ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1216455

EXAMPLES OF BOW-TIE RISK ANALYSIS AT MARITIME TRANSPORT

Leszek Smolarek

Gdynia Maritime University
Department of Transport and Logistic
Morska Street 81-87, 81-225 Gdynia, Poland
tel.: +48 586901838, fax: +48 586216618
e-mail: leszsmol@am.gdynia.pl

Abstract

There are different approaches to risk assessment. The SOLAS Convention is the most important safety instruments at maritime transport. The biggest risk is a major navigational incident because it can result in fatalities and pollution. Possibly the major cause of collision incidents is not fully understanding and complying the COLREGS rules. It is not possible to create a simple flowchart to define a suitable approach to risk assessment of a ship. However, some of broad factors can be used to aid the selection of a suitable risk assessment approach in maritime transport. In the literature, we can find many methods and applications for maritime transportation risk analysis. There is a recent focus on foundational issues in risk analysis, especially for intensified research on fundamental concepts and principles. This paper presents the attempt of applying the Bow-Tie methodology at maritime transport. The benefits of using Bow-Tie diagrams for risk assessment have been showed at use, for many of technical systems and processes. This methodology known as barrier diagrams, provide a readily understandable visualization of the relationships between the causes of the failure's event, the escalation of such events to a range of possible outcomes, the controls preventing the event from occurring and the preparedness measures in place to limit the consequences. The Bow-Tie is very useful for structured assessment and communication of risks.

Keywords: *transport, risk analysis, Bow-Tie method, AHTS ships*

1. Introduction

There is no single correct approach for a safety activity. There are different approaches to risk assessment and some of that are more suitable than others [1, 2]. It is not always obvious which of the many different specific methods should be selected.

The safety of life at sea has been a matter of concern to IMO since its inception, and in this time many regulations and conventions have been adopted to improve operational safety conditions by IMO, [21]. At first to improve safety we can use a process known as formal safety assessment. It is a process for assessing the risks associated with shipping activity and for evaluating the costs and benefits of reducing hazards.

It is not possible to create a simple flowchart to define a suitable approach to risk assessment of a ship. But some of broad factors can be used to aid the selection of a suitable risk assessment approach in maritime transport. [4, 7-9]. These factors include, Fig. 1:

- Lifecycle stage,
- Major hazard potential,
- Risk decision context.

After that, we would select amongst the wide range of methods for risk assessment.
These include [4, 5, 7, 10-15]:

- Hazard identification tools:
  - Judgement,
  - FMEA – Failure Modes and Effects Analysis,
  - SWIFT – Structured What-If Checklist Technique,
  - HAZOP – Hazard and Operability Study.

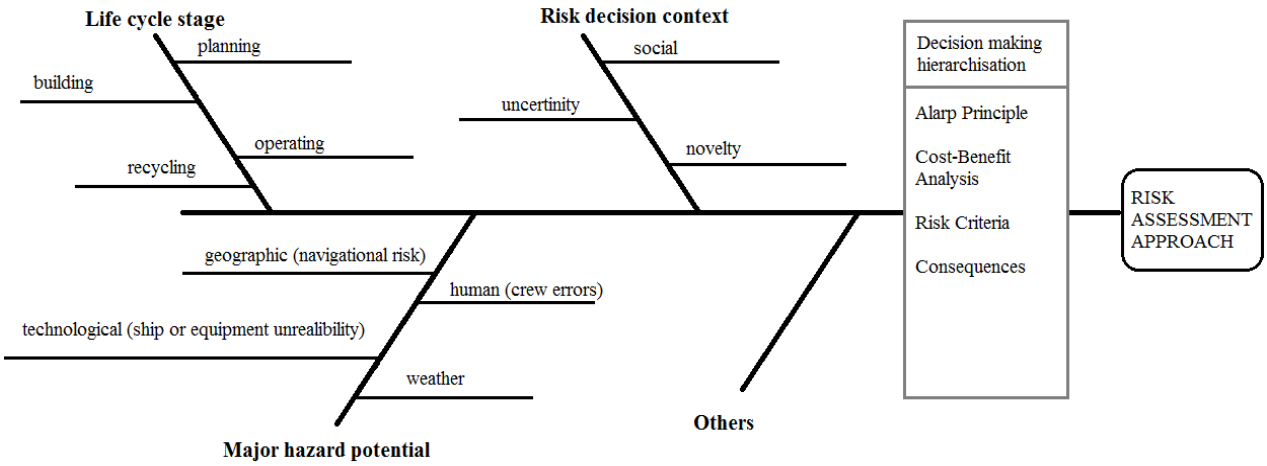

Fig. 1. Examples of factors can be used to aid the selection of risk assessment approach in maritime transport

