# Analysing the modal shift from road-based to coastal shipping-based distribution – a case study of outbound automotive logistics in India

This paper analyses the modal shift from a primary road-based to coastal shipping-based freight distribution. A mathematical model is developed to optimize the coastal shipping route planning under a multimodal distribution scenario. The model is applied to a case study of the outbound automotive logistics in India. Exploratory insights on the enablers and challenges to adopting coastal shipping-based distribution are presented along with the route configuration and the level of modal shift achievable based on the model results. The results of the study suggest that the current business and regulatory environment is appropriate to achieve almost one-third shift to intermodal coastal shipping, although investments in infrastructure and substantial cost reductions in ship and port operations need to be implemented to ensure further modal shift.

Keywords: liner shipping; coastal shipping; outbound automotive logistics;
modal shift; India

## 1. Introduction

There is a worldwide impetus to the development of intermodal transportation by a modal shift towards rail or waterborne transportation. Countries with access to navigable waterways, which include coastal shipping and inland waterways, are focusing on this mode as it helps in the decongestion of existing road and rail infrastructures and offers the potential to reduce the economic, environmental and social costs of transportation. This is echoed by the European Union calling for a significant modal shift and advocating short sea shipping[1] for medium to long-distance trade (European Commission, 2009). US Department of Transport has also provided active support to the same. Despite the support, this sector faces many challenges in terms of regulatory issues and integration with the intermodal transportation systems (Reis, 2014). The focus of this study is the development of intermodal transportation using coastal shipping to facilitate efficient freight movement within the disparate geographical boundaries of a country or a trade block.

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[1] Short Sea Shipping is a related term to Coastal shipping

Development of domestic waterways as a part of an intermodal transportation system entails the identification of route design, the number of types of ships to be deployed, along with the deployment plan (Yang et al., 2014). Route design for coastal shipping is different from ocean liner shipping network design, as the former directly competes with roadways and railways, as a part of the intermodal transportation system. In addition to the optimal liner shipping network design, the status of coastal shipping in a country needs to be outlined. The analysis of the above two aspects yields insights on the viability of using coastal shipping as a successful means of freight movement.

India has a vast navigable coastline. Despite this, the development of coastal shipping has been very limited as compared to Europe, USA and China. Indian coastal shipping has faced many regulatory and infrastructural bottlenecks, which have curtailed its development in the past. Now with the improvements in port infrastructure and the introduction of supporting policies and incentives from the government, supply chains can attempt a modal shift to achieve reduced logistics cost and improved environmental performance. The development of coastal intermodal shipping entails the development of ports for coastal shipments to regional markets and the establishment of maritime logistics solutions from the industry. The economic sustainability of coastal intermodal supply chains is mainly dependent on consistent freight demand from specific firms or industries, like automotive, consumer retail, energy sector, etc. Thus, the modal shift to coastal shipping can be analysed at an industry level. The automotive industry is one of the fastest growing industries in India with extensive distribution across the length and breadth of the country. This industry can benefit substantially from a modal shift to coastal intermodal shipping. In this regard, this paper attempts to address the issue of the viability of a modal shift to coastal shipping from road-based mode at a strategic level. The paper explores the problem by using a mathematical model to identify the optimal liner shipping network design, fleet size and mix, and a deployment plan along with the level of modal shift achievable. Additionally, this paper explores the regulatory framework and business environment under which the coastal shipping and related logistics sector functions, and identifies the enablers and bottlenecks under the proposed scheme.

The next section reviews the related literature in this domain. Section 3 describes the problem in detail using a mathematical model, followed by a presentation on the selected case study with detailed data analysis of the model. Section 5 presents qualitative discussions on enablers and challenges in running coastal ships in the given scenario. Finally, we state our concluding remarks in Section 6.

## 2. Literature review

In this section, we review some of the literature related to route design in coastal shipping and some, important qualitative studies in this area. Several excellent surveys exist within liner shipping network design, see for instance (Brouer et al., 2014), Christiansen et al. (2013) and (Meng et al., 2014). However, these surveys are mainly focused on ocean container shipping in geographically spread areas. We focus on literature concerning short sea shipping and inland river transportation with similarities to our study on coastal shipping. The extent of contributions in this area is limited compared to design of global ocean shipping networks (Yang et al., 2014).

Fagerholt (1999) considers determining an optimal fleet size and mix and the design of a liner network for a feeder transportation system for transportation of containers between ports along the Norwegian ports to/from the European Continent. The problem is solved using a set partitioning approach with a priori generation of feasible ship routes, similarly to as what we do. The same problem was later studied by Sigurd et al. (2005), but they use a column generation solution approach. Another similar problem from Norway was recently studied by Holm et al. (2018), however they assumed a hub-and-spoke system where daughter ships, acting as feeder vessels, meet with mother ships at suitable locations at sea to tranship cargo. Fagerholt (2004) studies a short sea liner network design problem in the case where the fleet of ships is given.

Other examples of network design in short sea shipping is provided by Karlaftis et al. (2009) and Polat et al. (2014). Karlaftis et al. (2009) consider a case with a hub-and-spoke system for the container transportation among 25 islands in the Aegean Sea. Polat et al. (2014) study the feeder network design problem in the Black Sea. They present a mixed-integer linear programming (MILP) model and propose an adaptive neighbourhood search algorithm to solve the problem of determining the fleet size and mix, as well as the routes.

Route design problems in coastal and inland waterways are presented as either context specific or as a part of intermodal freight transportation problem. Liu and Qin (1994) consider the problem of determination of ship types for a coastal line in Japan. Sambracos et al. (2004) present a problem dealing with the design of container freight shipping in the Aegean Sea using optimization models. In terms of geographical context, the liner network design on the Yangtze River has received noticeable attention, given its importance to the Chinese domestic freight movement. Luo and Sun (2006) analyse the navigable condition of Yangtze River by designing and evaluating five schemes. Jia, Zhang and Yang (2006) explore the preference of water transport over land transport by analysing the container transportation in the upstream Yangtze River, by employing an analytical hierarchical modelling technique for comparison. Yang et al. (2014) present an integer programming model to optimize the container liner network on the Yangtze River by minimizing the total transportation cost. The model can determine the shipping routes, calling ports, calling sequences, number and type of the used ships. Zheng and Yang (2016) develop a hub and spoke system network design model for container shipping along the river using a MILP model. Yang and Wang (2017) analyse the development potential of a bulk shipping network on the river using an optimization model. As per our investigation, very few studies discuss liner route design in the context of automobile shipment using ro-ro ships. A major difference of ro-ro liner shipping from the container liner shipping is that transhipment, which is very common in container shipping, although rare in ro-ro shipping. This is particularly true for short-sea liner shipping route design for automobile distribution.

