




# Efficient trade lane selection: A total economic cost perspective on shipping lines



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**Background:** Efficient logistics performance is vital for global trade, yet traditional cost assessments often overlook the economic impact of time delay variability. Especially in maritime logistics, these delays can generate substantial indirect costs. This study addresses a critical gap by integrating time-related uncertainty, which contains the implicit cost aspects, into logistics cost modelling to support better decision-making in trade lane selection.

**Objectives:** The study aims to quantify both direct and indirect logistics costs arising from time delays and variability across international shipping routes. Focusing on South Africa's import trade, it introduces a replicable total economic cost (TEC) model that enables cargo owners and freight forwarders to optimise route and shipping line choices based on holistic cost performance.

**Method:** Using a dataset of 5374 import shipments (2017–2023) from a South African freight forwarder, the study segments total logistics chains into ocean, port and land legs. Time delays and their variability are analysed per segment. Direct and indirect costs – such as the cost of capital tied up in inventory, stock shrinkage and lost sales – are modelled using percentile-based TEC calculations across buffer stock strategies.

**Results:** The ocean leg was the largest contributor to time delays and cost variability. Shipping lines with lower delay variability enabled significantly lower TEC values and smaller buffer stocks. The TEC model revealed that variability-driven costs often exceeded direct logistics expenses.

**Conclusion:** Minimising delay variability, and not just transport time, can significantly reduce logistics costs. The TEC model supports better strategic alignment of shipping line and trade lane choices.

**Contribution:** This study provides a practical, data-driven methodology for quantifying total logistics cost under uncertainty and enabling optimal choices of trade lanes and service providers, addressing a key challenge in global supply chain optimisation.

**Keywords:** trade lane; logistics; total economic cost; time variability; statistical distributions.

## Introduction

Ocean transport is the primary mode for global merchandise shipping and handles the largest share of international goods movement, especially in developing countries (UNCTAD 2023). Choosing the most appropriate shipping line and port combinations is therefore critical to obtaining improved logistics performance (Aaby 2012; Song 2011).

Logistics performance is typically measured through transit times, financial outlays and the consistency of service delivery. As transit time delays can be translated into cost (Haartveit, Kjostelsen & Jacobsen 2007), cost remains the primary output measurement of logistics performance. Research on logistics costs emphasises monitoring and controlling expenditures at multiple levels (Andrejić et al. 2018). However, traditional frameworks often overlook indirect costs.

This study applies a 'Total Economic Cost' (TEC) model that converts delays in logistics processes into their equivalent economic cost. The TEC translates all time-related economic impacts into monetary terms, thus eliminating the need to account for time and cost separately. The TEC model incorporates opportunity costs, hidden logistics costs and externalities, providing a holistic measure of logistics performance (Hoffman, Mutendera & Venter 2023). The model accounts for a

range of direct and indirect expenses, including financing charges tied to inventory, reductions in stock levels and the costs associated with stockouts. This study extends earlier research (Hoffman 2019; Hoffman, Lusanga & Bhero 2013; Minken & Johansen 2019 and most notably, Hoffman et al. 2023). Using a TEC model provides a comprehensive framework to quantify logistics performance costs, ensuring key metrics such as time delays and service reliability are accurately translated into economic terms, which is crucial for optimising decision-making in maritime logistics.

Because freight forwarders manage and integrate activities across the logistics chain, they are uniquely positioned to observe real-world operational processes and associated economic outcomes (see Özcan et al. 2024). Accordingly, the empirical evidence used in this analysis was sourced from a South African forwarding company and captures the conventional sequence of activities in an import process. Although this study focuses on South Africa, the methodology can be applied to any country participating in global trade.

The paper is structured as follows: the 'Literature review' section provides an overview of logistics performance and the TEC model. The 'Objective of the total economic cost for this study' section states the objective of this article. The 'Methodology' section outlines the assessment method and data collection. The 'Total economic cost model specification' section outlines the theoretical foundation of the TEC model, which underpins this study's methodological approach. The empirical findings are presented in the 'Results and findings' section, and the 'Conclusion, limitations and recommendations' section offers concluding remarks together with recommendations for improving logistics efficiency.

## Literature review

Logistics networks are integral to extended supply chains and must maintain predictability, sustainability, reliability and agility. The coronavirus disease 2019 (COVID-19) pandemic placed exceptional stress on these capabilities, testing system resilience and revealing several system weaknesses (Notteboom, Pallis & Rodrigue 2021:180).

Notteboom et al. (2021) analysed the timing and geographic spread of COVID-19 supply and demand shocks and compared them with those of the 2008/2009 financial crisis. The evidence suggested enhanced resilience across shipping lines, terminal operators and ports, attributable to a combination of renewed risk recognition and structural organisational modifications. Also, COVID-19 reconfirmed the market position and bargaining power of shipping lines, with an upsurge in freight rates and a positive impact on their financial results (Notteboom et al. 2021:207). These developments emphasise the value of understanding logistics costs when navigating major disruptions.

However, they warned of the potential impact over the longer term amid 'highly uncertain conditions generated

by a new wave of COVID-19 cases and restrictions in countries around the world' (Notteboom et al. 2021:186). Although the acute phase of COVID-19 was relatively short lived, Notteboom et al. (2021) noted that the broader uncertainty during the period could affect logistics networks beyond the immediate crisis. Similar observations were made in later work (e.g., Ciravegna & Michailova 2022:173), and the longer-term impact was also experienced in the logistics industry in developing contexts such as South Africa (see Grater & Chasomeris 2022). The pandemic therefore serves as a useful historical example of how rapidly logistics performance can deteriorate and why a comprehensive analysis of logistics costs remains essential for improving resilience and supporting informed decision-making.

Further research assessing logistics costs (e.g. Andrejić et al. 2018) emphasised the significance of monitoring and controlling logistics expenditures at global, national and organisational levels. However, while the existing research tends to cover major cost categories like transportation, warehousing and handling, it does not fully account for the full range of direct and indirect or implicit costs. A TEC model offers the potential to accurately quantify opportunity costs, hidden logistics costs and externalities caused by variable time delays, and in this regard, the TEC model provides a holistic measure of logistics performance.

Hoffman et al. (2023) applied a TEC model to transport corridors in the SADC region, using Zambia and Lusaka as examples. They found that variability in time delays significantly impacts total logistics costs, often more than only direct transport costs. For instance, the Beira corridor, despite its low direct transport cost, had high total costs because of time delay variability, making it less favourable compared to other corridors. Within this scenario, the financial impact of time delays could represent up to 80% of the total costs associated with the corridor.

Consequently, these findings highlight the usefulness of applying a TEC model to improve understanding of logistics costs. The following sections will explain how the TEC model is applied to the South African import trade lanes analysed in this study.

## Objective of the total economic cost for this study

Logistics performance is contingent upon the successful execution of multiple sequential steps, each following a logical flow within the logistics process. For international shipping, this includes purchasing, forwarding and clearing, international shipping events and final delivery. The TEC framework facilitates comparison across alternative supplier routes by examining the sources of friction that impede trade flows, including delays at sea, at borders and within ports, as well as service-related disruptions captured in the data.

The version of the TEC applied here draws on the freight forwarder's direct cost structure (covering freight, landside operations, storage, transport and similar charges) and incorporates the indirect cost factors documented in prior studies. Therefore, the TEC components explained in Table 1 are included in the model.

