Tanker inspection regime in correlation with maritime accident risks and management decisions

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Abstract: *The paper analyses and addresses various tanker ship survey regimes, determining a certain amount of overlapping between specific survey regimes. The results of the study indicate that there are inconsistencies in the frequency of surveys and over inspections of some ships. These uncoordinated surveys affect the costs as well as the mental and physical condition of the crew. The mentioned indicates the necessity of the overall tanker survey rationalization, having in mind that the rationalization must not have the negative impact on the safety of the ship. In this paper, the authors proposes the implementation of the unified tanker survey model that would integrate components of all survey regimes. The comprehensive analysis of the risks arising from non compliance, oversights or absence of surveys, have resulted in setting up the optimal time needed to conduct surveys with respect to the technical, technological and economic specifications of the ship. The implementation of the unified survey would eliminate the negative effects found during present surveys and enhance the safety of the ship as well as the quality of the management.*
***Keywords**: TANKER SURVEY, UNIFIED INSPECTION, VESSEL MAINTENANCE, SAFETY OF NAVIGATION, SURVEY COSTS*

1. Introduction

The basic precondition for the successful operation of all on board systems is the implementation of adequate controls of ship systems. There are four basic groups of inspections for tankers: inspections performed by representatives of the flag state and port, inspections performed by representatives of recognized organizations, inspections performed by representatives of clubs and foundations, and inspections performed by company representatives. In addition to the above categories, it is necessary to mention special inspections that are characterized by different intensity and manner of inspections: inspections of shipyards and manufacturers of machinery / equipment, inspections of potential buyers of the ship and inspections of the crew.

The correctness of ship systems, as well as the integrity of the ship's construction are elements of the ship's operability that are ensured by adequate control and maintenance of the ship in accordance with the manufacturer's recommendations. For the purpose of successful operation of all systems on board, it is necessary to control them [1], [2]. For crude oil ships, there are 13 control regimes, divided into two groups:

External control:
1. port state control (PSC),
2. flag state control (FSC),
3. annual inspection of the recognized organization - ship register (Annual class survey),
4. examination of club representatives (P&I - Protecting and Indemnity),
5. inspection of the ship for charter (Vetting),
6. International Ship and Port Facility Security (ISPS) inspection,
7. inspection of safety management (ISM audit - International Safety Management),
8. inspection of working and living conditions on board (MLC audit - Maritime Labour Convention audit),
9. inspection of the Green award Foundation.

Internal control:
1. general inspection of the technical inspector of the ship,
2. internal ISPS audit,
3. internal audit of the safety management system (Internal ISM Audit),
4. internal Maritime Labour Convention audit.

In addition to the above regimes, there are certain inspections that are specific in intensity and manner of examination and in this paper are classified into a special group:

Special control:
1. inspections of shipyards and manufacturers of machinery/ equipment,
2. inspections of potential buyers of the ship,
3. crew inspections.

This research has identified overlaps in inspections between certain regimes, increasing costs and psychophysical load of the ship's crew [1], [2]. This research focuses on purpose and effect of the inspection regimes, addressing improvement of the existing level of safety on tankers for crude oil and petroleum products.

2. Existing inspection regimes

Based on a detailed analysis of the records from five tankers and consultation with experts from the practice, all items from all 13 current inspection regimes were considered. Comparative analysis found that 1685 survey items can be reduced to 529 items, from which it can be seen that the overlaps in the regimes are 69%.

On all analysed ships in the four-year period, the number of inspection regimes that were performed within one month have been marked, which is shown in the following table.

Table 1: *Intensities of monthly surveys over a four-year period.*

	Number of surveys in one month					
Ship	1	2	3	4	5	Total
1 survey	4	8	7	6	6	31
2 surveys	13	5	4	10	10	42
3 surveys	0	3	3	1	1	8
4 surveys	1	2	1	0	3	7

Two inspections per month are the most common on all analysed ships. The reason for such a schedule of inspections is usually related to the time the ship stays in port. Since there are many regimes inspecting tankers, and the number of ports of call of tankers in one month is two to three times, during the stay of the ship in a favourable port, several regimes come under inspection. The term favourable port means a port that is well connected by roads, flights and other means of transportation. Since inspectors are not geographically distributed, which means that, for example, an inspector from Europe often goes to inspections in African and American ports, transport connections are extremely important.

