
CHAPTER 5

Analysis of possible risks, which affect energy efficiency of the ship while maneuvering and mooring

Oleksandr Sagaydak

Abstract

The aim of this study is analyzing possible risks connected to the energy efficiency of the ship, specifically at the time of ship's maneuvering in the restricted waters on the way to the port and during mooring operations. The situation in the world's merchant fleet significantly changed during recent years – speed of the ships and their sizes significantly increased, many new technologies appeared. So, another aim of the research is to learn new risks, imposed in the modern shipping. Also, the aim was to search connection of energy efficiency risks to the other aspects of the ship's safety. Nowadays, there are some new safety aspects appeared: cybersecurity, safety of new fuels (which were not used before on-board ships), problems of the crew competency in new technologies and new operations, use of autonomous tugs, possibility of war risks, use of artificial intelligence. These new aspects should be taken into account, as well as the probability of sudden changes in the situation, like weather change, current effect, breakdown of the equipment or traditional human error. It is analyzed also several methods of the risk's calculation, including adding of the environmental condition and human element to the traditional formula of the risk calculation. All risk parameters were grouped into ten groups, possible methods of the risk assessment for each parameter were learned. Also use of the new digital technologies is reflected, the best way of avoiding human error seems to be computer-based risk assessment, which would be more effective if independent server or special platform is used. Such platform to be belonged to insurance company, per example. The best effectiveness of such electronic system expected to be achieved by using round-circle risk assessment, which includes calculation of risks of all participants of operation and general risk assessment of the whole process. The particular attention is given to the new risk parameters, recently imposed into the maritime industry and to the new opportunities of the risk management, given to us by the modern technologies, in particular IT technologies and artificial intelligence.

Keywords

Energy efficiency, risk analysis, risk assessment, maneuvering, mooring, ship operations.

5.1 Introduction

The speed of the ships and their sizes significantly increased in the recent years. At the same time the speed loading and discharging operations also increased. Those operations, which took weeks a decade ago, now could be done withing days or even hours. In view of this, ship managers and charterers are taking all possible efforts to speed up auxiliary operations, like maneuvering, mooring, bunkering, receiving supply, etc.

On the other hand, there is a requirement to keep energy efficiency of the ship at some certain acceptable level during the whole trip of the ship. Moreover, such very important operations as docking, undocking, maneuvering in the port waters and during approaching the port must be fulfilled safely with all necessary safety precautions.

This task becomes more difficult because port traffic is constantly increasing all over the world, thus it is necessary to provide ship managers and the ship's staff with the effective and reliable tools for the risk assessment of such operations.

Traditionally, some risk evaluation models are used [1], based on complex analysis of various stages of the operation [2], however it is not fully corresponded to the modern requirements, dictated by high-speed changes of the situation. In such circumstances the big room of errors and delays appears, which can lead to damage, financial losses and even bigger negative consequences [3].

It is also necessary to mention, that usually risk management on board of the ship is fulfilled by simple filling up the checklists and tickling proper boxes prior beginning the operation [4]. Such approach has many disadvantages: possible formal approach (without checking real situation before tickling box), filling up the checklist post factum (after operation is completed, because very often ship's officers have very limited time to do this before the operation commenced), possibility of human error due to rush, caused by necessity to do a lot of actions in the very limited time and by the shortened crew (which is more and more often nowadays).

So, it is essential to have the tool, which will give an opportunity to fulfil risk assessment in the real time mode. This was recognized by the International Maritime Organization, which highlighted the need for simplified assessment methods suitable for real-time applications. Energy efficiency is one of the key topics of IMO agendas [5, 6], which is also important to take into account while planning and fulfilling auxiliary port operations, such as maneuvering and mooring of the ship.

5.2 Energy efficiency during maneuvering operations

Maneuvering and mooring mode is significantly different from the sea mode of the ship. It is characterized by higher energy consumption by its nature – many auxiliary mechanisms to be started (additional generators, thrusters, mooring winches, windlass, capstan, pumps, etc.), main engine consuming more fuel in maneuvering mode. Additional energy consumers and risks associated are shown in the **Table 5.1**.