Based on the step-by-step timing recorded in the dataset, the analysis shows that the ocean-freight segment required an average of 35.97 days, whereas the entire physical chain amounted to approximately 40.40 days. Thus, the duration of the ocean segment and the choice of export origin and carrier emerge as the key factors in limiting total physical delays and improving logistics performance in terms of both time and cost.

## Methodology

This study builds on previous work (Hoffman 2019; Hoffman et al. 2013, 2023; Minken & Johansen 2019) and uses a TEC model to quantify logistics performance costs. The TEC framework incorporates a combination of direct and indirect cost elements, including capital charges tied to inventory, shrinkage-related losses and the financial impact of stockouts.

Although the shipping environment is dynamic and conditions evolve continuously, the TEC model retains practical relevance because it functions as a flexible framework rather than a fixed prediction tool. Freight forwarders routinely capture the operational data required to apply the model, allowing TEC estimates to be updated as conditions change. Importantly, while many implicit costs – such as stock-in-transit financing, buffer-stock requirements

and disruption risks – are recognised by practitioners, they are seldom evaluated collectively. The TEC consolidates these components into a single cost measure, enabling cargo owners and forwarders to compare trade lanes and carrier options systematically and to quantify the economic impact of variability in delivery performance. In this way, the model complements existing decision-making rather than serving as a purely theoretical construct.

The empirical evidence for this study is drawn from transaction-level records compiled by a South African freight forwarder for the period July 2017 to August 2023. The dataset covers around 5374 individual shipments and integrates information from technical service providers, including documentation process timelines, container-tracking data reflecting the physical movement of cargo and associated financial records.

Table 2 summarises the dataset that was obtained for this study.

The TEC model developed by Hoffman et al. (2023) was adapted for this study into the steps explained in Table 3.

As shown in Table 3, the TEC framework was adapted for this study to translate the detailed shipment-level data into a unified measure of total logistics cost across different trade lanes. The adaptation integrates direct charges, operational cost components and the time variability captured in the dataset to evaluate how delays and route-specific performance influence overall logistics efficiency. A more detailed description of the framework is published in Van Rensburg (2024). By aligning the model with the structure of the available freight-forwarder data, the TEC output provides a comparable cost measure for each origin–shipping line combination, allowing the identification of the factors that most strongly affect end-to-end trade lane performance.

## Total economic cost model specification

This section outlines how the aggregated cost inputs were combined to calculate the different components that constitute the TEC.

### Direct costs

The cost parameters applied for direct cost calculations are indicated in Table 4. The majority of the cost parameters

**TABLE 1:** Cost components included in the total economic cost model.

| Cost components                                 | Variable  |
|---|---|
| 1. Direct logistics and transport costs         | <ul style="list-style-type: none"> <li>Charges for freight movement and landside operations.</li> <li>Fees paid to third-party logistics providers (e.g. customs processing, communication, and agency services).</li> <li>Costs associated with warehousing or temporary holding facilities.</li> <li>Inland or domestic transport expenses.</li> <li>Port-related charges such as cargo handling, terminal dues and similar levies.</li> <li>Costs linked to customs procedures and inspections conducted by border or regulatory agencies.</li> </ul>                    |
| 2. Indirect logistics costs arising from delays | <ul style="list-style-type: none"> <li>Financial costs incurred while goods remain in transit (e.g. interest or capital tied up).</li> <li>Losses because of product deterioration, shrinkage or damage.</li> <li>Expenses linked to maintaining safety or buffer stock levels.</li> <li>Missed sales opportunities when delayed cargo fails to replenish inventory in time.</li> <li>Reduced customer confidence or reputational loss resulting from unreliable delivery performance (often expressed as a portion of foregone sales relative to gross margin).</li> </ul> |
| 3. Storage-related costs                        | <ul style="list-style-type: none"> <li>Fees for storage at terminals, depots and other holding facilities.</li> <li>Costs associated with keeping stock in inventory (excluding transport-related charges).</li> </ul>  |
| 4. Inventory-related costs                      | <ul style="list-style-type: none"> <li>Capital costs or interest associated with funds invested in inventory.</li> <li>Annual inventory-holding costs expressed as a share of total stock value.</li> <li>Average losses because of shrinkage or deterioration for each day goods remain in storage.</li> </ul>   |

**TABLE 2:** Datasets used in the study.

| Dataset     | Description   | Number of files | Number of containers |
|-------------|---|-----------------|----------------------|
| Documentary | Timestamped process-flow records extracted from the ShipShape platform.   | 5374            | 9433                 |
| Physical    | Timestamped process-flow records extracted from the Customer platform.  | 6731            | 13 910               |
| Financial   | ZAR invoice amounts for all shipments (forwarding, clearing, warehousing, bonded storage by customs) from the Financial Portal. | 6602            | 13 910               |

ZAR, South African Rand.

**TABLE 3:** Total economic cost model adaptation process.

| Adaptation process  | Variable   |
|---|--|
| 1. Combine shipments by origin–shipping-line pairs and calculate annual averages per destination (see tables in Appendix 1).    | <ul style="list-style-type: none"> <li>Use ‘cargo delivered’ as the standard endpoint for comparability.</li> <li>Minor timing differences between Gauteng warehouses are treated as negligible.</li> </ul>  |
| 2. Determine direct logistics and transport costs for a 40-ft container from each origin to Gauteng (see tables in Appendix 1). | -  |
| 3. Model transport costs from each port to Gauteng using distance and time under equal competitive conditions.                  | <ul style="list-style-type: none"> <li>Add operating costs for trucks and vessels (labour, fuel, handling, finance) to the direct transport costs.</li> <li>Apply assumed parameters to estimate monthly ownership and operating costs.</li> <li>Convert monthly costs to per-trip values using round-trip transit times.</li> <li>Calculate time-dependent costs across delay percentiles to obtain an average.</li> <li>Repeat the process under different buffer-stock scenarios to find the cost-minimising level.</li> <li>Combine time-dependent and inventory-related costs with direct charges to derive TEC.</li> </ul> |
| 4. Calculate TEC for each origin–Gauteng route by modelling all direct charges along the full trade lane.                       | <ul style="list-style-type: none"> <li>Compare alternative shipping lines and inland transport providers.</li> <li>Include indirect costs (financing, shrinkage, stock holding, disruption costs).</li> <li>Estimate these costs by quantifying delay variability across all process segments.</li> </ul>  |
| 5. Use timestamp data (see Table 2) from ‘shipped on board’ onward to capture delay variability.                                | <ul style="list-style-type: none"> <li>Segment delays by key stages (ocean, customs, port, inland, etc.).</li> <li>Generate segment-level delay statistics using product-level detail.</li> <li>Estimate each segment’s TEC contribution for every origin–shipping-line pair.</li> <li>Identify which segments most strongly influence logistics cost and performance.</li> </ul>  |
| 6. Assess how buffer-stock choices affect costs arising from delivery-time variability.   | <ul style="list-style-type: none"> <li>Assume cargo owners select the cost-minimising buffer level.</li> <li>Higher buffers increase holding costs but reduce disruption risk; lower buffers do the opposite.</li> <li>Given a. and b. calculate total costs across a range of buffer-stock durations.</li> <li>Greater time-delay variability results in higher buffer levels that minimise TEC and higher total costs.</li> <li>Buffer-stock levels calibrated using historical delay patterns reflect the cost impact of trade-lane performance.</li> </ul>   |

Source: Adapted from Hoffman, A.J., Mutendera, C. & Venter, W.C., 2023, ‘Comparing transport corridors based on total economic cost’, *Journal of Advanced Transportation* 2023, Article ID 6336630, 1–15. <https://doi.org/10.1155/2023/6336630>

Note: Please see the full reference list of the article, Hoffman, A., Van Rensburg, J. & Grater, S., 2026, ‘Efficient trade lane selection: A total economic cost perspective on shipping lines’, *Journal of Transport and Supply Chain Management* 20(0), a1272. <https://doi.org/10.4102/jtscm.v20i0.1272>, for more information.

