МОРСЬКИЙ ТА ВНУТРІШНІЙ ВОДНИЙ ТРАНСПОРТ

UDC 656.614.32:338.47
DOI https://doi.org/10.32782/2521-6643-2025-2-70.38

Drozhzhyn O. L., Candidate of Technical Sciences,
Associate Professor, Associate Professor at the Department
of Fleet Operation and Sea Transport Technologies
Odesa National Maritime University
ORCID: 0000-0002-9695-9296

Onyschenko S. P., Doctor of Economic Sciences, Professor,
Professor at the Department of Fleet Operation and Sea Transport
Technologies
Odesa National Maritime University
ORCID: 0000-0002-7528-4939

IMPACT ASSESSMENT OF LINER SCHEDULE DISRUPTION ON FLEET EFFICIENCY BASED ON TIME CHARTER EQUIVALENT

The article discusses the problem of liner schedule disruption (LSD) and its impact on the economic efficiency of shipping companies. It has been determined that failure to comply with container ship schedules leads to direct economic losses, which are reflected in a decrease in the time charter equivalent (TCE) indicator, which is a universal indicator of the profitability of ship operation regardless of the form of chartering. It is shown that schedule disruptions have a double negative effect: on the one hand, a decrease in efficiency due to an increase in voyage time, and on the other hand, a deterioration in the carrier's image, which in the long term reduces demand and market share.

The paper proposes a mathematical model for quantitative assessment of losses from delays in port and during the voyage. Analytical dependencies allow determining the decrease in TCE due to an increase in downtime in ports and the time a vessel spends in sea transit. The calculations showed that delays during ship movement are 2–3 times more costly than delays of equivalent duration in port, due to high bunker fuel costs and the need to recover the schedule by increasing speed.

The assessment methodology developed by the author allows analyzing the economic consequences of schedule non-compliance for both individual voyages and the entire line or fleet of the company as a whole. It takes into account the difference in the size of vessels and their contribution to the total volume of transportation, which ensures the adequacy of the assessment in strategic planning. The results obtained are of practical importance for optimizing management decisions in the field of liner shipping, in particular for improving the reliability of schedules, minimizing operational risks, and reducing financial losses.

Thus, the proposed approach transforms the abstract problem of schedule disruption into a specific financial indicator that can be used as a tool for monitoring performance and making decisions in real time, as well as for long-term strategic planning of container transport development.

Key words: *liner shipping, container, Time Charter Equivalent, schedule, delay, risk, disruption.*

Дрожжин О. Л., Онищенко С. П. Оцінка впливу порушення розкладу руху лінійних суден на ефективність флоту на основі тайм-чартерного еквіваленту

У статті розглянуто проблему порушення розкладу регулярних лінійних перевезень (Liner Schedule Disruption, LSD) та її вплив на економічну ефективність виробничої діяльності судноплавних компаній. Визначено, що недотримання графіків руху контейнерних суден призводить до прямих економічних втрат, які можуть бути виражені через зниження показника time charter equivalent (TCE), і розглядається виразником економічної ефективності від експлуатації суден незалежно від форми фрахтування. В роботі зазначено, що збої у розкладі мають подвійний негативний ефект: з одного боку – зменшення ефективності, з іншого – іміджеві втрати перевізника, що впливає зниженням попиту з боку вантажовласників; представлена робота присвячена вивченню тільки першої групи втрат. Було запропоновано математичну модель для кількісної оцінки втрат від затримок під час стоянкової і ходової операції. Аналітичні залежності дозволяють встановити рівні зниження TCE унаслідок збільшення часу простою під час перебування суден в портах та й на переходах між портами. Проведені розрахунки показали, що затримки під час ходової операції є у 2–3 рази більшими, ніж еквівалентні за тривалістю затримки у порту. Методика оцінки, розроблена авторами, дозволяє здійснювати аналіз економічних наслідків недотримання розкладу як для окремого рейсу, так і для всієї лінії

© O. L. Drozhzhyn, S. P. Onyschenko, 2025

Стаття поширюється на умовах ліцензії CC BY 4.0

чи флоту компанії в цілому. Вона враховує різницю у розмірах суден та їх внесок у загальний обсяг перевезень, що забезпечує адекватність оцінки при стратегічному плануванні. Отримані результати мають практичну значущість для оптимізації управлінських рішень у сфері лінійного судноплавства, зокрема для підвищення надійності графіків, мінімізації операційних ризиків та зменшення фінансових втрат.

Таким чином, запропонований підхід перетворює абстрактну проблему порушення розкладу на конкретний фінансовий показник, що може бути використаний як інструмент моніторингу ефективності та прийняття рішень у реальному часі, а також для довгострокового стратегічного планування розвитку контейнерних перевезень.

Ключові слова: *лінійне судноплавство, контейнер, тайм-чартерний еквівалент, розклад, затримка, ризик, порушення.*

Introduction. Risks are an integral part of the shipping business, covering both the technological aspects of maritime transport and commercial aspects. A distinctive feature of the liner shipping (LS) sector is that the source of significant costs (both for the LS- company and for the cargo owner) is non-performance, deviation, or disruption of the schedule. Like all types of commercial risks, the consequences of non-performance of the schedule are economic losses, which consist of two components. First of all, the consequences of failure to comply with the schedule, caused by delays in ports or on the route between ports, which usually leads to an increase in transit time, i.e., the voyage time for ships operating on the line, are a decrease in economic efficiency, i.e., the time charter equivalent. Second, failure to comply with the schedule negatively affects the image of the carrier company, which gradually leads to a decrease in demand in favor of competing companies. This, in turn, reduces the company's transport volumes and market share, which in monetary terms also results in certain economic losses. While these losses can only be assessed by experts by comparing the company's competitiveness with its competitors in the more or less long term, the first component of the economic consequences of schedule non-compliance can be assessed on the basis of information on voyage delays.