Table 5.1 Additional energy consumers during maneuvering and mooring operations and risks to energy efficiency associated

Energy consumers	Risks
<ul style="list-style-type: none"> – main engine in maneuvering mode; – additional auxiliary engine(s); – windlass and capstan; – mooring winches; – thruster(s); – additional pumps; – additional bridge equipment; – additional lights 	<ul style="list-style-type: none"> – failure of the mechanism due to technical problems; – failure due to poor maintenance; – failure due to poor quality of fuel; – failure due to overload; – failure due to human error

However, there are some risks, which can increase energy consumption even more, such as necessity to reverse main engine in emergency, presence of strong current or simply worsening of the weather conditions. Besides that, there are some new risks appeared last decades because of technology progress [7] (**Table 5.2**).

Table 5.2 Risks associated with emergency and new risks

Emergency risks	Possible preventive measures
1	2
Emergency revers failure	Check the reverse before maneuvering
Overload due to the current	Learn the situation with the current before entering the area
Overload due to the wind squall	Learn weather forecast, engage spare generator in advance
Wrong actions of pilot	Monitor actions of pilot in order to avoid human error
Wrong actions of tug	Monitor the whole process of operation, have anchors ready to drop
New risks	Possible preventive measures
Failure due to unknown properties of new fuel	Have ready traditional fuel, not to overload engines
Cyber attack	Cyber protection

Continuation of Table 5.2

1	2
Militant attack	Avoiding enter ports under possible military attack
Failure of the new technology mechanism due to lack of crew training	Provide a crew training in time
Collision due to mistake of remotely operated autonomous tug	Always be alert and ready to use anchors and other measures
Artificial intelligence mistake	Double check devices using AI, have readily available conventional equipment

Energy efficiency during maneuvering operations and mooring is worse than in normal sea mode. It is highly depending on some accidental risks, which should be taken into account. In addition, in the recent time, new risks arisen, which are also quite important to take them into consideration.

5.3 Risks calculation

Usually, risk evaluation could be assessed by multiplying the probability of the risk and the severity of the possible consequences of the event

$$R = P \times C, \tag{5.1}$$

where P represents the probability of occurrence and C indicates the severity of the consequence.

It is particularly valued for its simplicity and effectiveness in quickly gauging risk levels [8].

However, this is not the only approach to the calculation of the risk. For example, International Maritime Organization, recognizing necessity of simplifying approach to the risk management on board the ships, anyway, added one more element to (5.1)

$$R = P \times C \times V, \tag{5.2}$$

where V means vulnerability of the system [9].

To our opinion vulnerability is more applicable to the cyber security, or other systems, where it is possible to assess this vulnerability more or less precisely before

getting down to the calculations. In the situation of the assessment of risks imposed to the maneuvering/mooring operations and energy efficiency, associated with them, another approach looks to be more feasible.

It is possible to delete vulnerability from (5.2), but to take into account some other factors, like effects of external environment (environmental conditions – wind squall, strong current, waves, decreasing of visibility, etc.) and, of course, influence of human element, which will be definitely present in any operation anyway.

Thus, let's use following formula

$$RF = P \times C \times E \times H, \quad (5.3)$$

where P – probability (to be evaluated based on historical data and operational records, considering incident frequency within similar conditions, type of the ship, and others); C – severity of the possible consequences (preferably to be classified on a five-point scale, ranging from minor impacts (e.g., minor property damage) to severe consequences (e.g., loss of the ship or major environmental damage); each consequence score is assigned based on previous incident reports and the potential impact of similar events on port operations; E – environmental conditions, means a variable accounting for external factors that affect the operation, including wind speed, current strength, wave height, and visibility (each environmental factor is rated on a scale from 1 (optimal conditions) to 5 (extremely adverse conditions)); H – human factors, means a component that reflects the influence of crew experience, training, and fatigue levels on risk (the human factor score is similarly scaled from 1 (highly competent and alert) to 5 (low competence or high fatigue)).