TEC, total economic cost.

were obtained from the datasets indicated earlier, and other costs were also incorporated based on the work by Hoffman et al. (2023):

Direct costs were calculated using the Equation 1:

$$RTD_i = 2 \times TD_i + 4 \quad [\text{Eqn 1}]$$

where  $RTD_i$  = denotes the round-trip delay (in days) for trade lane  $i$ , and  $TD_i$  represents the one-way delay from origin to destination.

$$DC_{trip,i} = \frac{DC_{monthly} \times RTD_i}{30} \quad [\text{Eqn 2}]$$

where  $DC_{trip,i}$  is the driver cost per trip for trade lane  $i$ , and  $DC_{monthly}$  is the monthly driver employment cost (Equation 2).

$$FC_i = \frac{2 \times Dist_i \times FuelCost}{FuelEcon} \quad [\text{Eqn 3}]$$

where  $FC_i$  is the cost of fuel lane  $i$ ,  $Dist_i$  is the origin to destination distance for trade lane  $i$ ,  $FuelCost$  is the fuel cost per litre and  $FuelEcon$  is fuel economy in km/litre (Equation 3).

$$DTC_i = DC_{trip,i} + FC_i + N3T + OC \quad [\text{Eqn 4}]$$

where  $DTC_i$  is the cost of a direct trip,  $N3T$  is the N3 toll fees, whereas  $OC$  represent other costs (e.g. subsistence payments for the driver) (Equation 4).

$$NumTripspm_i = \frac{30}{RTD_i} \quad [\text{Eqn 5}]$$

where  $NumTripspm_i$  is the amount of monthly trips for the  $i$ -th trade lane (Equation 5).

$$TCpm_i = NumTripspm_i \times DTC_i + Instpm \quad [\text{Eqn 6}]$$

where  $TCpm_i$  is the total monthly truck cost for the  $i$ -th trade lane, and  $Instpm$  is the monthly instalment for each truck (Equation 6).

$$TranspCost_i = \frac{TCpm_i \times RTD_i}{30} \quad [\text{Eqn 7}]$$

where  $TranspCost_i$  is the total trip cost for the  $i$ -th trade lane (Equation 7).

Transport costs for each trade lane were expressed as a proportion of the cargo value, consistent with the retail and tyre-import categories represented in the sample.

### Variable time delay costs

To minimise overall costs, cargo owners implement a specific buffer stock policy. Above-average delivery delays can still cause stock-outs and economic losses despite cost-minimising buffer stock levels. Therefore, calculating the TEC requires assessing the costs across all possible time delays. This involves determining the percentiles of time delays for each trade lane and calculating the expected TEC for each percentile. By combining these components, the model yields the total expected cost of cargo deliveries based on the observed distribution of time delays from the cargo and truck datasets. Beyond the direct transport costs, the following indirect cost elements were identified for import operations, following the approach of Hoffman (2019):

**Time delay impact:** Because time-dependent costs rise as stock remains longer in transit, the total cost is calculated by integrating the cost incurred at each possible delay duration with the probability of the delay occurring:

$$TotCost = \int_{t=0}^{\infty} Cost(t) p(t) dt \quad [\text{Eqn 8}]$$

where  $Cost(t)$  is the cost associated with a delay of length  $t$ , and  $p(t)$  is the probability distribution of transit times (Equation 8). As the true distribution is not known, an empirical approximation is used by averaging across all observed delay percentiles (Equation 9):

$$TotCost = \frac{\sum_{i=1}^{100} Cost_i}{100} \quad [\text{Eqn 9}]$$

where  $Cost_i$  denotes the cost corresponding to the  $i$ -th percentile of observed delays. This method is applied to all time-dependent cost components that follow; for brevity, the summation form is not repeated for each category:

**Interest on stock-in-transit:** The importer carries the financing cost of goods from the point at which ownership transfers – typically when the cargo leaves the origin facility or is loaded on board (in approximately 88% of cases in this dataset, under EXW and FOB terms<sup>1</sup>) – until final delivery. The interest cost for stock-in-transit is therefore expressed as a fraction of the cargo value over the duration between shipment and receipt (Equation 10, Equation 11, Equation 12).

$$CI = \sum_{i=1}^{100} IR \times VGIT_i \quad [\text{Eqn 10}]$$

$$VGIT_i = \frac{VAC \times TD_i}{365} \quad [\text{Eqn 11}]$$

Therefore:

$$\frac{CI}{VAC} = \frac{IR \times TD_i}{365} \quad [\text{Eqn 12}]$$

where:

- $CI$  = Cost of interest p.a.
- $IR$  = Interest rate p.a.
- $VGIT$  = Value of goods in transit
- $VAC$  = Value of annual consumption
- $TD_i$  = Transit delays (calculated in days) for the  $i$ -th percentile

**Shrinkage in transit:** Because shrinkage losses rise with longer transit times, total shrinkage was estimated by averaging the shrinkage cost across all observed delay percentiles (Equation 13 and Equation 14):

$$TotShrinkage = \frac{\sum_{i=1}^{100} Shrinkage_i}{100} \quad [\text{Eqn 13}]$$

$$Shrinkage_i = Shrinkagepd \times (1 - Shrinkage_{i-1}) \\ (TDPercCorr_i - TDPercCorr_{i-1}) \\ + Shrinkage_{i-1} \quad [\text{Eqn 14}]$$

where  $TotShrinkage$  denotes the total shrinkage across all possible transit times,  $Shrinkage_i$  is the shrinkage associated with the  $i$ -th percentile,  $Shrinkagepd$  is the daily shrinkage rate and  $TDPercCorr_i$  represents the transit time (in days) for the  $i$ -th percentile. The formulation reflects that, as each day passes, a smaller quantity of stock remains exposed to further shrinkage.

