DEFICIENCY ANALYSIS IDENTIFIED IN PSC INSPECTIONS USING EVENT TREE ANALYSIS

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Abstract: In the study, PSC inspections data performed in Paris MoU between the years 2016 and 2020 were analysed with the purpose of providing reasonable decision supports for key stakeholders such as ship operators, national and international authorities, cargo owners and classification societies in terms of enhancing safety on board ship and minimizing sub-standard ships in maritime transport. The probabilistic analysis is conducted with the help of Event Tree Analysis (ETA) method on deficiency risk areas respect to the number of deficiencies in each area. In the analysis, the deficiency risk areas are prioritized respect to the different combination of ship type and ship age. In the analysis made on the inspections data, it was found that the number of deficiencies detected under each relevant main item (deficiency risk areas) show significant variation for type of ship and age of ship. With the conducted analysis, in the study, it is aimed to contribute to the more effective inspection by focusing on certain deficiency risk areas in line with the ship type and ship age in the ship inspections.

Key words: deficiency risk area, Event Tree Analysis (ETA), Port State Control (PSC), ship inspection

1. INTRODUCTION

With a total transportation volume of 11.08 billion tons reached in 2019, maritime transportation is the indispensable instrument of the global freight transportation, and it is expected to expand by 4.8 percent in 2021 [1]. On the other hand, maritime transportation is one of the most dangerous industries with its hazardous shipboard operations [2]. Therefore, it is an essential issue for shipping companies to ensure the safe transport of cargoes with the aim of minimizing potential damages to life, property and environment. In order to provide the safety of life, property and environment in the maritime transportation and to prevent irreversible accidents and incidents and to reduce the existing risks, the shipping companies are responsible for ensuring the ships under their management comply with the requirements of the international maritime regulations. According to the researches, one of the critical causes of the increasing number of accidents in maritime transportation are defined as the sub-standard ships. Researchers such as Bateman (2011) [3] and Pike et al. (2012) [4] examined the effects of sub-standard ships in shipping accidents. Ship-related accidents can cause serious losses both for the maritime industry and for society [5].

The primary responsibility of assuring the ships to comply with the international maritime standards rests with the flag states. However, the accidents experienced show that the flag states cannot fully fulfil this responsibility at the desired level. With the inspections carried out by the port states, this inadequacy is tried to be eliminated with the aim of the determination substandard vessels [6]. Therefore, port state control (PSC) inspections have been accepted as a one of the critical safety barriers in maritime transportation since from the marine accidents caused catastrophic consequences such as Amoco Cadiz accident in 1978 and Castilla de Belfer accident in 1983 [7]. Subsequently was signed in in 1982, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Switzerland and the United Kingdom signed a Paris Memorandum of Understanding (Paris MoU) on PSC and with the inspection of the ship with foreign flags has started. The coordination of PSC activities by groups of port states working under a Memorandum of Understanding (MoU) has enabled a more unified approach to inspection. Today, after the Paris MoU, eight more MoUs have been signed and port state controls have been expanded worldwide: Vina del Mar Agreement (1992), Tokyo MoU (1993), Caribbean MoU (1996), Mediterranean MoU (1997), Indian Ocean MoU (1998), Abuja MoU
(1999), Black Sea MoU (2000), and Riyadh MoU (2004). The general purpose of the nine MoUs established with the participation of port states is to inspect all foreign flagged vessels approaching ports and detection of substandard vessels.

Factors such as the increase in the number of ships, growth of the handled volumes and acceleration in port activities affect the logistic performance of coastal countries in terms of speed [8]. However, the limited number of PSC Officers in charge of the inspections is an important constraint for the efficient inspection of all foreign flagged ships at ports. With the aim of improving the efficiency of PSCs with the limited human resources, in 2011, a new inspection regime (NIR) was introduced by Paris MoU. Within the scope of the inspection regime, parameters such as ship type, ship age, ship flag performance, ship class performance (recognized organization), ship company, number of detention and number of deficiencies are evaluated and ship risk profiles are calculated for each ship entered to ports. The general ship risk profile calculation model introduced by Paris MoU is presented in Table 1 [9], [10].