The significance of the problem of schedule disruptions is the focus of attention for many scientists: since a container ship operates from one port to another across the globe, a disruption by these unexpected events can cause delay, deviation, stoppage, or loss of service platform [1], considering the problem on four levels: delay, deviation, stoppage, and loss of platform service. The seriousness of the requirement to adhere to the schedule is explained by the so-called “knock-on effect” [7], which is related to the fact that a delay that occurred at the previous port of call can also cause delays at subsequent ports of call. Considering that LS is part of a broader system, intermodal delivery, it can be argued that the delay goes beyond the “sea leg” and spreads throughout the supply chain.

In scientific literature, risks that can affect the cost level of a liner operator can be described in different ways. Management articles refer to them as “business risk “ or “business environment-based risk” a multidisciplinary set of economic, political, social, natural, and other risks. Based on the environment of origin, the authors distinguish between macro and micro levels.

Literature review. The authors consider delays in LS and schedule disruptions to be sources of the following risks: financial risks [1]; risks of losing customers [3]; article [4] discusses congestion risk associated with disruptions to liner schedules in the context of the pandemic; in [5], “emission risks” are considered as a consequence of disruptions to container ship schedules; the article is devoted to LS [6] classifies “Transportation Delays” as “Risk Associated with Physical Flows,” highlighting the following causes: “industrial action, port congestion, terminal productivity, weather conditions, empty container management, container shortages, planning and scheduling problems, customs inefficiency, oil (and bunkers) prices, pandemics.” In [7], schedule unreliability in LS is considered a cause of “risk of a stock-out.” T. Nottebom sees delays as a cause of negative impact on logistics costs and reputation [8].

The faults that can lead to delays in LS can be of various levels. Undoubtedly, incorrect assessment of supply and demand for transportation in the trade region [16, 18], assessment of the level of competition, the size of ships in the fleet [10, 15, 17], connection of the line to the service network [11, 12], and the level of service provided by the line [13, 14] are among the most common [16, 18], assessment of the level of competition, the size of ships on the line, fleet composition [10, 15, 17], connection of the line to the service network [11, 12. 13, 17, 18] are planning issues and lie at the strategic level [9]. Some scholars refer to shipping route design as a strategic decision-making level [19, 14].

The development of the schedule itself is considered a tactical task, while the problem of restoring the schedule is solved by regulation and lies at the operational level of decision-making [21].

Figure 1, compiled on the basis of a literature review, illustrates how complex and multifaceted the problem of schedule disruption is in terms of its impact on business. The purpose of this article is to develop an LSD assessment tool that is acceptable for fleets operating under various forms of chartering.

The purpose of the article. To assess the economic impact of delays, we propose using Time Charter Equivalent (TCE) as a generalized indicator used in the maritime economy to measure the profitability of vessel operation, regardless of the form of chartering. In LS, various forms of vessel chartering are used: voyage charter, time charter, spot agreements, etc. TCE allows these different forms to be reduced to a single measure that reflects the “equivalent rental rate for a given period” and facilitates comparison of the impact of schedule disruptions for all forms of chartered vessels involved in the liner network.

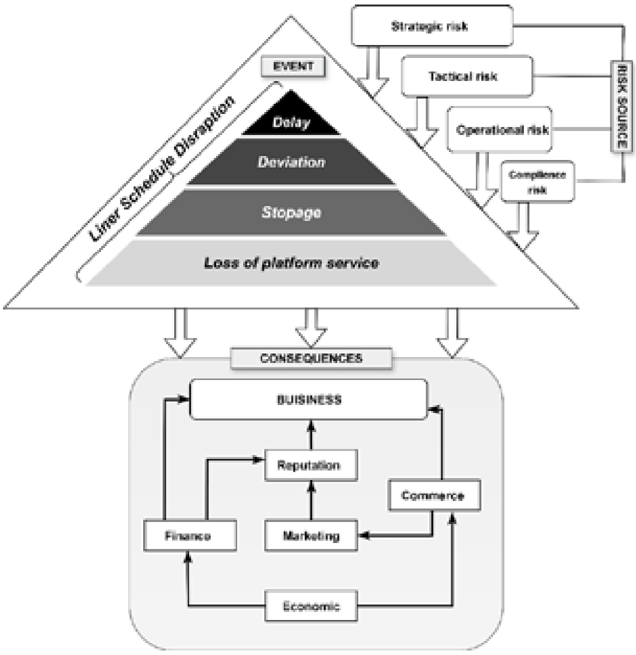

Fig. 1. LSD-problem: Risk Source-Event-Consequence (by the literature analysis basis)

It is evident that the issue of schedule disruption (LSD) can lead to significant reputational risks, threatening a loss of demand and even the closure of the regional service network. This article focuses solely on assessing the costs incurred by linear operators.

Mathematical LSD-problem representation. Therefore, the economic losses of the shipping company can be described mathematically as follows. Let us introduce the following symbols:

$i=\overline{1,n}$ – lines of the company under consideration, n – total number of lines;

$s=\overline{1,S_i}$ – ships of the company operating on the i-line S_i – total number of ships of the company on this line;

$k=\overline{1,K_s^i}$ – voyage of vessel *s* on line *i*,

K_s^i – the number of voyages of vessel s on line *i* within the period under consideration (e.g., a year);

T_s^{ik} – actual transit time for vessel s on line *i;*

T_s^{*ik} – scheduled transit time for vessel s on line *i*.

Transit time consists of two components: the time the vessel spends in the ports of the line and the vessel's underway time $T_s^{p\_ik}$ (transit between the ports of the line) $T_s^{m\_ik}$:

$$T_s^{ik}=T_s^{p\_ik}+T_s^{m\_ik}\ . \quad (1)$$

$T_s^{p\_ik}$ is formed from the time the vessel spends in the ports of the line. If we take $l=\overline{1,L_i},i=\overline{1,n}$ – the index of ports on line i, L_i – the total number of ports of call on the line, then:

$$T_s^{p\_ik}=\sum_{l=1}^{L_i}T_s^{p\_ikl}\ , \quad (2)$$

$T_s^{p\_ikl}$ is the ship's layover time in port l. We will also introduce indicators that reflect the planned total layover time of the ship in ports, the ship's layover time in each port of the line, and the ship's sailing time on the line, respectively, $T_s^{*p\_ik}$, $T_s^{*p\_ikl}$, $T_s^{*m\_ik}$.