A group of studies on the development of coastal or inland waterways explores its integration with intermodal transportation. Ayar and Yaman (2012) study a multi-commodity routing problem for an intermodal transportation scenario using ground and maritime transportation. Chen et al. (2014) present a new liner route design model for intermodal networks based on the user equilibrium assignment model, in the context of coastal shipping in China. Park and Suh (2011) suggest the possibility of modal shift from road to coastal shipping by developing a mobile harbour with a container crane on board for container transport. Rodrigues et al. (2015) compare five alternative multimodal scenarios in the UK to access possible carbon mitigation strategies. Zeng et al. (2013) present a transport allocation problem of cars as a commodity across the road, rail, and sea when all the routes and demand are fixed.

Several studies discuss the challenges of developing coastal shipping as a part of regular transportation networks under different contexts. Paixao and Marlow (2002) discuss the strengths and weaknesses of short sea shipping with an aim to help identify the right strategies. Various country/region specific studies on coastal shipping extend this discussion on the growth of coastal shipping, like Saldanha and Gray (2002) for Britain, Wood (2004) in the context of Tanzania, Brooks and Frost (2004) for Canada, Perakis and Denisis (2008) for USA, and Lekakou (2007) for Greece. Venkatesh et al. (2017) conduct a detailed cause and effect analysis of the barriers to Indian coastal shipping. Important obstacles in the growth of coastal shipping which come out of these studies are lack of collaboration between logistics providers, government policies and lack of incentives, poor marketing of services by the coastal shipping companies, and difficulty in connecting with other modes of transportation.

There exist also a few studies where optimization has been used in the planning of various aspects in ro-ro shipping operations; see for example Pantuso et al. (2016) on fleet renewal, Fischer et al. (2016) on fleet deployment and disruption management, and Øvstebø et al. (2012) on ro-ro stowage planning. Chandra et al. (2016) present a fleet deployment problem combined with inventory management at the ports in the context of ro-ro shipping. However, all of these are in a different planning context as the problem considered in this paper.

As per our investigation, the current literature has given less emphasis on examining the potential for the growth of coastal shipping under a given policy structure, infrastructure, and supply chain practices. We try to bridge this gap.

## 3. Problem description and mathematical model

In this study, a full-scale strategic scenario is considered to analyse the cost viability of implementing a modal shift to coastal shipping-based intermodal distribution of automobiles. The route and fleet design are considered in an integrated supply chain scenario for a commodity traded domestically across a country. A mixed integer linear programming (MILP) model is employed to determine optimal route alternatives, ship types, lead time performance, and the share of shipment volumes taken up by the coastal intermodal channel. To study the development of coastal shipping as an intermodal service, we consider a single inland origin source connected to an origin port for coastal shipping. The origin source may be a production facility or a central warehouse (henceforth referred to as inland origin). There are two modal options available – road-based mode, directly from the inland origin to the demand locations (henceforth called destinations) using trucks, and another option is coastal shipping-based intermodal delivery. We assume a set of ships are available for chartering, which consists of different types in terms of capacity and cost characteristics. The planning horizon of a year is considered with each period being a month. In a single period, a ship may serve a certain number of voyages across a trade route by loading cargo at the first port of each route. The same ship discharges cargo at subsequent ports along the same route. A destination may be served either by direct truck delivery or by last mile truck delivery from a port that is included in some of the trade routes being served. The objective of the model is to minimize the total cost of inland and intermodal transportation.

In the following, we present the notation and mathematical model used for analysing the problem.

### *3.1 Notation*

Sets

| | |
|---|---|
| $\mathcal{K}$ | Set of all destinations, $k \in \mathcal{K}$ |
| $\mathcal{V}$ | Set of available ship types, $v \in \mathcal{V}$ |
| $\mathcal{R}_v$ | Set of all shipping routes that can be served by ship type $v$, $r \in \mathcal{R}_v$ |
| $\mathcal{P}$ | Set of unloading ports, $i \in \mathcal{P}$ |
| $\mathcal{P}_r$ | Set of unloading ports along route $r$, , $i \in \mathcal{P}_r$ |
| $\mathcal{T}$ | Set of time periods (i.e. months), $\{0, 1, 2, 3, \ldots, \lvert T\rvert\}$, $t \in \mathcal{T}$ |

Parameters

| | |
|---|---|
| $C_v^{FS}$ | Fixed cost of hiring a ship (FCS) of type *v* in the planning horizon |
| $C_{vr}^{S}$ | Cost of completing a voyage on route *r* by a ship of type *v* and coming back to the origin port. It includes the daily shipping cost charged by the shipping company (VCS) and the fixed costs of using ports along each served route. |
| $C_i^{VH}$ | Loading and discharging cost per unit when discharging at port *i* |
| $C_k^{T}$ | Direct trucking cost per unit between the inland origin and destination *k* |
| $C^{OT}$ | Inland transportation cost per unit between the inland origin and the origin port for coastal shipping |
| $C_{ik}^{KT}$ | Inland transportation cost per unit between port *i* and destination *k* |
| $D_{kt}$ | Estimated demand in units at destination *k* in time period *t* |
| $T_{vr}$ | Number of days to complete a voyage on route *r* by a ship of type *v* |
| $\bar{Q}_v$ | Maximum carrying capacity of a ship of type *v* in units |

| | |
|---|---|
| $\bar{T}$ | Number of days in a single time period |
| $T^{OT}$ | Truck travel time from the inland origin to the origin port |
| $T_k^{KT}$ | Truck travel time directly from the inland origin to destination *k* |
| $T_{vri}^{S}$ | Shipping time from the origin port to port *i* with a ship of type *v* traversing route *r* |
| $T_{vri}^{P}$ | Time spent in port *i* of route *r* by a ship of type *v* |
| $T_{ik}^{T}$ | Truck travel time from port *i* to destination *k* |

Decision variables

| | |
|---|---|
| $f_{kt}^{T}$ | Units transported from the inland origin directly to destination *k* with a truck in time period *t*, $\forall k \in \mathcal{K}, t \in \mathcal{T}$ |
| $f_{ikt}^{S}$ | last mile deliveries made from port *i* to destination *k* in time period *t*, $\forall i \in \mathcal{P}, k \in \mathcal{K}, t \in \mathcal{T},$ |
| $u_v$ | Number of ships of type *v* used in the planning horizon, $\forall v \in \mathcal{V}$ |
| $y_{vrt}$ | Number of voyages served by ships of type *v* on route *r* in time period *t*, $\forall v \in \mathcal{V}, r \in \mathcal{R}_v, t \in \mathcal{T}$ |
| $q_{vrt}^{L}$ | Number of units loaded at the origin port of route *r* in time period *t* by ships of type *v*, $\forall v \in \mathcal{V}, r \in \mathcal{R}_v, t \in \mathcal{T},$ |
| $q_{ivrt}^{U}$ | Number of units unloaded at port *i* of route *r* in time period *t* by ships of type *v*, $\forall v \in \mathcal{V}, r \in \mathcal{R}_v, i \in \mathcal{P}_r, t \in \mathcal{T}$ |

### *3.2 Mixed-integer linear programming model*

The planning problem involves deciding which routes to be served in each time period of the planning horizon and how many ships of each type to be used in the planning horizon. The fleet deployment along the different selected routes provides the necessary capacity for intermodal shipments from the origin port to the different discharge ports.