| Table 1. Ship Risk Profile [9], [10] |

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of ship</td>
<td>Chemical tanker</td>
<td>All types</td>
<td>All types</td>
</tr>
<tr>
<td>Age of ship</td>
<td>Chemical tanker</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Flag</td>
<td>Black, MFR, HR, M&amp;FF</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Company Performance</td>
<td>Chemical tanker</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Deficiency</td>
<td>Chemical tanker</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Weighting points</td>
<td>Chemical tanker</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Criteria</td>
<td>Chemical tanker</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Considering the ship risk profiles, it is aimed to make an efficient inspection planning by determining the type and period of the inspections. However, in the introduced inspection regime by Paris MoU, there are some prerequisites for determining the type of inspection in line with the ship risk profile. Carrying out the expanded inspection to ships with low and standard risk profile, the ship age has to be over 12 years and ship type has to be a bulk carrier, a tanker and a passenger ship, or clear ground has to be detected by the PSCO for detailed inspection [11]. This situation narrows the scope of the inspection by determining the type of inspection as initial inspection for ships with low and standard risk profile. There are a limited number of studies in the literature on solving this problem. Most of the studies in the literature have focused on solving the relationships between the Ship Risk Profile (SRP) criteria, rather than the SRP, and the deficiency risk areas by different methods for an effective ship inspection. As one of the example studies, Mejia at al. (2010) analysed the deficiency risk areas and the variables of ship age, ship flag, ship type, ship class using the probit regression model and it was determined that focusing on certain deficiency risk areas by evaluating the ship parameters can increase the inspection efficiency [12]. Another example study, Cariou at al. (2012) found that the ship type and deficiency risk area are the parameters that affect the ship detention and stated that these parameters should be examined while determining the inspection period [13].

In this study, to present a solution for the above-mentioned problem, it is aimed to shape ship inspections within the framework of risky areas arising from ship age and type with using the Event Tree Analysis (ETA). In the shaping of ship inspections, a new approach based on the ship risk profile based on the Paris MoU inspection regime has been tried to put forward an inspection model based on the relationship between ship risk factors and deficiency risk areas. It is aimed to contribute to the more effective inspection by focusing on certain deficiency risk areas in line with the ship risk factors in the ship inspections to be conducted with the inspection model.

2. EVENT TREE ANALYSIS (ETA)

The ETA was first introduced in the atomic energy field and extended to other fields in the following years [14]. The ETA is an inductive risk analysis technique to assess likelihood (in a probabilistic context) of an accident [15]. It is applied in order to analyse an initiating event which has influences on a variety of results and it is a suitable way to analyse the reasons for a disaster. In the ETA, an initiating event such as the malfunctioning of a system, process, or construction is considered as the starting point and the predictable accidental results, sequentially propagated from the initiating event, are presented graphically. It is called an event tree because the graphical presentation of sequenced events grows like a tree as the number of events increase. An event tree consists of an initiating event, probable subsequent events and final results caused by the sequence of events. Probable subsequent events are independent to each other and the specific final result depends only on the initiating event and the subsequent events following. Therefore, the occurrence probability of a specific path can be obtained by multiplying the probabilities of all subsequent events existing in a path. The main steps to perform ETA can be described as follows [16]:

41
1. Identification of the initiating events
2. Identification of the safety barriers
3. Identification of the intermediate events
4. Building of the event tree diagram
5. Description of the (potential) resulting accident sequences
6. Determination of the event failure probabilities
7. Calculation of the probabilities for the identified consequences
8. Presentation of the analysis results

ETA provides the possibility of bottom-up approach for each path and enables comparing/estimating of various paths in the tree [17]. It also provides a quantitative evaluation by calculating the probability values of each possible outcome. In this way, it makes it possible to rank among the results and to identify the riskier paths for taking preventive measure. Therefore, ETA method is widely used in safety critical industries such as chemical and nuclear industries [18], [19]. From the perspective of the maritime industry, there are some studies utilizing ETA for risk assessment such as ship collision [20], marine accident [21], mooring operation [22], and marine pollution [23]. Different from these studies, we use ETA to analyse the PSC inspections data to obtain precious findings for the improvement of PSC efficiency.

3. ANALYSIS OF PARIS MoU INSPECTIONS: 2016 – 2020

In this study, PSC inspections data performed in Paris MoU between the years 2016 and 2020 were analysed. In the preliminary analysis made on the inspections data, it was determined that the number of deficiencies detected under each relevant main item (deficiency risk areas) show significant variation for type of ship and age of ship. Accordingly, the probabilistic analysis is conducted using Event Tree Analysis (ETA) method on the deficiency risk areas with respect to the number of deficiencies in each area. In the analysis, the deficiency risk areas are prioritized respect to the different combination of ship type and ship age. The analysis procedure of this study is structured on the steps in Section 2 and it is illustrated in Figure 1.

With respect to the analysis, it is aimed to contribute to the more effective inspection by focusing on certain deficiency risk areas in line with the ship type and ship age. Additionally, it is expected to provide reasonable decision supports for key stakeholders such as ship operators, national and international authorities, cargo owners and classification societies in terms of enhancing safety on board ship and minimizing substandard ships in maritime transport.

3.1 Step-1/Identification of the initiating event:

In the study, 84,824 ship inspections performed under the Paris MoU between 2016 and 2020 obtained from THETIS [24] database were examined. According to the analysed dataset it is seen that 2,871 ships were detained. In this study, ship detention was considered as the initial event for examining risky areas in ships.