The basic indicator for assessing the efficiency of ships is the time charter equivalent, which allows not only to draw conclusions about efficiency, but also to compare different options for operating ships.

The general expression of the time charter equivalent for a specific vessel on a specific line is as follows:

$$TCE_s^{ik}=\frac{F_s^{ik}-\left(R_{sik}^{port}+R_{sik}^{can}+R_{sik}^{bunk}\right)}{T_s^{ik}},i=\overline{1,n},s=\overline{1,S_i},k=\overline{1,K_s^i}\ , \quad (3)$$

F_s^{ik} – freight (income) for vessel s on line i, R_{sik}^{port} port expenses, $R_{sik}^{can},R_{sik}^{bunk}$ costs of passing through channels/straits and bunker expenses.

It should be noted that, on the one hand, can be considered as conditionally constant and independent of time. Even with an increase in the time spent in port, these costs remain almost unchanged. In some cases, may increase due to certain port charges R_{sik}^{port} that depend on the time the ship spends in port. For example, in Ukrainian ports, the sanitary fee is divided into two categories: "up to 10 days of stay" and "more than 10 days of stay," with a difference of about 60 %. Therefore, when summarizing the impact of schedule non-compliance on efficiency, the possible dependence R_{sik}^{port} on the time of stay should be taken into account in some cases:

$$R_{sik}^{port} = \sum_{l=1}^{L_i} R_{sikl}^{port}\left(T_s^{p\_ikl}\right), i = \overline{1,n}, s = \overline{1,S_i}, k = \overline{1,K_s^i} \quad (4)$$

$r_{si}^{bunk\_p}, r_{si}^{bunk\_m}$ – port fees and charges.

Bunker costs are determined by the underway time and layover time, taking into account the relevant fuel consumption standards:

$$TCE_s^{ik}\left(T_s^{p_{ik}}, T_s^{m_{ik}}\right) = \frac{F_s^{ik} - \left(R_{sik}^{port}\left(T_s^{p_{ik}}\right) + R_{sik}^{can} + R_{sik}^{bunk}\left(T_s^{p_{ik}}, T_s^{m_{ik}}\right)\right)}{T_s^{p_{ik}} + T_s^{m_{ik}}}, i = \overline{1,n}, s = \overline{1,S_i}, k = \overline{1,K_s^i}, \quad (5)$$

the $r_{si}^{bunk\_p}, r_{si}^{bunk\_m}$, respectively, are the fuel consumption standards for the vessel's time underway and vessel's time in port.

Thus, summarizing the above regarding the dependence of individual components of the time charter equivalent on the time of the components of the voyage and the voyage as a whole, we obtain the following expression:

$$TCE_s^{ik}\left(T_s^{p_{ik}}, T_s^{m_{ik}}\right) = \frac{F_s^{ik} - \left(R_{sik}^{port}\left(T_s^{p_{ik}}\right) + R_{sik}^{can} + R_{sik}^{bunk}\left(T_s^{p_{ik}}, T_s^{m_{ik}}\right)\right)}{T_s^{p_{ik}} + T_s^{m_{ik}}}, i = \overline{1,n}, s = \overline{1,S_i}, k = \overline{1,K_s^i} \quad (6)$$

Therefore, changes in the TCE under the influence of changes in transit time and compared to the base are estimated as follows:

$$\Delta TCE_s^{ik}\left(T_s^{p_{ik}}, T_s^{m_{ik}}\right) = TCE_s^{*ik} - TCE\left(T_s^{p_{ik}}, T_s^{m_{ik}}\right) = \frac{F_s^{ik} - \left(R_{sik}^{port}\left(T_s^{*p_{ik}}\right) + R_{sik}^{can} + R_{sik}^{bunk}\left(T_s^{*p_{ik}}, T_s^{*m_{ik}}\right)\right)}{T_s^{*p_{ik}} + T_s^{*m_{ik}}} -$$

$$- \frac{F_s^{ik} - \left(R_{sik}^{port}\left(T_s^{p_{ik}}\right) + R_{sik}^{can} + R_{sik}^{bunk}\left(T_s^{p_{ik}}, T_s^{m_{ik}}\right)\right)}{T_s^{p_{ik}} + T_s^{m_{ik}}}, i = \overline{1,n}, s = \overline{1,S_i}, k = \overline{1,K_s^i} \quad (7)$$

In expression (7) TCE_s^{*ik} – is the planned efficiency of the vessel's operation on the line, taking into account the accepted work schedule. If the vessel did not adhere to the schedule on a given voyage, i.e., there were delays in ports or during transit between ports, then: $\Delta TCE_s^{ik}\left(T_s^{p_{ik}}, T_s^{m_{ik}}\right) > 0$.

If the schedule is met, then $\Delta TCE_s^{ik}\left(T_s^{p\_ik}, T_s^{m\_ik}\right) = 0$. It should be noted that a situation is theoretically possible where $\Delta TCE_s^{ik}\left(T_s^{p\_ik}, T_s^{m\_ik}\right) < 0$, which means that the ship also did not meet the schedule, but the flight time was less than planned. However, as a rule, this situation is purely theoretical, practically $\Delta TCE_s^{ik}\left(T_s^{p\_ik}, T_s^{m\_ik}\right) \geq 0$.

One more comment on (7) and (8): determining the economic consequences of not adhering to the schedule on a particular voyage involves taking into account only changes in the voyage's time parameters $T_s^{p\_ik}, T_s^{m\_ik}$; the other components of (7) are considered constant. Therefore, (7) reflects a decrease in efficiency only due to exceeding the flight time. In fact, there is a possibility that the freight amount will be different due to the cancellation of a certain number of containers or, conversely, the presence of additional "last minute" shipments. In any case, only changes in time are taken into account. This allows us to analyze the impact of the "time" factor.