Figure 1 represents the two modal options of coastal and direct truck delivery from the inland origin to the destinations including the variables related to the units transported and (un)loaded.

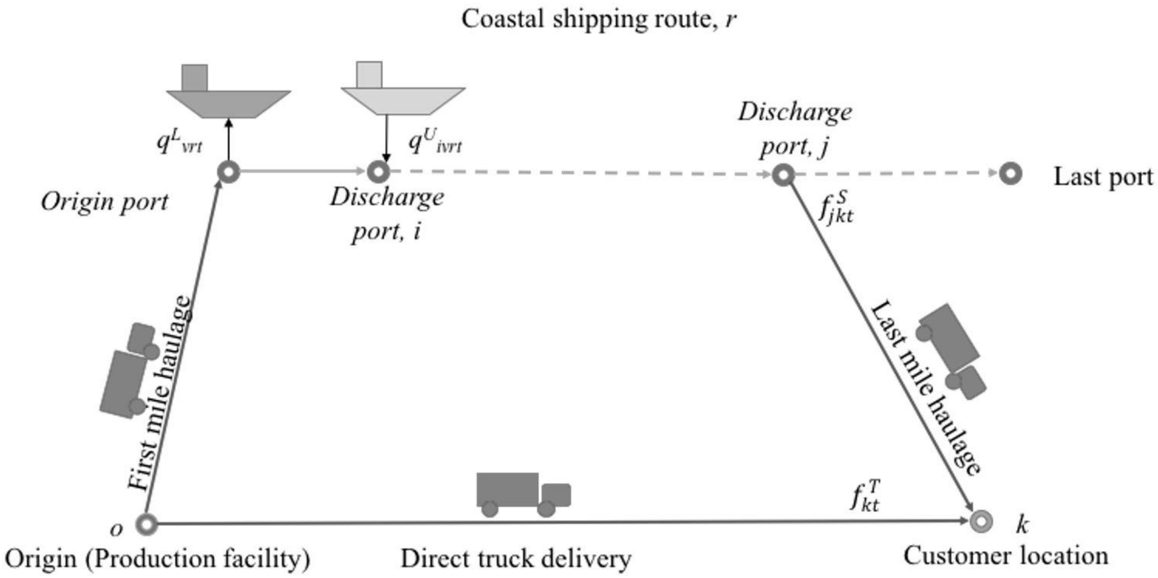

Figure 1: A representation of the multi-modal network

$$
\begin{aligned}
\text{minimize} \quad z = &\sum_{k\in\mathcal{K}}\sum_{t\in\mathcal{T}} C_k^T f_{kt}^T + \sum_{v\in\mathcal{V}} C_v^{FS} u_v + \sum_{v\in\mathcal{V}}\sum_{r\in\mathcal{R}_v}\sum_{t\in\mathcal{T}} C^{OT} q_{vrt}^L \\
&+ \sum_{v\in\mathcal{V}}\sum_{r\in\mathcal{R}_v}\sum_{t\in\mathcal{T}} C_{vr}^S y_{vrt} + \sum_{i\in\mathcal{P}}\sum_{k\in\mathcal{K}}\sum_{t\in\mathcal{T}} C_{ik}^{KT} f_{ikt}^S \\
&+ \sum_{v\in\mathcal{V}}\sum_{r\in\mathcal{R}_v}\sum_{i\in\mathcal{P}_r}\sum_{t\in\mathcal{T}} C_i^{VH} q_{ivrt}^U
\end{aligned} \tag{1}
$$

Subject to

$$q_{vrt}^L - \sum_{i\in\mathcal{P}_r} q_{ivrt}^U = 0, \quad \forall v \in \mathcal{V}, r \in \mathcal{R}_v, t \in \mathcal{T}, \tag{2}$$

$$\sum_{v\in\mathcal{V}}\sum_{r\in\mathcal{R}_v} q_{ivrt}^U - \sum_{k\in\mathcal{K}} f_{ikt}^S = 0, \quad \forall i \in \mathcal{P}, t \in \mathcal{T}, \tag{3}$$

$$f_{kt}^T + \sum_{i\in\mathcal{P}} f_{ikt}^S \geq D_{kt}, \quad \forall k \in \mathcal{K}, t \in \mathcal{T}, \tag{4}$$

$$q_{vrt}^L - \bar{Q}_v y_{vrt} \leq 0, \quad \forall v \in \mathcal{V}, r \in \mathcal{R}_v, t \in \mathcal{T}, \tag{5}$$

$$u_v - \frac{1}{\bar{T}} \sum_{r \in \mathcal{R}_v} T_{vr} y_{vrt} \geq 0, \quad \forall v \in \mathcal{V}, t \in \mathcal{T}, \tag{6}$$

The objective function (1) minimizes the total cost of shipping from the inland origin to all destinations over the planning horizon. The terms are: 1) Costs of direct truck deliveries, 2) costs of chartering ships over the planning horizon, 3) truck transportation costs from the inland origin to the origin port, 4) variable costs of operating ships along the selected routes including the fixed port visit costs, 5) costs of last-mile trucking from delivery ports to respective destinations, and 6) the variable port handling costs.

Constraints (2) ensure that the units loaded at the first port of a route is equal to the units discharged at subsequent ports of the same route in the same time period. Constraints (3) ensure that the units discharged at a port is equal to the units distributed to the nearby destinations from the same port. Constraints (4) are demand fulfilment conditions. Constraints (5) restrict the units carried by coastal shipping to the total maritime transportation capacity available. Constraints (6) ensure that the number of ships of each type is sufficient for the ships' voyage activity. The variables $u_v$ and $y_{vrt}$ are declared as integer, while the rest of the variables are considered continuous due to their considerable size. The valid index combination for each variable is given in the definition of the variables.

