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Technology-based risk calculation methodology in coastal container liner shipping

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ABSTRACT

The methodology of business and technology risk evaluation and management in shipping is based on three key factors: the voyage duration, the detected spots of technological differences and the spots of consequence costs.
The lowest costs of a vessel on a voyage or on a segment of a voyage are considered to be the optimal costs of a certain vessel on the voyage or on the segment of the voyage. Each cost that arises on a voyage or on a segment of a voyage which is higher than the lowest recorded cost is a consequence of a threat or a danger that has come to be. The initial value of the consequence cost is the lowest recorded cost or the optimal cost. The standard deviation is proposed to be the measure of the consequence cost i.e. of the degree of risk. The consequence cost that is higher than the ideal cost by two standard deviations is within the limits of the acceptable risk.

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1. Introduction

Coastal container liner shipping (CCLS) is a container supply network where feeder container vessels transport containers from a central container terminal or hub to different ports or a place where they will be loaded onto a different means of intermodal transport or vice versa [1]. The system incorporates a required number of vessels of certain capacity and speed with or without their own cargo handling tools or ramps, depending on the port requirements. Such a supply system must be scheduled, cyclic and interactive with other means of transport (a container train or road vehicles).

Technology-based risk is the product of the probability of an adverse event occurrence resulting from a technology-based decision and the damage that would result from such an event [2]. A technology-based decision is a decision regarding the planned set of actions in a given period of time. Technology-based risk is present in businesses which use advanced technology and technical devices of high value. In coastal container liner shipping technology-based risk depends on making technology-based decisions regarding the choice of technology-based solution affecting the business outcome.

Assessment of the consequence cost and its frequency in spots of increased threat directly affect the value of technology-based risk in coastal container liner shipping.

In order to assess technology-based risk in coastal container liner shipping it is necessary to identify the spots of increased threat or spots where it is necessary to establish the measure of threat in order to make a quantitative and qualitative comparison of different types of loading/unloading technology and technology used in transport process as well as of selected ports of call in coastal container liner shipping.

A hypothesis has been formulated that CCLS is a part of modern container traffic on a container market which is limited to a specific geographical area in terms of number of ports and the quantity of cargo, and its business results largely depend on the quality of technology-based risk management.

2. Characteristics of coastal container liner shipping

A voyage (PUT) is the basic unit according to which the ship operator monitors the business performance. Each voyage is assigned a serial number. Voyage duration is expressed in days. The total voyage duration (T_{PUT}) is a unit of measurement expressed in days. It begins with loading of the containers in the port of departure (P_1), includes the sailing time (t_S), the time spent unloading in the port of destination (P_x) and loading new containers for the return voyage, and it ends with unloading of the last unit of cargo after returning back to the port of departure.

A successful voyage as far as safety is concerned is the voyage ending without any losses or damage to the vessel, the vessel equipment or the cargo after which the vessel is ready for a new voyage.

It is assumed that CCLS carries out its activity with due care of an average ship operator who has all the information about the vessel, the ports of call, the shipping line and the timetable.

Taken the distance (d) between two subsequent ports (p) on voyage (n), the total voyage duration (D) is as follows:

$$D = \sum_{j=1}^{p-1} d_j. \tag{1}$$

If the observed voyages are labelled 1...n for $n \in N$, and segments of the voyage 1,2,...,L where $L \in N$, then the time that the vessel spends on each segment of the voyage can be shown with the following matrix:

$$\begin{matrix} t_{(1,1)} & t_{(1,2)} & \cdots & t_{(1,L)} \\ t_{(2,1)} & t_{(2,2)} & \cdots & t_{(2,L)} \\ \vdots & \vdots & \cdots & \vdots \\ t_{(n,1)} & t_{(n,2)} & \cdots & t_{(n,L)} \end{matrix} \tag{2}$$

A segment of the voyage is considered the sailing time between ports, the time the vessel spends in the ports and the time spent waiting for berth. Depending on the requirements of CCLS, it is possible to divide the voyage into more segments, but the aforementioned division is the most commonly used one.