Empirical estimates for the liner vessel. Figure 2 shows, for example, a vessel operating on a route with a transit time of 30 days, the dynamics of the time charter equivalent depending on the increase in voyage time separately from the increase in underway time time ($+\boldsymbol{T_{uw}}$) and vessel time in port $+\boldsymbol{T_p}$.

Exploratory calculations were performed for a container shipping line on the route Suez – Jeddah – Colombo-Singapore – Shanghai (planned TT 30 days and TT 40 days).

It should be noted that these dependencies do not take into account changes in ship speed and corresponding changes in fuel consumption, but they allow us to see in general terms that an increase in voyage time significantly affects efficiency, with the impact of the underway component being significantly higher due to the cost of bunkering.

It should be noted that for this example and a transit time of 30 days, an increase in layover time by 0.5 days leads to a decrease in the time charter equivalent by an average of 3%, but an increase in sailing time by 0.5 days leads to a decrease in efficiency by 7 %-10 %.

Figure 3 for the same example of initial data shows the theoretical dependence of the time charter equivalent on both the underway time and the vessel's time in port, which allows us to trace the decrease in the time charter equivalent under the influence of the components of transit time simultaneously.

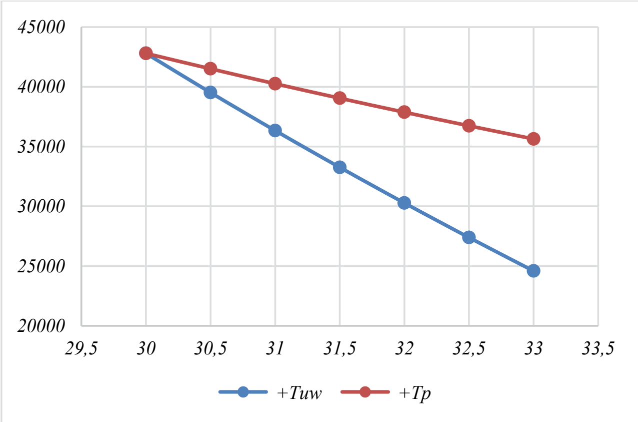

Fig. 2. Dependence of the TCE (USD/day) on the increase in TT (days) for a planned TT 30 days

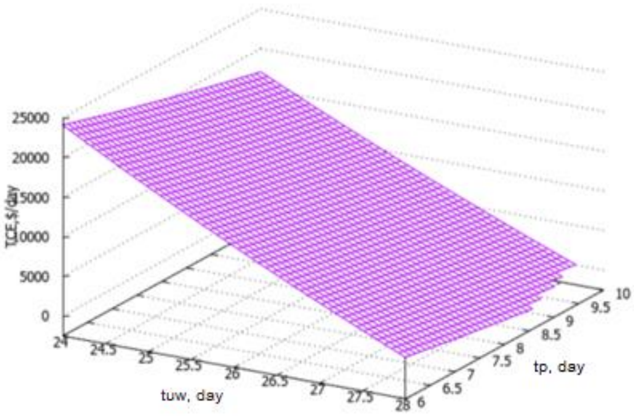

Fig. 3. Dependence of the TCE (USD/day) on underway time (days) and vessel's time in port (days) for a base TT 30 days

Similar calculations were performed for a transit time of 40 days, taking into account the corresponding changes in the sum of freight, port, and other costs.

Figures 4 and 5 indicate the dependence of the TCE on the increase in transit time and its two components. It should be noted that for longer TT, an increase in its components by 0.5 days leads to smaller changes in efficiency – 4-6 % for underway time and 1.5-1.8 % for time in port.

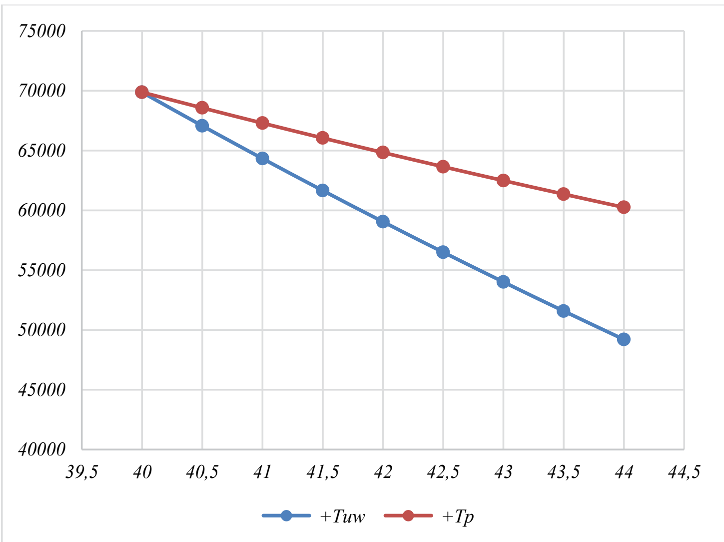

Fig. 4. Dependence of the TCE (USD/day) on the increase in TT (days) for a planned base TT of 40 days

Therefore, an increase in transit time of up to 10% can lead to a 20% or even greater reduction in the time charter equivalent.

Assessment of the LSD impact on fleet efficiency over the planned period. All of the above was based on a single voyage and a cernain vessel, but if we consider the results of a vessel's operation on a route over a certain period of time (a year, for example), the average efficiency of the vessel can be expressed as follows:

$$TCE_s^i = \frac{\sum_{k=1}^{K_s^i}\left(F_s^{ik} - \left(R_{sik}^{port} + R_{sik}^{can} + R_{sik}^{bunk}\right)\right)}{\sum_{k=1}^{K_s^i} T_s^{ik}}, i = \overline{1,n}, s = \overline{1,S_i}. \quad (8)$$

$T_s^{ik} = T_s^{p\_ik} + T_s^{m\_ik}$ – is the time of the *k*-voyage of the *s*-vessel on line *i*.

