PRODUCTION & MANUFACTURING | RESEARCH ARTICLE

Modelling the optimal delivery of spare parts to vessels: Comparison of three different scenarios

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Abstract: Spare parts management on ships is a notable segment of total transportation costs being able to become a significant factor in the process of cost optimization, given the increasingly unpredictable economic circumstances and unstable geopolitical relations. This study aims to determine the optimal parcel delivery scenario to the ship based on the created mathematical model, using the delivery option of air freight service, express service, and consolidation service on the examined transportation route. The model uses a predefined set of variables such as total shipping cost, delivery time, and total distance, which were compared according to the different conditions of parcel delivery requirements and additional weight units. The research results show that the air freight delivery scenario is the optimal solution when the total cost is considered the most weighted function value. When time is set the most significant, the express delivery scenario proves to be the optimal solution. In the case when the distance is considered the most weighted function value, both first and second scenarios are optimal. According to the model results, the consolidation service was neither economically preferred nor advantageous comparing to the alternative delivery options. However, in certain circumstances, full exploitation of its economic advantages is possible. These research findings significantly contribute to the efficiency and productivity of the

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PUBLIC INTEREST STATEMENT

An efficient and productive supply chain in product delivery to specific destination is a vital component of modern businesses. This is particularly significant in shipping, due to the complexity and uniqueness of the ship’s operational environment, where reliability and safety are particularly essential. Considering the projections of the overall annual average growth rate in the world maritime trade and rising ship operational costs, there is a great need to optimize the route planning in the delivery process of essential ship’s spare parts. The optimization process considers time, distance and total cost as key variables, which should determine the most efficient solution among alternatives. Hence, this paper provides the insight of the problem and derived solutions for the model created.
logistic chain. They enable decision-makers to empirically determine the optimal network of parcel delivery between two locations.

Subjects: Supply Chain Management; Production Research & Economics; Supply Chain Management; Ship Operations; Sustainable Transport Engineering; Engineering Economics

Keywords: delivery; modelling; optimization; spare parts; ship; transportation route

1. Introduction

An efficient supply chain of spare parts has become an important element in maintaining ship operational activities but also in the overall cost optimization process of a shipping company, taking into account the rising expenses of running ships. The philosophy of the supply chain management includes coordination of all subjects involved, having the objective to maximize profit and proportionally to optimize costs (Giri & Bardhan, 2014). Considering the projections of overall annual average growth rate in the world maritime trade of 3.4% for the period 2019–2024 (UNCTAD, 2019), the spare part management and availability have become more substantial than ever. This is particularly significant due to the complexity and uniqueness of the ship operational environment, where reliability and safety are particularly essential (Nenni & Schiraldi, 2013). As the faultless functioning of necessary components is a crucial requirement of asset-intensive industries (Braglio & Frosolini, 2013) the tendency is to establish efficient spare part maintenance, procurement and ordering processes to prevent long machine downtimes or disruptions in the production or service system (Kian, Bektaş, & Ouelhadj, 2019). The challenge is to effectively coordinate and manage ship inventory to endeavor the optimal number of necessary spares, due to the increasing pressure to remain competitive in the market and reduce costs (Ben Hmida, Regan, & Lee, 2013). Forecasting the needed requirements, considering the service spare part management, is a rather complex and challenging task. (Wang & Syntetos, 2011). This is even more significant due to the dynamic conditions which ships encounter during the voyage, so ensuring the proper procedures of the ship maintenance is essential (Sirisena & Samarasekera, 2018). Planning the maintenance process of ship spares is performed on a time-based schedule. The replacement frequency is planned through a preventive maintenance program (Vaughan, 2008), a protocol advocated by most studies (Kian, Bektaş, & Ouelhadj, 2019). When determining the maintenance process of components at each breaking period, the indicators of the minimum overall costs, time variable and reliability should be considered (Duan et al., 2018). An example of the preventive maintenance databases is ship’s Planned Maintenance System (PMS), where replacement frequency is planned in intervals determined by specifications of maker’s Instruction manuals for the shipping equipment, the shipowner’s company policies and rules, the classification society requirements for the vessel and ship’s flag state requirements (Stazić et al., 2018).