3.2 Step-2/Identification of the safety barriers:

In the Paris MoU inspection regime, “ship age” and “ship type” parameters have great importance in the definition of the ship risk profile [25-33]. When calculating the ship risk profile, 2 points are given if the ship type is in high risk group and 1 point is given if the ship age is in high risk group. This rating indicates that ship type is more important than ship age when determining ship risk profile. So, while the ship risk profile is handled with the event tree, the first safety barrier is identified as ship type and the second is the “ship age”.

3.3 Step-3/ Building of the event tree diagram:

In the ETA, deficiency risk areas were analysed with respect to the safety barriers identified in Step-2 for the detained ships to define which deficiency risk areas are affected by ship age and ship type. Deficiencies detected in ships inspected under the Paris MoU are classified 17 different risk areas presented in Table 2. In this way, it is aimed to determine the risky areas that should be concentrated in ship inspection by considering ship age and type.

Table 2. Deficiency Risk Areas [34]

<table>
<thead>
<tr>
<th>Codes</th>
<th>Deficiency Risk Area</th>
<th>Codes</th>
<th>Deficiency Risk Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>Documentation</td>
<td>R10</td>
<td>Safety of navigation</td>
</tr>
<tr>
<td>R2</td>
<td>Structural condition</td>
<td>R11</td>
<td>Lifesaving appliances</td>
</tr>
<tr>
<td>R3</td>
<td>Watertight/Weathertight condition</td>
<td>R12</td>
<td>Dangerous goods</td>
</tr>
<tr>
<td>R4</td>
<td>Emergency Systems</td>
<td>R13</td>
<td>Propulsion and auxiliary machinery</td>
</tr>
<tr>
<td>R5</td>
<td>Radio communications</td>
<td>R14</td>
<td>Pollution prevention</td>
</tr>
<tr>
<td>R6</td>
<td>Cargo operations</td>
<td>R15</td>
<td>ISM</td>
</tr>
<tr>
<td>R7</td>
<td>Fire safety</td>
<td>R16</td>
<td>ISPS</td>
</tr>
<tr>
<td>R8</td>
<td>Alarms</td>
<td>R17</td>
<td>MLC 2006</td>
</tr>
<tr>
<td>R9</td>
<td>Living and working conditions</td>
<td></td>
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</tr>
</tbody>
</table>

Figure 1 Flowchart of ETA [16]
According to the aforementioned information, the constructed event tree diagram is illustrated in Figure 2.

3.4 Step-4/ Description of the (potential) resulting accident sequences:

In the analysis, detained ships were selected as initial condition. Following, detained ships were categorized according to the ship age and ship type respectively. Finally, the obtained intermediate events are divided into the deficiency risk areas as seen in Figure 2.

The probabilities for the deficiency risk areas according to the ship age and ship type were calculated by Equation (2).

\[
P(\text{Deficiency Risk Area} | \text{Ship Detention}) = P(T_i \cap A_j \cap R_k) = P_{T_i} P_{A_j} P_{R_k} \tag{2}
\]

where \( T \) is risk of ship type with \( i \) is neither high risk or low risk.

where \( A \) is risk of ship age with \( j \) is neither high risk or low risk.

where \( R \) is deficiency risk area with \( k \) is 1, 2, 3, 4, 5, 6, …., 17.

3.7 Step-7/Presentation of the analysis results:

With the help of Equation (1) and (2), the calculated probabilities for the ship type risk, ship age risk, deficiency risk areas, and consequences of each scenario are presented in Figure 3.
4. FINDINGS & DISCUSSION

In the study four different event tree scenarios were analysed: (i) high risk ship type – high risk ship age, (ii) high risk ship type – low risk ship age, (iii) low risk ship type – high risk ship age, (iv) low risk ship type – low risk ship age. The findings of the research show that, the deficiency risk areas that cause the ships to be detained show variations according to the ship age and ship type factors. In Figure 4, the obtained results for each event tree scenario were graphically presented with the line colours defined as follows:

- High risk type - high risk age (HR.T-HR.A blue line)
- High risk type - Low risk age (HR.T-LR.A red line)
- Low risk type - High risk age (LR.T-HR.A green line)
- Low risk type - Low risk age (LR.T-LR.A grey line)

![Figure 4 Ship detention probabilities based on ship risk factors and deficiency risk areas](image)

It is seen from the result the highest detention rate belongs to the low-risk ship types with high risk ship age, while the lowest detention rate belongs to the high-risk ship types with low risk ship age. In each event tree scenario, “International Safety Management (ISM)” deficiency risk area has the highest detention probability. Therefore, improvement of the implementation effectiveness of the ISM Code still is an important issue to be focused on in maritime transportation. The ranking of the deficiency risk areas with respect to their probabilities for each event tree scenario is presented in Table 3 in descending order.