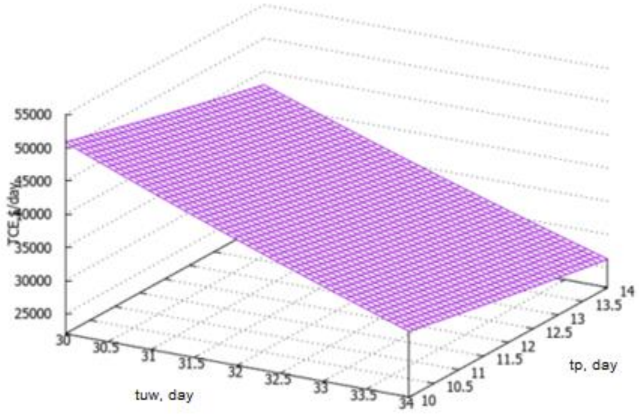

Fig. 5. Dependence of the TCE (USD/day) on underway time (days) and vessel time in port (days) for a planned TT 40 days

Therefore, by analogy with (7), the reduction in efficiency for a ship on a route over a certain period of time is estimated as:

$$\Delta TCE_s^i\left(T_s^{p\_ik}, T_s^{m\_ik}\,|_{k=\overline{1,K_s^i}}\right) = TCE_s^{*i} - TCE_s^i\left(T_s^{p\_ik}, T_s^{m\_ik}\,|_{k=\overline{1,K_s^i}}\right) = \frac{\sum_{k=1}^{K_s^i}\left(F_s^{ik} - \left(R_{sik}^{port} + R_{sik}^{can} + R_{sik}^{bunk}\right)\right)}{\sum_{k=1}^{K_s^i}\left(T_s^{p\_ik} + T_s^{m\_ik}\right)}, i = \overline{1,n}, s = \overline{1,S_i}. \quad (9)$$

Average efficiency of all vessels operating on the line:

$$TCE^i = \frac{\sum_{s=1}^{S_i}\sum_{k=1}^{K_s^i}\left(F_s^{ik} - \left(R_{sik}^{port} + R_{sik}^{can} + R_{sik}^{bunk}\right)\right)}{\sum_{s=1}^{S_i}\sum_{k=1}^{K_s^i} T_s^{ik}}, i = \overline{1,n}. \quad (10)$$

It should be noted that if the vessels on the line differ significantly in size (container capacity), then for "averaging" it is necessary to take into account the share of the container capacity of the vessels in the total container capacity of the fleet operating on the line, therefore (10) is transformed as follows:

$$TCE^i = \sum_{s=1}^{S_i}\lambda_s \cdot TCE_s^i = \sum_{s=1}^{S_i}\lambda_s\left[\frac{\sum_{k=1}^{K_s^i}\left(F_s^{ik} - \left(R_{sik}^{port} + R_{sik}^{can} + R_{sik}^{bunk}\right)\right)}{\sum_{k=1}^{K_s^i} T_s^{ik}}\right], i = \overline{1,n}, \quad (11)$$

$\boldsymbol{C_s}$ – container capacity of the vessel, $\sum_{s=1}^{S_i}\boldsymbol{C_i}$ – total container capacity of vessels operating on the line:

$$\lambda_s = \frac{C_s}{\sum_{s=1}^{S_i} C_i}, s = \overline{1,S_i}. \quad (12)$$

This approach allows for the unequal impact of each vessel on the average efficiency of vessels on the line.

Therefore, the average decrease in efficiency due to increased voyage time and failure to meet the schedule is determined as follows:

$$\Delta TCE^i = \sum_{s=1}^{S_i} \lambda_s \cdot \Delta TCE_s^i, i = \overline{1,n}. \quad (13)$$

This indicator characterizes the average decrease in the efficiency of ships on the line over a certain period of time, where ΔTCE_s^i – changes in the average efficiency of each ship on the line located at the base (9).

Taking into account the “daily” nature of the time charter equivalent, in absolute terms, the economic losses in efficiency amount to:

– for a specific voyage of a specific vessel on a route:

$$\Delta E_s^{ik} = \Delta TCE_s^{ik}\left(T_s^{p\_ik}, T_s^{m\_ik}\right) \cdot T_s^{ik} = \Delta TCE_s^{ik}\left(T_s^{p\_ik}, T_s^{m\_ik}\right) \cdot \left(T_s^{p\_ik} + T_s^{m\_ik}\right), i = \overline{1,n}, s = \overline{1,S_i}, k = \overline{1,K_s^i} \quad (14)$$

– for a specific vessel on a route during a specific period of time:

$$\Delta E_s^i = \Delta TCE_s^i\left(T_s^{p_{ik}}, T_s^{m_{ik}} |_{k=\overline{1,K_s^i}}\right) \cdot \sum_{k=1}^{K_s^i}\left(T_s^{p_{ik}} + T_s^{m_{ik}}\right), i = \overline{1,n}, s = \overline{1,S_i} \quad (15)$$

– for all vessels operating on the line:

$$\Delta E^i = \Delta TCE^i \cdot T' = i = \overline{1,n} \quad (16)$$

T' – the period of time under consideration.

For example, in the case considered above, if the base flight time is 30 days, and if the durations of the five flights were 30, 30.5, 31, 31.5, and 32 days, respectively, then the average decrease in efficiency is $\Delta TCE_s^i = 2502$ USD/day, and the total decrease in efficiency for this period is $\Delta E_s^{ik} = 387844$ USD/day.