### *3.3 Lead time performance*

Lead time of delivery is an important consideration in the study of coastal shipping for freight logistics. Even though the model (1) - (6) is optimized with respect to costs, the results can also be used to derive the measures of overall lead time performance of the maritime logistics system. The weighted average lead time of all shipments by truck from the production facility to the customer locations are:

$$WALT_T = \sum_{k \in \mathcal{K}} \sum_{t \in \mathcal{T}} D_{kt} T_k^{KT} \Big/ \sum_{k \in \mathcal{K}} \sum_{t \in \mathcal{T}} D_{kt} \tag{7}$$

The weighted average lead time of all the shipments through coastal intermodal delivery option with values on all variables from model (1) – (6) are:

$$WALT_C = \sum_{i \in \mathcal{P}} \sum_{k \in \mathcal{K}} \sum_{t \in \mathcal{T}} \left( T^{OT} + \sum_{v \in \mathcal{V}} \sum_{r \in \mathcal{R}_v} T_{vri}^{S} y_{vrt} + \sum_{v \in \mathcal{V}} \sum_{r \in \mathcal{R}_v} T_{vri}^{P} y_{vrt} + T_{ik}^{T} \right) f_{ikt}^{S} \Big/ \sum_{i \in \mathcal{P}} \sum_{k \in \mathcal{K}} \sum_{t \in \mathcal{T}} f_{ikt}^{S} \tag{8}$$

## 4. Case study and data analysis

To analyse the viability of coastal shipping in an industry segment and explore the challenges involved, we present the case study of outbound logistics of automobiles in India for a major automotive manufacturer (henceforth called auto-manufacturers). India has developed a strong automotive industry owing to rising domestic demand and its gradual development as a regional manufacturing base for major auto-manufacturers in the world (Chandra et al., 2016). As per the Society of Indian Automobile Manufacturers, the domestic automobile sales in India stood at 20.5 million units in the 2015-16 financial year. As much as around 95% of the outbound distribution of finished vehicles to the customers throughout India is carried out through specially designed trucks, with a small percentage dispatched through the railways for long-haul deliveries. Thus, to alleviate the inland modes of transportation from getting overburdened and providing an efficient and socially acceptable means of transport, coastal shipping has received substantial attention in the recent past from both the Government and corporate sectors.

The port city of Chennai located in the south-eastern part of India is home to many finished auto-manufacturers, such as Hyundai, Ford and Nissan. One of the major auto-manufacturers located in Chennai recently started using coastal shipping based intermodal distribution of automobiles to the western part of India using a Roll-on/Roll-off (ro-ro) ship. The auto-manufacturer has hired the services of a logistics service provider (LSP) to manage the coastal shipping. These operations were started on a trial basis, and the auto-manufacturer sees positive results from it.

In the following, we first present an empirical analysis of automotive distribution data with the optimization model to access the cost viability of the coastal shipping model.

Figure 2: Important ports and sample routes in the Indian coastal shipping

We consider the port nearest to the auto-manufacturer, Chennai, as the origin port for coastal shipping. 14 ports are considered as potential discharge ports. Figure 2 illustrates some of the relevant ports in India and two route options. Several different route options consisting of visits to subsets of the chosen ports are generated. All the possible shipping routes originate and end at the port of Chennai.

### *4.1 Data estimation*

Data were estimated from a real scenario faced by the LSP managing coastal intermodal shipping for the auto-manufacturer. In India, a car dealer is associated with a single auto-manufacturer. Dealers within the same district or city block are identified as one demand destination. A total of 261 destinations are identified for the auto-manufacturer. Online mapping applications (Google Maps 2017) are used to record the road distance between the origin and each destinations. Similarly, the road distances between each possible discharge port and all customer locations are recorded. To estimate monthly demand district-wise, we relied on secondary data sources (SIAM 2017; Capitaline 2017). Data sources on automotive sales in India publish data related to month-wise total sales, annual sales data for each auto-manufacturer, state-wise annual sales, and region-wise[2] sales data and percentage share of each auto-manufacturer. On analyzing the number of cars sold state-wise with the state GDP (gross domestic product) (DistrictsofIndia 2017), state population and state per capita income, it was found that the number of cars sold in a state has a high correlation with the GDP of the region. We therefore used the GDP per district to allocate the total number of cars sold in each district. Then the percentage share of the auto-manufacturer in the respective region was used to calculate the number of cars sold in each district each month.

Truck freight rates are estimated from primary sources. Truck freight rates between 200 location pairs were shared by the managers involved in automotive logistics on request. We ran a simple regression to develop a 2-part tariff model for car-carrier trucking in India. Equation (15) presents the resulting regression model for estimating the trucking costs per Car Equivalent Unit (CEU). All the trucking rates in USD between different pairs of locations were estimated using this model.

$$Freight\ \ Rate = 185.69 + 1.46\ \ \times\ \ Distance\ \ (km) \tag{15}$$

We chose a set of ship types having varied characteristics in terms of capacity, speed and costs. The LSP provided estimates for the fixed for hiring each type of ship for a period of one year, as well for the variable costs. Table 1 presents the available ship types we have chosen to include with their characteristics. Port charges are taken from the published tariff rates by Indian ports for ro-ro ships. As per the tonnage tax rule, as amended for coastal ships in 2004, ships are charged in proportion to their GRT (Gross Registered Tonnage). For the considered ship types, Table 1 presents the estimates related to ship capacities in terms of CEU, ship sizes in terms of GRT, average ship speeds in knots, variable cost of running the ships at sea (VCS), variable cost of ship's port stay (VCP), and the fixed costs of hiring ships (FCS). VCS consists of the daily ship running cost charged by the shipping company to the LSP, while the ship is in operation. VCP consists of daily port charges of berthing a ship in a port, excluding the variable cost of automobile loading or discharging.

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[2] A region is defined as a group of states segregated geographically, e.g. North-west, North-East, Central, etc.

Table 1: Ships types with characteristics

| **Ship type** | **Capacity (CEU)** | **GRT** | **Average speed (*knots*[3])** | **Variable cost at sea (USD/day)** | **Variable cost at port (USD/day)** | **Fixed cost (USD/year)** |
|---|---:|---:|---:|---:|---:|---:|
| 1 | 800 | 8,081 | 10.2 | 3,218 | 3,467 | 1,073,465 |
| 2 | 3,518 | 42,401 | 11.2 | 6,568 | 15,925 | 2,147,112 |
| 3 | 4,800 | 46,800 | 13.2 | 7,992 | 20,636 | 2,890,283 |
| 4 | 6,000 | 59,317 | 12.1 | 9,207 | 25,530 | 3,534,478 |

### *4.2 Model analysis*

The mathematical model presented in Section 3.2 is implemented in the academic version of IBM CPLEX 12.6.2 optimization library on Python 2.7.10 programming language. The computational tests are carried out on a Dell Precision T5610 with Intel Xeon CPU E5-2620 v2 @ 2.10 GHz 6 cores CPU and 32.0 GB RAM. To compare existing operations and practices with prospective operations, two scenarios were considered. In scenario 1, only direct trucking mode was considered, and in scenario 2, both coastal shipping and direct trucking options were considered as modal options. Analysis of the second scenario is carried out on various cost parameter configurations, as shown in Table 2. Scenario 1 is represented by configuration 1, while configurations 2 - 22 represent scenario 2 with various cost combinations of the coastal shipping mode. Configuration 2 is based on the cost estimates presented in Table 1. Configurations 3 - 22 are derived by individually reducing the various cost components from the original cost estimates, as shown in columns 2 - 4 of Table 2.