**Out-of-stock losses:** Losses in sales or production may occur when delivery delays exceed the expected arrival window ('delivery expected' to 'cargo delivered'). If buffer stock is maintained, losses only arise when an unexpected delay surpasses the duration that the buffer can cover (Hoffman 2019):

**Retail:** For retail operations – such as those represented in this model – it is assumed that sales losses occur once the buffer stock is exhausted and the next delivery has not yet arrived (Equation 15, Equation 16, Equation 17, Equation 18).

$$\frac{LRI}{VAC} = FSL \times GM \quad [\text{Eqn 15}]$$

where

$$FSL = \frac{OTL}{ADT} \text{ if } OTL > 0, FSL = 0 \text{ otherwise} \quad [\text{Eqn 16}]$$

$$OTL = ADT - SDT - BSP \quad [\text{Eqn 17}]$$

$$BSP = \frac{BSS}{UR} \quad [\text{Eqn 18}]$$

where:

- $LRI$  = Loss in retail income
- $FSL$  = Fraction of sales lost
- $GM$  = Gross margin
- $OTL$  = Operational time loss
- $ADT$  = Actual delivery time
- $SDT$  = Standard delivery time
- $BSP$  = Buffer stock period
- $BSS$  = Buffer stock size
- $UR$  = Usage rate

**Storage costs incurred in maintaining buffer stock, calculated as a share of the cargo value (Equation 19; Equation 20; Equation 21):**

$$\frac{SC}{VAC} = \frac{SR \times MIS}{VAC} \quad [\text{Eqn 19}]$$

$$MIS = (BSP + SDT - MDT) \times UR \quad [\text{Eqn 20}]$$

Therefore:

$$\frac{SC}{VAC} = \frac{(BSP + SDT - MDT) \times SR \times UR}{\text{One Year}} \quad [\text{Eqn 21}]$$

where:

- $SC$  = Storage cost p.a.
- $SR$  = 1 year storage rate per unit
- $SRFrac$  = 1 year storage cost as fraction of unit value
- $MIS$  = Max inventory size in units
- $MDT$  = Min delivery time

<sup>1</sup>EXW (Ex Works) and FOB (Free On Board) are Incoterms indicating when responsibility and risk transfer from seller to buyer: at the seller's premises under EXW and once goods are loaded on board the vessel under FOB.

Equations 1–21 provide a framework for expressing the total cost arising from transport and logistics delays as a fraction of the overall value of goods purchased.

$$TEI = CI + SC + LRI \quad [\text{Eqn 22}]$$

where in Equation 22:

$TEI = \text{Total economic impact}$

As noted earlier, the TEC is evaluated at the buffer-stock period (BSP) that minimises total cost. Because TEC depends on the full distribution of actual delivery times – and no closed-form expression exists for this distribution – the optimal BSP cannot be derived analytically. The BSP is therefore identified through a numerical procedure that evaluates TEC across observed delay percentiles for different BSP values. The BSP that yields the lowest TEC is then selected as the optimum.

### Total economic cost sensitivity concerning cost parameters

The preceding equations show that the TEC, from the cargo owner's perspective, is dependent on various cost parameters. To assess this sensitivity, TEC was recalculated across a range of parameter values, as outlined in Table 5.

## Results

This section discusses the results generated by the TEC model and presents the key findings derived from the analysis.

### Direct transport and logistics cost

Table 6 presents a summary of direct transport and logistics costs for each origin–destination combination, together with the average distance from the origin port to Durban, the corresponding model-based transport cost and the charges observed in the dataset.

### Total economic cost model costs

For each origin–shipping-line combination, delay percentiles were calculated for the ocean, port and land segments and for the total trade lane. The cost contribution of each of the segments to the overall TEC was then quantified. When isolating the TEC impact of a specific segment (e.g. the ocean leg), the model applies average values for the remaining segments (e.g. port and land). By isolating the contributions to time variability of each segment of the total trade lane, it was possible to separately calculate the TEC component contributed by each trade lane segment. This approach highlighted the significant impact of the ocean segment on delivery time variations.

Figure 1 illustrates delay percentiles across all segments. The ocean leg clearly dominates total transit time, highlighting

**TABLE 4:** Direct logistics and transport cost parameters.

| Cost category  | Parameter description                                   |
|--|---|
| Container-related charges                                | Container cargo dues (per unit) – R3730                 |
| Customs processing costs                                 | Customs clearance cost per HS classification – R141 677 |
| Ocean freight† charges (Incoterm- and time-dependent)    | R50 863 per container                                   |
| Landside fees  | R1439 per container                                     |
| Logistics service fees                                   | R712 per container                                      |
| Storage-related costs                                    | R615 per container                                      |
| Inland transport fees                                    | R9736 per container                                     |
| Monthly vehicle financing interest rate                  | 1.0% (at 12% per annum)                                 |
| Financing duration (over 6 years)                        | 72 months‡  |
| Average cost of a vehicle (~\$200 000)                   | R1 800 000 per truck                                    |
| Monthly vehicle repayment (~\$3911)                      | R74 309 per month                                       |
| Average fuel consumption                                 | 1.5 km/L  |
| Fuel price   | R15.56 per litre  |
| Monthly driver cost (~\$1000)                            | R19 000   |
| Trip-related overheads (~\$180)                          | R3420   |
| Road usage charges                                       | R1080   |
| Annual cost of capital for inventory financing (%)       | 12  |
| Gross margin (%)   | 50  |
| Annual inventory holding cost (share of stock value) (%) | 40  |
| Average daily shrinkage rate during storage (%)          | 1   |
| Average customs value per container                      | ~R2 270 000   |
| Mean ocean transit duration                              | 35 973 days   |

Source: Adapted from Hoffman, A.J., Mutendera, C. & Venter, W.C., 2023, 'Comparing transport corridors based on total economic cost', *Journal of Advanced Transportation* 2023, Article ID 6336630, 1–15. <https://doi.org/10.1155/2023/6336630>

†, Freight insurance is included in the freight charges, depending on the Incoterm applied; ‡, The financing period is used to derive monthly ownership and financing costs and is not a direct cost parameter.

**TABLE 5:** Range of values applied to calculate total economic cost sensitivity.

| Category  | Minimum value (%) | Maximum value (%) |
|---|-------------------|-------------------|
| Interest rate (p.a.)  | 1                 | 20                |
| Gross margin  | 10                | 90                |
| Annual inventory cost (percentage of the cargo's customs value) | 10                | 100               |

Source: Adapted from Hoffman, A.J., Mutendera, C. & Venter, W.C., 2023, 'Comparing transport corridors based on total economic cost', *Journal of Advanced Transportation* 2023, Article ID 6336630, 1–15. <https://doi.org/10.1155/2023/6336630>

p.a., per annum.

**TABLE 6:** Direct transport and logistics cost parameters (inbound road transport).

| Cost category                    | JHB        |
|----------------------------------|------------|
| Maritime shipping distance† (km) | 12 197.000 |
| Road transport distance (km)     | 539.000    |
| Duration of a round trip in days | 1.959      |
| Amount of monthly transits       | 10.139     |
| Driver cost per trip (ZAR)       | 1873.952   |
| Fuel cost per trip (ZAR)         | 5591.349   |
| Truck expenses per month (ZAR)   | 74 309.000 |
| Transport cost per trip (ZAR)    | 64 267.301 |
| Retail: Transport cost share (%) | 2.831      |
| Freight forwarder's fee (ZAR)    | 712.000    |

Source: Adapted and calculated from Hoffman, A.J., Mutendera, C. & Venter, W.C., 2023, 'Comparing transport corridors based on total economic cost', *Journal of Advanced Transportation* 2023, Article ID 6336630, 1–15. <https://doi.org/10.1155/2023/6336630>

JHB, Johannesburg; ZAR, South African Rand.

†, A gravity-based approach was used to compute shipment-weighted distances from each origin port to Durban, which were then converted from nautical miles to kilometres.

the need to select the best-performing supplier–shipping-line route. The ocean segment averaged 35.97 days compared with 40.40 days for the entire physical chain.

The second graph in Figure 1 indicates that delays on the waterside and landside occur at similar levels. This implies that terminal performance affects total delay equally, regardless of whether inefficiencies arise from ship-to-shore crane operations or landside handling activities.