Although spare parts and inventory management problems have previously and individually been studied in various scientific approaches (Gharaei et al., 2019a, 2019b; Kazemi et al., 2016), their integration in supply chain management to optimize ordering policy and reduce transportation costs of spares in the maritime industry has not yet received adequate attention in the literature. There is a great diversity of spare parts ordering and delivery process in the maritime sector, considering the diverse voyage characteristics of liner cargo vessels and vessels carrying dry or liquid bulk cargo commodities. The port call times (arrivals and departures) are predictive for liner cargo vessels through published timetables and schedules. On the contrary, the procedures for bulk cargo trades are more complex and require proper coordination and planning as the port call schedule is determined for each voyage, and often consisted of the ballast and no-backhaul voyages (Stopford, 2009). The inability of timely and detail route planning contributes to the uncertainty of spare parts procurement and ordering. Furthermore, the distinction should be given for the various components’ replacement scenarios, whether as for the stock shortage which has fallen below the threshold, predetermined maintenance or emergency replacement (Kostidi & Nikitakos, 2018). The state of replacement urgency will influence decision-maker on the maintenance of adequate procurement and ordering method. Generally, the spare parts are
available on-board ship in the spare inventory area. It is especially appertained to the spares nominated as the critical components, which are intended to maintain safe operation. These elements are found on ship in limited amounts, due to the limited space and economic reasons (Eruguz, Tan, & Van Houtum, 2017), and are available through the supply chain of on-shore suppliers. As the inventory management on-board ship is restricted, significant cost savings are provided by an efficient and timely planned ordering process of spare parts. The overall idea is to eliminate the costs of downtime, unnecessary delays and long waiting time in ports due to long delivery time of spare parts and increasing operating costs (Sirisena & Samarasekera, 2018; Kian, Bektaş, & Ouelhadj, 2019). Also, there is a pretension to optimize the transportation costs when there is a need for an individual component. In the course of ship’s exploitation, over 170 deliveries of spare part parcels are predicted to be done annually, and they closely depend on the efficient coordination between the ship, shipping company, and supplier in the overall supply chain of services (Socius, 2019). The process of planning of the supply chain implies the importance of selection of sustainable suppliers in the sustainable supply chain (Rabbani et al., 2019). The spare part management and replacement dynamics consider the number of orders related to state of originality and other alternative versions of spare parts, timely maintenance, but also the recommendations of ship’s designer and quality in general. The other important element in the management of spare parts on vessels is in the quality of the established network of suppliers and long-term contracts which could influence the efficiency and economic implications of the business activity. These relationships usually result in loyalty discounts, delivery fees, and in particular volume incentive rebates which are financially significant for the stability and continuation of shipping company’s business activities. Ordered spare parts can be delivered to any port on the operating traffic flow (Kian, Bektaş, & Ouelhadj, 2019). As the transportation costs are in correlation with the location of the vessel, these costs are negligible when the succeeding port is predictable but become significant when the ship is operating at a remote area (Eruguz, Tan, & Van Houtum, 2017). Shipping companies endeavour to provide fast and safe delivery of spare parts to any harbour (Mihanović, Ristov, & Belamarić, 2016), and usually, shipments arrive at a country as air freight or sea freight (Sirisena & Samarasekera, 2018). Considering the trends and perspectives of spare part management on ships, sustainable transportation planning has become a crucial element in managing the resources effectively (Sayyadi & Awasthi, 2018a), along with the creation of collaborative environment in achieving sustainability (Hao, Helo, & Shamsuzzoha, 2016). This is made possible by conducting the sustainable mobility solutions and evaluations of individual plans from decision-makers in involved in transportation activity (Awasthi & Omrani, 2019) or the impact of sustainable transport policies in a transportation system (Sayyadi & Awasthi, 2018b).

Following the complexity of spare part management on-board ships determined as the research problem, the aim of this study is set to calculate the possible savings in the ship’s supply chain, focusing on delivery management of the selected spare parts. Due to the rising costs in operating ships and unstable external environment, the necessity to optimize the delivery costs of spare components is imposed as a requirement in reaching efficiency. The objective of the paper is to perform cost calculation between three different scenarios of delivery possibilities, and to highlight the optimal solution from the cost-effectiveness standpoint. These possibilities are comprised of the air freight service, express service, and consolidation service delivery option, and examined considering the set variables of total shipping costs, time of delivery, and overall distance between nodes on the selected transportation route. The research is based on utilizing air transport service as a primarily transportation mode for an on-board inventory supply of a medium-range (MR) product tanker ship, operating on the selected traffic flow. The transportation route was determined between the origin location(s) of individual spare part supplier, and the ship’s proceeding port of call in Panama. The authors used an innovative approach which was based on the mathematical modelling method for the calculation of all costs incurred in the delivery process through the predetermined variables. It should be mentioned that the model considered the weight of individual variables which were integrated into the calculation, so based on the switch between the larger and smaller weight of individual variables, the conclusions were generated.
This enabled to determine the key variables for the decision making of a shipping company and the network optimization based on the determined business policy. Considering the vessels specific operating environment, rising overall costs as a result of recent environmental initiatives as IMO 2020 and Ballast Water Management Convention, overcapacity on the shipping market and unstable geopolitics, the tendency of transportation cost optimization in spare part delivery has become an important segment of the vessels supply chain management. The subsequent sections of the paper are organized as follows: the review of relevant literature is presented in the second section, followed by a brief presentation of on-board processes of spare parts management in the vessel supply chain during the voyage. Section 4 contains a formal definition of the problem, model design, and preparation of relevant data for the case study cost-effectiveness analysis. Section 5 provides the results of the conducted research. Finally, Section 6 provides the discussion with limitations and recommendations for further research followed by the conclusions set out in the final part of the research.

