Delay Monitoring in Liner Shipping
Increasing the Transparency of Maritime Supply Chains

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Extended Abstract

Summary. Our work discusses the importance of service quality and reliability in commercial shipping: Four key factors influence shipper satisfaction, namely reliability, speed, responsiveness, and value, with reliability being the most important. An approach to add transparency in liner shipping by analyzing AIS data is presented. The approach is based on detecting recurring behavior, such as stopping points, and can identify vessels engaged in liner services, calculate time spent at berth, analyze the composition of transit time, and estimate transit delays. The approach was applied to an AIS dataset of 2019 from the Danish Maritime Authority to benchmark terminals and vessels for four use cases. The proposed method involves generating a grid with points at predefined locations, assigning reported GPS positions to the closest grid point and has benefits regarding computational complexity for post-analysis of huge AIS datasets and real-time capabilities for online services.

1. Introduction

1.1. The importance of Service Quality

The rise in complexity of supply chain configurations and higher synchronization of logistics processes is shifting the preferences of shippers towards service quality: While price and availability of cargo-space and equipment remain hygiene factors; transparency, reliability and transit time length have become important carrier selection criteria in commercial shipping:

In a study conducted by Yuen and Thai (2015), 183 responses to their questionnaire were analysed. The purpose of the study was to put service quality and customer satisfaction within liner shipping into context and highlight the most critical variables resulting in high customer satisfaction. The study identifies four key factors influencing customer satisfaction, namely reliability, speed, responsiveness, and value. Reliability describes attributes such as error-free documentation and, more importantly, consistency in service. The transportation itself, i.e. transit times, idle times, accuracy of cargo tracking, etc., is grouped under "speed", with "value" being the pricing and costs of services rendered. Lastly, responsiveness discusses supporting elements such as involvment in green shipping, promptness of customer service, etc. This supports the notion, that liner shippers prioritise attributes relating to speed and reliabilty over price, with value being the least important factor in customer satisfaction of the four mentioned factors. The analysis of Gailus (2015) showed that, while reliability plays a lesser role in the spot market – it is one of the most important carrier selection criteria in long term contracts, directly impacting the market share of liner services. Further, carrier selection criteria of 105 freight forwarding organisations have been analyzed by Fanam, Nguyen and Cahoon (2018), where the most important identified criterium was found to be schedule reliability, followed by accurate documentation. This hypothesis is further supported by the Drewery Satisfaction Surveys (Drewry-ESC, 2017; Drewry-ESC, 2018; Drewry-ESC, 2019; Drewry-ESC, 2020) which show the satisfaction of shippers with selected parameters such as transit time and cost, and also by E. Hirata (2019), where a similar study to Yuen and Thai (2015) was conducted with similar results. In the Drewry surveys, the satisfaction in prices sits roughly at the average value of around 3.1 points, whereas service quality parameters, i.e. responsiveness and speed, rank below average in the years from 2016-2019, which are the only years the survey was conducted in. This explicitly shows the dissatisfaction in service quality parameters and implies either underdeveloped systems in these sectors or unmet expectations. The aformentioned studies and surveys are sufficient in order to classify price of services in liner shipping as a hygiene factor after Herzberg. This signals a change in the central paradigms of the shipping market, given that in the aftermath of the Grand Financial Crisis in 2008 competition seemed to be first and foremost based on cost leadership (Notteboom, Pallis and Rodrigue, 2021).

1.2. Inventories under uncertainty

To explain the importance of reliability to shippers, it is worthwhile to explore the topic of inventory management under uncertainty. In general, any company will try to have the least amount of inventory on hand to achieve a determined cycle service level (CSL), thus aiming for a pareto optimum between the probability of stock-outs and inventory costs. In their paper on "Managing variability in ocean shipping" Harrison and Fichtinger (2013) conducted a sensitivity analysis of supply chain inventories and their associated costs under varying lead times, sailing frequencies, and schedule reliabilities: Lead time is an important driver of (pipeline-) inventories. However, the variability of transit times, i.e., the reliability, has the most impact on overall inventory costs as it directly affects safety stocks needed to maintain the CSL. Rising inventories result in more bound capital (i.e. opportunity cost) as well as higher inventory holding costs (Vernimmen, Dullaert and Engelen, 2007). Holding costs include warehousing cost, depreciation, insurance, handling costs and obsolescence, i.e. stock that is unlikely to ever be sold, usually because it is outdated in function or design (Wild, 2017). Holding costs depend on the kind of goods stored and are estimated in a range between 16% and 20% of unit cost per annum (Gurtu, 2021). This provides a strong incentive to shippers to select reliable carriers, as the choice can heavily influence overall supply chain costs beyond freight rates.