The bottom graph in Figure 1 indicates that inbound road transport has the smallest overall impact on delays, although notable disruptions occur from the 96th percentile onward. The pattern also suggests that the prevailing inbound approach (short haul to a depot, then long haul to destination) may merit reassessment, given the prolonged dwell times at depots or warehouses that increase storage costs and influence buffer-stock decisions.

The next results illustrate a clear pattern in how TEC changes with the buffer-stock period. We initially examine how buffer stock levels influence each cost component (interest costs, stock holding costs, lost sales costs) and their impact on total cost, explaining why a cost-reducing stock level minimises costs. We then calculated TEC contributions by each trade lane segment (ocean, port and road) as a function of buffer stock level to quantify their relative contributions.

Figure 2 illustrates the relationship between logistics costs and the buffer-stock period.

The variables considered include interest on inventory, storage costs, lost-sales costs and delay-related costs. Increasing the buffer-stock period raises interest and storage costs but reduces lost-sales risk. Interest and storage costs therefore rise directly with longer buffer periods (see top left and right panels of Figure 2). The ocean leg contributes most to delays, with the loss of sales eliminated at around 70 days of buffer stock. The graph shows an initial decline in total costs with increasing buffer stocks, reaching a minimum at the ideal buffer stock level and then rising again as interest and stockholding costs further increase with further buffer stock increases.

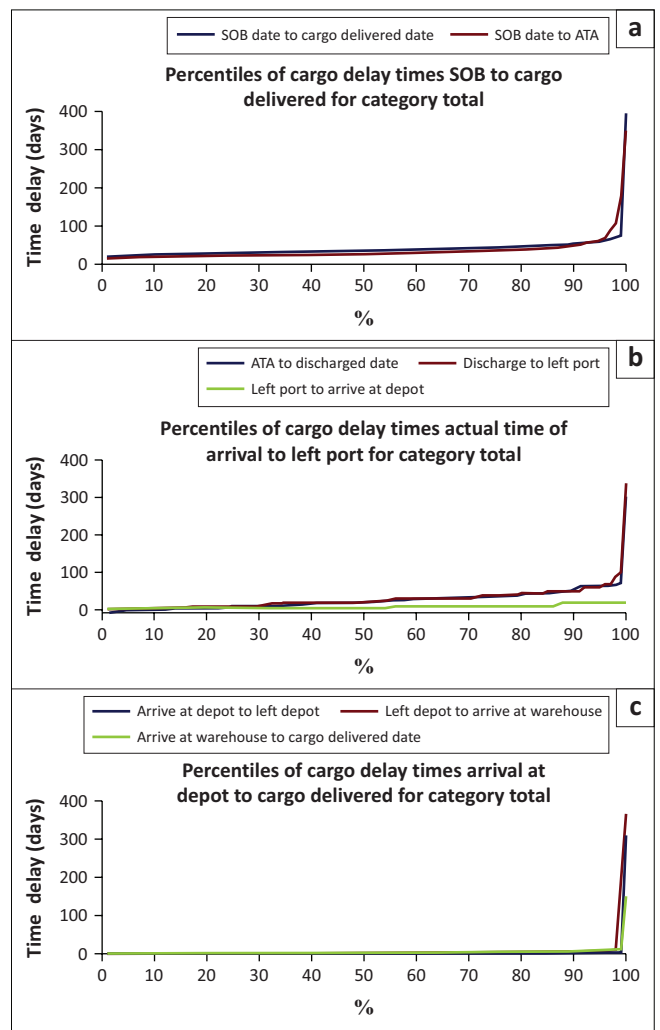
As the performance of individual trade-lane components differs substantially, the calculations were repeated by isolating the delay and variability associated with each specific segment. In this approach, one segment was allowed to vary while all others were held at their average delay values. This made it possible to quantify the separate contribution of each segment to the overall TEC.

Figure 3 illustrates how the cost contributions of the ocean, port and road segments change with different buffer-stock levels. Each curve shows a clear minimum point – the ideal buffer-stock period. For the total trade lane, this optimal level is approximately 34 days, closely matching the average duration of the ocean leg. When segment-level variability is considered individually, the minimum cost point aligns roughly with that segment's average transit time. As with earlier findings, the ocean leg remains the dominant contributor to time-related logistics costs. Importantly, lower

delivery-time uncertainty allows firms to maintain smaller buffer stocks without incurring significant sales losses.

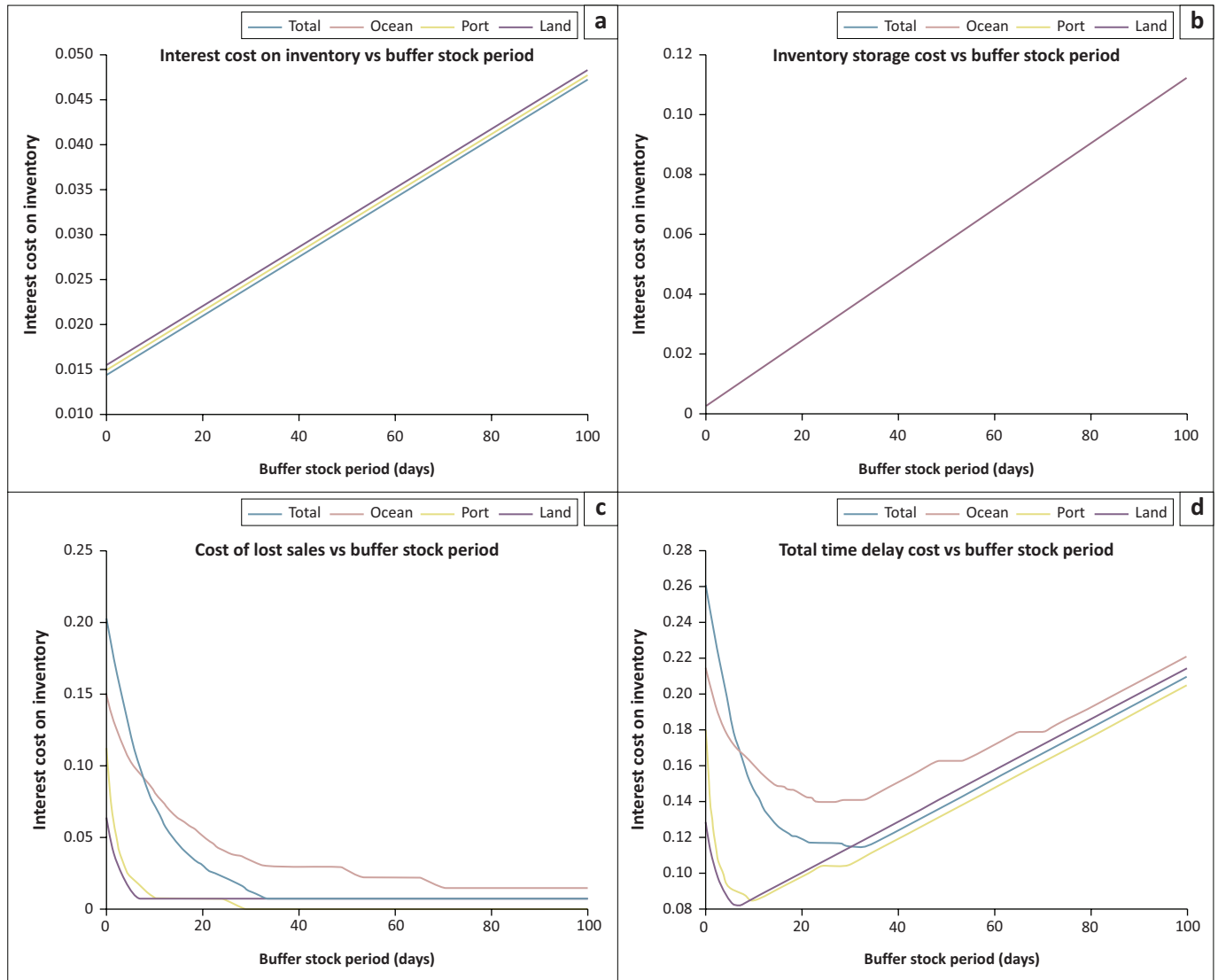
When the cost impacts associated with delay variability are disaggregated, the ocean leg is the most significant contributor to time-related logistics costs for imports into South Africa. Table 7 indicates the transport and logistics costs arising from delay variability, expressed as a fraction of cargo value for each trade lane. The analysis covers the top 14 origin countries and the top 10 shipping lines (see the tables in Appendix 1). A dash (–) indicates that a particular country–shipping-line combination is not serviced and is therefore not applicable.