2. Literature review
A brief literature overview on cost optimization of ordering, transportation, supply, and other processes related to spare part management in the vessel supply chain shows an insufficient interest of researchers. Also, a limited number of relevant studies have been carried out on the management of the delivery process on vessels, which contributes to the originality and actuality of this research. The modelling of the supply chain management, associated with sustainable development, was a research problem of numerous studies (Tsao, 2015; Hoseini Shekarabi, Gharaei, & Karimi, 2019; Dubey, Gunasekaran, & Singh, 2015; Rabbani et al., 2020; Gharaei, Karimi, & Shekarabi, 2020; Yin, Nishi, & Zhong, 2015; Shoh, Chaudhari, & Cárdenas-Barrón, 2020; Giri & Masanta, 2020), having the final outcome of network optimization from diverse perspectives and aspects. The ordering cost reduction in the supply chain was a research problem in the work of Sarkar and Giri (2020), which showed that the savings in the supply chain are possible with the decrease of time, costs and defective rate. Gharaei, Karimi, and Shekarab (2018) indicated the strong need to integrate the elements of quality control and environmental policies within the supply chain and inventory systems, which is an essential phase to realize success factor of organizations. Conducting a cost analysis to determine the most feasible and effective solution among the alternatives was a premise applied in the work of Nazarnia et al. (2020), who conducted a study of the impact of sea level rise on civil infrastructure. Travel time optimization scenarios and the need to reduce travel time loss was a central figure in a study by Yuniar et al. (2020), which showed the influence of the behaviour of a decision maker, a driver, on the travel time and travel speed used in performing transportation activities. Borowski (2020), pointed out that adequate supply levels and the associated demand, as well as physical supply conditions, are a strategic challenge for the economy when considering the analysis of the energy sector. While Qasim and Hasan (2020) emphasized the importance of the use of numerical simulation when determining three different scenarios of the ship impact, Lampetey and Serwaa (2020) studied the efficiency of the use of unmanned aerial vehicles (UAV) as an alternative method in delivery of essential parcels on various distances. The most prominent study on the research topic was conducted by Kian, Bektas, and Ouelhadj (2019) where the authors analyzed spare part management problem for vessels maintenance scheduling on the selected maritime route, indicating the port of the spare part delivery and maintenance operation for various cases. They used mathematical programming model and formulations and dynamic programming algorithm to show the benefits of using the Condition-based Monitoring (CBA) systems on vessels. Eruguz, Tan, and Van Houtum (2017) combined Markov decision process and numerical experiments considering integrated maintenance and spare part optimization problems, having the objective to minimize delivery costs of spares, replacement, and inventory holding on a case study from the maritime sector. Ben Hmida, Regan, and Lee (2013) proposed an economically efficient multicriteria inventory policy of an offshore vessel company. They used an inventory classification method integrated with a preventive maintenance program, while Nenni and Schiraldi (2013) used spare parts criticality analysis to propose a procedure for the initial level of vessels spare part inventory optimization. Sirisena and Samarasekera (2018) used the Analytical Hierarchy Process (AHP) and Factor Rating
Method to determine the most suitable distribution center location for the efficient supply chain of vessels spare parts while maintaining operational ship activities. While Azizah and Subiono 2018 used Petri Net and Max Plus Algebra model to schedule the ordering of the vessel’s components, Jiang, Kong, and Liu (2011) used a multi-weighted optimization model to determine the type and amount of spare parts to storage on-board vessels. Moon, Hicks, and Simpson (2012) analyzed the demand for spare parts in the South Korean Navy using the hierarchical forecasting method for predicting the demand for consumable spare parts in their case to minimize forecasting errors and inventory costs. A research on utilization of Additive manufacturing in the maritime industry was carried out by Kostidi and Nikitakos 2018 with an objective to increase the availability of spares directly on vessels. This proportionally increases the efficiency of the maintenance process, reduces costs and shortens the supply chain of the provided services.

The general objective of analyzed literature was to determine the level of spare part management, by evaluating the research components of the overall ship’s supply chain, like inventory, maintenance, supply, location, and other parts. These conclusions confirm the relevance and necessity of research and the actuality of the chosen research topic.

3. Spare part supply chain process on-board vessels during voyage
The overall objective of inventory management is to provide an optimal demand level at minimum cost (Harris, 1997), a principle which is in close correlation with spare part management on vessels. Akyuz and Celik (2017) and Gajić, Poljak, and Orović (2018) discussed the complexity of maintenance planning procedure on-board ship, containing a vast number of constraining factors in process implementation and large numbers of involved subjects having specific requirements. In line with maintenance planning requirements prescribed in Chapter 10 of International Safety Management Code (ISM Code) (Revised ISM Code, 2015), the shipping company is obligated to select the most convenient planned maintenance system (PMS) and effective maintenance strategies to meet the principles of reliability, safety, and efficiency of shipboard operations (Akyuz & Celik, 2017). When the need for spare parts on-board vessels occurs during the voyage, without getting into its causes, and if the specific spare part is out of stock in the vessel’s spare inventory, the chief engineer notifies the land office and requests appropriate replacement component (Kostidi & Nikitakos, 2018). Once the request is received, it is processed by the procurement department, after the approval from the technical department. The purchase order is then distributed to the already established spare part supplier network or independent suppliers in the area requesting quotations, depending on the vessel’s position. It should be noted that, based on the company policy, decision, circumstances, state of urgency and availability, financial state or other causes, the shipping company can choose between diverse available spare part variants. They vary depending on the state of originality, and can be classified as genuine spares, Original Equipment Manufacturer (OEM) or spares ordered from the third party (used spares) having particular specifications, cost, quality, and durability. The suppliers, after processing the request, issue an offer in the form of a quotation for the requested components differentiated by price, time availability, and quality (Azizah & Subino, 2018). The purchase process continues by selecting the most suitable supplier and issuing the order which is after received from the supplier, finalized with an invoice. Furthermore, the selected supplier timely delivers the ordered components to a specified location, which in this case is the next port of call. The selection of appropriate transport mode and method for the spare part delivery depends on numerous circumstances, but an express delivery by air as the most expensive variant can be avoided with timely planning of all phases in the process. Usually, urgent deliveries on vessels are related to items like lubricants and food supplies but primarily depend on the state of emergency conditions on-board vessels which could jeopardize ship or crew safety. The spare part supply chain process on-board vessel during the voyage, including entities of vessels crew, land office, and suppliers is shown in Figure 1.

4. Model design and problem description
The mathematically formulated problem for determining the economical shipping route among alternatives with an aim to optimize the shipping costs is presented as follows:
Minimize $TSC(x)$  \hspace{1cm} (1) 

where $TSC(x)$ is the variable of total shipping costs on the route $x$, and

$$ETA(Zx) - ETA_{req} \leq 0$$  \hspace{1cm} (2) 

where $ETA(Zx)$ is estimated time of arrival of the package $Z$ on the route $x$ and $ETA_{req}$ is requested estimated time of arrival.

