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Cause-and-effect analysis of ship fires using relations diagrams

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Abstract

This paper analyses the causes of fires on board merchant ships and fishing vessels. The study attempts to identify the causes of fire occurrence on board ships and to determine their interrelations using the relations diagram, also known as the interrelationship diagram or digraph. This diagram identifies relations not only between causes and effects but also between two or more causes. Elements of the diagram, which have the greatest number of directed connections from/to, are the starting points for further ship safety analysis. The relations diagram is used as a basis for planning corrective measures and actions directly increasing shipping safety at sea. Knowing the various causes of fire occurrence, it is possible to eliminate or to reduce their number in the future by revising and drawing up relevant maritime transport regulations. This, in turn, can enhance shipping safety.

Introduction

Despite advancements in production technologies of ship components, safety systems and ship automation, accidents in maritime transport continue to happen. However, making use of marine accidents analysis (Bogalecka, Markowski & Rutkowska, 2001), we can minimize risks in maritime transport by selecting appropriate construction materials, applying fire detection and suppression systems, and appropriate ship operation and safety management (Łusznikow & Ferlas, 1999; Girtler, Kuszmider & Plewiński, 2003). This includes regular maintenance, training of crew members, and appropriate procedures regarding hot work permits. The knowledge of the causes and effects of marine accidents will allow their future prevention, consequently raising the level of safety. The study of relevant literature (Bogalecka, 2015) and the author's research of available data (Łusznikow & Ferlas, 1999; Bogalecka, Markowski & Rutkowska, 2001; Girtler, Kuszmider & Plewiński, 2003) has revealed that collisions, the main cause of marine accidents in 2009–2014, accounted for 23% of all accidents (Figure 1). Fires, which represented 20% of cases, were the second major cause of accidents. Because damage caused by ship collisions has been the subject of many considerations and analyses, this work will focus on fires on board ships.

By definition, a fire is an uncontrolled, spontaneous process of combustion of inorganic and/or organic materials. For a fire to occur there must be three basic components, forming the so-called combustion, or fire triangle: oxidizer, flammable material and a source of thermal energy (Figure 3). These factors combined together result in the spread of fire and often lead to tragic consequences, especially at sea. An example of the percentage fire distribution by ship type is presented in Figure 2, while consequences of fires on all the mentioned ship types (in the examined period of time) are presented in Figure 4.

Fatalities or missing persons as a result of fire represent the highest percentage (18%) on all types of ships. The second major effect is damage to a ship (14.8% of ship required repair, while 10.2% of damaged ships could continue their voyage).

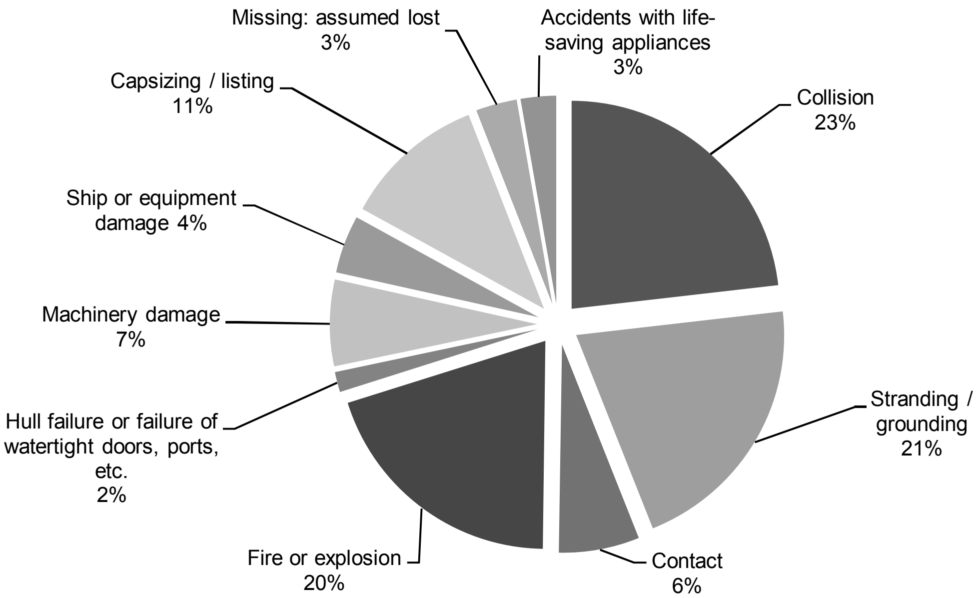

Figure 1. Types of marine accidents (author's findings based on 2009-2014 data (IMO-GISIS, 2015))