- Risk Assessment approaches:
  - Rules based approaches: regulations, approved codes of practice, Class Rules,
  - Engineering judgement,
  - Qualitative risk assessment,
  - Semi-quantitative risk assessment,
  - Quantitative risk assessment,
  - Value-based approaches.
- Risk Assessment techniques:
  - Qualitative (risk matrix),
  - Semi-Qualitative use of structured tools (fault trees, events trees) – Bow-Tie approach,
  - Quantitative risk assessment (coarse and detailed levels),
  - Stakeholder consultations.
- Hierarchy of Options approaches for risk reduction:
  - Eliminate the hazard,
  - Prevent the occurrence,
  - Mitigate the consequences,
  - Escape, Evacuation, Rescue and Recover,
  - Decision-making.

The SOLAS Convention is the most important safety instruments at maritime transport. The biggest risk is a major navigational incident because it can result in fatalities and pollution. Possibly the major cause of collision incidents is not fully understanding and complying the COLREGS rules.

2. Bow-Tie method

Bow-Tie – a diagram, shaped like a Bow-Tie, which visualises the risk (hazards, barrier, consequences) in one picture. The diagram creates a differentiation between proactive and reactive risk management [8, 17, 20]. It gives you an overview of multiple plausible scenarios, in only one picture and provides visual explanation of a risk.

The Hazard is a beginning of any Bow Tie. The idea of a Hazard is to find the operation, at maritime transport process that could have a negative impact on ship, cargo, crew or environment. They should be formulated as normal aspects of the transport system. The rest of the Bowtie is devoted to how we could keep that normal but hazardous operation from turning into disaster. Using HAZID, we could get a list of all possible Hazards [8]. Bowties are useful for Hazards with a high potential to harm.

At first we chose the Hazard than define the Top Event. This is the event, which activated the Hazard. The Top Event is chosen simply just before events start causing actual damage. The Top Event can start with a generic "Loss of control", [17]. During the Bowtie preparing process, we should revisit it a couple of times to sharpen the formulation.

At the left side we have threats, everything which cause the Top Event. Consequences, at right, are the result from the Top Event. For some Top Events could be more than one Consequence (specific Consequence event descriptions).

After that you should think about Barriers, how you want to prevent for example environmental damage, [20]. The actual scenario makes easier to come up with specific Barriers. Barriers interrupt the scenario so that the threats do not result in the Top Event or do not escalate into the consequences. Barriers are never perfect. The Escalation factor describes anything that will make a Barrier fail.

Diagram has several advantages for use in safety cases, it shows:

- the full range of initiating events,
- the intervening safeguards,
- the actual way in which these combine and escalate,
- the consequences side shows barriers in an equivalent manner
- the many possible consequence outcomes,
- the linkage of the barriers to the safety management system.

Bow-tie analysis represents the semi-quantitative approach to risk [20], Tab. 1.

Tab. 1. Example of application of Bow-Tie method [23]

Risk Level	Risk Management	Level of Analysis and Control
High Risk	Reduce to medium or low level	Detailed Analysis
Medium Risk	Risk reduction to ALARP	Performance Measurement
Low Risk	Continue operations	Standard Competence

The diagram shows us if the suitable safeguards ae considered for any hazard.

3. Examples of using Bow-Tie for maritime transportation risk analysis

In the literature, we can find many methods and applications for maritime transportation risk analysis. There is a recent focus on foundational issues in risk analysis, especially for intensified research on fundamental concepts and principles.

A maritime risk analysis consists of two steps:

- determination of the probability of a ship accident,
- estimation of the consequences following the accident.

To determine the probability of an accident researcher needs to analyse the accident scenarios. The paths of Bow-Tie method help in preparations of the scenarios, Fig. 3.

3.1. Anchor Handling Tug Supply Vessels

Anchor handling tug supply vessel (AHTS) can carry out several major operations like towing, anchor handling, supply, standby and so on offshore [3, 6, 8].