Data for each variable (P , C , E , and H) were gathered through a combination of historical analysis and port records [10]. Statistical methods were used to identify typical values for each variable under various port conditions. The extended R model might be applied to various scenarios within the port environment to evaluate its effectiveness in risk identification. Each scenario to be analyzed by computing an R score, which was then used to categorize risks as low, moderate, or high. This categorization helps prioritize response strategies and preemptively address high-risk situations based on the calculated R . Of course, in the absence of the statistics, the other methods of the assessment of probability and severity to be used – like expert assessment for example [11].

Let's apply the model, described in [11] to the calculations of risks, connected to the energy efficiency during the maneuvering and mooring operations. **Table 5.3** shows calculation of risks in various possible scenarios.

Table 5.3 Risk calculation in different scenarios

Sample scenarios	Probability (P)	Consequence (C)	Environmental (E)	Human element (H)	Risk (R)
Scenario 1: optimal weather, experienced crew	2	3	1	1	6
Scenario 2: moderate weather, inexperienced crew	3	4	2	4	96
Scenario 3: poor weather, experienced crew	3	5	4	2	120
Scenario 4: high risk, adverse weather, fatigued crew	4	5	5	5	500

Assumptions for sample scenarios:

- *P* (Probability): assumed based on frequency of incidents in similar operational contexts; scaled from 1 (low probability) to 5 (high probability);
- *C* (Consequence): defined based on the potential impact of incidents, ranging from minor property damage (1) to severe environmental or human harm (5);
- *E* (Environmental conditions): rated on a scale from 1 (optimal conditions, clear weather, low currents) to 5 (highly adverse conditions, poor visibility, high currents);
- *H* (Human factors): rated from 1 (high crew expertise, alertness) to 5 (low crew expertise, high fatigue).

The results indicate that the *R* value varies significantly depending on the values assigned to *E* and *H*, highlighting the importance of environmental and human factors in real-time risk assessment. For instance:

- Scenario 1 represents a relatively low-risk situation due to optimal weather and an experienced, alert crew, resulting in an *R* of 6;
- Scenario 2 shows increased risk (*R* = 96) due to a moderately adverse environment combined with an inexperienced crew, suggesting that additional precautions or adjustments in operation may be necessary;
- Scenario 3 depicts an even higher risk (*R* = 120) due to poor weather conditions, even with a skilled crew. This score indicates the potential need to delay the operation until conditions improve;
- Scenario 4 represents a high-risk scenario (*R* = 500) with both adverse weather and a fatigued crew, strongly advising against proceeding with tug operations under these conditions.

Such method of the risk calculation improves situational awareness: the extended *R* model enables ship operators and crews to assess risk dynamically, adjusting operations based on real-time information.

It gives also possibility for efficient resource allocation: high RF values in specific scenarios suggest when additional resources or preventive measures are necessary, allowing the ship to take a decision on more generators engagement to avoid overload or even blackout in the emergency situation (in most cases it gives an opportunity to avoid emergency situation at all).

Using this method, it is possible to be sure in our decision-making, thus it is possible to take informed decisions on whether to proceed, delay, or adjust operations, balancing safety and operational efficiency.

The results support the use of the extended R model as a practical tool for maritime risk assessment while maneuvering, particularly within the confined, high-traffic conditions of port areas, where it is possible to take care about ship's energy efficiency anyway.

5.4 Risk management using IT technologies

As is mentioned above, it is necessary to process the data constantly, in the real-time mode – it is necessary a continuous monitoring of the risks during the whole process of the operation. Such opportunity gives using of modern IT technologies, which will allow to process much more data, then human can do, also electronic server can process all data (even changeable) in the real time mode.

All data, which are necessary for risk assessment process, could be divided into three types: constant data (which are unchangeable and could be upload from ship's computer – type of the ship, year of build, name, IMO number, type of engine, type of fuel, etc.); data, which need operator's assistance (checkup of readiness of the mechanisms as example); live data from ship's mechanisms and devises (engine mode, start/stop of the mechanisms, loading conditions of the motors, etc.). The process of the data transfer goes on separately for these various types of data (Fig. 5.1).

