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Enhancing the role of coastal shipping in outbound automotive logistics- a viability study

Saurabh Chandra

saurabh@iimidr.ac.in

Kjetil Fagerholt

kjetil.fagerholt@ntnu.no

Marielle Christiansen

mc@ntnu.no

WP/02/2018-19/OM&QT
December 2018

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Abstract

Indian automotive manufacturers rely mainly on direct truck deliveries from their assembly plants to the customers across the country. As India has an extensive coastline, companies should be able to develop efficient distribution with coastal shipping. We select a major Indian automotive manufacturer based in southern India with the major ports in India considered as potential roll-on/roll-off terminals to analyze the modal shift from primary road based distribution to coastal intermodal shipping. The computational study of a mathematical model along with the analysis of current regulatory framework estimates current potential and suggests requirements for a successful modal shift.

Keywords: Coastal shipping, automotive logistics, India, sustainability analysis

1. Introduction

The Government of India recognizes the importance of coastal shipping as an energy efficient and comparatively cheaper mode of transport. In 1992, a working group was set up involving high ranking officials from the ministries and other organizations to study the development of coastal shipping (Directorate General of Shipping, 2017). Most of the recommendations of the working group were accepted by the government, which signifies a boost to the coastal shipping in the future. The road network and railways are already overburdened, and the development of coastal shipping could help in decongesting the overall transport network in the country. It also provides an opportunity to consolidate long-distance cargo, as the transport quantities are generally much higher in this mode (TSMG, 2013). Shipping is no longer an isolated mode of transportation but forms a part of intermodal transportation networks including roads and railways. Thus, the focus is on the development of intermodal transportation using coastal shipping to facilitate efficient freight movement within the disparate geographical boundaries of the country. This trend is in line with the impetus for the development of intermodal transportation in the European Union and calls for a modal shift towards rail or waterborne transport (Reis, 2014).

The development of successful intermodal supply chains requires economies of scale, high level of coordination across different parties and uniform regulatory framework (Slack, 2001). The existing freight networks in India are primarily reliant on roadways as a mode of transportation. Supply chains in India have followed a traditional structure, characterized by fragmented distribution networks, low level of information and communication technology usage and unorganized operations (Saldhana et al., 2015). Thus, most freight is transported over roads, additionally incentivized by indirect subsidization of road freight, through subsidy in the sale of diesel fuel (Shah and Suresh, 2009). Coastal shipping in itself has faced many regulatory and infrastructural bottlenecks, which have curtailed its development in India.

Now with government incentives and port infrastructure in place, supply chains can attempt a modal shift to achieve reduced logistics cost and improved environmental performance. With the recent introduction of the GST (goods and service taxes) bill in the Indian parliament, a centralized taxation structure is planned for the country. This will enable implementation of efficient logistics solutions across the country, by removing cascading taxation across state borders and many of the local taxes (Saripalle & Chebolu-Subramanian, 2017). 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. An effective modal shift to coastal shipping network would require substantial investment and planning from the logistics industry in terms of procurement of suitable vessels, the design of coastal shipping network, and establish first and last mile connectivity. This initiative will get a major push if the users of freight transport like manufacturers, retailers, etc., take measures to design their supply chains based on intermodal logistics (Woodburn et al., 2007). It is hypothesized that large firms planning their future supply chains based on multimodal logistics strategies are to gain from the reduction in logistics costs. 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 analyzed 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. We present a case study from the outbound logistics of automobiles[1] in India, where a firm has initiated coastal intermodal shipping for part of its outbound automotive logistics. The port city of Chennai located in the southern part of India is home to many finished automotive manufacturers (henceforth called auto-manufacturers) like Hyundai, Ford, Nissan, etc. Customers are located throughout India, and more than 95% of the deliveries are made directly from the production facility to the dealers by specially designed car carrier trucks. 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 ro-ro vessel. The vessel transported around 800 cars from the port of Chennai in the southern state of Tamil Nadu to the port of Pipavav in the western state of Gujrat (Cross, 2016). 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. So, the coastal intermodal delivery of a part of cargo between Chennai and Pipavav has become a regular activity. Now the question is: Can this mode of delivery be scaled up to achieve a higher degree of modal shift to coastal shipping? To answer this question, the LSP must make a strategic plan in terms of which delivery ports it wants to serve across the country,

[1]Outbound automotive logistics refers to the part of automotive supply chains where the finished vehicles are shipped from the final manufacturing facilities to the automotive dealers or customers (Chandra et al., 2016)

how many and what types of ships it needs, how much of the cargo it can profitably deliver using coastal intermodal channels and how to route the vessels from the origin port (Chennai) to the delivery ports. The answers to these questions would lay down a detailed maritime logistics design and operational plan, which can sustain the long-term viability of coastal intermodal shipping for automotive distribution. More importantly, it is required to be seen whether the current policy framework can sustain the scaling up efforts by the corporate sector. How should the industry and government support to develop sustainable maritime logistics solutions?