Furthermore, if we consider the company's fleet as a whole, which operates on all routes, the total efficiency losses for the period T' are:

$$\Delta E = \sum_{i=1}^{n} \Delta E^i = \sum_{i=1}^{n}\left(\Delta TCE^i \cdot T'\right) = T' \sum_{i=1}^{n} \Delta TCE^i \quad (17)$$

It should be noted that the consequences of increased voyage time have different significance for vessels of different sizes, taking into account the length of the route. Therefore, it is important to determine the share of a particular vessel and a particular route in the total economic losses (16-17). The following indicators can be used for this purpose:

$$I_{\Delta E}^{is} = \frac{\Delta E_s^i}{\Delta E^i}, i = \overline{1,n}, s = \overline{1,S_i}, \quad (18)$$

$$I_{\Delta E}^{i} = \frac{\Delta E^i}{\Delta E}, i = \overline{1,n}, \quad (19)$$

where $0 \le I_{\Delta E}^{is} \le 1$ – is the share of vessel s in the total losses on line *i*, $0 \le I_{\Delta E}^{i} \le 1$ – is the share of line *i* in the total losses of the carrier company. These indicators supplement the information for analysis that can be obtained on the basis of (14)-(17) for a more complete description of the situation.

Figure 6 shows a diagram that summarizes the view of the formation of economic losses of ships on the line due to failure to comply with the schedule. Thus, the diagram shows the chain of formation of absolute indicators of economic losses ΔE for each ship and line.

Results and discussions. The developed TCE framework methodology is capable not only of quantitatively determining the economic losses of a liner operator from LSD, but also, critically, provides the necessary detail, distinguishing between the economic impact of delays and deviations from announced schedules while docked in port and underway. The conclusion that delays during vessel movement ($\boldsymbol{T_{uw}}$) are two to three times more expensive than equivalent delays in port ($\boldsymbol{T_p}$) is key to operational strategy and should be taken into account in the context of specific issues.

The established sensitivity ratio between delays at sea and in port confirms the need for a detailed approach to managing schedule-related risks. This differentiated impact arises primarily from the fuel consumption component, which is exacerbated by the International Maritime Organization (IMO) decarbonization program. The pressure to improve energy efficiency means that any unplanned time recovery requires high-speed steaming, which directly contradicts emissions targets and incurs significant, often unplanned, bunkering costs. This conclusion is strongly supported by the analysis of Meng et al. (2023) [5], who highlight the complex trade-offs between schedule reliability, bunker consumption, and necessary speed adjustments under the Carbon Intensity Indicator (CII). Our results provide a concrete financial multiplier that justifies why minimizing unexpected speed adjustments is economically preferable to enduring minor port congestion.

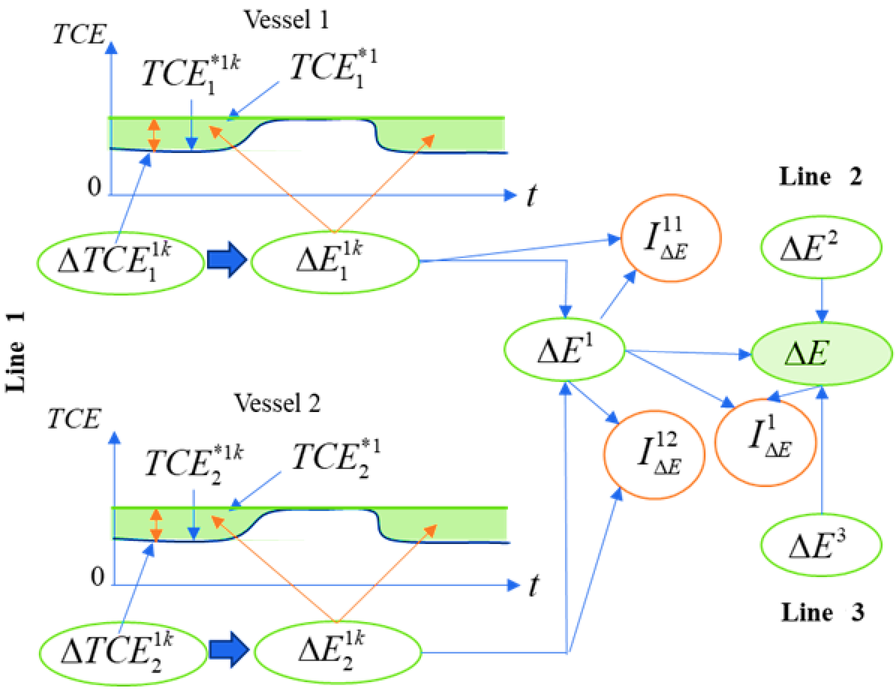

Fig. 6. Formation of economic losses of ships in a linear chain due to failure to comply with the schedule

The quantified severity of economic losses is consistent with recent studies that highlight the high systemic cost of unreliability. The most analysed articles on LSD-problem emphasize the broad systemic nature of the risk of schedule disruption, and our concept transforms this abstract risk into a concrete, measurable financial indicator. By providing daily losses, the model transforms the LSD problem from operational inefficiency to direct financial liability. This diagnostic tool promotes the idea of ensuring supply chain resilience by enabling real-time decisions based on whether the cost of restoring the schedule exceeds the projected losses in TCE.

Furthermore, the aggregated loss metric is instrumental in advancing strategic fleet planning. Traditional models for network design often rely on generalized or historical cost averages. The high-resolution operational cost data generated by the TCE framework can refine strategic planning exercises, providing more realistic inputs for optimal fleet deployment and network configuration. The consistent application of this TCE-based methodology, therefore, enables LS companies to move beyond simply acknowledging schedule unreliability to actively attributing and monetizing the financial compromises across their entire operational portfolio, ensuring strategic decisions are grounded in real-world economic impacts.

Conclusion. The difference between the planned time charter equivalent and the actual time charter equivalent forms changes in the time charter equivalent, which justifies changes in efficiency over a certain period of time, which, in general, for all lines and vessels, forms an integral indicator of economic losses.

Thus, failure to comply with the line schedule in the context of delays, which is associated with a variety of factors, leads to a decrease in the efficiency of the vessel, as measured by the time charter equivalent. In this situation, the resource of vessels – their carrying capacity over a certain period of time – decreases, which leads to a decrease in daily and overall efficiency. Monitoring changes in efficiency is the basis for taking appropriate organizational measures to ensure the necessary (planned) level of efficiency.