The total duration of the voyage (T_n) can be expressed in the following way:

$$\begin{aligned} \mathrm{T}_1 &= \mathrm{t}_{(1,1)} + \mathrm{t}_{(1,2)} +...+ \mathrm{t}_{(1,L)} = \sum_{j=1}^{L} t_{(1,j)} \\ \mathrm{T}_2 &= \mathrm{t}_{(2,1)} + \mathrm{t}_{(2,2)} +...+ \mathrm{t}_{(2,L)} = \sum_{j=1}^{L} t_{(2,j)} \\ &\dots \\ \mathrm{T}_n &= \mathrm{t}_{(n,1)} + \mathrm{t}_{(n,2)} +...+ \mathrm{t}_{(n,L)} = \sum_{j=1}^{L} t_{(n,j)} \end{aligned} \tag{3}$$

Consequently:

- the mean value of the total voyage time $\overline{T_n} = \dfrac{1}{n}\sum_{j=1}^{n} T_j$, and
- the mean value of the voyage segments $\overline{t_L} = \dfrac{1}{n}\sum_{j=1}^{n} t_{(j,L)}$.

Further analysis of the observed voyages shows the following range:

- of the voyage duration $\min(T_j) < T_j < \max(T_j), j \in 1...n$
- of the voyage duration on segments $\min(t_{(j,L)}) < t_{(j,L)} < \max(t_{(j,L)}),\ j \in 1...n$
- of the relative variability of the voyage duration $\dfrac{s\,(T_j)}{\overline{T_j}} \times 100\,[\%], j \in 1...n$
- of the relative variability of the voyage segments $\dfrac{s(t_{(j,L)})}{\overline{t_{(j,L)}}} \times 100\,[\%], j \in 1...n$ (Standard deviation of voyage duration on segment.)

If the shortest voyage duration is considered to be the optimal voyage duration of a vessel (T_I), then:

$$T_I = \min(T_j), j \in 1...n \tag{4}$$

and it can be assumed that any longer voyage duration than T_I is a consequence or appearance of an undesired event or a threat.

Similarly, the shortest voyage duration on segment is considered to be the optimal segment duration, i.e.:

$$T_{I(L)} = \min(t_{(j,L)}), j \in 1...n \tag{5}$$

Cond_x refers to safety conditions 1...x, which must be fulfilled during the voyage.

In order to calculate the technology-based risk, 'loss or damage to the cargo' is considered to be only the loss or the damage to the cargo caused by endangering the maritime safety of the vessel, such as a loss or damage to the cargo which is a consequence of an irrational decision to continue the voyage in very rough seas.

Safety conditions ($Cond_i$) and the limits of those successful-voyage conditions (G_i) are set by the management of the ship operator.

The conditions are considered to be fulfilled if the following is the case:

$Cond_i \le G_i, i \in 1\ldots x$

Therefore, the ideal voyage duration is the following:

$$\mathrm{T_I} = \begin{cases} \min(T_j),\ j \in 1...n;\ Cond_i \le G_i,\ i \le 1...x \\ ND,\ Cond_i > G_i,\ i \in 1...x \end{cases}, \tag{6}$$

ND – Not Defined, refers to all the other cases which do not meet the agreed safety conditions.

And the optimal duration of a voyage segment is the following:

$$\mathrm{t_{I(L)}} = \begin{cases} \min(t_{(j,L)}),\ j \in 1...n;\ Cond_i \le G_i,\ i \in 1...x \\ ND,\ Cond_i > G_i,\ i \in 1...x \end{cases} \tag{7}$$

It is important to point out that as a rule the sum of the optimal voyage durations on segments is shorter than the optimal total voyage duration T_I, i.e. it can be stated:

$$T_I \geq \sum_{j=1}^{n} t_{I(j,L)}. \tag{8}$$

Namely, the optimal voyage segment durations are recorded in different voyages. Accordingly, the value which is the sum of the shortest voyage segment durations is the one that CCLS aspires to.