The table yields several insights. For France, Cosco achieves the lowest TEC from time delays (3.9% of cargo value) and Mediterranean Shipping Company (MSC) the highest (12.1%), a notable gap given that direct logistics costs average about 9.2% of product value. This difference reflects Cosco's shorter average ocean transit time (22.6 days) compared with MSC (38 days). Such differences may arise from several operational factors, including vessel size and deployment,



SOB, Shipped on board; ATA, Actual time of arrival.

**FIGURE 1:** Distribution of time-delay percentiles by logistics segment: (a) Shipping on Board date to Cargo Delivered date (b) Actual time of arrival at port to date cargo left the port (c) Arrival at depot to cargo delivered date.



**FIGURE 2:** Trade-lane cost drivers linked to time-delay variability: (a) Interest cost on inventory versus buffer stock period (b) Inventory storage cost versus buffer stock period (c) Cost of lost sales versus buffer stock period (d) Total time delay cost versus buffer stock period.

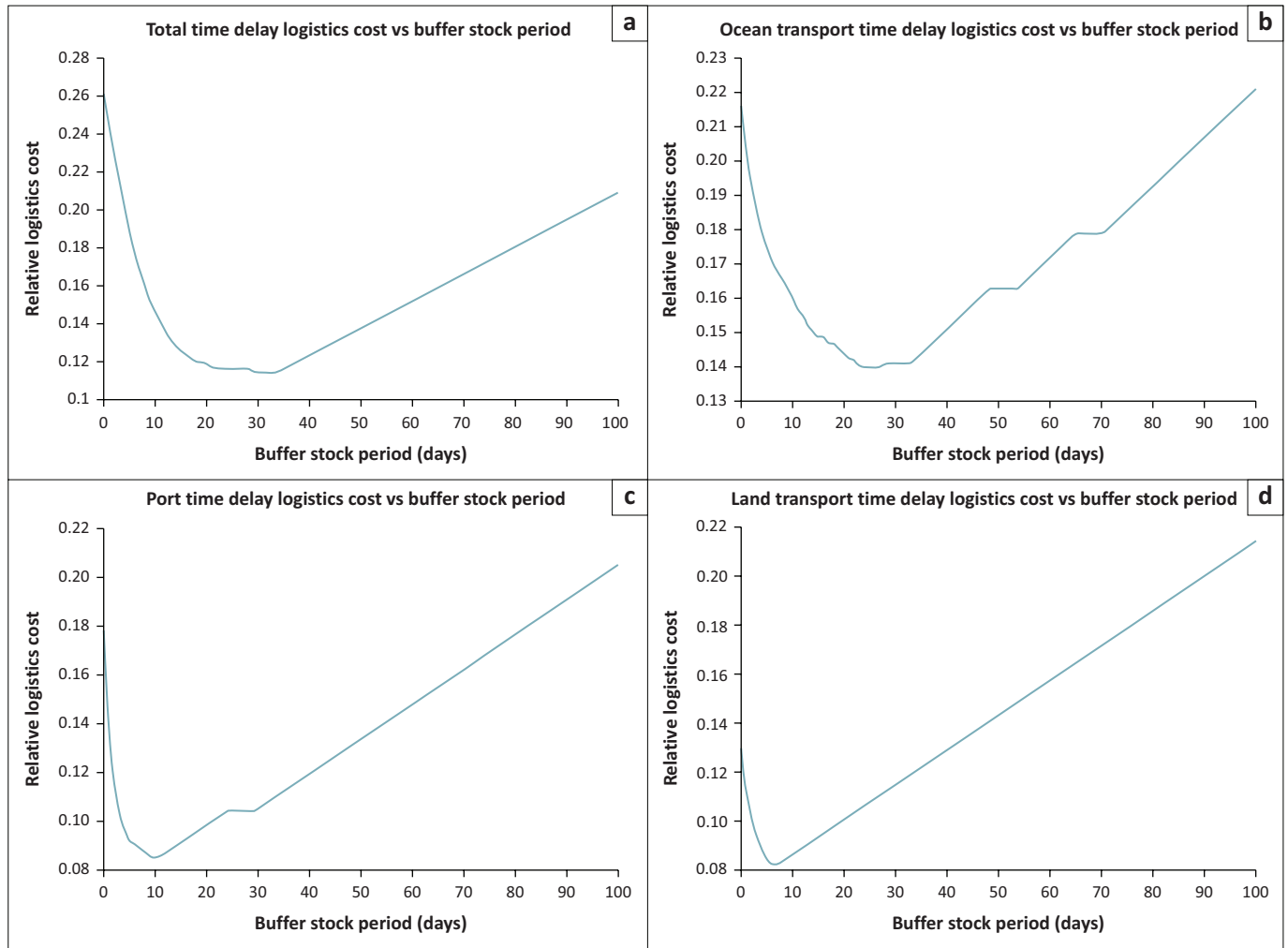
route structure, service frequency and the number of intermediate port calls. While the dataset does not permit isolation of these individual drivers, the observed transit times capture their combined effect as experienced by cargo owners. From a decision-making perspective, these differences are economically meaningful, as longer and more variable transit times increase buffer-stock requirements and implicit costs, thereby influencing freight forwarders' carrier-selection decisions.

Across shipping lines, considerable variation is observed in both average ocean transit times and their variability. Evergreen shows the longest average delays, although with relatively low variability, suggesting consistently slow performance. In contrast, MSC and ONE exhibit the largest standard deviations, indicating highly inconsistent transit times. Cosco, Maersk and Gold Star Line display shorter and more stable transit times, while CMA-CGM and Orient Overseas Container Line (OOCL) rank among the best performers in terms of both average duration and consistency. These differences in reliability directly influence the TEC outcomes for each trade lane.

The shipping lines with the highest variability in ocean transit times are ONE and MSC, with standard deviations of 28.63 and 24.68 days, respectively. At the opposite end, OOCL and Gold Star Line show the lowest variability, with standard deviations of 3.79 and 4.43 days. This indicates that ONE and MSC exhibit far more dispersed transit-time outcomes – leading, on average, to higher time-delay costs – whereas OOCL and Gold Star Line display more consistent performance and therefore lower associated delay costs.