1.3. Reliability in Liner Shipping

Data from the Global Liner Performance Report shows that on average in January 2023 the number of ships arriving on schedule – i.e., in the correct 24-hour period, has decreased by 3.8 percentage points to 52.6% compared to December 2022.This development follows a year of slow improvements after reliability started falling to a historic low mid-2020. Most of the poor performance between 2020 and 2023 can be attributed to the pandemic. In the years before, global average reliability was typically higher, averaging at 74.3 %. It can be expected that once the last remainders of COVID19 have passed, global reliability will revert to these values (Sea-Intelligence, 2023). This poses the question how more reliable operations can be planned and executed.

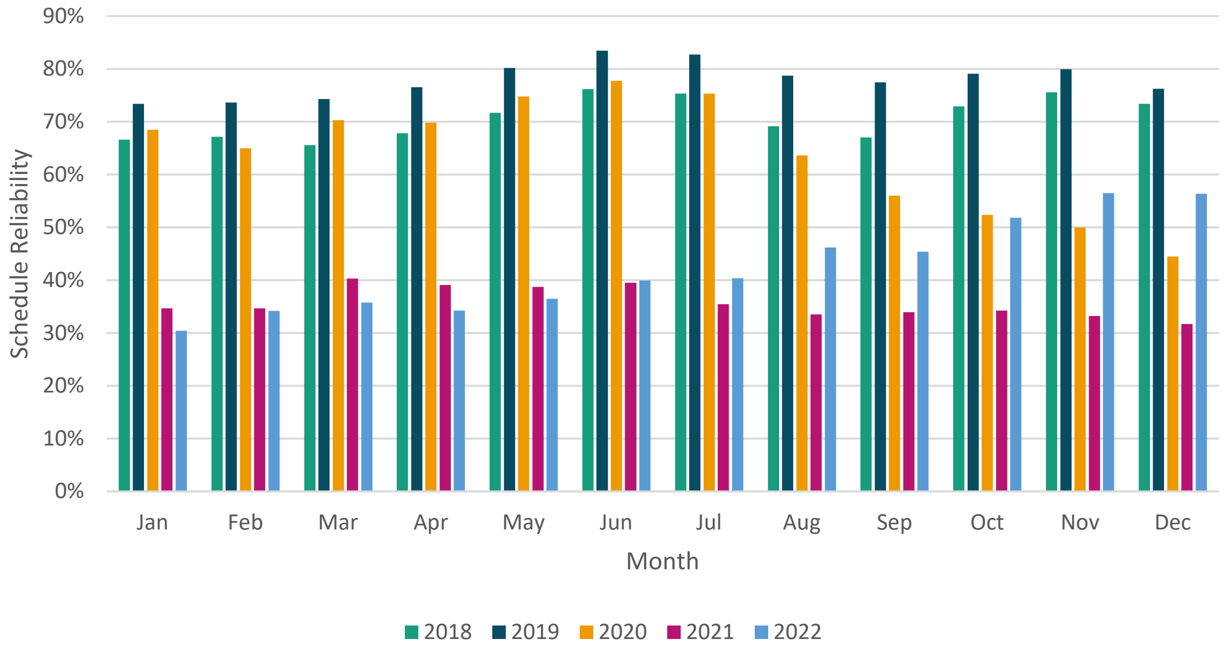

Figure 1. Global Schedule Reliability 2018 to 2022 (Sea-Intelligence 2023)

1.4. Liner Network Design

Liner network design is mainly conducted based on complex constrained linear optimization models. Elmi et al. (2022) conducted an extensive literature review on the incorporation of quantified uncertainties and schedule recovery strategies in the network design process. Of the analyzed literature only three models included schedule reliability in their objective functions and less than half of the literature included any form of uncertainty as a parameter. If uncertainty is included, it is limited to a single source, e.g., waiting time or handling time. One of the central research gaps defined was that further data is required to meaningfully analyze and quantify the detailed composition of disruptions at individual ports. This is, among others, further supported by Verschurr, Koks and Hall (2020).

Most disruptions in liner networks are attributed to ports, where they are associated with waiting times before berthing, irregular handling times, pilot availability etc. (Notteboom, 2006). On the operations level, recovery strategies include skipping of ports, cut-and-run-actions, and speed adjustments. These strategies are reactive in nature, meaning they are only employed after a delay has manifested (Notteboom, 2006; Elmi et al., 2022). While speed adjustments are connected with increases in fuel consumption and can therefore quickly become cost prohibitive to employ, strategies such as port skipping lead to a situation where often not the nodes responsible for delays (e.g., by being congested) are disadvantaged, but the nodes next in the port rotation. This provides little incentive for ports/terminals to facilitate higher reliability.