The purpose of indicated formulas is in correlation with the model design, which is to determine the weight variable of the most optimal shipping route based on the requirement for a shipping company. Formula (1) appears as an objective function, meaning that the total costs $TSC$ of individual route $x$ should be minimal. The restrictive function of the model, determined by Formula (2), provides the requirement to deliver the specific package at the required time. The used notations of this paper are summarized in Table 1.
4.1. Model design

When assessing the efficiency and competitiveness of individual route from the standpoint of the optimization of transportation (delivery) costs for specific spare parts, the network (route) endpoints can be divided into two segments, the origin and destination (OD) points. In some cases, both points can appear simultaneously as the origin and destination nodes, depending on the number of networks (routes) and their characteristics. The nodes relate to arcs, representing the distance between nodes, and having a specific value of variables such as time, cost, and other parameters. The process of selecting the optimal shipping route among alternatives of transporting a parcel from the origin to destination point includes determining the key variables for the decision making. In accordance with the research problem, the following variables were set: total shipping costs, time of delivery, and overall distance between nodes. These variables are evaluated by decision-makers in

| Table 1. Notations used in the mathematical model |
|-----------------------------------------------|
| TSC (x)                                      |
| ETA (Zx)                                     |
| ETAreq                                       |
| Osrx                                         |
| minTSCx                                      |
| Tx                                           |
| Dx                                           |
| Fr_{ij}                                      |
| Cc_{ij}                                      |
| Phl_{ij}                                     |
| Ahl_{ij}                                     |
| La(w)                                        |
| Br_{w}                                       |
| Ac_{ij}                                      |
| Ao_{ip}                                      |
| Ccu_{ip}                                     |
| Ps_{ip}                                      |
| Cl_{ip}                                      |
| Lhl_{ip}                                     |
| Ft_{ip}                                      |
| St_{ip}                                      |
| DdD                                          |
| Trw_{ij}                                     |
| Trj_{ip}                                     |
| Br_{ip}                                      |
| Trx_{ij}                                     |
| Td_{ij}                                      |
| estimated time of arrival of the package Z on the route x |
| requested estimated time of arrival          |
| optimal shipping route x                     |
| minimum total shipping cost of the route x   |
| total parcel delivery time in days on a route x |
| overall distance                             |
| freight rate of n parcel transported from region i to region j (weight * USD/kg) |
| customs clearance fee charged for every n package arriving at each port |
| airport handling fee charged to each n individual package handled in a specific port |
| airline company charge for each n package handling (increases with the weight of a package) |
| logistic operator charge for warehousing and other necessary procedures (n) |
| brokerage fee                                |
| additional charges of package delivery transported from region i to region j |
| airborne offline charge per shipment         |
| customs custody charge per shipment          |
| port security charge per shipment            |
| customs liquidation per shipment             |
| labor handling charge per shipment           |
| forklift handling charge per shipment        |
| storage charge per shipment                  |
| door-to-door service                         |
| transportation fee of the package from manufacturer warehouse w to airport i (weight * USD/kg) |
| transportation fee of the package from airport j to the port of destination p (weight * USD/kg) |
| barge fee of package delivery from the port j to vessel anchorage location a |
| transit time (days)                          |
| time delay in regions                        |
the logistic chain to create a model of the optimal network of parcel delivery between two locations. The above-mentioned relations can be mathematically formulated as follows:

\[
Osr_x = \sum_{i=1}^{n} \min \ TSC_x, Tx, Dx
\]  

(3)

where \( Osr_x \) is the optimal shipping route \( x \) which takes into account the following variables, \( \min TSC_x \) which is the condition of the minimum total shipping cost of the route \( x \), \( Tx \) is a variable of total parcel delivery time in days on a route \( x \) and \( Dx \) is the overall distance.

The overall shipping costs for a company incurred in purchasing and ordering spare parts, with a specific time window and location, are as follows:

\[
TSCx_{ij} = \sum_{i=1}^{n} n^* (Fr_{ij} + Cc_{ij} + Phl_{ij} + Ahl_{ij} + Lo_w + Brf_{iw} + Ac_{ij})
\]  

(4)

where \( TSCx_{ij} \) is the total shipping cost of the route \( x \) from region \( i \) to region \( j \), \( Fr_{ij} \) is a freight rate of \( n \) parcel transported from region \( i \) to region \( j \) (weight * USD/kg), \( Cc_{ij} \) is a customs clearance fee charged for every \( n \) package arriving at each port, \( Phl_{ij} \) is an airport-handling fee charged to each \( n \) individual package handled in a specific port, \( Ahl_{ij} \) is an airline company charge for each \( n \) package handling (increases with the weight of a package), \( Lo_w \) is a logistic operator charge for warehousing and other necessary procedures (\( n \) if cargo consolidation is used, or brokerage fee \( (Brf_{iw}) \), and \( Ac_{ij} \) are the \( n \) possible additional charges of package delivery transported from region \( i \) to region \( j \) e.g., value-added services as handling perishable goods, handling of hazardous goods or pick up services. It should be mentioned that the regions \( i \) and \( j \) may also emerge as a hub location where consolidation service is performed. Also, the variable \( n \) depends on the number of packages, so the charges like clearance and port handling function relate to every package in a specific airport, or only one package if consolidation service is utilized. Customs clearance fee \( (Cc_{ij}) \) can be calculated in detail as follows (per air waybill—AWB, i.e. shipment):

\[
Cc_{ij} = \sum_{i=1}^{n} Ao_{sp} + Ccu_{sp} + Psc_{sp} + Cl_{sp}
\]  

(5)

where \( Ao_{sp} \) is airline offline charge per shipment, \( Ccu_{sp} \) is customs custody charge per shipment, \( Psc_{sp} \) is port security charge per shipment, and \( Cl_{sp} \) is customs liquidation per shipment. Furthermore, airport handling fee \( (Phl_{ij}) \) can be decomposed as follows (per AWB; i.e. shipment):

\[
Phl_{ij} = \sum_{i=1}^{n} Lhl_{sp} + Flh_{sp} + Stc_{sp}
\]  