Anchoring handling is a dangerous task. In this process, some of the risk factors such as long hours, bad weather, slippery decks, hand and finger pinch hazards and proximity to heavy buoys and wires under strain are involved. Anchor handling is connected with a number of special marine operations, Fig. 2. The high tensions experienced in chains and wires may cause high heeling moments and may cause high transverse and/or astern movements of the anchor-handling vessel. The vessels motion through the water may also be affected by high hauling speed on the anchor-handling winch or as result of any loss of bollard pull [6, 8].

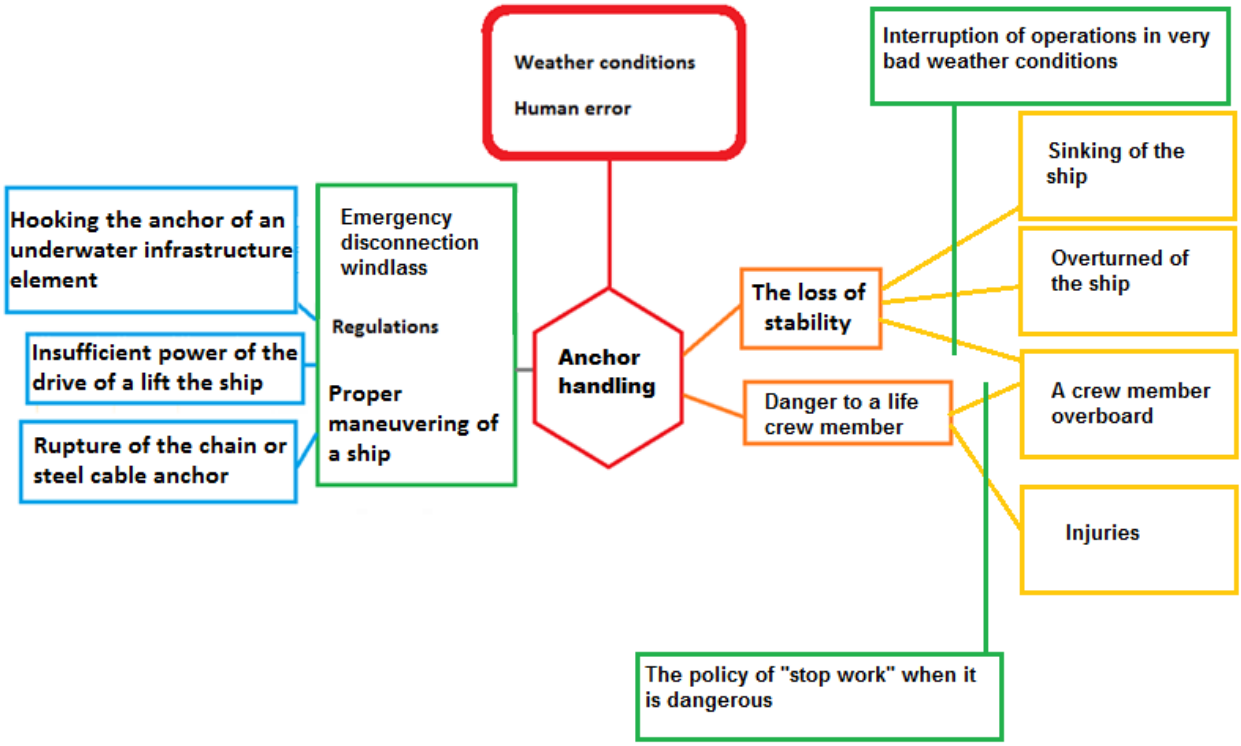

Fig. 2. Diagram Bow-Tie for threats of anchor handling

As an example, we use the case of AHTS vessel "Bourbon Dolphin" on the North Sea (12.04.2007). The crew performed work setting anchors with full knowledge of exceedance load lobby. This resulted in an immediate overturning of the ship [16].

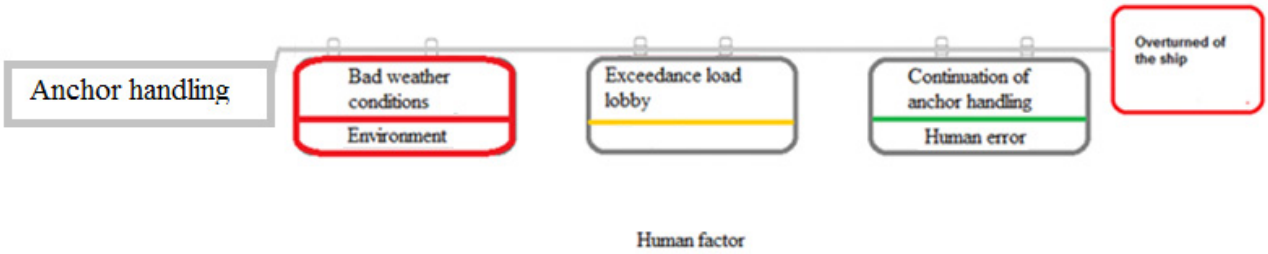

Fig. 3. Path Bow-Tie method of initiating event leading to the overturning of the ship