Thus, there is an opportunity to have live risk assessment during the whole time of the operation. Server, to be used for such data processing, should be allocated with the company, however ideally, such server to be independent (belonging, for example, to insurance company) for the purpose of processing other important data at the same time (data of the other participants of the operation in particular).

As was said above, the data are divided by type, at the same time they are divided in time as well: some are processed before the operation, but some data to be processed continuously during operation in the real-time mode. In the next figure (Fig. 5.2) is shown the possible algorithm of various data processing.

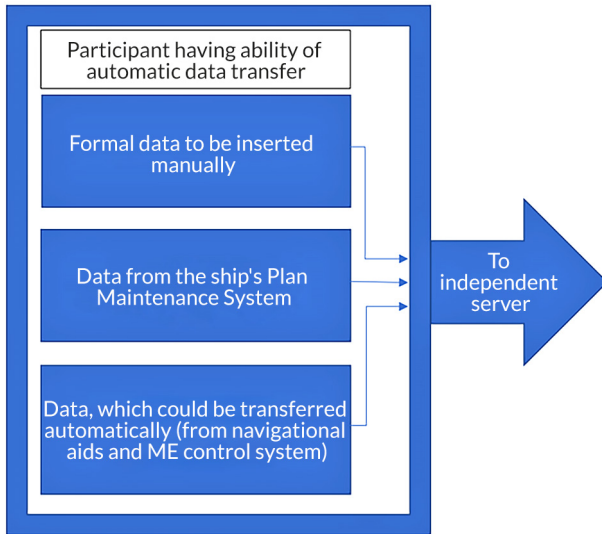


Fig. 5.1 Three types of data, generated by the ship to be processed by the special independent server
Source: [12]

In order to have real results and manage the risks in the most efficient way, it is necessary to indicate risk parameters, which are important for the particular purpose (energy efficiency in our case) and decide which methods of the risk assessment are possible to use. Better to group risk parameters for better understanding, as it is done in the **Table 5.4**.

It is necessary to add some comments to the **Table 5.4**: in the first group there are parameters, which might be dependent from other: for example, actual condition of the ship depends not on its age only, but on its type, so it should be taken into consideration. Also it might be not enough certain data for statistical analysis of the age of the ship, because ship's condition also highly depends on proper maintenance (rating of the shipping company could be very useful). Such problems could be mitigated by application of expert assessment method; however, such method require quite big number of experts for obtaining correct data.

Each flag and each classification society have their own requirements to safety; thus, it is possible to use for assessment their ratings (PSC and/or P&I and/or MoU – all of them are rating flags and classification societies). All of these data to be collected from various sources: PSC, MoUs, GISIS, Equasis, etc. for Statistical analysis.