Based on the LSP's experience with the modal shift, we consider a full scale, strategic scenario and try to analyze the cost viability of implementing the modal shift. A mixed integer linear programming model is developed to determine optimal route alternatives, ship types, lead time performance, and the share of shipment volumes taken up by the coastal intermodal channel. Data analysis is done using estimated data from existing cost and time parameters. Sensitivity analysis is carried out by creating multiple data configurations using reductions in different cost components. For each configuration, the results give the percentage of road-based freight that can be optimally shifted to coastal intermodal shipping and the expected reduction in overall costs. Additionally, the model also gives inputs in terms of infrastructure requirements in ports and the design of maritime logistics system appropriate for the engaging firms. Discussions related to the sustainability of these operations follow the analysis. Thus, this paper contributes to the literature by comprehensively analyzing the potential development of the coastal shipping for outbound automotive logistics in a major emerging economy through the juxtaposition of policy implications over scale economics in transportation.

This paper is organized as follows. Section 2 briefly reviews the related literature in coastal shipping mode choice, liner network design, and fleet sizing literature in maritime transportation. In Section 3, the coastal shipping for outbound automotive logistics is described using a case study from the Indian automotive logistics industry while Section 4 presents the proposed research methodology and data analysis. In Section 5, discussions related to the results derived from qualitative and data analyses are presented. Finally, Section 6 summarizes the main conclusions of the research and recommends directions for future research in this area.

2. Literature review

Owing to the pressures of improving transportation efficiency, reducing congestion in the land-based modes and reduction in environmental pollution, governments, and regulatory authorities around the world have been focusing on developing short sea shipping, which includes coastal shipping for sharing the load of both freight and passenger trades. Consequently, academic research in transportation and logistics has also given substantial attention to this mode. The focus has been on diverse areas ranging from policy formulation and evaluation, designing optimal networks and transportation mix, assessing the environmental impact of this mode, etc. In the remaining section, we discuss literature that is relevant to our study.

2.1. Coastal shipping- scope and potential

Paixao and Marlow (2002) discuss the strengths and weaknesses of short sea shipping with an aim to help identify the right strategies. It is pointed out that to maintain the door-to-door transport service after introducing the sea leg, some factors that need to be considered are: the concept of mode interoperability and complementarity of other modes of transport. One of the disadvantages identified is that it is a disconnected mode and requires collaboration with rail and road modes for the pre- and end- carriage. It also needs a network of dedicated terminals and well-located inland terminals. Various country/region specific studies on coastal shipping extend this discussion on the growth of coastal shipping, like Saldhana 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 (2008) 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, etc.

2.2. Multimodal logistics design including coastal shipping

Ayar and Yaman (2012) study a multi-commodity routing problem for an intermodal transportation scenario using ground and marine transportation. Chen et al. (2013) 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. The model determines ports of call, call sequence, ship type and service frequency simultaneously with the objective of minimizing state subsidies for coastal shipping operators under a given carbon emission reduction target for the entire intermodal network. A network-topology method (Temporal–Spatial Expansion) captures differences in traffic assignment between waterway and highway networks. A genetic and Frank–Wolfe hybrid algorithm are used to solve the model. Similarly, in the context of South Korean coastal shipping, Park et al. (2014) present a system dynamics based model to simulate and solve the planning problems related to ship deployment. 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.

The current study also borrows from service network design, fleet sizing and mix, and fleet deployment literature in liner shipping. Design of liner shipping network involves route selection across a given set of ports. Fagerholt (2004) describes a method of apriori generation of feasible routes. A mathematical model selected the best set of routes among all possible routes in a liner shipping network. To develop a new coastal shipping mode, fleet sizing becomes an important criterion. Fagerholt (1999) explains a method to estimate optimal fleet design in ship routing problem, while Pantuso et al. (2014) present a survey of different methods applicable to fleet sizing and mix in maritime transportation. Fagerholt et al. (2009) present a fleet deployment model in liner shipping.