Bibliography:

1. Gurning R.O.S. Maritime disruptions in the Australian-Indonesian wheat supply chain: An analysis of risk assessment and mitigation strategies. University of Tasmania, 2011. Thesis. DOI: https://doi.org/10.25959/23210093.v1

2. Elmi Z., Singh P., Meriga V. K., Goniewicz K., Borowska-Stefańska M., Wiśniewski S., Dulebenets M.A. Uncertainties in Liner Shipping and Ship Schedule Recovery: A State-of-the-Art Review. *Journal of Marine Science and Engineering*. 2022. Vol. 10, № 5. P. 563. DOI: https://doi.org/10.3390/jmse10050563

3. Zhou J., Zhao Y., Yan X., Wang M. Strategy and Impact of Liner Shipping Schedule Recovery under ECA Regulation and Disruptive Events. *Journal of Marine Science and Engineering.* 2024. Vol. 12, № 8. P. 1405. DOI: https://doi.org/10.3390/jmse12081405

4. Gui D., Wang H., Yu M. Risk Assessment of Port Congestion Risk during the COVID-19 Pandemic. *Journal of Marine Science and Engineering*. 2022. Vol. 10. P. 150. DOI: https://doi.org/10.3390/jmse10020150

5. Meng L., Wang X., Jin J., Han C. Optimization Model for Container Liner Ship Scheduling Considering Disruption Risks and Carbon Emission Reduction. *Journal of Marine Science and Engineering*. 2023. Vol. 11, № 7. P. 1449. DOI: https://doi.org/10.3390/jmse11071449

6. Baştuğ S., Haralambides H., Akan E., Kiraci K. Risk mitigation in service industries: A research agenda on container shipping. *Transport Policy*. 2023. Vol. 141. P. 232–244. DOI: https://doi.org/10.1016/j.tranpol.2023.07.011

7. Vernimmen B., Dullaert W., Engelen S. Schedule unreliability in liner shipping: Origins and consequences for the hinterland supply chain. *Maritime Economics & Logistics*. 2007. Vol. 9, № 3. P. 193–213.

8. Notteboom T. E. The time factor in liner shipping services. Maritime *Economics and Logistics*. 2006. Vol. 8. P. 19–39. DOI: http://dx.doi.org/10.1057/palgrave.mel.9100148

9. Brouer B. D., Karsten C. V., Pisinger D. Optimization in liner shipping. *4OR*. 2017. Vol. 15, № 1. P. 1–35. DOI: https://doi.org/10.1007/s10479-018-3023-8

10. Mulder J., Dekker R. Methods for strategic liner shipping network design. *European Journal of Operational Research*. 2014. Vol. 235, № 2. P. 367–377. DOI: https://doi.org/10.1016/j.ejor.2013.09.041

11. Wilmsmeier G., Notteboom T. Determinants of liner shipping network configuration: a two-region comparison. *GeoJournal*. 2011. Vol. 76, № 3. P. 213–228. DOI: https://doi.org/10.1007/s10708-009-9333-2

12. Wilmsmeier G., Hoffmann J. Liner shipping connectivity and port infrastructure as determinants of freight rates in the Caribbean. *Maritime Economics and Logistics*. 2008. Vol. 10. P. 130–151. DOI: https://doi.org/10.1186/s41072-017-0019-5

13. Márquez Ramos L., Martínez Zarzoso I., Pérez Garcia E., Wilmsmeier G. The interrelationship of maritime network connectivity, transport costs and maritime trade. 14th Annual Congress of the International Association of Maritime Economists (IAME), Melbourne, 3–5 July 2006.

14. Kim H. J., Son D. H., Yang W., Kim J. G. Liner ship routing with speed and fleet size optimization. *KSCE Journal of Civil Engineering*. 2019. Vol. 23, № 3. P. 1341–1350. DOI: https://doi.org/10.1007/s12205-019-0564-6

15. Silva L.M.R., Wang H., Soares C. G. A strategic fleet size and mix vehicle routing model to analyse the impact of demand fluctuation on river-sea liner shipping. *Ocean Engineering*. 2024. Vol. 307. P. 118096. DOI: https://doi.org/10.1016/j.oceaneng.2024.118096

16. Del Rosal I. Trade effects of liner shipping across world regions. *Maritime Business Review*. 2024. Vol. 9, № 1. P. 2–16. DOI: https://doi.org/10.1016/10.1108/MABR-06-2023-0040

17. Baird A. J., Lindsay A. J. Strategic choice in the global container shipping industry: A resource-based approach. Proceedings of the 1996 IAME Conference. Vancouver, 1996.

18. Robinson R. Liner shipping strategy, network structuring and competitive advantage: a chain systems perspective. *Research in Transportation Economics*. 2005. Vol. 12, № 1. P. 247–289. DOI: https://doi.org/10.1016/S0739-8859(04)12008-8

19. Tavasszy L., Minderhoud M., Perrin J.F., Notteboom T. A strategic network choice model for global container flows: specification, estimation and application. *Journal of Transport Geography*. 2011. Vol. 19, № 6. P. 1163–1172. DOI: https://doi.org/10.1016/j.jtrangeo.2011.05.005

20. D'agostini E., Nam H.-S., Kang S.-H. Gaining Competitive Advantage at Sea: An Overview of Shipping Lines' Strategic Decisions. *International Journal of Transportation Engineering and Technology*. 2019. Vol. 5, № 4. P. 74–81. DOI: https://doi.org/10.11648/j.ijtet.20190504.12

21. Meng Q., Wang S., Andersson H., Thun K. Containership routing and scheduling in liner shipping: Overview and future research directions. *Transportation Science.* 2014. Vol. 48, № 2. P. 265–280. DOI: https://doi.org/10.1287/trsc.2013.0461

22. Dulebenets M. A., Pasha J., Abioye O. F. et al. Vessel scheduling in liner shipping: a critical literature review and future research needs. *Flexible Services and Manufacturing Journal*. 2021. Vol. 33. P. 43–106. DOI: https://doi.org/10.1007/s10696-019-09367-2