Table 2 presents the computational results for various configurations under the two scenarios. The total cost to deliver 431,272 cars in a year is USD 109 million when using only the direct truck delivery mode (i.e. scenario and configuration 1). The results for configuration 2 show a 9.1% reduction in total cost in comparison to scenario 1, with the share of coastal shipping coming as 33%. Two large ships of type 4 are employed. Successive reductions in the fixed cost of shipping are tested in configurations 3 - 6. A gradual cost reduction of 9.3 - 10% compared to the direct truck delivery mode is seen

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[3] *knots* stands for nautical miles per hour, a measure of ship speed

with the share of coastal shipping going up from 33% to 53%. Only when the fixed cost is reduced by 30%, the ship deployment plan changes to one ship of each type 2, 3 and 4, along with an overall share of coastal shipping jumping to 40%.

Table 2: Computational results for different configurations

| **Config.** | **Reduction in per unit shipping cost considered under the three categories (%)** | | | **Comp. time (sec)** | **Opt. objective (mill. USD)** | **Reduction from config. 1 (%)** | **Share of coastal shipping (%)** | **Ship types used (number of ships deployed)** | **WALTc (days)** |
|---|---|---|---|---|---|---|---|---|---|
| | **FCS** | **VCS** | **VCP** | | | | | | |
| 1 | - | - | - | - | 109 | - | 0 | - | - |
| 2 | 0 | 0 | 0 | 85 | 99.1 | 9.1 | 33 | 4(2) | 8.5 |
| 3 | 10 | 0 | 0 | 84 | 98.9 | 9.3 | 33 | 4(2) | 8.3 |
| 4 | 20 | 0 | 0 | 79 | 98.7 | 9.4 | 33 | 4(2) | 8.3 |
| 5 | 30 | 0 | 0 | 314 | 98.5 | 9.6 | 40 | 2(1), 3(1), 4(1) | 7.9 |
| 6 | 50 | 0 | 0 | 98 | 98.1 | 10 | 53 | 2(1),3(2),4(1) | 7.6 |
| 7 | 0 | 10 | 0 | 266 | 98.8 | 9.4 | 33 | 4(2) | 8.5 |
| 8 | 0 | 20 | 0 | 300 | 98.6 | 9.5 | 33 | 4(2) | 8.5 |
| 9 | 0 | 30 | 0 | 260 | 98.3 | 9.8 | 33 | 4(2) | 9.5 |
| 10 | 0 | 50 | 0 | 94 | 97.3 | 10.7 | 33 | 4(2) | 8.5 |
| 11 | 0 | 0 | 10 | 383 | 97.4 | 10.6 | 33 | 4(2) | 8.5 |
| 12 | 0 | 0 | 20 | 10,596 | 96.0 | 11.9 | 33 | 4(2) | 8.5 |
| 13 | 0 | 0 | 30 | 86,403 | 94.3 | 13.5 | 33 | 4(2) | 8.5 |
| 14 | 0 | 0 | 50 | 13,575 | 90.0 | 17.4 | 33 | 4(2) | 8.3 |
| 15 | 50 | 10 | 0 | 45,242 | 89.7 | 17.7 | 53 | 2(1),3(2),4(1) | 7.7 |
| 16 | 50 | 20 | 0 | 32,399 | 89.4 | 18 | 53 | 2(1),3(2),4(1) | 7.6 |
| 17 | 50 | 30 | 0 | 13,530 | 89.1 | 18.3 | 53 | 2(2),3(2),4(1) | 7.5 |
| 18 | 50 | 50 | 0 | 85,363 | 88.4 | 18.9 | 53 | 2(1),3(1),4(2) | 7.6 |
| 19 | 50 | 0 | 10 | 13,464 | 89.4 | 18 | 53 | 2(1),3(2) ,4(1) | 7.5 |
| 20 | 50 | 0 | 20 | 8,468 | 89.0 | 18.3 | 53 | 2(1),3(2),4(1) | 7.4 |
| 21 | 50 | 0 | 30 | 84,939 | 88.5 | 18.8 | 63 | 2(1),3(2),4(1) | 7.1 |
| 22 | 50 | 0 | 50 | 86,405 | 87.4 | 19.8 | 57 | 2(1),3(2),4(1) | 7.4 |

Further, a 50% reduction in the fixed cost of shipping leads to an additional ship deployment of type 2 with the share of coastal shipping going up to 53%. Reductions in variable shipping cost (configurations 7 - 10) do not lead to any change in the fleet deployment plan and an increase in coastal shipping share, although the overall cost reduction increases from 9.4% to 10.7%. We have considered costs charged by a shipping line to an LSP, so there may be a possibility of a reduction in ship operational costs through better collaboration between the shipping line and LSP.

The possibility of a shipping line offering coastal shipping based logistics solutions may also lead to reductions in the above costs. Reductions in variable port costs (configurations 11 - 14) also do not lead to any change in fleet deployment plan and share of coastal shipping, although larger reductions in total cost from 10.6% to 17.4% are seen. Configurations 15 - 18 are the cases with reductions in variable ship costs with a 50% reduction in the fixed shipping cost. Cost reductions of 17.7% to 18.9% are seen, with the share of coastal shipping stuck at 53%, showing no effect of variable shipping cost reductions on the same. The fleet deployment plan consists of one or more units of ship types 2, 3 and 4 used in the planning horizon.

Configurations 19 - 22 test reductions in variable port costs along with a 50% reduction in the fixed shipping cost. Cost from 18% to 19.8% are seen along with a high share of coastal shipping ranging from 53% to 63%. The fleet deployment plan consists of one or more units of ship types 2, 3 and 4 used in the planning horizon.

Apart from the costs, other important considerations in logistics planning are lead times and port usage patterns. The only trucking option under scenario 1 has a $WALT_T$ of 4.4 days. The estimates of the $WALT_C$ for the intermodal coastal shipping mode vary from 7.1 days to 8.5 days, as listed in Table 2. An increase in the share of coastal shipping, with the reduction in operating costs, also tends to improve the lead time performance. This is because of the spread in port usage. In all configurations, Kolkata and Mundra appear as the major discharge ports with a combined share of more than 50% in most of the configurations. Figure 3 illustrates the coastal intermodal network characteristics of the two extreme configurations 2 and 21. The major routes suggested in the coastal shipping mode consist of single discharge ports.