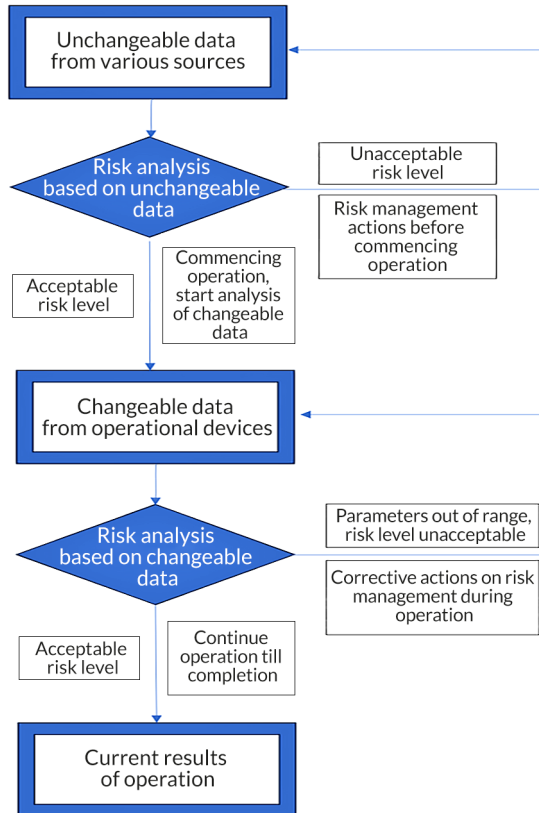


Fig. 5.2 Algorithm of data processing at the independent server

Table 5.4 Risk parameters and possible methods of their assessment

Group of parameters	Risk parameter	Method of assessment
1	2	3
I group (unchangeable parameters)	Year of built of the ship	Expert assessment
	Type of the ship	Expert assessment
	Name of the shipping company (ship's manager)	Expert assessment
	Flag of the ship	Ratings
	Classification society	Ratings

Continuation of Table 5.4

1	2	3
II group (depends on ship/company names)	Number of non-conformities by PSC	Statistical analysis
	Number of detentions by PSC	Statistical analysis
	Number, type and level of accidents, the ship was involved	Statistical analysis
	If the ship participates in the Green award programme or similar	Statistical analysis
III group (Ship's docs)	If all ship's documents are available	Statistical analysis
	If ship's documents are valid	Statistical analysis
	If some of the documents is not valid – analysis of the type of document and reason of invalidity	Statistical analysis
IV group (crew docu- ments)	If crew complement is in order according to the Minimum safe manning certificate	Statistical analysis
	If crew STCW documents all are valid	Statistical analysis
	If all crew STCW documents are verified, verification based on access to national verification system of the particular seafarer	Statistical analysis
	Experience of the seafarers – total seervice of each seafarer and its seervice on the particular type of the ship	Statistical analysis
V group (Ship's SMS)	Age of the seafarers	Statistical analysis
	How many nonconformities issued	Statistical analysis
	How many of them connected to the mooring operations/equipment	Statistical analysis
	How many accidents connected to mooring operations/equipment happened	Statistical analysis
	If there were repeated accidents	Statistical analysis
	How many near miss cases, connected to mooring operations/equipment found	Statistical analysis
VI group (Ship's equip- ment)	Number of navigational aids on board – is there sufficient number or redundant number of navigational aids	Statistical analysis
	Manufacturers of navigational aids (their rating in the industry)	Ratings
	Is there sufficient number or redundant number of auxiliary engines and how many are in operation	Statistical analysis
	Number of mooring aids	Statistical analysis
	Number of thrusters	Statistical analysis

Continuation of Table 5.4

1	2	3
VII group (Ship's PMS)	Was maintenance and check of the mooring equipment done as per plan	Events tree analysis
	Were spare parts requested for mooring equipment delivered and installed	Events tree analysis
	Were mooring ropes changed/checked according to schedule	Events tree analysis
VIII group (variable parameters)	Working parameters of ship's main engine – if there any malfunction, tendency to change to dangerous level	Bayesian networks or Markov chains
	Working parameters of steering gear – if there any malfunction, tendency to change to dangerous level	Bayesian networks or Markov chains
	Working parameters of auxiliary engines – if there any malfunction, tendency to change to dangerous level	Bayesian networks or Markov chains
	Navigational parameters – if any tendencies to run aground, if any risk to run against navigational obstacle, if any risk of collision	Bayesian networks or Markov chains
	Parameters of inertial navigation system	Bayesian networks or Markov chains
IX group (weather conditions)	Weather shore station and ship's meteorological station – if any tendency to worsen	Bayesian networks or Markov chains
	Light conditions – from light sensors	Bayesian networks or Markov chains
X group (cybersecurity data)	Data exchange with the ship in order to find potential risk of interference into the system	Bayesian networks
	Continuous ship's system checks on the matter of optimal performance	Bayesian networks

Sources of data for the first and second groups could be easily found with the help of Artificial Intelligence. Several AI tools could be used for such purpose (Table 5.5), but the best result seems to be obtained with the help of Perplexity. It is necessary to stress, AI could be used just for searching the sources of data, but not for collecting data themselves at present.