For a proactive approach to become feasible, where congested ports can be actively avoided or speed can be reduced if waiting times are anticipated, however, data on the current terminal productivity (e.g., Turnaround times for a specific terminal) and realized sailing times would need to be available in real time. The introduction of AIS in 2004 opened up opportunities to derive this information from ship positions through big data analysis (Scheidweiler and Jahn, 2019).

Our work proposes a novel approach to calculate descriptive statistics on the performance of individual ports and terminals to help close this gap in current market intelligence, thus facilitating better informed network design. Additionally, further development of the algorithm into a live solution showing current terminal performance indicators is envisioned, which is expected to be a necessary tool to successfully employ proactive operational planning and increase reliability of maritime transport chains.

2. Methodology

Our approach is based on the detection of recurring behavior which is assumed to be inherent for vessels conducting liner services in AIS data. The proposed method identifies stopping points of liner vessels at a spatial resolution of up to 10 meters, hence it is suitable to investigate stopping points in ports and across terminals or piers. This in turn allows several analyses to generate insights for liner services, terminal operators and public authorities.

We apply our approach to an AIS dataset of 2019 from the Danish Maritime Authority (DMA). The AIS data consists of commercial shipping and vessel tracks in the Western Baltic Sea. The approach was employed to benchmark vessels and terminals with four questions in mind:

How can a vessel conducting liner services be detected in AIS data?

To identify vessels engaged in liner services, loops or round-trips need to be detected and derived from AIS data. A round-trip is a specific voyage behavior where a vessel tends to continuously visit and stay at certain locations, i.e., ports and terminals. Our method is suited to extract such behavior for one vessel or a set of vessels from AIS position reports.

First, an equisized grid with points at predefined locations is generated recursively to discretize the GPS positions of a vessel reported in the AIS messages. A vessel can be identified uniquely via its Maritime Mobile Service Identity (MMSI). The initial grid starts at a resolution of 1.000 km and covers the whole globe. A neighborhood function assigns any reported GPS position to the closest grid point. Secondly, at each grid point which has GPS positions assigned to it, a smaller grid with a resolution ten times smaller than the previous grid is established. Grids are generated until the resolution, i.e., distance between two grid points, is equal to 10 m, which is assumed to be the lower bound due to GPS accuracy. Furthermore, the termination of the discretization at 10 m keeps the number of grid points much smaller than the number of raw AIS position reports which in turn keeps the amount of grid points comparatively low. A small number of grid points implies benefits for the computational complexity to do analyses, hence the discretization greatly reduces computation time which is a prerequisite to enable capabilities for real time liner services.

Since grid points keep the sequence of reported GPS positions along with their timestamps, entry and exit to any grid point in time can be extracted. Therefore, the total number of visits and stays can be calculated for any grid point. An analysis of the visits and stays at a given grid point permits the identification of stopping points. Subsequently, an analysis of the order of stopping points allows to identify liner services. Exemplary for identifying a liner service vessel, Fig. 2 shows a cargo ship conducting liner services and its stopping points in the Baltic Sea with reported and gridded AIS positions in a period of 6 month.