(6)

where \( Lhl_{sp} \) is a labor-handling charge per shipment, \( Flh_{sp} \) is a forklift-handling charge per shipment, and \( Stc_{sp} \) is a storage charge per shipment. If the door-to-door service \( (DtD) \) is utilized as an acquired and requested service, the following equation should be added and included in above-defined relations (Formula 4):

\[
DtD = \sum_{i=1}^{n} n^* (Trf_{iw} + Trf_{ip} + Bc_{sp})
\]  

(7)

where \( Trf_{iw} \) is a transportation fee of the package from manufacturer warehouse \( w \) to airport \( i \) (weight * USD/kg), \( Trf_{ip} \) is a transportation fee of the package from airport \( j \) to the port of...
destination \( p \) (weight * USD/kg), and \( Bc_{j,a} \) is possible barge fee of package delivery from the port \( j \) to vessel anchorage location \( a \). The total time along the transportation route can be expressed as:

\[
Tx = \sum_{i=1}^{n} Trx_{ij} + Tdx_{ij}
\]  

(8)

where \( Tx \) is a total time on transportation route \( x \), \( Trx_{ij} \) is a transit time (days), \( Tdx_{ij} \) represents a possible time delay in regions as a variable of reliability e.g., due to the slow clearance procedures like inspections (days). The transit time parameter \( (Trx_{ij}) \) on a specific route \( x \) also contains the required time for shipment paperwork preparation intended for import or export.

The liability for shipments of goods is defined by Incoterms, standard commercial terms used in contracts on the sale of goods (International Chamber of Commerce (ICC), 2020a), so the responsibility for the costs related to the shipment of packages will depend on the contract agreements between two parties. Standard Incoterms for air transport include, Ex Works (EXW), Free Carrier (FCA), Carrier Paid To (CPT), Carrier and Insurance Paid To (CIP), Delivered at place Unloaded (DPU), Delivered at Place (DAP), and Delivered Duty Paid (DDP) rules (International Chamber of Commerce (ICC), 2020b). The calculation framework of delivery costs on-board ship, in the spare supply chain is shown in Figure 2.

4.2. Problem description
A practical case from daily operations of a shipping company is selected to analyse the spare part delivery cost optimization using three different air transport delivery methods for a vessel performing commercial activities during the voyage on a non-predefined freight flow. Three different spare part groups for a medium-range (MR) product tanker were taken into the analysis for determining the research problem, namely main engine (ME) spares for a diesel engine, separator spares and fire, bilge and GS pump spares. The spare part names and makers’ references were taken from the ship’s PMS system along with other relevant specifications. The aim was to calculate the costs of three different direct air transport delivery methods of spare part groups to determine the most cost-effective shipping mode. The origin and destination points along the individual routes were taken from the supplier’s warehouse location (Korea, Poland, and the Netherlands—port of Rotterdam) to the vessel’s succeeding port of call located in Panama. The objective of this research can be divided into three different scenarios comprising three transportation routes as follows:
• delivery costs of the individual spare part group from the supplier’s location to Panama direct by regular freight (scenario 1),
• delivery costs of the individual spare part group from the supplier’s location to Panama by express delivery (scenario 2),
• subcriteria or derivate of the third scenario which contains delivery costs of individual spare part from the suppliers’ location to Rotterdam warehouse by regular service (where shipping company logistic operator is situated), cargo consolidation of all spare part groups and unified (one) cargo parcel forwarding by regular service to the final destination in Panama (scenario 3a), and
• subcriteria or derivate of the third scenario which contains delivery costs of individual spare part from the suppliers’ location to Rotterdam warehouse by express service (where shipping company logistic operator is situated), cargo consolidation of all spare part groups and unified (one) cargo parcel forwarding by express service to the final destination in Panama (scenario 3b).

The main difference in comparing standard (regular) and express shipping service is in simplification and speed of the process of transporting goods in favour of express service, which allows value-added, door-to-door transport and next-day delivery of shipments (Oxford Economic Forecasting, 2005), but also has higher transportation costs. Overall, the utilization of express service and global door-to-door delivery service reduces the delivery cycle time, enables more reliable transit times, and less complex custom clearance procedures (Li & Du, 2005). In order to optimize shipping costs of components and avoid individual spares forwarding per purchase, shipping companies endeavour to establish a hub warehouse location where shipment consolidation of individual orders to the same destination as a delivery option is possible. Consolidation service significantly reduces costs and risks of delivery (Filopoulos, 2010), while also optimizes forwarding procedures, like customs. The purpose of selected research is to compare the costs of different delivery scenarios, determine the possible savings in the supply chain focusing on transportation costs, and select the optimal delivery method from an economic standpoint. The supplier’s country of origin of selected spare part groups and spares prices were obtained directly from the suppliers which were contacted by a shipping company from an already established spare part supplier network, regarding the long-term business cooperation. Based on the shipping company business policy, the hub warehouse was situated in Rotterdam, the busiest European seaport and one of the 20 leading global ports measured by total tons of all cargo handled (UNCTAD, 2018). It was assumed that the logistic operator collects the individual packages (spare part groups) in Rotterdam port and forwards the unified cargo parcel, one package, to the final destination by air transport service. Furthermore, the vessel was planned for a voyage having the succeeding port of call in Panama. The air freight charges were calculated based on the weight

| SPARE PART GROUP | SPECIFICATIONS | COUNTRY OF ORIGIN | PARTS OF ORIGIN | WEIGHT (APPROX.) | DIMENSIONS | VALUE (USD) |
|------------------|----------------|-------------------|-----------------|------------------|------------|-------------|
| Main engine      | Hyundai B&W 6G50ME-B9.3 | Republic of Korea (Busan) | Genuine + OEM parts | 270 kg | 60 x 60 x 80 | 23,790.00 |
| Fire, bilge and GS pump | Centrifugal pump 280 m³/h Shin Shin, SVF200F | Republic of Korea (Busan) | OEM parts | 50 kg | 80 x 60 x 50 | 2,669.10 |
| Purifier spares  | HFO Separator S937 | Poland (Krakow) | OEM parts | 60 kg | 80 x 80 x 50 | 4,235.74 |
| Consolidated package | All | The Nederland's (Rotterdam hub) | All | 400 kg | 100 x 100 x 100 | 32,694.84 |

Source: own elaboration
and volume of the individual package (Chao & Li, 2017), differentiating from gross weight or volumetric weight. Additionally, all the costs along the supply chain of package delivery to the final destination were included in the calculation, except optional costs of door-to-door service. The authors applied Ex Works (EXW) incoterms rule in the research, which was assumed to indicate the importance of the ship inventory management and timely planning of spares delivery. All the required data were obtained from the contacted suppliers and as shown in Table 2.