Voyage costs in coastal container liner shipping are proportional to the total voyage duration or the voyage duration on segment. For that reason it is necessary to monitor both the voyage duration and the costs arising from the voyage.

3. Vessel costs on a voyage in coastal container liner shipping

Since the vessel costs on a voyage as a rule depend on the voyage duration (fixed costs) as well as on the segment of a voyage (fuel and lubricant costs are not the same when the vessel is underway or in a port, there are port fees, which depend on the quantity of cargo to be loaded and on the contracts with third parties), taking into consideration the duration of each voyage segment, voyage costs of a vessel can be calculated [1].

Taken that C_n is the value of the total voyage cost and c_L is the amount of a voyage segment cost of the voyage n, total vessel costs can be shown with the following matrix:

$$\begin{matrix} c_{(1,1)} & c_{(1,2)} & \cdots & c_{(1,L)} \\ c_{(2,1)} & c_{(2,2)} & \cdots & c_{(2,L)} \\ \vdots & \vdots & \cdots & \vdots \\ c_{(n,1)} & c_{(n,2)} & \cdots & c_{(n,L)} \end{matrix} \tag{9}$$

Accordingly, voyage costs of a vessel expressed in monetary units can be calculated in the following way:

$$\begin{aligned} C_1 &= c_{(1,1)} + c_{(1,2)} +..+ c_{(1,L)} = \sum_{j=1}^{L} c_{(1,j)} \\ C_2 &= c_{(2,1)} + c_{(2,2)} +..+ c_{(2,L)} = \sum_{j=1}^{L} c_{(2,j)}. \\ &\ldots \\ C_n &= c_{(n,1)} + c_{(n,2)} +..+ c_{(n,L)} = \sum_{j=1}^{L} c_{(n,j)} \end{aligned} \tag{10}$$

According to the vessel costs at different voyage segments and the total vessel cost at voyage, can be presented as:

- the mean value of the total costs $\overline{C_n} = \frac{1}{n}\sum_{j=1}^{n} C_j$,
- the mean value of the voyage segments costs $\overline{c_L} = \frac{1}{n}\sum_{j=1}^{n} c_{(j,L)}$,
- the range of total costs $\min(C_j) < C_j < \max(C_j)$, $j \in 1...n$,
- the range of the costs at voyage segments $\min(c_{(j,L)}) < c_{(j,L)} < \min(c_{(j,L)})$, $j \in 1...n$
- relative variability of voyage costs $\frac{\sigma(C_j)}{\overline{C_j}} \times 100\,[\%]$, $j \in 1...n$, (standard deviation of the cost value range)
- relative variability of the costs at voyage segments $\frac{\sigma(c_{(j,L)})}{\overline{c_{(j,L)}}} \times 100\,[\%]$, $j \in 1...n$.

If C_I is referred to the optimal voyage costs, i.e. c_I referring to the optimal costs of a voyage segment:

- $C_I = \min(C_j)$, $j \in 1...n$ and
- $c_{I(L)} = \min(c_{(j,L)})$, $j \in 1...n$.

As mentioned previously, it is important to fulfill safety conditions set by the ship operator.

Accordingly, the ideal total costs of a voyage

$$C_I = \begin{cases} \min(C_j),\ j \in 1...n; Cond_i \leq G_i, i \in 1...x \\ ND, Cond_i > G_i, i \in 1...x \end{cases}. \tag{11}$$

Therefore, a conclusion can be drawn that the optimal costs of a voyage segment equal to the following:

$$c_{I(L)} = \begin{cases} \min(c_{(j,L)}),\ j \in 1...n; Cond_i \leq G_i, i \in 1...x \\ ND, Cond_i > G_i, i \in 1...x \end{cases}. \tag{12}$$

ND – Not Defined, refers to all the other cases which do not meet the agreed safety conditions.

The optimal vessel costs are the lowest recorded costs on a voyage or a voyage segment. The optimal cost is not a fixed value. With repeated voyages, i.e. over time it is expected to record costs which are even lower than the previously recorded lowest or optimal cost and such lower costs then become the new optimal cost. In other words, costs that have been considered optimal before is not considered optimal any more.