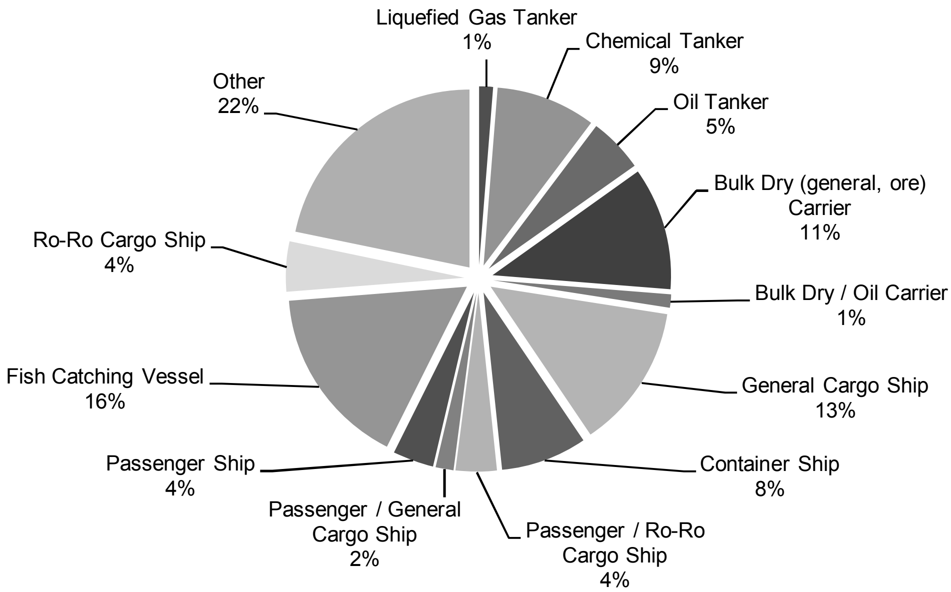

Figure 2. Fire accidents distribution by ship types (author's findings based on data from the years 2009–2014 (IMO-GISIS, 2015))

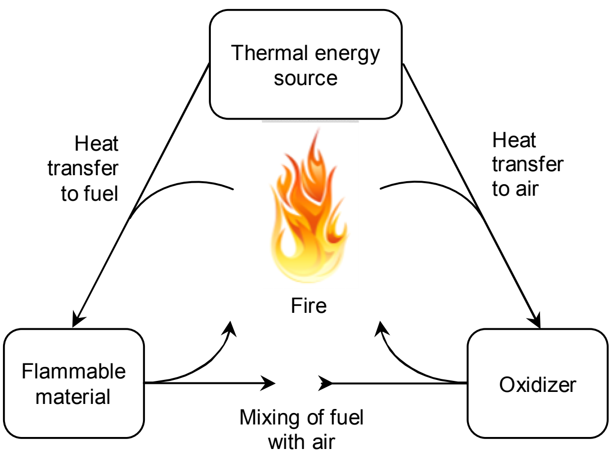

Figure 3. Combustion triangle (Kordylewski, 2008)

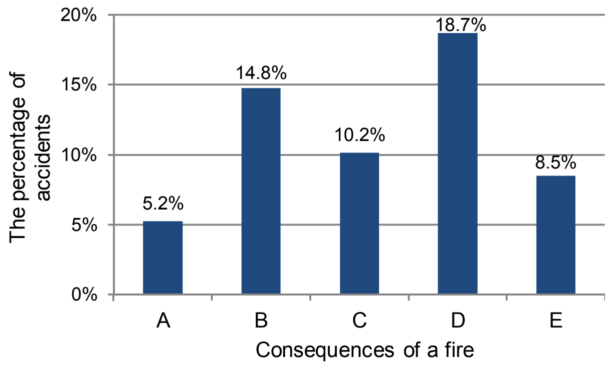

Figure 4. Consequences of fires at sea (A – total damage of a ship, B – a ship rendered unfit to proceed, C – a ship remains fit to proceed, D – fatal accidents or missing persons, E – wounded persons (author's findings based on data for years 2009–2014 (IMO-GISIS, 2015))

The next 8.5% fraction corresponds to injured persons, while 5.2% of accidents resulted in the total destruction of the ship. The determination of the causes of marine events leading to accidents, including fires, proposed in the IMO document (MSC-MEPC.3/Circ.3.Rev.1, 2014) is not sufficient, as the cause of an accident is complex. That is why it is important to determine the causes of fires on sea-going ships, label them unequivocally, group them and find their interrelationships.