The results also illustrate the extent of market coverage provided by each shipping line. MSC serves nearly all listed markets, Maersk connects to 11, and ONE to 10. All three lines operate services to Thailand, which emerges as the best-served origin and also the one with the widest range of delay-related TEC outcomes (from 4.2% to 24.5%).

The minimum buffer-stock period varies considerably across origin–shipping-line combinations. For example, shipments from Thailand require anywhere from fewer than five days to more than 33 days of buffer stock, depending on the



**FIGURE 3:** Logistics cost shares across trade lanes for different buffer-stock periods: (a) Total time delay cost versus buffer stock period (b) Ocean transport time delay cost versus buffer stock period (c) Port time delay cost versus buffer stock period (d) Land transport time delay cost versus buffer stock period.

**TABLE 7:** Cost of time delays for origin-shipping line pairs (% of value).

| Combination (shipping line vs. country) | BE   | BR   | FR   | DE   | IN  | IT   | NL   | PL   | PT   | RO   | SL   | ES   | TH   | US   |
|---|------|------|------|------|-----|------|------|------|------|------|------|------|------|------|
| CMA-CGM                                 | -    | 6.7  | 8.8  | -    | -   | -    | -    | -    | -    | 13.4 | 14.0 | -    | 8.8  | 12.8 |
| Cosco                                   | -    | -    | 3.9  | -    | -   | -    | -    | -    | -    | -    | -    | -    | 13.3 | -    |
| Evergreen                               | -    | -    | -    | -    | -   | -    | -    | -    | -    | -    | -    | -    | 24.5 | -    |
| Gold Star Line                          | -    | -    | -    | -    | -   | -    | -    | -    | -    | -    | -    | -    | 7.4  | -    |
| Hapag-Lloyd                             | 5.3  | 6.3  | 4.9  | -    | -   | 8.5  | -    | -    | 10.4 | 12.5 | 10.6 | -    | 6.0  | -    |
| Maersk                                  | 8.1  | 17.8 | 6.5  | 10.8 | 6.9 | 5.7  | 5.1  | 10.0 | -    | -    | -    | 5.9  | 6.2  | 8.0  |
| MSC                                     | 7.5  | 8.3  | 12.2 | 7.4  | -   | 13.9 | 10.0 | 15.2 | 6.0  | 9.3  | 21.1 | 14.4 | 8.4  | 12.5 |
| ONE                                     | 7.2  | -    | 9.7  | 16.1 | 8.4 | 8.4  | 18.3 | 8.6  | -    | -    | -    | 11.2 | 9.9  | 9.8  |
| OOCL                                    | -    | -    | -    | -    | -   | -    | -    | -    | -    | -    | -    | -    | 6.0  | -    |
| Safmarine                               | 10.6 | -    | 8.0  | 7.5  | 4.7 | -    | 6.1  | 9.9  | -    | -    | -    | 9.1  | 4.2  | 10.1 |

Source: Adapted and calculated from Hoffman, A.J., Mutendera, C. & Venter, W.C., 2023, 'Comparing transport corridors based on total economic cost', *Journal of Advanced Transportation* 2023, Article ID 6336630, 1–15. <https://doi.org/10.1155/2023/6336630>

BE, Belgium; BR, Brazil; FR, France; DE, Denmark; IN, India; IT, Italy; NL, Netherlands; PL, Poland; PT, Portugal; RO, Romania; SL, Slovenia; ES, Spain; TH, Thailand; US, United States; MSC, Mediterranean Shipping Company; ONE, Ocean Network Express; OOCL, Orient Overseas Container Lines.

carrier; a similar range is observed for shipments from the Netherlands. A clear pattern emerges: shipping lines with lower variability in transit times consistently enable shorter buffer-stock requirements, thereby reducing total logistics costs. This illustrates how freight forwarders can improve overall performance by selecting carriers whose delay variability aligns best with the specific origin market.<sup>2</sup>

<sup>2</sup>For the purposes of this article, all numerical results were not included but are available at a detailed level from the authors.

## Conclusion, limitations and recommendations

This study developed a TEC model to support more informed logistics decision-making in international trade. The TEC model quantifies the impact of time delay variability on direct and indirect logistics costs across different trade lanes. It built on previous work and added factors like time delay variability, shrinkage of stock and

out-of-stock losses. Although the shipping environment is dynamic, the TEC framework remains operationally relevant because it can be recalculated as new data becomes available, enabling ongoing comparison of trade lanes and carrier performance. While the results show that shipping-line choice plays a particularly influential role given its strong impact on transit-time variability, the value of the TEC model extends beyond carrier selection alone. The framework also informs buffer-stock policies, highlights the cost implications of reliability differences across logistics segments and enables systematic comparison of trade-lane configurations as operating conditions evolve.

The findings reveal substantial differences in transit times across consignments, with delays ranging from only a few days to well over 100 days in certain cases. This underscores the need to quantify how delivery-time variability affects TEC from the cargo owner's perspective. It also highlights the importance for freight forwarders to carefully evaluate trade-lane and shipping-line choices, as differences in delay performance can materially influence the overall economic cost of imported goods.

The ocean segment, averaging 35.97 days, had the strongest influence on total delays. Waterside and landside port operations contributed similarly, while inbound road transport had the smallest effect except for occasional large disruptions past the 96th percentile. The findings also suggest a review of the short-haul-long-haul inbound model, given the extended time many consignments spend in depots or warehouses.

Investigation of different buffer stock scenarios revealed that for each shipping line-trade lane combination, an ideal buffer stock period can be found. This results from the fact that interest and storage costs rise, while the cost of lost sales or production decreases, with increased buffer stock periods. For the available data set, an ideal buffer stock level of around 34 days minimised total logistics costs. For those shipping lines with low time delay variability, the buffer stock period could, however, be reduced to below 10 days. The findings emphasise the importance of aligning shipping lines with specific origin countries, as lower optimal buffer-stock requirements signal more reliable services and reduced TEC.

These results offer practical guidance for freight forwarders and cargo owners seeking to enhance logistics performance by selecting the most suitable shipping lines for specific routes, where sufficient operational and historical data are available. They also support the identification of appropriately calibrated buffer-stock levels by highlighting origin-carrier combinations that minimise TEC.

In addition, the variation in optimal buffer-stock requirements sheds light on how inventory decisions interact with key cost drivers affected by time delays – such as interest on stock in transit, storage costs and the risk of lost sales.

Despite the substantial dataset that was available for this research, several limitations remain.

Firstly, the dataset used, although substantial, represents only a sample of 5374 shipments, which may not fully capture the broader variability in global trade patterns. Secondly, the analysis focuses on limited combinations of country of origin and shipping line schedules, restricting the generalisability of the findings to other trade routes and logistical conditions. Thirdly, the TEC model relies on available data for specific elements, and gaps in comprehensive information, particularly indirect costs, could affect the model's accuracy.

Lastly, the analysis is constrained by historical data and may not account for evolving trends in shipping practices or regulatory changes impacting logistics performance. These limitations suggest areas for further research to enhance the model's robustness and applicability.