Also, it is important to indicate that as a rule the sum of the optimal costs at different voyage segments is lower than the optimal total voyage costs. In fact, it is expected that those costs were recorded on different voyages l...n.

Consequently, the optimal voyage is the one on which the lowest costs have been recorded with safety conditions being fulfilled.

The concept of a successful voyage is used in cost management as a measurement unit of economical business operations in CCLS [3]. Therefore it is important to consider what a successful voyage refers to. From the point of view of the ship operator, a successful voyage is the one which:

1. has made higher profit than costs,
2. has been completed within the established time frame,
3. which has been completed without any damage to people, vessel or cargo,
4. in which all the cargo has been loaded and unloaded on time, and

5. makes the vessel available for the subsequent voyage.

Whether or not a voyage has been successful is a decision made by the ship operator based on aforementioned criteria comparing a given voyage with a previous one, with the average of previous voyages or with the preset parameters for a successful voyage.

No wide range of cost variability is expected in CCLS: As most of the costs depend on the duration of the voyage, large cost variability would point to a deviation from the sailing schedule. The possible causes of frequent deviations from the sailing schedule must be thoroughly examined and they can be an indication of a defect in the system. Frequent deviations from the sailing schedule might lead to a modification of the sailing schedule or even termination of the shipping line.

Technology-based risk is a measurable and a comparable value. Its components are frequency of event happened and related consequence.

A consequence as a risk component is an undesired result of an event. The total voyage costs are the sum of the lowest recorded voyage costs (C_l) in a sequence of observed voyages on the line and the consequence costs (Cc).

Accordingly, the voyage costs equal the following:

$$C_n = C_{l(j)} + Cc_n, j \in 1...n \tag{13}$$

where the consequence cost (Cc) expressed in monetary units is a negative consequence of a technology-based risk. In other words, voyage consequence costs of a vessel are the portion of the voyage costs which is higher than the ideal costs. The consequence costs are risk-based costs.

$$Cc_n = \sum_{j=1}^{L} c_{(n,j)} - C_{l(n),} \tag{14}$$

and

$$cc_L = \sum_{j=1}^{n} c_{(j,L)} - c_{l(L)} \tag{15}$$

where n is the number of voyages, and L refers to the voyage segments.

The cost range is obviously a stochastic value consisting of various events which are behave unpredictable so it can be considered stochastic as well. Accordingly, it can be assumed that costs follow a normal distribution. The hypothesis that the costs follow a normal distribution is confirmed by a chi-squared test in a research based on 54 voyages of a ship in coastal container liner shipping [3]. In cases when this hypothesis is disproved, it is assumed that the cost range follows a different distribution. In such cases it is important to identify the causes of events leading to increased consequence costs or deviations in the cost system. Some of the causes might be an insufficient number of observed voyages or a lack of the shipping operator's familiarity with the actual cost amount of the vessel. As it is liner shipping i.e. the service of transporting goods by means of ships that transit regular routes on fixed schedules, it can be assumed that after just a few voyages a regular cost pattern can be seen. In fact, in CCLS almost all the costs should be known in advance and/or contracted before the shipping line is initiated.

4. The standard deviation as a measure of extraordinary costs in coastal container liner shipping

Assuming that the costs in CCLS follow a normal distribution, the value of the standard deviation can be a reliable measure of extraordinary costs. Hence, the standard deviation has been proposed to be a measure of consequence costs or risk.