Basing on the characteristics of the platforms, it is possible to say that several platforms might be used for placing of the risk-assessment system. It might be more feasible, than ordinary server. However, it is necessary to realize that for full-scale tasks of the system, AI tool should be properly trained, otherwise many errors can happen. The only purpose, which could be fulfilled by AI for the moment – searching the sources of information. The best results were achieved with Proplexity.

It is necessary to stress: searching of particular data is not guaranteed (for example: statistics of accidents with particular ship – results not be found or found erroneous data), but searching for the sources gives quite good result. Basing on such results, system can obtain proper data using the ordinary search machine.

Table 5.5 Suitability of various AI tools for the purposes of risk assessment

AI name	Applicability for the risk assessment
Microsoft Azure	Platform, which could be used for placing the system
TensorFlow	Limited application for our purposes
OpenAI (includes ChatGPT)	Very limited abilities, high probability of errors
Google AI Platform	High opportunities, however, prospects of use for our purposes are not so clear
Amazon Web Services	Platform, which could be used for placing the system
NVIDIA Deep Learning AI Software	Not suitable
Dataiku	Could be used for our purposes
H2O.ai	Could be used for calculation and analysis of data, might be used for our purposes
Rainbird	Not suitable
Caffe	Not suitable
Perplexity	Suitable as a search engine

Source: [12]

While applying statistical analysis to the parameters in the fifth group (**Table 5.4**), it seems absolutely necessary to take into account Heinrich law (in a workplace, for every accident that causes a major loss, there are 29 accidents that cause minor losses and 300 accidents that cause no losses).

A very important part of this concept is adding to the list of parameters to be assessed some variable data – means data which are changing during operation. Modern state of IT technologies gives the opportunity to analyze such data in the real time mode, which allow to predict possible malfunctions of mechanisms or dangerous change of the situation.

Every of these ten groups, even every risk parameter needs specific approach to calculate probability of the negative event. There are various methods to be used for that. The task for designers of the risk management system is to choose the most suitable method for every parameter. In reality it could be adjusted after practical implementation of first version of the risk monitoring internet platform.

5.5 Practical importance

Actually, the importance of the correct energy efficiency risk assessment is not about energy efficiency only. Almost all factors, which are important for the safety of the ship, affect also its energy efficiency. On the other hand, mistake in energy efficiency calculation may lead to overload of the electrical equipment, and, in worst case, to breakdown of the all system.

As an example, breakdown itself may cause half a million losses, besides that, fine for the possible pollution could be around hundred thousand dollars and the idling of the ship due to accident can cause another one-two hundred thousand dollars [13].

Such consequences might be caused by the same risk factors, which can cause in-compliance with energy efficiency. Among them are: poor maintenance of the mechanisms and equipment, unknown parameters of new fuels, lack of crew training, crew incompetence, human errors, sudden weather change, etc.

Thus, correct approach to the energy efficiency risk analysis will lead to correct analysis of the risks, associated with the other safety aspects.

Using of the modern digital technologies can make the process of the risk assessment easier and more effective. Practically, "paper" risk assessment is not effective any more: on the most ships at least shipboard computer is used for this purpose. It might be also computer of the management company, but the most reliable solution seems to be use of the independent server of the insurance company. Such computer (or any independent platform with the special software) might be also used for the complex round-circle risk assessment for the all participants of the operation. Such approach will give the opportunity to make independent assessment not of every participant only, but of all operation in complex, highlighting "weak links" and making risk management much more effective [14–16].

Also there is a wide room for improvement of this concept and the whole algorithm of the risk assessment in general [17].

5.6 Conclusions

Energy efficiency of the ship is a significant part of seafarers' job now. It is not a simple task, which is much more difficult to achieve, when the ship is on the way to the port – maneuvering and in the process of mooring alongside. Assessment of the risks, associated to the energy efficiency, is helpful to the other aspects of the ship's safety risk assessment – it is not about the environment protection only, but about general safety issues of the ship in the maneuvering mode.

Same, like with the other aspects of mooring operations, energy efficiency risk assessment is better to fulfil with the help of modern technologies – special internet platform for round-circle risk assessment, artificial intelligence and other tools.

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