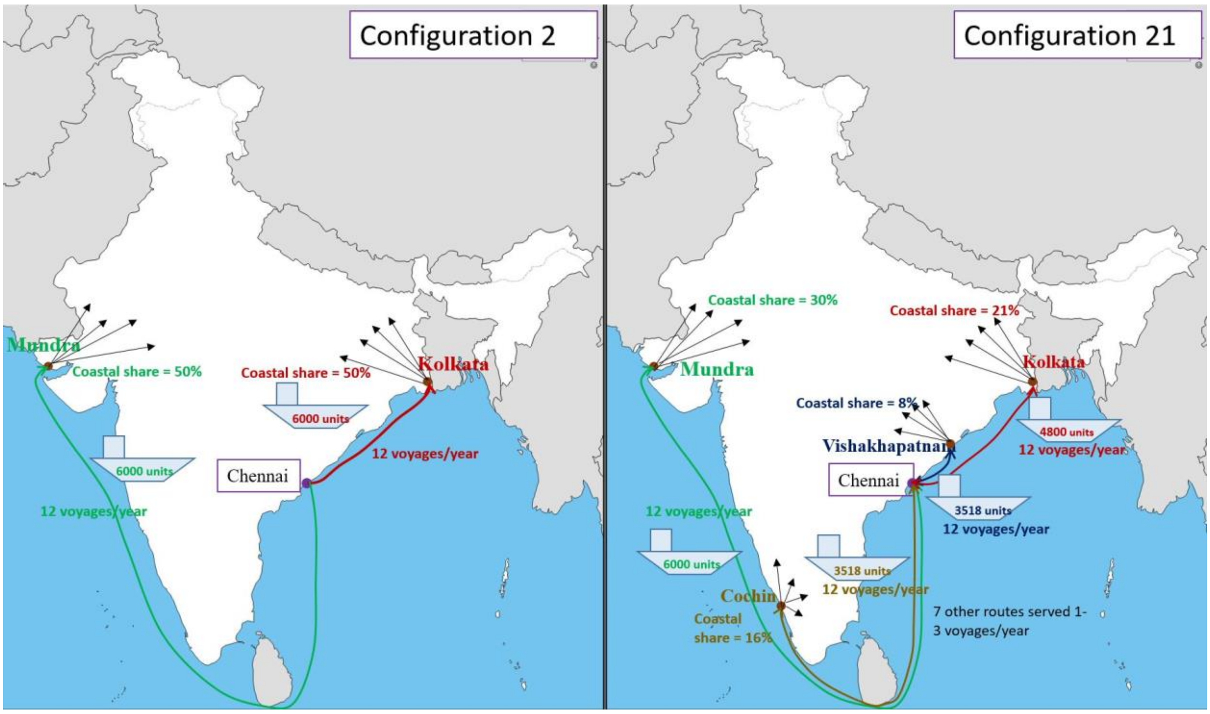

Figure 3: Coastal intermodal network characteristics for two extreme configurations

## 5. Enablers and challenges in the coastal shipping operations

The empirical analysis with the optimization model shows that substantial savings in transportation costs can be achieved by at least of one-third of modal shift to coastal intermodal shipping. The current section qualitatively explores the issues involved in coastal shipping operations under the given context.

India has a long coastline of 7517 kilometres, which covers a major perimeter of the country. This coastline is served by 12 major and around 187 minor ports (Ministry of Shipping 2017). However, the investment in shipping has mainly been focused on the development of overseas shipping (Sundar and Jaiswal 2007), so coastal shipping lacks supporting infrastructures like dedicated ports and terminals. As a result of this, only a small percentage of overall freight is moved on the coastal route. While major ports would provide the main infrastructure for the handling of the projected coastal traffic in the short term, a sustained effort is required to develop minor ports for this trade. There are some other important issues that seem to curtail the development of coastal shipping.

Customs procedures at the Indian ports are cumbersome. High import duties are charged on bunker fuel and spares for the coastal ships. Due to restricted manning requirements for officers and crew on coastal ships, the industry faces a shortage of personnel and has to incur high manning costs. Furthermore, the regulatory specifications related to the construction of coastal ships have been almost as stringent as that for ocean-going ships. Many experts suggest that since the working conditions in coastal shipping are not that tough, the construction standards for the coastal ships may be relaxed.

The LSP offering integrated coastal intermodal shipping services to auto-manufacturers in India has been serving voyages using a single chartered foreign-flagged ro-ro ship, across fixed trade routes comprising of a sequence of a few important ports. One of the biggest challenges they face is arranging car carrier trucks for last-mile delivery at every location. The company hires the services of independent trucking companies for road transportation on both sides. Since a major chunk of automobile deliveries is made directly using car-carrier trucks, from the factories to the dealers, most of these road carriers are deployed along the existing trade paths. Picking up vehicles from distant ports is a relatively new and small-scale opportunity.

Another challenge is that ro-ro ships have hydraulically operated ramp-ways which are opened and laid down on the jetty. Vehicles are loaded or discharged on to the ship by driving them along these ramp-ways. The ramp is at an angle to the jetty, based on the level of the sea at the berth. High tide occurrences at sea may increase this angle beyond operational limits and hinders cargo work at some port. Coastal shipping of automobiles to the west coast ports, particularly those located in Gujrat, is challenging as a result of this, as almost eight hours of cargo work are lost every day because of this.

Auto-manufacturers have existing long-term relationships with many LSPs offering road-based logistics solutions, which they may not be ready to jeopardize. The coastal route invariably takes more time than the direct truck route, and it may be difficult to persuade them for longer delivery times.

The development of a coastal shipping network calls for large investments. Even though some auto-manufacturers are showing interest in using the service, they might not be ready to commit long-term business. This does not induce enough confidence for the LSP to invest for the long term. Indian ship owners are not eager to invest in ro-ro ships, so availability of Indian-flagged ships is currently difficult. Foreign-flagged ships, after they have been licensed to do coastal shipments in India, can be chartered for a minimum period of three months. Although the policy of allowing the foreign-flagged ship to serve coastal shipping in India has been a big facilitator in developing the ro-ro service, the shipping costs are higher due to the high ship chartering rates. The government policies aimed at simplifying and expediting regulatory procedures in ports for coastal shipping are not fully applicable to foreign-flagged ships converted to coastal ships. One of the major concerns is whether the current port infrastructure and regulatory procedure will be able to cope up with the increase in the scale of coastal ro-ro operations. Inability to improve upon the existing scenario would lead to severe congestion at ports and lead to unacceptable delays in cargo delivery.

The above discussion reveals several insights. The coastal ro-ro service for automotive deliveries is a feasible business in India and has the potential to grow as a strong alternative logistics option, although the ro-ro shipping would be financially sustainable only at a certain scale of operations, as shown in the data analysis in the previous section. We summarize the findings of the qualitative study as enablers and challenges of implementing coastal shipping in Figure 4.