The analysis revealed that there are a large number of cases in which the intensity of inspections is greater than two per month. These are inspections that have a negative effect on the psychophysical condition of the crew. The psychophysical condition of the crew is an element that needs to be constantly analysed for the safety of the ship, cargo and sea environment. In the same way as the number of inspection visits in one month is considered, one can also consider the number of months without inspection visits to the ship, which is shown in the table 2. The time mismatch between the inspection regimes results in the emergence of potentially dangerous time periods in the analysed four-year period. Time periods in which there are no inspections on ships can pose a potential hazard [3, 4, 5].

***Table 2:** Intensity of non-coverage of inspections in a four-year period.*

	Number of months without surveys					
Ship	1	2	3	4	5	Total
2 months	6	1	0	0	3	10
3 months	2	3	3	3	1	12
4 months	1	4	4	2	3	17

In these terms, the inspection of ship maintenance, assessment of the quality of work, etc. is left exclusively to the ship's crews. Without the inspection of external stakeholders, the safety and technical correctness of the ship is potentially declining, which was the reason for the analysis of the current inspection regimes. From interviews with seafarers, inspectors in the ship owner's office, inspectors of recognized organizations and port authorities, and other maritime experts, it follows that the ideal schedule of visits to inspection regimes should be adjusted to ship crews [6, 7]. This should be done in such a way that at least one inspection of the external inspection regime is performed for the assumed average duration of the contract of the crew member on the tanker, i.e. 4 months. The reason for this is the psychological impact that inspections are left on crew members only [8, 9].

3. Optimisation of inspection regime

T will indicate the time in months between 2 unified inspections. In order to ensure that the consolidated inspection is accepted by the ship owner, care must be taken to ensure that the annual inspection price for the ship owner is lower than the existing one. Here, it will be assumed that the current price is USD 33,600, and that the cost of the unified review is USD 6,040 per survey. Therefore, the annual cost of a unified inspection is:

$$\frac{12}{T} \cdot 6040 \leq 33600 \quad (1)$$

and the conditional limitation is:

$$T \geq \frac{12 \cdot 6040}{33600} = 2.16 \quad (2)$$

The annual price of the unified inspection of shipping companies increases linearly with the number of inspections, or inversely according to the time between 2 inspections, which can be written as $66040 \cdot \frac{12}{T}$, which is illustrated in the following figure.

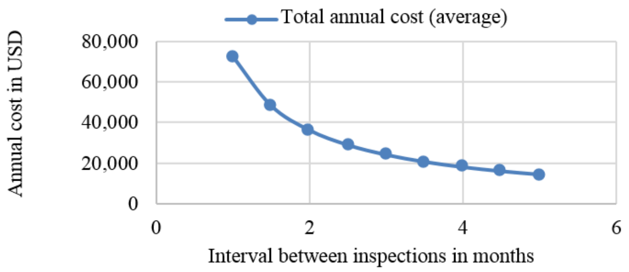

***Fig.1** Inspection cost.*

As mentioned earlier, there is a safety risk that there are no inspections in one crew contract. The requirement for each crew contract (which is estimated in this research to be a minimum of 4 months due to most of the companies whose officers were interviewed) to have at least one unified inspection, can be written by inequality:

$$T < 4 \quad (3)$$

The safety requirements to be met require that the annual number of items inspected be greater than the existing sum of items (1685). The unified inspection envisages 529 items. So it follows:

$$\frac{12}{T} \cdot 529 > 1685 \quad (4)$$

and condition:

$$T < \frac{12 \cdot 529}{1685} = 3.76 \quad (5)$$

which is shown in the following figure.

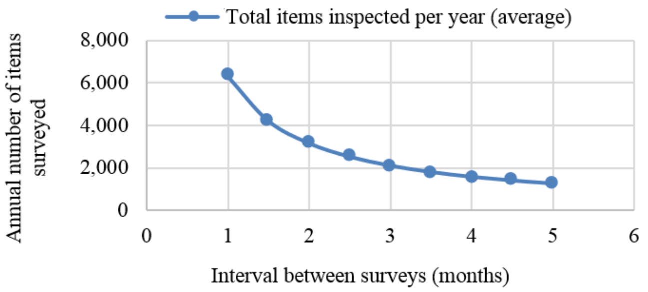

***Fig.2** Total items inspected per year.*

From the above model it can be concluded that from the point of view of cost for the ship owner and safety, the optimal interval between inspections is in the range of 2.16 to 3.76 months.