References:

1. Gurning, ROS (2011). Maritime disruptions in the Australian-Indonesian wheat supply chain: An analysis of risk assessment and mitigation strategies. University of Tasmania. Thesis. https://doi.org/10.25959/23210093.v1

2. Elmi, Z., Singh, P., Meriga, V. K., Goniewicz, K., Borowska-Stefańska, M., Wiśniewski, S., & Dulebenets, M. A. (2022). Uncertainties in Liner Shipping and Ship Schedule Recovery: A State-of-the-Art Review. *Journal of Marine Science and Engineering*, *10*(5), 563. https://doi.org/10.3390/jmse10050563

3. Zhou, J., Zhao, Y., Yan, X., & Wang, M. (2024). Strategy and Impact of Liner Shipping Schedule Recovery under ECA Regulation and Disruptive Events. *Journal of Marine Science and Engineering*, *12*(8), 1405. https://doi.org/10.3390/jmse12081405

4. Gui, D.; Wang, H.; Yu, M. (2022). Risk Assessment of Port Congestion Risk during the COVID-19 Pandemic. J. Mar. Sci. Eng. 10, 150. https://doi.org/10.3390/ jmse10020150

5. Meng, L., Wang, X., Jin, J., & Han, C. (2023). Optimization Model for Container Liner Ship Scheduling Considering Disruption Risks and Carbon Emission Reduction. *Journal of Marine Science and Engineering*, *11*(7), 1449. https://doi.org/10.3390/jmse11071449

6. Baştuğ, S., Haralambides, H., Akan, E, Kiraci, K. (2023) Risk mitigation in service industries: A research agenda on container shipping, *Transport Policy*, Volume 141. 232–244, https://doi.org/10.1016/j.tranpol.2023.07.011.

7. Vernimmen, B., Dullaert, W., & Engelen, S. (2007). Schedule unreliability in liner shipping: Origins and consequences for the hinterland supply chain. *Maritime Economics & Logistics*, *9*(3), 193–213.

8. Notteboom, T. E. (2006). The time factor in liner shipping services. *Maritime Economics and Logistics*, 8, 19–39. http://dx.doi.org/10.1057/palgrave.mel.9100148

9. Brouer, B. D., Karsten, C. V., & Pisinger, D. (2017). Optimization in liner shipping. *4OR*, *15*(1), 1–35. https://doi.org/10.1007/s10479-018-3023-8

10. Mulder, J., & Dekker, R. (2014). Methods for strategic liner shipping network design. *European Journal of Operational Research*, *235*(2), 367–377. https://doi.org/10.1016/j.ejor.2013.09.041

11. Wilmsmeier, G., & Notteboom, T. (2011). Determinants of liner shipping network configuration: a two-region comparison. *GeoJournal*, *76*(3), 213–228. https://doi.org/10.1007/s10708-009-9333-2

12. Wilmsmeier, G., & Hoffmann, J. (2008). Liner shipping connectivity and port infrastructure as determinants of freight rates in the Caribbean. Maritime Economics and Logistics, 10, 130–151. https://doi.org/10.1186/s41072-017-0019-5

13. Márquez Ramos, L., Martínez Zarzoso, I., Pérez Garcia, E. & Wilmsmeier, G. (2006). The interrelationship of maritime network connectivity, transport costs and maritime trade. 14th annual congress of the international association of maritime economists (IAME) in Melbourne, July 3-5 2006.

14. Kim, H. J., Son, D. H., Yang, W., & Kim, J. G. (2019). Liner ship routing with speed and fleet size optimization. *KSCE Journal of Civil Engineering*, *23*(3), 1341–1350. https://doi.org/10.1007/s12205-019-0564-6

15. Silva, L. M. R., Wang, H., & Soares, C. G. (2024). A strategic fleet size and mix vehicle routing model to analyse the impact of demand fluctuation on river-sea liner shipping. *Ocean Engineering*, *307*, 118096. https://doi.org/10.1016/j.oceaneng.2024.118096

16. Del Rosal, I. (2024). Trade effects of liner shipping across world regions. *Maritime Business Review*, *9*(1), 2–16. https://doi.org/10.1016/10.1108/MABR-06-2023-0040

17. Baird, A. J., A. J. Lindsay. (1996). Strategic choice in the global container shipping industry: A resource-based approach. Proceedings of the 1996 IAME Conference, Vancouver.

18. Robinson, R. (2005). Liner shipping strategy, network structuring and competitive advantage: a chain systems perspective. *Research in Transportation Economics*, *12*(1), 247–289. https://doi.org/10.1016/S0739-8859(04)12008-8

19. Tavasszy, L., Minderhoud, M., Perrin, J. F., & Notteboom, T. (2011). A strategic network choice model for global container flows: specification, estimation and application. *Journal of transport geography*, *19*(6), 1163–1172. https://doi.org/10.1016/j.jtrangeo.2011.05.005

20. Enrico D'agostini, Hyung-Sik Nam, Seog-Hwan Kang. Gaining Competitive Advantage at Sea: An Overview of Shipping Lines' Strategic Decisions. *International Journal of Transportation Engineering and Technology*. Vol. 5, No. 4, 2019, pp. 74–81. https://doi.org/10.11648/j.ijtet.20190504.12

21. Meng, Q., Wang, S., Andersson, H., Thun, K. (2014). Containership routing and scheduling in liner shipping: Overview and future research directions. *Transportation Science*, 48 (2). 265–280. DOI: https://doi.org/10.1287/trsc.2013.0461

22. Dulebenets, M. A., Pasha, J., Abioye, O. F. et al. (2021). Vessel scheduling in liner shipping: a critical literature review and future research needs. *Flex Serv Manuf J* 33, 43–106. https://doi.org/10.1007/s10696-019-09367-2

Дата надходження статті: 03.10.202
Дата прийняття статті: 10.11.2025
Опубліковано: 30.12.2025