3.2. Oil tanker vessel

Tanker is a very large ship, which carries petroleum products in several or many big tanks. Tankers are in the hazards as any other ship but there are some other hazards that are specific to it [5, 11-14, 19]. The main hazards are:

- collision,
- environment pollution,
- explosion,
- fire,
- sinking.

Categories of initiating events that could lead to cargo losses, fatalities or environmental damage, with involving losses of a ship are described below:

- External factors – (severe weather, collision, etc.),
- Personnel factors – (commercial exploitation or maintenance incidents, human error),
- Internal factors – (ship unreliability, error in design or construction).

Oil tankers pose the highest environmental risk, Fig. 3, 4.

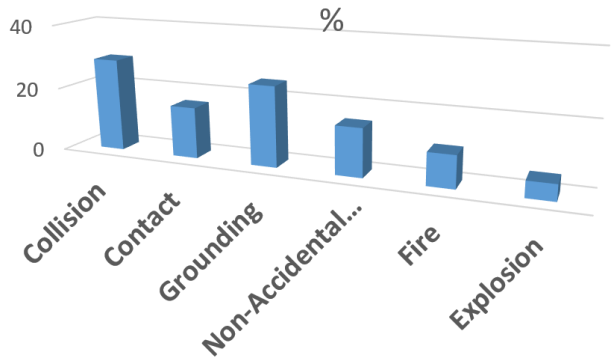

Fig. 3. The distribution of the accident categories under investigation pertaining to AFRAMAX tankers, according to POP&C analysts [14]

Bow-Tie diagrams could be used to depict an environmental risk connected with oil tanker accidents, Fig. 4.

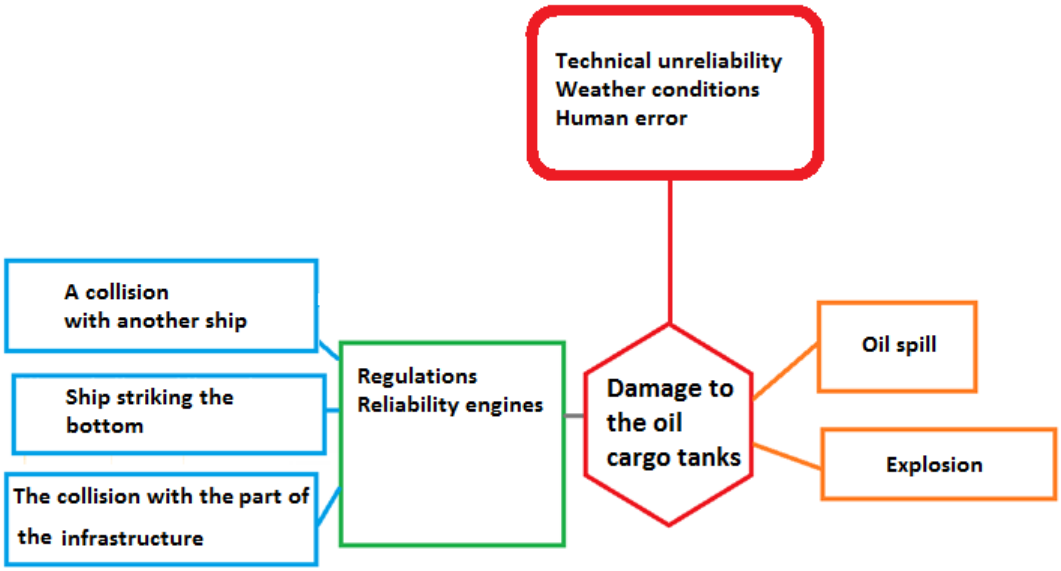

Fig. 4. Diagram Bow-Tie for threats of damage to the oil cargo tanks

4. Conclusions

Bow-Tie diagrams could be a very useful tool to depict and maintain a real-time, working risk management system in maritime transport. According of their graphical nature, the biggest advantage of Bow-Tie diagrams is the ease to understanding of hazards management by all crew members. The method could be used to express the basic causes and consequences of potential accidents. Bow-Tie gives a clear visualization of correlations between causes, escalations, controls and consequences. The Bow-Tie is very useful for structured assessment and communication of risks.