4. Inspections correlated with the risk of a maritime accident

Not one possible solution arises from the previous chapter, but several T between 2.16 and 3.76. The shorter the time between two inspections, the higher the annual price of the inspection, i.e. if the time between the two inspections is longer, the safety risk also increases. The general consensus of all stakeholders involved in the maritime enterprise in the process of preparing this paper is that the risk (probability) of an accident at one point depends on the elapsed time since the last inspection. The precise form of this dependence is dubious, but it is clear that it is growing. The simplest model is obtained by assuming that the dependence is linear (Figure 3), from which it follows that the total risk in the period between two inspections depends on the square of time T.

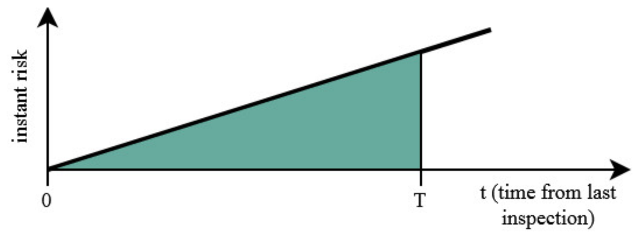

***Fig.3** Linear dependence.*

This can be expressed by an equation:

$$\int_0^T tgt = T^2 \quad (6)$$

Since the number of inspections per year is equal to $\frac{12}{T}$, it follows that the average risk depends on $\frac{12}{T}$. The expression $T^2 12T$ depends linearly on T. Therefore, the longer the time T the higher the risk. The direction coefficient is a parameter that stands next to x. It shows how fast the direction is growing upwards. For a tangent to a curve, the direction coefficient is equal to the derivative of the function. Therefore, positive derivatives mean that the function increases, and negative derivatives mean that the function decreases (Figure 4 a).

The tangent $y = 2x - 1$ to the curve of a quadratic function at a point with parameter 1. The direction coefficient is equal to the derivative of the function at that point. The link of any two points on the curve of a quadratic function is located above the curve itself because it is a convex function. A positive curvature is the curvature that corresponds counterclockwise, and a negative curvature is a clockwise curvature. Concavity is another name for negative curvature, and convexity for positive curvature. The second derivative measures the curvature of the function. When the second derivative is positive then the function is positively curved, and when the second derivation is negative then the function is negatively curved (Figure 4 b).

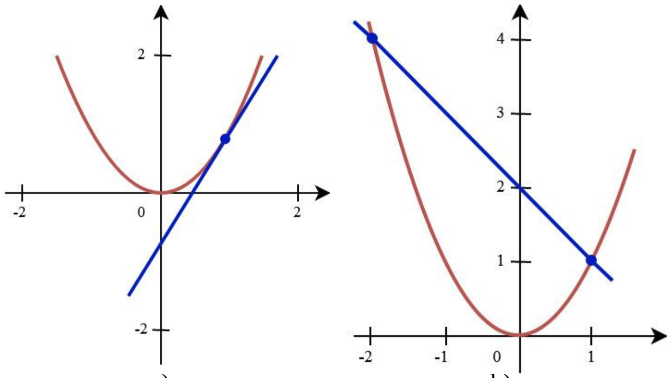

Fig.4 *a) Relationship of 1st derivation with growth and decline of function. b) Relation of the 2nd derivative with the curvature of the function.*