For the high-risk ship type with high risk ship age, ISM (R15), cargo operations (R6) and living and working conditions (R9) are the top three deficiency risk areas respectively to be concentrated on. For the high-risk ship type with low risk ship age, ISM (R15), Dangerous Goods (R12) and Alarms (R8) are the highest deficiency risk areas. ISM (R15), Alarms (R8) and Cargo operations (R6) are found as the highest deficiency risk areas for the low-risk ship type with high risk ship age. ISM (R15), Dangerous goods (R12) and Cargo operations (R6) are found as the highest deficiency risk areas for the low-risk ship type with low risk ship age. The findings of the study present information about the deficiency risk areas that should be focused on for the port authorities, and for the ships will be inspected, it gives information about which deficiency risk areas they should prepare before the inspection. Additionally, the findings help to optimize necessary measures to be taken to improve the safety.

Table 3. Ship deficiency risk area rankings as per event tree scenarios

<table>
<thead>
<tr>
<th>Ranking</th>
<th>High Risk Type - High Risk Age</th>
<th>High Risk Type - Low Risk Age</th>
<th>Low Risk Type - High Risk Age</th>
<th>Low Risk Type - Low Risk Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R15</td>
<td>R15</td>
<td>R15</td>
<td>R15</td>
</tr>
<tr>
<td>2</td>
<td>R6</td>
<td>R12</td>
<td>R8</td>
<td>R12</td>
</tr>
<tr>
<td>3</td>
<td>R9</td>
<td>R8</td>
<td>R6</td>
<td>R6</td>
</tr>
<tr>
<td>4</td>
<td>R8</td>
<td>R9</td>
<td>R16</td>
<td>R8</td>
</tr>
<tr>
<td>5</td>
<td>R5</td>
<td>R5</td>
<td>R4</td>
<td>R9</td>
</tr>
<tr>
<td>6</td>
<td>R2</td>
<td>R4</td>
<td>R5</td>
<td>R4</td>
</tr>
<tr>
<td>7</td>
<td>R4</td>
<td>R2</td>
<td>R2</td>
<td>R13</td>
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<tr>
<td>8</td>
<td>R16</td>
<td>R13</td>
<td>R12</td>
<td>R14</td>
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<tr>
<td>9</td>
<td>R13</td>
<td>R16</td>
<td>R3</td>
<td>R5</td>
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<tr>
<td>10</td>
<td>R10</td>
<td>R3</td>
<td>R9</td>
<td>R3</td>
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<tr>
<td>11</td>
<td>R14</td>
<td>R10</td>
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<td>R2</td>
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<tr>
<td>12</td>
<td>R11</td>
<td>R6</td>
<td>R11</td>
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<tr>
<td>13</td>
<td>R12</td>
<td>R14</td>
<td>R7</td>
<td>R17</td>
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<tr>
<td>14</td>
<td>R3</td>
<td>R11</td>
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<td>R16</td>
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<tr>
<td>15</td>
<td>R1</td>
<td>R7</td>
<td>R10</td>
<td>R10</td>
</tr>
<tr>
<td>16</td>
<td>R7</td>
<td>R17</td>
<td>R17</td>
<td>R7</td>
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<tr>
<td>17</td>
<td>R17</td>
<td>R1</td>
<td>R1</td>
<td>R1</td>
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</tbody>
</table>

5. CONCLUSION

Port state controls is one of the essential instruments to ensure the safety in maritime transportation via monitoring and detecting substandard ships. At this point, increasing the efficiency of PSCs through development of the optimized inspection plan can be accepted as a significant consideration. In this study, PSCs performed in Paris MoU between the years of 2016 and 2020 were analysed using ETA to figure out most frequently detected deficiency risk areas depending on ship age and ship type factors. As a result of the analysis, unlike the risk factors (ship age and ship type factors) accepted in the Paris MoU inspection regime, the higher detention rate of the ships with low risk indicates that the inspection regime can be improved. On the other hand, it is possible to give priority to different risk areas according to ship risk factors and thus it will possible to perform more efficient PSC. In addition, the results obtained in the study concretely reveal which
deficiency risk areas should be paid attention by the ship management companies in the PSCs depending on the ship type and ship age factors.

In conclusion, the findings of this paper provide precious information for maritime industry stakeholders. For port states, it provides information to increase the effectiveness of PSC inspections. It offers a new approach for flag states to monitor and to analyse the inspection performance of ships flying their flags. For ship management companies, it provides information that can improve the inspection performance of the ships under their management. Further researches will be focused on improving the analysis results by including other risk factors used in the determination of ship risk profile to perform an in-depth analysis.

6. ACKNOWLEDGMENTS

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7. REFERENCES


