits, hot works, electric arcs, static electricity, combustible gas accumulation/leakage, periodical inspection maintenance of electrical installations/devices, self-ignition or ignition of incorrectly declared dangerous goods, operation and emergency procedures and risk analysis onboard ships. The recommendations stated on the accident investigation reports of the TSIC/UEİM should be monitored and considered by the Companies as well as by the other relevant parties.

Ship masters should also pay special attention to the effective implementation and continuous improvement of the ISM/SMS on-board ships in a close cooperation with the Company. They should pay special attention to reviewing the SMS and reporting its deficiencies to the Company, and motivating the crew in the observation of shipboard safety policy and procedures. Ship engine and deck officiers and ratings should pay special attention to the safe machinery and cargo operations, specially to the sources of oil/gas leakage and sources of ignition in the machinery spaces and other spaces, such as cargo holds, enclosed spaces, etc.

Meanwhile, there are also many domestic small passenger/recreational vessels and private-commercial yatchs involving the shipboard fire/explosion casualties in the Turkish SAR area. Such ships are subject to neither the SOLAS Chapter IX / ISM Code requirements nor the national ISM implementation. Therefore, focusing on improving fire safety of such domestic ships is of special importance. Accordingly, it can be recommended that the national technical rules may be further improved in terms of fire safety of such ships. This improvement action can be started from the effective inspection for marine type approval of portable electrical devices & equipment using on such vessels and providing fixed fire pumps to be driven remotely. Furthermore, some applicable ISM requirements, for example; emergency abandon ship drills etc., may be partly applied to the domestic small passenger/recreational vessels and commercial yachts, carrying more than 12 passengers, as well as to the domestic passenger ferries. Inspections to the domestic passenger ferries may be

increased in terms of national ISM/SMS implementation including fire safety management. Some additional fire safety measures may be considered for both Turkish flagged and foreign-flagged private yachts as well.

Conclusion

Depending on the data available, this study was designed to cover all types of ships with the aim of better understanding what is general profile of shipboard fire/explosion casualties occurred in the Turkish SAR area. In the future, it would be useful to conduct further studies focusing on ship fire/explosion casualties for each types of ships with a detailed data set including each causal/contributing factors of shipboard fire/explosions, separately.

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Compliance with Ethical Standard

Conflict of interests: The authors declare that for this article they have no actual, potential or perceived conflict of interests.

Ethics committee approval: -

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Appendix – Table 1. A summary on possible causes of shipboard fires/explosions and recommendations according to the TSIC/UEİM's investigation reports (TSIC/UEİM, 2020a; 2020b; 2018; 2015; 2014).

TSIC/UEİM – Accident Investigation Report No	Serious/Very Serious Shipboard Fire/Explosion Casualties Investigated by the TSIC/UEİM	Possible Causes of Shipboard Fires/Explosions	Recommendations
41/DNZ-07/2020	Explosion & fire on-board an Italian flagged LPG tanker, on 01.07.2019 in İzmir, while cargo loading at an LPG terminal/platform.	• Gas leakage due to rupture of the hose used for connection between ship and shore, as a result of over pressure on the hose. • Static electricity. (possible ignition source)	• Within the scope of ISM "Cargo Loading Procedure", necessary measures should be taken to ensure effective tank level monitoring and/or a warning mechanism must be integrated into the system, against over pressure. • Periodical abondon ship drills sould be effectively carried out with participation of all crew members in accordance with the ISM. • Terminal should also take some measures in order to increase the efficiency of continuously monitoring of gas tranfer process & line pressure.
29/DNZ-04/2020	Capsizing due to a fire on-board a Turkish flagged wooden recreational vessel (gulet), on 16.09.2019 in Göcek, while at anchor.	• Overheating of electical caples connected with electrical devices in the kitchen of the vessel. (possible ignition source)	• A procedure should be developed for the effective inspection of the suaitability and adequacy of portable electrical devices & equipments used on-board vessels not under supervision of classification societies for marine type approval. • A regulation should be arranged so that the fixed fire pumps on such ships can also be driven remotely. • Especially in the certification process of such ships, effective measures sould be taken to control the fact that periodical emergency drills are carried out and recorded, including informing passengers about emergency situations.
DNZ-04/2018	Explosion & fire on-board a Turkish flagged LPG tanker, on 29.04.2017 in İzmit, while at an LPG terminal/platform.	• Gas leakage due to improper discharge of LPG vapor accumulated in cargo tanks. • Improper supply operation. (possible ignition source)	• ISM should be reviewed in order to rectify all non-conformities found during the accident investigation, in particular cargo operation related ones. • Deck Officers who are on duty for cargo operations should be given a refreshment training. • ISM internal audits should be done more frequently and ship fire drills should be done more effectively. • Terminal should review the compliance of its fire-fighting equipment on the LPG ship platform with international standards.

08/2015	A fire on-board a Togo flagged general cargo ship, on 14.01.2015 in İskenderun, while loading the cargo (straw) at a port.	• Burding of dry cargo (straw balls) due to cigaratte or self-ingition of cargo. (possible ignition source)	• Number of inspections and controls of dangerous cargo loading/unloading operations should be increased at ports. • Realistic drills should be carried out against fires and other similar emergency situations at ports. • A regulation should be arranged to measure the moisture content of the straw cargo before loading and to determine the straw transport conditions, especially on the deck.
01/2014	Explosion on-board a Turkish flagged chemical tanker, on 20.01.2014 in Tuzla- İstanbul, while at achor.	• Improper gas-free operation. Chemical (explosive) gas accumulation in enclosed spaces, cofferdams. • Improper hot work (spiral cutting) on the deck. (ignition source) (Without a hot work permission from Harbour Master Authority, without an on-board meeting about hot work planning, without informing the ship crews about their roles during the hot work, without completing the hot work permit forms, without gas measurement before hot work.)	• Company should give further trainings to its personnel and all crew members working on-board the ships managed by it in order to increase their ship safety culture. • Company should carry out internal ISM audits, which should also include gas-free and hot work operations, from time to time as possible, even while the ships are navigating. • Company should ensure that written permission must be obtained from itself before any "hot work" on-board ships under its management. • Company should check and monitor that the necessary records regarding explosive gas measurement of enclosed spaces are kept on-board ships under its management. • Company should establish and implement an ISM procedure in order to evaluate masters, officiers and engineers, before employment and boarding and after leaving the ships. • The efficiency of Administrative controls regarding ISM practices should be increased.