Diagram of interrelationships leading to a fire

Interrelationship diagrams are used for graphical presentation of a set of factors affecting the final result of a process (in this case – fire). They are mostly used to indicate source causes of specific problems. The interrelation diagram effectively illustrates mutual connections between particular causes. In this approach, all elements of the diagram, although labeled as causes, may be considered both as causes and effects. Therefore, interrelationship diagrams allow the definition of cause-and-effect dependencies and indicate relations between particular causes of a problem (Figure 5).

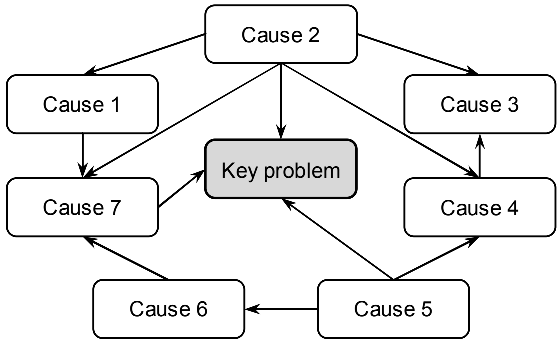

Figure 5. Example interrelationship diagram (Hamrol, 2012, pp. 291–293)

Interrelationship diagrams are most often used when a problem is complex (they facilitate the determination of dependencies between various factors) when it is very important to set forth a proper sequence of actions or when we have to find out if a given problem is a cause or an effect in the global approach. Drawing an interrelationship diagram should consist of the following phases:

– description of a problem as a central node of the diagram;
– indication of causes of a problem, forming the other nodes of the diagram;

Table 1. Characteristics of basic fire causes and the influencing factors

Basic causes of fires	Factors influencing the fire causes
1. Damage to electrical equipment and cables	a) Improperly selected material or its aging (Gawdzińska & Gucma, 2015). b) Improper handling / lack of equipment maintenance (regular surveys). c) Bad quality of the prepared safety mechanisms and connections. d) Design/structure errors (lack of proper ventilation, placement of equipment in wrong places). e) Influence of environmental conditions (exposure to atmospheric conditions – dust and humidity). f) Lack or malfunction of safety systems (insulation resistance measurement, fuses, etc.). g) Human error (flooding, cutting, negligence of service work etc.)
2. Damage to mechanical equipment (e.g. fires and explosions in ship power plant)	a) Improperly selected material or its aging (Chybowski & Kuźniewski, 2015). b) Extreme conditions of device operation (overheating or mechanical overload). c) Lack or malfunction of safety devices. d) Bad quality of prepared safety mechanisms, connections or materials (Gucma, Gawdzińska & Kwiecińska, 2015). e) Spill of fuel or working fluids. f) Human error (improper use of tools or machines, negligence of maintenance work, non-compliance with safety rules) (Bejger & Drzewieniecki, 2015)
3. Damage to ship's hull or its equipment	a) Improper ballasting of the ship. b) Spill of fuel or working fluid as a result of fracture in the ship's hull. c) Improperly designed hull plating. d) Improperly selected material or its aging. e) Improper ship's operation during loading (overloading the hull with bending/torsional forces). f) Human error (collision, grounding)
4. Damage caused by external factors, so-called force majeure	a) Atmospheric conditions (storm, electrical discharges). b) Lack of control of port, tug boat operators, cranes due to lack of communication etc.
5. Damage occurring during maintenance work/repairs, e.g. while welding, soldering, grinding etc.	a) Non-compliance with occupational safety rules(leaving oiled rags or containers with operational liquids in a wrong place, wrongly planned work, smoking in forbidden places). b) Failures to follow work permit procedures (lack of permission, improperly secured work area, lack of fire extinguishers, improper assessment of work conditions)
6. Spontaneous ignition of cargo (in cargo holds, containers, receptacles etc.)	a) Improper cargo protection during transport or un/loading operations