References

[1] Aven, T., *Quantitative risk assessment: the scientific platform*, Cambridge University Press, New York, USA 2011.
[2] Aven, T., *Risk Analysis: Assessing Uncertainties beyond Expected Values and Probabilities,* John Wiley & Sons, Ltd, University of Stavanger, Norway 2008.

[3] Chen, W., *Design and Operation of Anchor Handling Tug Supply Vessels (AHTS),* University of Stavanger, 2013.
[4] COWI. Risk analysis of sea traffic in the area around Bornholm, P-65775-002, 2008.
[5] Cross, R. B., (V), ABSG Consulting and Jorge E. Ballesio (V), *A Quantitative Risk Assessment Model for Oil Tankers*, Principal Engineer, American Bureau of Shipping, ABS Technical Papers, pp. 343-357, 2003.
[6] Digital version, Anchor Handling Manual, Anchor manual, www.vryhof.com, Vryhof Anchors BV, 2010.
[7] Debnath, A. K., *Traffic-conflict-based modelling of collision risk in port waters*, PhD dissertation. National University of Singapore, Singapore 2009.
[8] Det Norske Veritas, Marine risk assessment, Offshore Technology Report 2001/063, London Technical Consultancy, Palace House, 3 Cathedral Street, London SE1 9DE, United Kingdom.
[9] Goerlandt, F., Montewka, J., *Maritime transportation risk analysis: Review and analysis in light of some foundational issues*, Reliability Engineering and System Safety, 138, pp. 115-134, 2015.
[10] Gucma, S., *Conditions of safe ship operation in sea waterway systems*. Zeszyty Naukowe, Akademia Morska w Szczecinie, 36(108), Z. 1, pp. 55-58, 2013.
[11] Gunton, T., *A Spill Risk Assessment of the Enbridge Northern Gateway Project*, School of Resource and Environmental Management Simon Fraser University, 2013.
[12] Akhtar, J., Bjørnskau, T., Jean-Hansen, V., *Oil spill risk analysis of routeing heavy ship traffic in Norwegian waters*, WMU Journal of Maritime Affairs, Vol. 11, Is. 2, pp. 233-247, 2012.
[13] Lindgren, K., Sosnowski, M., *Safety Assessment for Oil Tankers and Container Vessels Focused on Fire and Explosion In the Machinery Space, Department of Fire Safety Engineering and Systems Safety*, Lund University, Sweden, Report 5312, Lund/Hamburg 2009.
[14] Papanikolaou, A., Eliopoulou, E., Mikelis, N., Aksu, S., Delautre, S., *Casualty Analysis of Tankers,* The Royal Institution of Naval Architects, Learning from Marine Incidents III, London, UK 2006.
[15] Przywarty, M., *Probabilistic model of ships navigational safety assessment on large sea areas,* In: Proceedings of the 16th International Symposiumon Electronics in Transport, Ljubljana, Slovenia 2008.
[16] Soliwoda, J., *Praktyczna ocena stateczności w eksploatacji a bezpieczeństwo statku*, Zeszyty Naukowe Akademii Morskiej w Gdyni, No. 69, pp. 95-104, 2011.
[17] Hamzah, S. Z., Use Bow Tie Tool for Easy Hazard Identification, 14th Asia Pacific Confederation of Chemical Engineering Congress, Singapore, 21-24 February 2012, http://rpsonline.com.sg/proceedings/9789810714451/html/SyedZaifulHamzah.pdf.
[18] http://www.marineinsight.com/videos/watch-dangerous-anchor-handling-process-crew-life-risk/, 13.06.2016.
[19] http://www.itopf.com/knowledge-resources/data-statistics/statistics/, 13.06.2016.
[20] Risktec, Practical HSE Risk Management – An Introduction to the Bow-tie Method Presentation to the International Conference for Achieving Health & Safety Best Practice in Construction, Dubai, UAE, 26th-27th February 2007 By Gareth Book, Risktec Solutions Ltdrisk, www.risktec.com, 13.06.2016.
[21] http://www.imo.org/en/OurWork/Safety/Pages/Default.aspx.