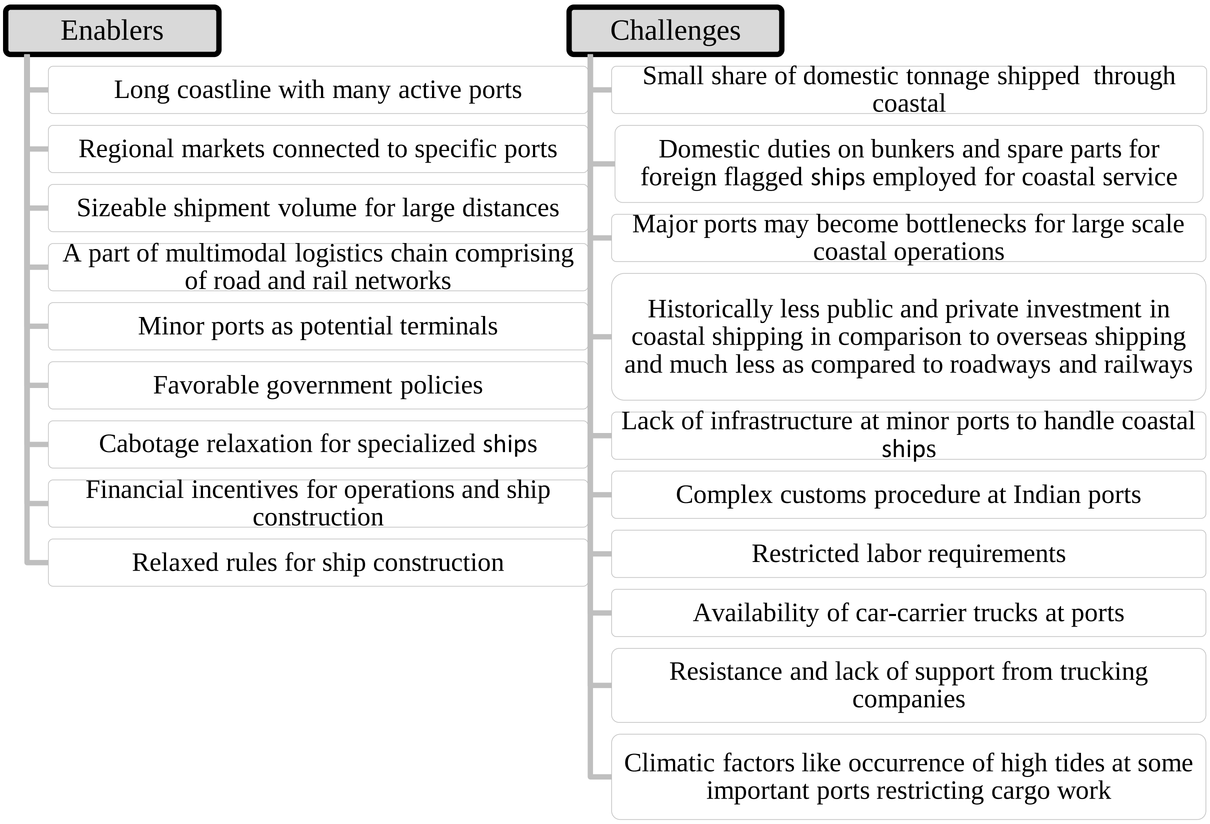

Figure 4: Enablers and challenges of implementing coastal shipping for outbound automotive logistics

## 6. Concluding remarks

Modal shift to coastal shipping has the potential to decongest the existing roadways infrastructure and reduce economic, social and environmental costs of transportation. In this regards, this paper develops a liner network design model as a part of a multimodal distribution system of a single commodity within a country. The model gives optimal system configuration in terms of routes, ship types and shipment quantities shared between competing modes.

The model is implemented on a case study of outbound automotive logistics in India. The mathematical programming based analysis suggests that the financial feasibility is sustainable only in the case of full utilization of existing ship capacities. With small and infrequent orders from the clients, it seems hard to manage the operations. A reduction in high distribution costs can be achieved by developing Indian ro-ro coastal ships by promoting and incentivizing Indian ship owners. Another way could be to enable LSPs to hire ships on a long-term to reduce costs. After achieving cost reductions in fixed shipping charges, reductions in port charges seem to have a major impact. The challenges faced at the operational level include inadequate business from clients, availability of last mile connectivity, high tides in the western coast, higher delivery times, the complex regulatory procedure for foreign-flagged ro-ro ships, the absence of Indian tonnage in ro-ro, and infrastructural and procedural sustainability for scaling up the operations.

It should be emphasized that the mathematical model and most of the qualitative insights from the case study are applicable to any similar context or commodity type shipped in bulk across a geography.

## References

Ayar B, Yaman H. 2012. “An intermodal multicommodity routing problem with scheduled services.” *Computational optimization and applications* 53(1):131-53.

Behera, T. 2008. “A review of coastal trade statistics of India”. Accessed 8 October 2017, from http://www.dgciskol.nic.in/Vaanijya0307/

Brooks, M. R., and Frost, J. D. 2004. “Short sea shipping: a Canadian perspective.” *Maritime Policy & Management* 31(4): 393-407.

Brouer, B. D., Alvarez, J. F., Plum, C. E., Pisinger, D., and Sigurd, M. M. 2013. “A base integer programming model and benchmark suite for liner-shipping network design”. *Transportation Science* 48(2): 281-312.

Capitaline database (automobiles - passenger cars: sector trends; accessed October 8, 2017). http://capitaline.com/SiteFrame.aspx?id=1

Chandra, S., Christiansen, M. and Fagerholt, K. 2016. “Combined fleet deployment and inventory management in roll-on/roll-off shipping.” *Transportation Research Part E: Logistics and Transportation Review* 92: 43-55.

Chandra, S., D. Ghosh, and S. K. Srivastava. 2016. “Outbound logistics management practices in the automotive industry: an emerging economy perspective.” *Decision* 43(2): 145-165.

Chen, K., Z. Yang and T. Notteboom. 2014. “The design of coastal shipping services subject to carbon emission reduction targets and state subsidy levels.” *Transportation Research Part E: Logistics and Transportation Review* 61: 192-211.

M. Christiansen, K. Fagerholt, B. Nygreen and D. Ronen. 2013. “Ship routing and scheduling in the new millennium”. *European Journal of Operational Research* 228, 467-483.

DistrictsofIndia. (GDP data on districts in India; accessed 10 January 2017) https://www.districtsofindia.com/index.aspx

European Commission. 2009. “COM (2009) 279 Final – A Sustainable Future for Transport: Towards an Integrated, Technology-Led and User-Friendly System”. Brussels, Belgium.