It should be emphasized that customs clearance charges, airport handling fees, and other charges were in some parts estimated for the purpose of this calculation, while the price levels were based on the consultancies and business relations of suppliers and shipping company experts. Flight frequency measurement as a dynamics and reliability parameter between specific locations was not taken into account. If door-to-door delivery service is used, all the incremental costs in ports and local delivery service are usually included in air freight and courier service rate. Barge charges relate to parcel delivery in conditions when the ship is at anchor. In this research, the time delay parameter was indicated as a constant variable. Finally, the distance variable was assigned between OD points but having the possibility of route variations between the nodes. The distance values were retrieved from the available online tools. The graphical representation of analyzed scenarios is shown in Figure Figure 3.

In order to verify the set null hypothesis (H1) that the utilization of consolidation service is economically pertinent as a solution, a regular service between the origin and the destination nodes were created. This enabled us to determine the overall costs of specific routes.

5. Results
The analysis and comparison of selected variables differing in the three delivery scenarios and route choices, with an objective to determine the most optimal solution from the cost-effectiveness perspective are presented in Tables 3–6. The results of the first scenario considering the airfreight delivery mode are shown in Table 3.

| Table 3. Airfreight shipping costs, distance, and time variables for the first scenario |
|------------------------------------|------------------------------------|---------------------------------|
|                                    | **MAIN ENGINE**                    | **CENTRIFUGAL PUMP**            | **PURIFIER**                    |
|                                    | **Korea—Panama**                   | **Korea—Panama**                | **Poland—Panama**              |
| Freight rate                        | 1,315.47 USD                       | 312.44 USD                      | 378.65 USD                     |
| Shipping costs (all costs)          | 2,270.00 USD*                      | 1,400.00 USD*                   | 1,490.00 USD*                  |
| Overall costs                       | 3,585.47 USD                       | 1,712.44 USD                    | 1,868.65 USD                   |
| TOTAL SHIPPING COSTS (all parcels)  | 7,166.56 USD                       |                                 |                                |
| TIME                                | 6 working days                     | 6 working days                  | 5 working days                 |
| DISTANCE                            | 14,109.20 km                       | 14,109.20 km                    | 9,954.47 km                    |

*charges assumed equal at both airports
### Table 4. Express delivery shipping costs, distance, and time variables for the second scenario

| Cargo | MAIN ENGINE Korea—Panama | CENTRIFUGAL PUMP Korea—Panama | PURIFIER Poland—Panama |
|-------|---------------------------|-------------------------------|------------------------|
| Freight rate | 3,526.30 USD | 806.99 USD | 812.33 USD |
| Shipping costs (all costs) | 2,270.00 USD* | 1,400.00 USD* | 1,490.00 USD* |
| Overall costs | 5,796.30 USD | 2,206.99 USD | 2,302.33 USD |
| TOTAL SHIPPING COSTS (all parcels) | 10,305.62 USD | 10,305.62 USD | 10,305.62 USD |
| TIME | 3 working days | 3 working days | 2 working days |
| DISTANCE | 14,109.20 km | 14,109.20 km | 9,954.47 km |

*charges assumed equal at both airports

### Table 5. Airfreight shipping costs, distance, and time variables utilizing consolidation service for the third scenario (3a)

| Cargo | MAIN ENGINE Korea—Rotterdam | CENTRIFUGAL PUMP Korea—Rotterdam | PURIFIER Poland—Rotterdam |
|-------|-----------------------------|---------------------------------|--------------------------|
| Freight rate 1 | 803.60 USD | 278.60 USD | 104.25 USD |
| Shipping costs (all costs) | 2,270.00 USD* | 1,400.00 USD* | 1,090.00 USD** |
| Time 1 | 5 working days | 5 working days | 2 working days |
| Distance | 8,685.10 km | 8,685.10 km | 1,009.04 km |
| Route | Rotterdam (hub)—Panama | | |
| Freight rate 2 | 1,670.00 USD | | |
| Time 2 | 6 working days | | |
| Shipping costs (all costs) | 3,100.00 USD* | | |
| Distance | 8,954.71 km | | |
| TOTAL SHIPING COSTS (all parcels) | 10,716.45 USD | | |
| OVERALL TIME | 11 working days | | |
| DISTANCE (OVERALL) | | min. 9,963.75 km/max. 17,693.81 km | |

*charges assumed equal at both airports; prices assumed equal to the first and second scenario level** no clearance—European Union

### Table 6. Express delivery shipping costs, distance, and time variables utilizing consolidation service for the third scenario (3b)

| Cargo | MAIN ENGINE Korea—Rotterdam | CENTRIFUGAL PUMP Korea—Rotterdam | PURIFIER Poland—Rotterdam |
|-------|-----------------------------|---------------------------------|--------------------------|
| Freight rate 1 | 2,986.73 USD | 606.35 USD | 286.47 USD |
| Shipping costs (all costs) | 2,270.00 USD* | 1,400.00 USD* | 1,090.00 USD** |
| Time 1 | 3 working days | 3 working days | 1 working day |
| Distance | 8,685.10 km | 8,685.10 km | 1,009.04 km |
| Route | Rotterdam (hub)—Panama | | |
| Freight rate 2 | 3,932.00 USD | | |
| Time 2 | 3 working days | | |
| Shipping costs (all costs) | 3,100.00 USD* | | |
| Distance | 8,954.71 km | | |
| TOTAL SHIPING COSTS (all parcels) | 15,671.55 USD | | |
| OVERALL TIME | 6 working days | | |
| DISTANCE (OVERALL) | | min. 9,963.75 km/max. 17,693.81 km | |