The extant literature on coastal shipping is diverse and on one hand, talks about opportunities and issues in coastal shipping growth and on the other it presents ways to design multimodal logistics systems based on coastal shipping as an alternative mode. 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 by presenting the current policy framework, government and industry initiatives addressing the development of coastal shipping in India and examine the extent of modal shift to coastal shipping within the context of the outbound automotive logistics industry using a mathematical model.

3. Coastal shipping for outbound automotive logistics

Figure 1: Important ports and routes in the Indian coastal shipping

India has a long coastline of 7517 kilometers, which covers a major perimeter of the country. This coastline is served by 12 major and around 187 minor ports (Ministry of Shipping, 2017). Figure 1 demonstrates the coastal boundary of India with some of the important ports and two coastal shipping routes. Coastal shipping is well suited for transportation of bulk cargoes at low cost. Additionally, it offers comparatively better standards in terms of pollution and safety impact of transportation. Shipping is a part of an intermodal transportation chain and is linked to other modes of transportation like railways and trucking. Despite its importance, this mode of transportation has experienced bottlenecks and capacity shortages and could not be used to take up a substantial share of the freight logistics in the country (Directorate General of Shipping, 2017). Impediments to the coastal movement have been cabotage laws restricting foreign-flagged vessels, domestic duties on oil and high tonnage taxes (Morgan Stanley, 2016). As per an estimate, only 6.5% of domestic cargo moves through the coastal route (Ministry of Shipping, 2015). Coastal shipping in India is primarily used for transporting petroleum, oil and lubricants, coal and iron ore, which account for about 85% of the overall coastal movement (Manoj, 2015). In view of these advantages, the central government has implemented policies and schemes to support the development of this sector. The schemes for development are related to providing financial support for related infrastructure development (Press Information Bureau, 2016) and offering tax and other monetary incentives for using the coastal shipping services (Manoj, 2015).

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 witnessed a 32% increase in sales from 2010-11 and stood at 20.5 million units in the 2015-16 financial year. During the same period exports stood at 3.6 million vehicles, with an increase of 24% from 2010-11 (SIAM, 2017). A major part of the outbound distribution of finished vehicles in India is carried out through specially designed trucks with a small percentage dispatched through the railways for long-haul deliveries. Major automotive manufacturing clusters in India have developed in a decentralized manner into three main ones, i.e., the Northern, Southern and Western clusters, with demand rising progressively throughout the country. 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. As per a recent government scheme to promote ro-ro shipping in India, transportation of vehicles through ro-ro vessels shall be eligible for incentives up to INR 300 per two-wheeler vehicle, INR 600 per three-wheeler vehicle, and INR 3,000 for other vehicles (Manoj, 2015).

3.1. Outbound automotive logistics in India

Chandra et al. (2016) describe the outbound logistics practices in the Indian automotive sector. As per this study, major auto-manufacturers in India have an in-house logistics division that manages the outbound logistics. They receive production and demand information from the operations planning department and corporate sales and coordinate with external service providers at various levels to plan, organize and execute the distribution of vehicles. LSPs in India consist of independent transportation and warehousing services providers. The use of a centralized consolidation hub for grouping and regional sorting was not economically viable in the country because of the pre-GST, differential taxation structure owing to the inter-state sales tax levied on every cross-border transfer of goods. For road transportation services, auto-manufacturers use the services of external suppliers offering trucking services for finished vehicles. The trucking industry in India is largely unorganized with a large number of service providers operating with small assets bases. Some trucking companies operate nationally and some at a regional level. An unorganized and fragmented trucking industry leads to a situation where the trucking freight rates vary widely based on a demand-supply mismatch, origin-destination locations, and the respective bargaining power of the transacting firms.

The LSP offering coastal 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. This firm offers integrated end-to-end logistics services right from the production facility to the dealers. Auto-manufacturers share their transportation requirements with the LSP in advance and share all the information related to pick-up quantities and timings. The LSP takes the responsibility of the first mile transfer to the nearest port in Chennai, consolidates cargo at the port stockyard, loads the vehicles onboard a designated Ro-Ro vessel, manages the sea transportation from origin port to subsequent delivery ports in Western part of India all the way to a final port in the state of Gujrat (Kandla as shown in Figure 1, is a port in Gujrat), and finally, the last-mile transportation from the delivery ports to dealers.