Fagerholt, K. 1999. “Optimal Fleet Design in a Ship Routing Problem.” *International Transactions in Operational Research* 6 (5): 453–464.

Fagerholt, K. 2004. “Designing optimal routes in a liner shipping problem.” *Maritime Policy & Management* 31(4): 259-268.

A. Fischer, H. Nokhart, H. Olsen, K. Fagerholt, J. Rakke and M. Stålhane. 2016. “Robust planning and disruption management in roll-on roll-off liner shipping”. *Transportation Research Part E* 91, 51-67.

Google Maps. (2017). Accessed 08 October 2017. https://www.google.co.in/maps

Holm, M. B., Medbøen, C. A. B., Fagerholt, K., and Schütz, P. 2018. “Shortsea liner network design with transhipments at sea: a case study from Western Norway”. *Flexible Services and Manufacturing Journal:* 1-22.

Jia, R. H., Y. Zhang, and B. Yang. 2006. “Project Optimization of Container Transport for the Upper Reach of the Yangtze River.” *Journal of Waterway and Harbor* 27 (2): 127–130.

Karlaftis, M. G., K. Kepaptsoglou, and E. Sambracos. 2009. “Containership Routing with Time Deadlines and Simultaneous Deliveries and Pick-Ups.” *Transportation Research Part E: Logistics and Transportation Review* 45 (1): 210–221.

Lekakou, M. B. 2007. “The eternal conundrum of Greek coastal shipping.” *Research in transportation economics* 21: 257-296.

Liu, J., and S. Qin. 1994. “Analysis of Container Ship Types and Transportation from the Yangtze River to Abroad.” *Journal of East China Shipbuilding Institute* 8 (4): 21–29.

Luo, H. B., and J. Y. Sun. 2006. “Study on Container Transportation Modes from Chongqing to Shanghai.” *Research on Waterborne Transportation* 2: 18–22.

Manoj, P. 2015. “Government takes a big stride to develop coastal shipping.” *Live Mint*. Accessed 08 October 2017 http://www.livemint.com/Opinion/zaHDZgo6l54hPdgfelCbFJ/Government-takes-a-big-stride-to-develop- coastal-shipping.html

Meng, Q., Wang, S., Andersson, H., & Thun, K. 2013. “Containership routing and scheduling in liner shipping: overview and future research directions”. *Transportation Science* 48(2): 265-280.

Ministry of Shipping. 2017. "Ports - Ministry of Shipping, Government of India." Accessed 08 October 2017 http://shipping.nic.in/index1.php?lang=1&level=0&linkid=16&lid=64

Ministry of Shipping. 2015. “Vision for coastal shipping, tourism and regional development.” Accessed October 08, 2017 http://shipmin.nic.in/showfile.php?lid=1959

Morgan Stanley. 2016. “India hears call of the sea.” Accessed 08 October, 2017 https://www.morganstanley.com/ideas/india-coastal-transport-growth

Paixaõ, A. C., and P. B. Marlow. 2002. “Strengths and weaknesses of short sea shipping.” *Marine Policy* 26(3): 167-178.

Pantuso, G., K. Fagerholt and S. W. Wallace. 2016. “Uncertainty in fleet renewal: a case from maritime transportation”. *Transportation Science* 50(2), 390-407.

Park, N. K. and S. C. Suh. 2011. “Modal shifting from road to coastal shipping using a mobile harbor.” *The Asian Journal of Shipping and Logistics* 27(3): 447-462.

Perakis, A. N. and A. Denisis. 2008. “A survey of short sea shipping and its prospects in the USA.” *Maritime Policy & Management* 35(6): 591-614.

Planning Commission of India. 2014. “Gross Fixed Capital Formation in Infrastructure” Accessed 8 October, 2017, http://planningcommission.gov.in/data/datatable/data2312/*DatabookDec*2014

Polat, O., Günther, H. O., and Kulak, O. 2014). “The feeder network design problem:

Application to container services in the Black Sea region". *Maritime Economics & Logistics* 16(3): 343-369.

Press Information Bureau. 2016. "Promoting coastal shipping in India under Sagarmala: Ministry enlarges the scope of Central Sector Scheme." Accessed 8 October, 2017 http://pib.nic.in/newsite/PrintRelease.aspx?relid=149310

Reis, V. 2014. "Analysis of mode choice variables in short-distance intermodal freight transport using an agent-based model." *Transportation Research Part A: Policy and Practice*, 61: 100-120.

Rodrigues, V. S., S. Pettit, I. Harris, A. Beresford, M. Piecyk, Z. Yang and A. Ng. 2015. "UK supply chain carbon mitigation strategies using alternative ports and multimodal freight transport operations." *Transportation Research Part E: Logistics and Transportation Review* 78: 40-56.

Saldanha, J. and R. Gray. 2002. "The potential for British coastal shipping in a multimodal chain." *Maritime Policy* & *Management* 29(1): 77-92.

SIAM. 2017. "SIAM monthly flash report on production and sales. Accessed 08 October, 2017. http://www.siamindia.com/public

Sambracos, E., J. A. Paravantis, C. D. Tarantilis, and C. T. Kiranoudis. 2004. "Dispatching of Small Containers via Coastal Freight Liners: The Case of the Aegean Sea." *European Journal of Operational Research* 152 (2): 365–381.

Sundar, S. and P. Jaiswal. 2007. "Bottlenecks in the growth of coastal shipping." Accessed 08 October, 2017 https://www.adb.org/sites/default/files/publication/30116/inrm14.pdf

TSMG (Tata strategic Management Group). 2013. "Coastal shipping – the neglected mode of transportation." https://www.tsmg.com/download/article/Coastal%20Shipping.pdf

Wood, G. 2004. "Tanzanian coastal and inland ports and shipping: crises and policy options." *Maritime Policy* & *Management* 31(2): 157-171.

Yang, Z., H. Shi, K. Chen and H. Bao. 2014. "Optimization of container liner network on the Yangtze River." *Maritime Policy & Management* 41(1): 79-96.

Yang, D. and Wang, S. 2017. "Analysis of the development potential of bulk shipping network on the Yangtze River." *Maritime Policy & Management* 44(4): 512-523

Zeng, T., D. Hu, G. Huang. 2013. "The Transportation Mode Distribution of Multimodal Transportation in Auto-motive Logistics." *Procedia-Social and Behavioral Sciences* 96: 405-417.

Zheng, J. and Yang, D., 2016. "Hub-and-spoke network design for container shipping along the Yangtze River." *Journal of Transport Geography* 55: 51-57.

Øvstebø, B. O., L. M. Hvattum and K. Fagerholt. 2012. "Routing and scheduling of RoRo ships with stowage constraints". *Transportation Research: Part C* 19, 1225-1242.