*charges assumed equal at both airports; prices assumed equal to the first and second scenario level** no clearance—European Union
The analysis of selected variables, for the first scenario—for the airfreight delivery mode, showed the total shipping cost of 7,166.56$ for three individual parcels on a predetermined traffic flow, without variations from the ideal airway route. The time of delivery varied from five to maximum six working days, depending on the place of origin. The airfreight delivery mode can be accompanied by scheduled and predictive maintenance and procurement of the vessel’s spare parts without an emergency as a requirement for timely delivery. The results of the second scenario are shown in Table 4.

Compared to the first scenario, the express delivery of three separate parcels to the final destination in Panama resulted in 10,305.62$ of total shipping costs, including the freight rate and voyage costs, and with a time of delivery varying from two to maximum three days depending on the spare part origin location. The distance variable was set the same as in the first scenario, analyzing the traffic route without variations from the ideally set airway route. The variable analysis of the second scenario provided the characteristics of the express delivery mode having the advantage of the shorter delivery time followed by higher overall shipping expenses, associated with unforeseeable, urgent, or unplanned procurement of critical spare parts for vessel system maintenance. Also, the service is viable and indispensable especially for dry and liquid bulk vessels, considering the unpredictability of route schedules and succeeding port of call. The results of the two remaining scenarios using consolidation service as a delivery mode, considering air freight and express delivery services as an option, are shown in Table 5. and Table 6.

The consolidation service considered the deviation from the ideal airway route as an option and included two segments of parcel delivery route, which contributed to an increase in the total distance on the transport route. The first part of the transportation route included the individual parcel delivery from the spare part origin warehouse (port) to the Rotterdam hub port while the remaining segment comprised a unified parcel delivery to the final destination in Panama. The total shipping costs on the transportation route using the consolidation service and airfreight as a delivery option were 10,716.45$ (scenario 3a) as opposed to 15,671.55$ (scenario 3b) when delivery of consolidated parcel was organized in the form of the express option. However, the delivery time variable in the third scenario was six (scenario 3b) versus eleven (scenario 3a) working days, which contributed to the advantage of the express delivery option. The analysis of the third scenario and variables comparison indicated the time of delivery for express option utilizing consolidation as competitive to the first scenario, while the total shipping costs of airfreight option of consolidated parcel considered in the third scenario (scenario 3a) are to some extent competitive to the values generated in the second scenario.

Door-to-door service costs, which was determined as the integral part of the spare part supply chain, included two road segments. It related to the parcel transportation from the manufacturer’s warehouse to the specific airport and the transport of the parcel from the airport to the final destination in the port. These costs were assumed equal for both segments, based on the industry expert’s feedback to facilitate the model creation and distinctness. The barge costs, as increasing costs in the transport delivery chain, were also included in the calculation, representing the

| Table 7. Road transportation costs on the two route segments |
|-------------------------------------------------------------|
| **MAIN ENGINE**    | **CENTRIFUGAL PUMP** | **PURIFIER**  | **CONSOLIDATION** |
| Door-to-door costs* | 290.00 USD          | 160.00 USD    | 190.00 USD       | 390.00 USD       |
| Time               | 0.5 days            |               |                |                 |
| Barge costs        | 750 USD             |               |                |                 |
| Time               | negligible          |               |                |                 |

*assumed equal; relate to two road segments: manufacturer warehouse—airport and airport—port of destination
potential cost of parcel delivery from the wharf to ship’s anchorage. The door-to-door costs and barge costs are presented in Table 7.

Finally, recapitulation and summary of the analyzed results conducted in this research according to the variable importance and weight for the created research model are shown in Table 8.

The first scenario of the research showed the shipping costs and distance variable as the optimal solutions to the research problem while the results from the second scenario indicated the time of delivery and distance variable as optimal parameters among alternatives. The analysis of consolidation service utilization in both variants of the third scenario resulted in higher levels of examined parameters.

### 6. Discussion

The objective of this case study was to investigate the economic feasibility of three different parcel delivery scenarios on a selected transportation route. For the purpose of this study the mathematical model was created with predefined variables which were compared to determine the optimal scenario according to the different state of parcel delivery requirements. Based on the generated results of the proposed model, the airfreight delivery scenario was indicated as the optimal solution, when the total costs (TSCx) of spare part delivery were considered as the most weight function value. In conditions when the time (Tx) was set as a variable of the most weight value in the calculation of optimal shipping route (Osrx), the express delivery scenario became more competitive than the remaining ones, while both the first and the second scenario were found optimal when the distance variable (Dx) was taken into consideration. It can be concluded that the weight of the time variable plays a significant impact on the shipping company in the selection of the delivery method. Typically, the need for urgent delivery of specific spare parts on vessels requires the use of express delivery, while the airfreight delivery method usually relates to the planned and regular requirements, which can be correlated with the proper use of planned maintenance systems on ships. The characteristics of the vessel and cargo type as well as risk-sharing between the spot and period market of ship’s contract terms are also important and require considerations.