As the expected costs are as a rule within the limits of two standard deviations according to a normal distribution, the following is proposed to be a measure of risk or consequence costs:

$$\begin{aligned} &C_l + \sigma = Cc_1, \\ &C_l + 2\sigma = Cc_2 \text{ (ALARP)}, \\ &C_l + 3\sigma = Cc_3, \\ &C_l + 4\sigma = Cc_4, ..., C_l + n\sigma = Cc_n. \end{aligned} \tag{16}$$

If the total consequence cost is lower than Cc_2, it can be assumed not necessary to take any measures in order to manage and reduce the value of technology-based risk. In fact, the value of consequence costs which is higher than the optimal value by two standard deviations can be considered to be an acceptable consequence cost or an acceptable ALARP value. Such a consequence cost value does not require taking any measures in order to manage and reduce the risk because it is the borderline of the acceptable technology-based risk, i.e. the borderline of consequence costs, and it will not significantly affect the success of the voyage.

For RCc_r referring to consequence cost classes, $R \in 1...r$, $r \in N$. The initial value is considered to be the ideal cost value, and the limits of each 'class' are increased by adding the value of the standard deviation of voyage costs or voyage segment costs. Although the number of classes is not finite, due to the nature of a normal distribution, it is assumed that it is not necessary to have more than 4 classes. In fact, according to the 3σ rule, the value of 99.7% of all the observed items following a normal distribution are within the limits of three standard deviations. In class four there are all the cost amounts which are higher than the optimal cost value and three standard deviations.

As the standard deviation is the average of the squared differences from the mean, it is important to point out that the standard deviation changes with every new item which is different from the mean.

Accordingly, the standard deviation and the RCc_r class limits change with each new item, where $r \in N$.

$$RCc_1 = C_I + \sigma(C_j),$$

$$RCc_2 = C_I + 2\sigma(C_j), \quad (17)$$

$$RCc_3 = C_I + 3\sigma(C_j),$$

…

$RCc_r = C_I + r\sigma(C_j)$, if $j \in 1...n$, and r refers to the ordinal number of the class.

According to the aforementioned, and especially from the experience of ship operators, the ALARP limit of the costs is proposed to be the value that is higher than the lowest recorded cost or the optimal cost by two standard deviations [3], i.e.

$C_I + 2\sigma(C_j), j \in 1...n$ i.e. RCc_2 = ALARP.

As each new item changes the mean and the value of the standard deviation, class limits and the ALARP amount change as well.

Consequently, hereby the ALARP limit is proposed to become a dynamic value attributed to voyage costs on a shipping line.

The relative frequency of reoccurrence of a certain voyage consequence cost value Cc_j or a voyage segment consequence cost value cc_j in n number of observed voyages is referred to as frequency v_j.

For m, $m \in N$, the number of monitored costs in class r during n number of voyages, $M = \sum_{j=1}^{M} m_j$, where M is the total number of cost monitoring.

$Cc_j, j \in R$ is the voyage consequence cost on an n voyage. The number of consequence costs within the limits of class Cc_{gi} can be determined using k(Cc_j) function as follows:

$$k(Cc_j) = \begin{cases} 1, \; for \; Cc_j > Cc_{gi}, i \in 1...r \\ 0, \; for \; Cc_j \le Cc_{gi}, i \in 1...r \end{cases}$$

In that case the number of consequence cost amounts higher than the class limit is the following:

$$m_i = \sum_{j=1}^{n} k(Cc_j), \; i \in 1...r$$

Accordingly, the frequency of occurrence of an extraordinary event

$$v_i = \frac{m_i}{M}, \; i \in 1...r.$$

The frequency of reoccurrence of a voyage segment consequence cost amount is determined in the same way. For cc_j, $j \in R$ voyage segment consequence cost on an n voyage, the number of voyage segment consequence costs within the limits of $cc_{gi(L)}$ class can be determined using $k(cc_j)$ function, as follows:

$$k(cc_j) = \begin{cases} 1, \; for \; cc_j > cc_{gi(L)}, \; i \in 1...r \\ 0, \; for \; cc_j \le cc_{gi(L)}, \; i \in 1...r \end{cases}.$$

In that case the number of voyage segment consequence cost amounts higher than the class limit is the following:

$$m_i = \sum_{j=1}^{L} k(cc_{(n,L)}), \; i \in 1...r,$$

and the relative frequency of reoccurrence of this extraordinary event is the following:

$$v_i = \frac{m_i}{M}, \; i \in 1...r$$

where frequency refers to the relative frequency of consequence cost reoccurrence (Cc ili cc) within different consequence cost classes (RCc_r) in the monitored cost 1...r number of classes.