3.2. Coastal shipping in India

The Indian coastline can be divided into the east coast and the west coast. The major ports on the west coast are Kandla, Mumbai, JNPT (Jawaharlal Nehru Port Trust), Marmagao, Mangalore, and Cochin, sequentially from North to South. The east coast ports sequentially from South to North are Tuticorin, Chennai, Vishakhapatnam, Paradip, Kolkata, and Haldia (refer to Figure 1). The major ports are the responsibility of the Ministry of Shipping, the Government of India, but are managed by semi-independent port trusts overseen by boards appointed by the ministry. Minor ports are run by regional (States and Union Territories in India) maritime administrations. In 2015-16, minor ports handled 43.5% of the total cargo of 1072 million tonnes (Indian Port Association, 2017). The development of coastal shipping could also lead to further capacity utilization and further development at minor ports. The entire transport system handles a freight of about a thousand billion-tonne kilometer, which is expected to double in the next decade (Behera, 2008). Coastal shipping needs efficient inland connectivity, so ports can be developed for coastal shipping only when proper road and/or rail connectivity is established. While major ports would provide the main infrastructure for handling of the projected coastal traffic in the short term, a sustained effort is required to develop minor ports for this trade.

In 2015 the Indian coastal tonnage comprised a fleet of 854 vessels, accounting for roughly 1.22 million gross tonnage, although this mostly included non-trading vessels, such as tugs and offshore supply vessels (Ministry of Shipping, 2015). There has been very little investment in the coastal shipping sector. As per the data published by the planning commission of India, out of the total gross capital formation of 18.3 trillion INR from 2004-2012 on infrastructure sector, merely 0.34% is reported for the development of ports, while roadways and railways have received about 6% and 2%, respectively (Planning commission, 2014). The investment in shipping was mainly focused on the development of overseas shipping (Sundar & Jaiswal, 2007). Thus, coastal shipping lacks supporting infrastructure like dedicated ports and terminals. This lack of policy measures to promote coastal shipping is another important reason for the low share of coastal shipping in the domestic freight movement.

Cabotage restrictions discourage the growth of coastal shipping since coastal tonnage is not adequate for most trades. There are some other important issues that seem to curtail the development of coastal shipping. Customs procedures at the Indian ports are quite cumbersome. It is difficult to get supportive financing to acquire coastal vessels. High import duties are charged on bunker fuel oils and spares for the coastal vessels. Due to restricted manning requirements for officers and crew on coastal vessels, the industry faces a shortage of personnel and has to incur a high manning cost. The regulatory specifications related to the construction of coastal vessels have been almost as stringent as that for ocean-going vessels, increasing the capital cost of construction. Many experts suggest that since the working conditions in the coastal waters are not that tough, the construction standards for the coastal vessels may be relaxed. Coastal vessels face congestion at major ports. Additionally, there is a lack of cargo handling facilities. Minor ports, although relatively free to accommodate coastal vessels, also lack in cargo handling facilities and are poorly connected to the national road network.

The government has implemented several policies to promote coastal shipping. Table1 lists the government policies implemented to date to facilitate coastal shipping in India.

Policy No.	**Year**	**Policy**	**Intended effect**
1	1997	Indian-flagged coastal ships exempted from filling a bill of coastal goods at load ports and bill of entry at the discharge ports (sections 92,93, and 94 of the customs act, 1962)	Simplification of customs procedure
2	1997	Indian-flagged coastal ships exempted from requiring a written order from a customs officer before leaving a port (section 97 of customs act, 1962)	Simplification of customs procedure
3	1997	Indian-flagged coastal ships exempted from loading and unloading goods from designated places only (section 33 of the customs act 1962)	Simplification of customs procedure
4	1997	Indian-flagged coastal ships exempted from loading and unloading goods under the supervision of customs officer only (section 34 of the customs act 1962)	Simplification of customs procedure
5	1997	Indian-flagged coastal ships exempted from loading and unloading goods on holidays observed by the customs department (section 36 of the customs act 1962)	Simplification of customs procedure
6	1998	Indian-flagged coastal ships exempted from delivery of the advice book on arrival at each port of call to the customs officer (section 95 of the customs act 1962)	Simplification of customs procedure
7	1999	Coastal ships exempted from light duties	Tariff reduction
8	2002	License to foreign-flagged vessels to operate as a coastal vessel for domestic trade for specialized services	Capacity development