Additionally, the research results were used to validate the hypothesis and it was confirmed that the usage of the consolidation service was not competitive in any model, so the hypothesis was rejected for this particular research, a case study. This decision to reject the hypothesis requires further explanation, especially in the segment of selection of transportation mode and route. The specificity of the transportation route chosen as the research problem of this model was in the regular business activity of shipping companies involved in the analysis, and their requirement to determine the optimal scenario using the given modes of transport and variables in the model. Thus, the scenarios involving the exact modes of transportation in the logistics chain were default variables. These relations influenced the results obtained in the model. The real economic benefits of utilizing the consolidation service commonly depend on the supplier’s location and its full potential is mainly exploited when intracontinental or local consolidation is used, thus when the

### Table 8. Summary of variables and scenarios conducted in the model according to the variable importance (grey and bold boxes represent the optimal solutions based on variable importance)

| Variable     | FIRST SCENARIO | SECOND SCENARIO | THIRD SCENARIO (3a) | THIRD SCENARIO (3b) |
|--------------|----------------|-----------------|---------------------|---------------------|
| TSCx ($)     | 8,556.56       | 11,695.62       | 12,496.45           | 17,451.55           |
| Tx (working days) | 5–6    | 2–3             | 11                  | 6                   |
| Dx (km)      | min. 9,954.47  | min. 9,954.47   | min. 9,963.75       | min. 9,963.75       |
|              | max. 14,109.20 | max. 14,109.20  | max. 17,693.81      | max. 17,693.81      |
distance between supplier's locations is reduced. This enables the logistics operators to manage the logistic chain more efficiently by utilizing road transport more, against the air transport mode, which can significantly reduce the overall shipping costs. An example of good practice is the territory of the EU where there are no customs duties paid on goods moving between the EU Member States or institutes of free zones which, in combination with lower road freight rates, can produce significant savings in parcel on-board delivery on the shorter intracontinental distances. More on the export and exit procedures out of the EU is available at the European Commission (2019). These relations raise the question on the use and competitiveness of road mode of transportation on shorter distances as a part of the supply chain of spare parts provided. It should be emphasized that the model did not consider delivery of the spare parts from the supplier's closest location, which for example, in the case of the main engine delivery would have been the manufacturer site located in Denmark. This would enable the transport of the parcel via road, costing 192.405 per pallet of up to 50 kg (1,038.96$ in total). This transportation method would significantly reduce the overall shipping costs. In general, the parcel delivery prices depend on the current state of the market and cargo availability. Throughout the analysis of the delivery process of shipping companies involved in the research, the cases of last minute offers and extraordinary circumstances were recorded, which enabled the optimization of the total delivery costs. These examples were closely correlated with the time variable and exclusively referred to the circumstances where the time component was determined as a marginal variable. When the time component became irrelevant and in that manner applied to this research, the transport of consolidated parcel from Rotterdam to Panama resulted in a freight rate of 944.00S increasing the competitiveness of the road service mode of transportation. The use of consolidation service in air transport generates benefits visible in a reduced number of parcels which eliminates issuing the separate air waybill (AWB) and individual clearance process at the customs decreasing the overall shipping costs, eliminates delays in delivery of the multiple parcels increasing the reliability of the service, reduces administrative procedures and increases productivity and efficiency of the whole logistics chain, and provides the creation of competitive advantage. Airfreight and express delivery modes are more convenient for intercontinental delivery options and longer distances representing the current level of economic relations. The above-mentioned assumptions have resulted in the use of air transport as the main mode of transportation of the entire logistics chain and this is something worth emphasizing.

Although this was the authors' first attempt to analyze the economic feasibility of three different parcel delivery scenarios on a selected transportation route, this research has some limitations. The study was conducted on a small sample, respectively, in the modeling of the single transportation route and a limited number of parcels, which can limit the relevance and objectivity of the obtained results. Due to limitations in data acquisition, some structural parts of overall shipping costs were estimated, while others were neglected such as additional costs of import and export taxes to facilitate the understanding and presentation of results. Additional charges, time delays, and reliability of individual modes of transportation were based on simplified assumptions and were labeled as constant variables, which in some parts could have decreased the competitiveness of individual routes, due to slow administration procedures and increased costs. It should be mentioned that the charges neglected in the model calculation were rather low, related to all three scenarios, and therefore could not have influenced the final results of the conducted research. Finally, the specific Incoterms rule for air transport was applied in the research which determined the calculation flow of the model created. Further research should include the application of the created model on a larger research sample, to show the performance and distribution of variables according to the different research conditions, particularly the economic implications. Also, the estimated cost prices and other constant variables should be quantified and calculated as exact values according to the recent operational data. Delivery options and selection of transportation mode in the supply chain of spare parts on-board ship delivery should be examined individually in the model, distinguishing the characteristics of specific methods applied to the different origin and destination points in the overall network of transportation geography.
7. Conclusions
The objective of this study was to compare the efficiency of shipping a spare parts parcel as a function of current market conditions and the urgency of parcel delivery to the ship’s subsequent port of call. The authors created a model of the shipping route considering three critical variables: total shipping cost, delivery time, and total distance. Three different scenarios of delivery options were examined depending on the delivery method, which included air freight service, express service, and consolidation service delivery option. With the claim of determining the optimal shipping route, the research results depended on the weight variable as a subjective parameter of the required condition of the individual package and the urgency condition of the ship. These relations depend on the close coordination between ship, shipping company and the management of the whole supply chain network. All variables were determined based on actual first-hand operational data provided by relevant stakeholders and publicly available data. The results of the model show the predominance of the air freight delivery mode when the cost variable is considered the leading weight variable, express delivery when the time variable is considered the most important, and both options when distance is chosen as the leading weight variable. One of the assumptions that emerged from this research is related to the economic benefits of consolidation service that can be fully achieved by using different modes of transportation on intercontinental and shorter distances between relevant suppliers as opposed to longer and intercontinental distances along the supply chain. The research results should play a crucial role in determining the optimal supply management system of the individual company and allow to increase the savings in the logistic chain.

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