Another characterization of positive curvature is the fact that for such functions the coupling of any two points on the curve is above the curve of the function itself. For example, if the left point is determined by the parameter a and the value of the function $f(a)$, and the right point is determined by the parameter b of the value of the function $f(b)$, then the point at the midpoint of the coupling is at the height $\frac{f(a)+f(b)}{2}$ always above the point on the curve of the function $f\left(\frac{a+b}{2}\right)$. In other words:

$$f\left(\frac{a+b}{2}\right) \leq \frac{1}{2}\big(f(a)+f(b)\big) \quad (7)$$

One generalization of the above inequality, which is taken forward, is the Jensen inequality (Needham, 1993) which for the convex function f and its n parameters $x_1, \dots, x_n$ reads:

$$f\left(\frac{\sum_{k=1}^{n} x_n}{n}\right) \leq \frac{1}{n}\sum_{k=1}^{n} f(x_n) \quad (8)$$

A ship is a specific system on which, from the point of view of safety, many components operate in a complex way: in series and in parallel [10]. It can be assumed that the essential components of the system (human, organizational or technical) whose failure would potentially lead to accident are protected by the so-called parallel safety components: e.g. component condition indicators such as signal warnings, preventive component inspections, etc. External inspections have a special role to play here to ensure correct and reliable operation. Their ultimate goal is to eliminate system failures [11]. The concept of component life expectancy is well known in maintenance theory. The same is true for complex systems, where the probability of significant failure can be described as a function of the probability of the lifetime of the system.

It should be noted that the complex system is now observed without an external inspection system, in such a way that the system is certified by external inspection at time t = 0, and further in time the system operates without inspections. The probability that the system will fail in a time interval corresponds to the area under the curve. Denoting with p the function of the probability density of the lifetime of a complex system without conducting an inspection, and its cumulative function, which expresses the probability that the system will fail from the last inspection to the moment T, follows:

$$H(T) = \int_0^T p(t)\, dt \quad (9)$$

The life expectancy of a system on a large random sample would correspond very well to the time when half of the sampled systems would fail. The existing ship inspection system is the result of long experience and development within the maritime profession which has led to historically low levels of accident frequency. The already existing system has provided inspections in periods that are significantly below the expected lifetime and the maximum probability density of the lifetime of the ship's system in operation without the share of external inspections.

As Figure 4.b. suggests, it will be assumed that within a period of 12 months from the last inspection the life-cycle probability density function increases. In other words, this means, starting from the assumption that in the period since the last inspection in 12 months, the probability density p (t) that the accident will occur at time t, increases with increasing time parameter. The fact that the mentioned function p is increasing can be written with the help of derivation:

$$p'(t) > 0 \quad (10)$$

On the other hand, the so-called the basic theorem of integral calculus gives the relation between the functions $H'(t) = p(t)$, so for $t < 12$ in months:

$$H''(t) > 0 \quad (11)$$

Therefore, the probability that the system will fail from the last inspection until the moment within the next 12 months is a convex function to which the Jensen inequality can be applied, which for $n = 4$ reads:

$$H\left(\frac{t_1+t_2+t_3+t_4}{4}\right) \leq \frac{1}{4}\big(H(t_1)+H(t_2)+H(t_3)+H(t_4)\big) \quad (12)$$

If in expression $t_1+t_2+t_3+t_4 = 12$ both sides of the inequality are multiplied by the number 4, the conclusion follows:

$$4H(3) \leq H(t_1)+H(t_2)+H(t_3)+H(t_4) \quad (13)$$

The preliminary result means that with the above assumptions, four ship inspections within 12 months would be optimally distributed at equal time intervals of 3 months.

5. Selecting the optimal inspection regime

The analysis of all parameters concluded that the optimal time to conduct a ship inspection is every three months. The stated intensity of inspections requires 4 inspections per year. From figure 5 it is possible to determine the time for the implementation of the unified inspection.

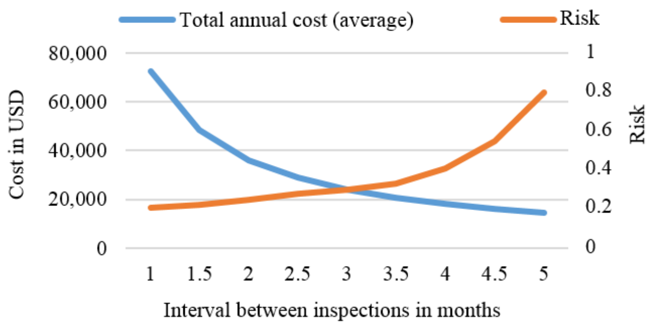

Fig.5 *Price and risk compromise.*

If the set conditions with the selected mode is observed, all the requirements are met:

- the average annual price is lower than the current annual level,
- the inspection time of the ship is shorter than the current one on an annual basis,
- crew members will be inspected at least once during their stay on board,
- the number of annual items for inspections will be higher than at present, which implies better safety of the ship and cargo.