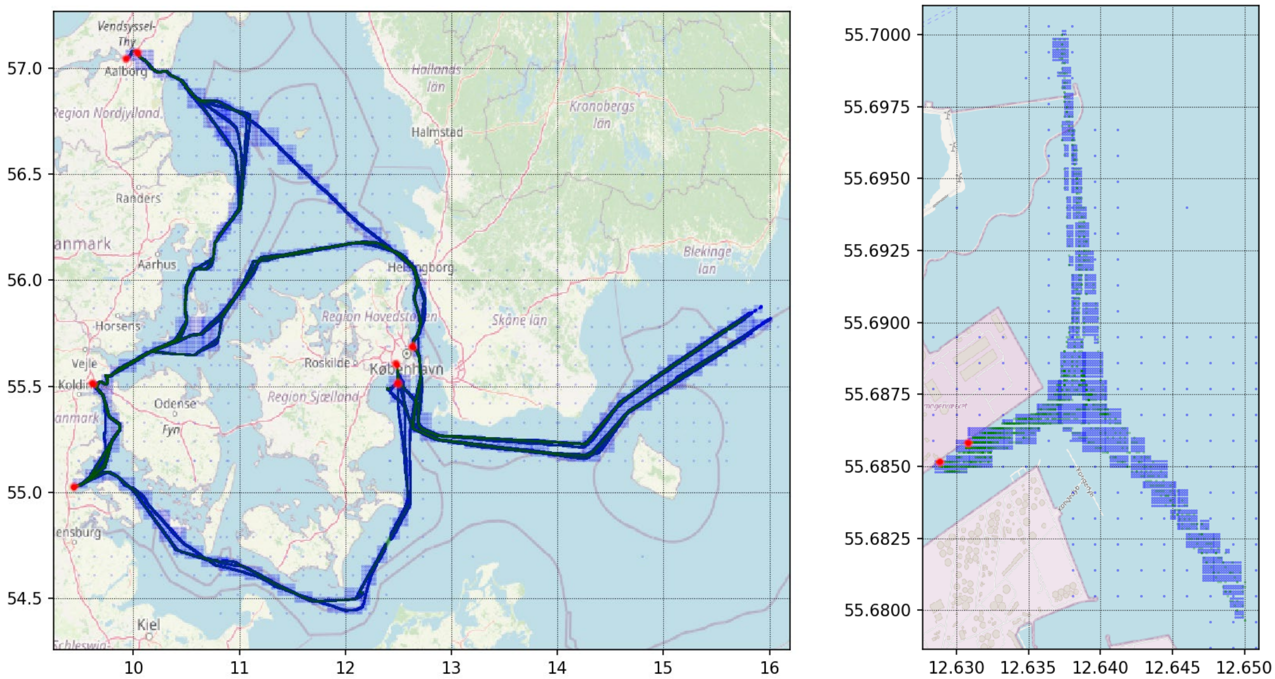

Figure 2. Reported and gridded AIS positions of a cargo ship in the first half of 2019 (blue) and the detected stopping points of that vessel (red); Baltic Sea (left) and port of Copenhagen (right); (Danish Maritime Authority 2020)

What is the time spent of a vessel at berth?

After the extraction of the stopping points of roundtrips and the sequences of visits, the overall time spent at the individual stopping point can be calculated. This includes primarily loading and unloading in terminals, anchorage or dead-in-water, and other stays in port. Our approach allows to estimate the average time spent at berth in any given timeframe for a particular vessel which can be applied to benchmark terminals and terminal operations. Since stopping points can be detected automatically and the time and timespans of visits is known at any grid point, no prior knowledge about terminal locations, i.e., geofences, is necessary.

What is the composition of transit time of any vessel?

By knowing the stopping points of a vessel conducting liner services, trips between stopping points can be extracted, thus the voyages between ports. This allows to analyze the time composition of the transit, i.e., what share of time a vessel spends at sea, at berth, in certain areas or simply the time spent waiting at anchorage or dead-in-water. The time shares of the transit phases from historical data are important for modelling the expected or estimated voyage of a vessel in a round-trip. This means, deviations are detectable and traceable from normal round-trip behavior, both, locally, i.e., transit delays, and globally, e.g., cancelling a visit to a port.

What is the actual delay of a vessel along a trip or in the round-trip?

The comparison between the average, fastest and slowest realized transit time and the distance made good with the current state of the voyage along a trip can be used to estimate and localize delays in liner services. Moreover, the expected time spent at berth at the destination port can be added to any transit delay to estimate the trip or round-trip delay. The actual delay of the vessel and its implications for a trip provide the basis for most online and offline analyses.

How can answers to these four questions be used to mitigate disruptions?

Automatically identifying liner vessels is the prerequisite to analyze liner traffic on scale, as AIS data is huge and can be hard to tackle. Having identified liner vessels, it opens the opportunity for more detailed analysis. The time spent at berth, is the most important indicator of port turnaround times and terminal utilization. As mentioned above, having accurate data on the terminal level is an important parameter for strategic network design decisions. They directly impact allocated buffer times, and therefore the resilience and reliability of any given service. Currently, there are no public providers of such datasets in a meaningful level of detail. Finally, information on the current delay of vessels can be used for better operational planning during a single voyage. If combined with current information on times spent at berth, liner operators can estimate future delays in their loop and may use proactive measures to avoid future delays altogether.

3. Future Work

As reliability directly impacts the probability of stock outs and therefore inventory costs, it represents a prerequisite for more efficient supply chains and a key selection criterion for shippers. However, higher transparency is required to be able to build more resilient schedules and to move from reactive schedule recovery to proactive delay mitigation. An approach was presented to derive needed information automatically from AIS Data.

The full paper will introduce the proposed approach and its associated methods in detail, providing a sensitivity analysis of the impacts of reliability on supply chains with maritime legs. Further, the results from applying our approach to the AIS dataset of the DMA will be shown and terminal productivity, time compositions of transit times as well as historic delays in the Baltic Sea will be discussed in detail.

Building on this, the technical feasibility and potential impact of delay detection in real time based on our approach will be demonstrated. Such a service would measure and provide descriptive statistics of transit times and handling times at individual terminals along maritime trade lanes in real time. Finally, it will be shown how the availability of live information can open avenues for new and more efficient operational measures.

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