The technology-based risk can generally be determined using the following equation:

$$PTR = v \cdot Cc$$

where:

PTR – technology-based risk
v – frequency of the event occurrence
Cc – consequence cost

Accordingly, the technology-based risk of a vessel on a voyage is the following:

$$PTR = \sum_{j=1}^{L} v_j \times cc_j. \quad (18)$$

Consequently, the technology-based risk of a CCLS is the mean technology-based risk on voyages 1...n

$$PTR_{line} = \frac{1}{n} \sum_{j=1}^{L} v_j \times cc_j, \text{ for } n \text{ number of voyages} \quad (19)$$

Adopting this method which uses the measurement of voyage success as a dynamic value is extremely helpful to a coastal container liner shipping operator. Namely, each voyage can push the limits of the optimal voyage as well as those of an acceptably successful voyage.

Table 1 Class limits and the number of monitoring

Class (R)	1	2	3	4
Limits (g)	$X < C_I + \sigma(C_j)$	$C_I + \sigma(C_j) < X < C_I + 2\sigma(C_j)$	$C_I + 3\sigma(C_j) < X < C_I + 4\sigma(C_j)$	$C_I + 4\sigma(C_j) < X$
Monitoring (M)	m_1	m_2	m_3	m_4

5. Conclusion

The proposed method of calculating the technology-based risk makes it possible for CCLS operators to monitor their business performance over a longer period of time and to plan future activities.

The presented methodology could be applied in planning and making strategic decisions in coastal liner shipping, as well as in establishing new lines, introducing new ships in the existing lines or introducing new main and intermediate ports of call as well as on the state of the market in the area of CCLS operation.

The lowest costs of a vessel on a voyage or on a segment of a voyage are considered to be the optimal costs of a vessel on the voyage or on the segment of the voyage. Each cost that a ship has on a voyage or on a segment of a voyage that is higher than the lowest recorded cost is a consequence of a threat or a danger encountered on the voyage. The initial value of the consequence cost is the lowest recorded cost or the optimal cost. The standard deviation is proposed to be the measure of the consequence cost i.e. of the degree of risk. The consequence cost that is higher than the optimal cost by two standard deviations is within the limits of the acceptable risk (ALARP).

References

[1] Bukša J., Zec D: Technology-Based Risk In Coastal Container Liner Shipping, POMORSTVO/Scientific Journal of Maritime Research 25/1(2011).

[2] Bukša J., Bukša Z., Quality Management In Coastal Container Liner Shipping From the Point of View of Cost Management, Pomorstvo/Scientific Journal of Maritime Research 25/2(2011).

[3] Bukša J, Technology-based Risk Management in Coastal Container Liner Shipping, Doctoral Dissertation, Rijeka 2010.

[4] Drljača, M., Mala enciklopedija kvalitete, V. dio – Troškovi kvalitete, Oskar, Zagreb, 2004.

[5] M. Luz Gámiz, K. B. Kulasekera, Nikolaos Limnios, Bo Henry Lindqvist., Applied Nonparametric Statistics in Reliability, Springer Series in Reliability Engineering, 2011.

[6] Möller, G., Risk assessment and risk management, II principles of environmental Ttxicology, University of Idaho, 2004.

[7] Stamatelatos, M. G., Probabilistic risk assessment procedures guide for NASA managers and practitioners, Washington, Office of Safety and Mission Assurance, NASA Headquarters, 2002.

[8] Maritime Economics, Martin Stopford, Branch Alan, Routledge, 1997.

[9] Risk and Risk Management, A Risk Management Agency Fact Sheet. United States Department of Agriculture, 2000. [www.rma.pdf] (2009).

[10] Upravljanje rizikom sa stanovišta Interne revizije, Institut za Internu reviziju Austria, IIA Austrija, Linde, 2006.