Table 3 shows the relation of inspection costs of the current and unified inspection and the total hours spent in inspection.

Table 3: *Savings through the unified inspection (USD).*

Regime	Total annual inspection time (hours)	Total annual inspection cost (USD)	Price per hour of inspection
All current regimes	89	33600	378
Unified inspection	64	24162	378
Savings	25	9438	
	28%	28%	

The combined time savings is 25 hours per year. The time savings can also be viewed in terms of the time required to prepare for the inspection, which is also equivalent to the money savings. The savings are about USD 10,000 a year. For a ship that exists in a very competitive market, it is an exceptional savings.

The following table compares the unified inspection and the current regimes by inspection items. Inspection items are the most important segment in the unified inspection regime [12, 13]. Their number increases by 30% on yearly basis.

Table 4: *Optimal number of items inspected.*

No.	Segment	Total annual items inspected (all regimes)	Number of unified inspection items	Annual intensity	Total annual number of items inspected (unified inspection)
1	Ship certificates	95	21	4	84
2	Crew certificates	57	20	4	80
3	Lifesaving appliances	75	13	4	52
4	Fire safety	112	27	4	108
5	Navigation	234	56	4	224
6	Ship's procedures	192	55	4	220
7	Bridge publications	49	32	4	128
8	Ship's records	195	74	4	296
9	Mooring/ anchoring	58	23	4	92
10	Structural condition – hull & deck	82	24	4	96
11	Structural condition – ballast & void spaces	20	12	4	48
12	Health & hygiene	92	26	4	104
13	Machinery space operations	149	50	4	200
14	Steering gear system	40	10	4	40
15	Environmental protection	64	24	4	96
16	Cargo worthiness, tanker	158	50	4	200
17	Cargo control room	13	12	4	48
	Total	1685	529		2116

Increasing inspection items will not negatively affect the psychophysical load of the crew because the timing of the inspection would be precisely defined. Situations that happen to current regimes that within a month a ship visits two or more regimes would be eliminated. Increasing the inspection items would positively affect safety.

6. Correlation between the degree of success of the unified inspection and value of ship on maritime market

The success of the unified ship inspection is directly related to its business value. Using the elements achieved by the proposed model, the correlation between the unified inspection and ship value could be described through the following items:

- elimination of overlaps in inspection items,
- increase in inspection items,
- reduced psychophysical load of the crew,
- reduced inspection costs,
- improved ship maintenance,
- increased safety on ships,
- extended life of the ship,
- facilitated operational planning of carriers,
- reduction of hull and machinery insurance premiums,
- reduced club insurance premium,
- easier planning of budget, service, procurement of spare parts and docking,
- more favourable and stable freight rates,
- greater business success and reputation of the ship owner.

All these elements increase the value of the ship in business.

7. Conclusion

Enhanced tanker inspection contributes to improved ship owner business. That is achieved by higher technical and technological safety of the ship through continuous inspections. Technological safety refers to all those components that contribute to better ship operations and are not technical components. Improved quality of work of ship's crew when performing the most demanding trade operations is the most important component of the unified inspection.

The ship owner business is directly related to the way the ship is inspected. This research showed that optimal inspection interval, from the point of view of cost for the ship owner and safety, would be in the range of 2.16 to 3.76 months, that is 4 times a year.

The improvement of the owner's business can be observed from several aspects. The first aspect is savings on maintenance costs. Maintenance costs can be viewed as costs that are directly related to the costs of the intervention and the costs of the maintenance service. In addition, there are indirect maintenance costs, which include all costs incurred as a result of downtime. Another aspect of the improvement can be observed through better crew performance. A crew whose psychophysical load has been reduced meets the precondition for a smaller number of maritime accidents and omissions. According to statistics from the International Maritime Organization, 80% of maritime accidents are the result of human error. This fact should be greatly reduced by the proposed model.

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