Regardless of these limitations, the study demonstrated that faster and more predictable movement of goods through the supply chain improves trade volumes and reduces logistics costs, highlighting the need for the industry to apply more robust data analytics in order to improve logistics performance. More specifically, where sufficient historical and operational data are available, the application of the TEC can significantly enhance the freight forwarder's ability to make informed shipping-line selection decisions for specific trade routes.

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## Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

## CRedit authorship contribution

Alwyn Hoffman: Conceptualisation, Methodology, Formal analysis, Software, Resources, Writing – review & editing, Supervision. Jacob van Rensburg: Methodology, Formal analysis, Investigation, Data curation, Resources, Writing – review & editing. Sonja Grater: Writing – original draft, Validation, Resources, Writing – review & editing, Supervision. All authors reviewed the article, contributed to

the discussion of results, approved the final version for submission and publication and take responsibility for the integrity of its findings.

## Ethical considerations

This article followed all ethical standards for research without direct contact with human or animal subjects.

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## Data availability

The majority of the data were obtained from a logistics company in South Africa (a permission letter for the use of the data is available upon request). The data were further supplemented with secondary, open-access data from Transnet National Port Authorities

## Disclaimer

The views and opinions expressed in this article are those of the authors and are the product of professional research. They do not necessarily reflect the official policy or position of any affiliated institution, funder, agency or that of the publisher.

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Appendices starts on next page →

## Appendix 1

**TABLE 1-A1:** Overview of the dataset by exporting country.

| Country of export    | Customs value (ZAR)   |
|----------------------|-----------------------|
| United States        | 6 793 901 671         |
| Thailand             | 5 828 943 994         |
| Italy                | 5 268 940 596         |
| Spain                | 4 272 415 535         |
| France               | 3 015 458 577         |
| Poland               | 1 976 591 234         |
| India                | 1 312 349 899         |
| The Netherlands      | 804 316 629           |
| Germany              | 700 255 169           |
| Belgium              | 379 946 451           |
| Portugal             | 317 780 470           |
| Romania              | 267 648 073           |
| Brazil               | 256 533 940           |
| Slovenia             | 159 044 607           |
| Hungary              | 85 192 350            |
| United Kingdom       | 72 400 286            |
| Czech Republic       | 22 885 120            |
| China                | 13 538 759            |
| United Arab Emirates | 12 553 838            |
| Sri Lanka            | 6 967 043             |
| South Africa         | 4 657 323             |
| Georgia              | 853 000               |
| Ireland              | 318 708               |
| Singapore            | 194 553               |
| <b>Grand total</b>   | <b>31 573 687 825</b> |

Table 2-A1 summarises the country of export in terms of total time delays from SOB to cargo delivered.

**TABLE 2-A1:** Country of export: Statistical summary maritime transport segment.

| Country              | Size   | Average <sup>†</sup> | Variance | Min | Max |
|----------------------|--------|----------------------|----------|-----|-----|
| United States        | 10 253 | 42.79                | 516.80   | 24  | 398 |
| Thailand             | 8403   | 36.39                | 65.10    | 22  | 84  |
| Italy                | 5927   | 43.81                | 98.94    | 23  | 93  |
| Spain                | 5437   | 32.94                | 81.44    | 17  | 79  |
| France               | 3879   | 39.28                | 84.05    | 1   | 84  |
| Poland               | 3510   | 50.76                | 110.71   | 32  | 128 |
| India                | 1031   | 35.44                | 60.04    | 20  | 58  |
| The Netherlands      | 974    | 33.78                | 50.02    | 21  | 61  |
| Germany              | 879    | 40.95                | 98.18    | 25  | 81  |
| Belgium              | 735    | 37.83                | 87.77    | 16  | 76  |
| Romania              | 523    | 67.64                | 255.22   | 39  | 92  |
| Portugal             | 479    | 26.42                | 23.20    | 20  | 78  |
| Brazil               | 269    | 34.60                | 143.32   | 14  | 77  |
| Slovenia             | 163    | 61.12                | 150.99   | 41  | 100 |
| Georgia              | 161    | 41.67                | 26.65    | 33  | 73  |
| Sri Lanka            | 40     | 52.45                | 6580.25  | 13  | 394 |
| China                | 20     | 39.80                | 8.91     | 33  | 46  |
| United Arab Emirates | 17     | 87.35                | 560.12   | 63  | 109 |
| Hungary              | 3      | 53.00                | 156.00   | 39  | 63  |
| Singapore            | 2      | 49.00                | 0.00     | 49  | 49  |
| Czech Republic       | 1      | 25.00                | 0.00     | 25  | 25  |
| Ireland              | 1      | 41.00                | 0.00     | 41  | 41  |

<sup>†</sup>, In statistical reporting, and in analyses of international shipping delays, the terms 'mean' and 'average' are generally used interchangeably. In the shipping context, however, 'average' typically refers to the arithmetic mean, which intentionally reflects the full delay experience, including outliers. Accordingly, all averages reported here incorporate extreme values.

Table 3-A1 shows the products (42 910 different lines – each representing a product imported) shipped via the respective shipping lines.

**TABLE 3-A1:** Shipping lines and corresponding shipments.

| Shipping line                        | Products shipped |
|--------------------------------------|------------------|
| Ocean Network Express (ONE)          | 11 706           |
| Mediterranean Shipping Company (MSC) | 11 560           |
| Safmarine Container Lines            | 4978             |
| CMA-CGM Group                        | 3393             |
| Maersk Line                          | 3153             |
| MOL                                  | 3110             |
| Hamburg Sud                          | 2438             |
| Gold Star Line                       | 1367             |
| Cosco Shipping Lines                 | 792              |
| Hapag-Lloyd                          | 159              |
| Evergreen Marine Corporation         | 134              |
| Dal Deutsche Afrika-Linien           | 61               |
| LMC                                  | 52               |
| Pacific International Line           | 7                |
| <b>Grand Total</b>                   | <b>42 910</b>    |

MOL, Mitsui OSK Lines; LMC, LMC Express.

Table 4-A1 reports descriptive statistics for the ocean transport segment (Shipped on Board and Actual Time of Arrival [SOB to ATA] for each shipping line represented in the dataset).

**TABLE 4-A1:** Shipping lines: Statistical summary of maritime segment time delays.

| Top 10 Shipping lines           | Size | Average | Variance | Min    | Max    |
|---------------------------------|------|---------|----------|--------|--------|
| MSC                             | 6285 | 40.04   | 609.12   | 17.66  | 350.52 |
| ONE                             | 4054 | 31.30   | 819.66   | 4.00   | 339.98 |
| Maersk Line                     | 2865 | 31.28   | 73.55    | 17.00  | 121.14 |
| CMA-CGM Group                   | 2695 | 30.59   | 466.51   | 19.00  | 323.53 |
| Gold Star Line                  | 1356 | 29.29   | 19.63    | 22.50  | 69.85  |
| Cosco Shipping Lines            | 444  | 48.60   | 709.08   | 22.66  | 153.88 |
| Evergreen Marine Corporation    | 134  | 175.96  | 42.87    | 151.65 | 177.71 |
| Safmarine Container Lines       | 127  | 39.39   | 161.45   | 21.00  | 55.00  |
| Orient Overseas Container Lines | 126  | 28.45   | 14.37    | 22.66  | 36.00  |
| Hapag-Lloyd                     | 113  | 69.74   | 209.21   | 10.45  | 83.00  |

MSC, Mediterranean Shipping Company; ONE, Ocean Network Express.