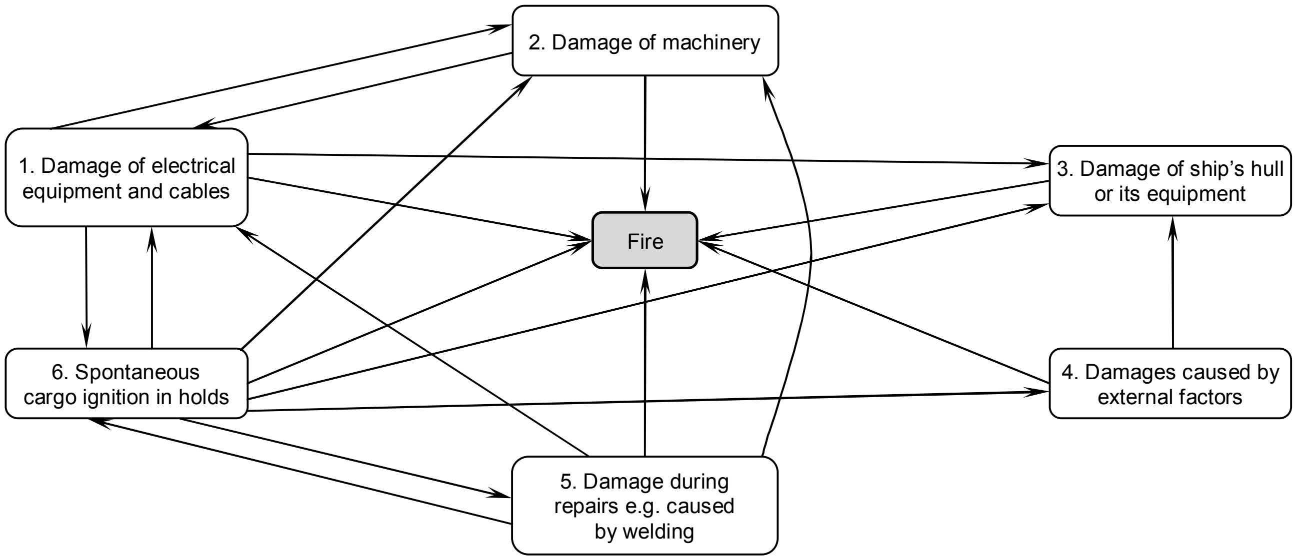

Figure 6. Diagram of interrelationship presenting cause-and-effect links leading to fires on ships

– indication of interrelations between the causes and connection of the related causes using arrows, determining an order of events (arrows should connect causes to corresponding effects, as well as relations between causes; the arrows have a direction from a cause to an effect, indicating a sequence of actions and relations between a cause/factor and an effect/result);
– quantification of the relations (each relation should be assigned a weight, defined by a number of points representing their strength of interaction, e.g.: 6 pts. – strong relation, 3 pts. – medium relation, 1 pt. – weak relation) (Hamrol, 2012, pp. 291–293);
– ranking of the analyzed factors based on the number of points.

The problem herein considered is fire on board ships, one of the most frequent marine accidents. On the basis of the conducted survey questionnaire (174 people employed in the shipping industry, a representative sample, according to (Sobczyk, 2013; Internetowy Podręcznik Statystyki, 2015)), this author has attempted to group, systematize, and label fire causes on merchant ships and fishing vessels. Table 1 divides the fire causes into six groups. It also contains factors influencing the causes of fire. Moreover, the strength of interaction of the particular causes with the other causes and effects is indicated, using an interrelationship diagram presented in Figure 6.

Summary and conclusions

The creation of interrelationship diagrams allows us to detect the most important problems and explain cause-and-effect relations in the case of complex problems (herein fires on board ships are the key issue). Fire on board ship is caused by a number of factors divided here into six main groups labeled as “fire causes”: damage to electrical equipment and cables, damage to machinery (for example, fire or explosion in the marine power plant), damage to ship’s hull or its equipment, damage caused by external forces – force majeure, damage occurring during maintenance work / repairs and spontaneous ignition of cargo. This classification of marine fire causes is the author’s proposal and may be modified.

The data from the conducted survey questionnaire led to an observation that spontaneous ignition of cargo has the greatest strength of connections (and interactions). It influences the greatest number of fire causes (with a total of eight connecting lines, some bidirectional, see Figure 6). Damage to electrical equipment and cables, is the second group regarding the strength of influence on the examined problem, with four direct relations: machinery damage, cargo spontaneous ignition, ship’s hull damage and damage during maintenance and/or repairs. This interaction is caused mostly by the factors such as material aging or human errors: flooding, cutting, negligence in maintenance or repair work, lack of equipment maintenance, bad quality of safety arrangements, improper connections or design errors. The situation is similar in the case of the following groups (Figure 6): damage during maintenance/repairs (five bidirectional interactions) and damage to machinery (four bidirectional interactions). The group whose influence on the other groups is the weakest represents ‘damage caused by external factors’ that is *force majeure*. Paradoxically, this group is the least "predictable" group of interactions. That is why the question arises: How much is safety at sea affected by factors influencing the causes of fire? This problem will be further studied and considered by the author and will be presented in consecutive publications. The interrelationship diagram is a starting point for further analyses.

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