9	2004	Tonnage tax introduced for coastal ships registered under Merchant shipping act 1958 as an alternative to regular corporate tax	Tax reduction
10	2013	Manning restrictions for foreign-flagged vessels licensed to serve as coastal vessels": 1/3rd Indian crew for 30-90 days' license and 1/2 Indian crew for more than 90 days' license	Safeguarding Indian sailors
11	2014	Separate norms for construction, survey, certification, and operation of Indian coastal vessels	Simplification and cost reduction in investments and operations
12	2015	Cabotage restrictions have been relaxed to encourage the movement of coastal goods. Vessels like Ro-Ro, Pure Car and Truck Carriers, Pure Car and Truck Carriers, LNG vessels, Over-Dimensional Cargo, or Project Cargo carriers, etc. are covered under the new relaxed policy guidelines for a period of 5 years i.e. up to 1st September 2020	Facilitating capacity development
13	2015	Online issuance of a license to foreign-flagged vessels for operating as coastal vessels	Facilitating capacity development
14	2015	Central sector scheme for providing financial support to major/ non-major ports/ state governments to build infrastructure to promote coastal shipping trade	Capacity development
15	2015	Green channel for clearance of coastal cargo	Simplification of customs procedure
16	2015	Scheme for incentivizing modal shift of cargo	Tariff reduction
17	2015	Dedicated terminals for coastal ships at various major ports	Reduce congestion at ports
18	2015	Relaxed manning scales for engine and deck sides	Reduce cost of operations
19	2015	Allowing shipping companies to charge service tax at an abated rate on freight income and availing CENVAT (central value-added tax) credit on input services	Reduce cost offer lesser freight rates
20	2015	Parity for Indian seafarers employed on Indian-flagged ships vis-à-vis those employed on foreign-flagged ships	Easy availability of crew for manning
21	2015	Reduction in vessel and cargo related charges for coastal ships (60% of that charged for foreign going vessels)	Tariff reduction
22	2016	Delivery of import and export manifests applicable to coastal ships berthing at EXIM (export/import) berths	To avoid EXIM cargo from availing the relaxations offered to coastal domestic cargo

23	2016	Containers carrying goods and non-containerized cargo shall be marked with words ”For coastal carriage only” on all sides. These coastal goods exempted from any examination. The container to be sealed with tamper proof one-time bottle seal and then same can be loaded on the vessel. Random checks by officials possible	Simplification of customs procedure

From the previous discussions, it can be seen that the regulatory framework to support coastal shipping in India has evolved a lot over the last two decades. It is high time the shipping industry takes advantage of this opportunity provided by the government and develop sustainable maritime logistics services for taking a sizeable share of domestic freight trade. The following section discusses challenges faced in the coastal shipping based outbound automotive logistics, rooted on the discussions with the LSP.

3.3. Challenges in coastal automotive distribution

The discussions with the LSP revealed several difficulties in running coastal shipping operations for this trade. 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 the 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. Also, as soon as they finish a delivery, they rush to production facility locations for more business. 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 vessel 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. The coastal shipping of automobiles to the west coast ports, particularly those located in Gujrat, is challenging, because of the high tides. Almost, eight hours of cargo work is lost every day because of this.

On the business side, auto-manufacturers were initially apprehensive about the ro-ro services in terms of higher possibilities of cargo damage through this route, although after several successful trials of the coastal intermodal deliveries the automotive industry has gained confidence in the LSP. However, the coastal route invariably takes more delivery time than the direct truck route from the production facility to the customer locations. Further, auto-manufacturers have existing long-term relationships with many LSPs offering road based logistics solutions, which they may not be ready to jeopardize. In this scenario, selling new alternative logistics solutions may be very difficult. Dealers pay upfront booking amount to the auto-manufacturers and are promised a delivery time for the ordered quantity. It may be difficult to persuade them for a longer delivery time if the coastal shipping route is utilized for the shipment.

Despite the initial support from some of the auto-manufacturers, maintaining the financial feasibility of this business is a challenge. The development of operation of a coastal shipping network calls for large investments. Auto-manufacturers are showing eagerness to use the service but are not ready to commit long-term business. This does not induce enough confidence in the LSP to invest for the long term. Indian ship owners are not eager to invest in ro-ro vessels, so availability of Indian-flagged vessels is currently difficult. Foreign-flagged vessels, after they have been licensed to do coastal shipments in India, can be chartered for a minimum period of 3 months. Although the policy of allowing the foreign-flagged vessel 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 margins charged by the shipping companies. The government policies aimed at simplifying and expediting regulatory procedures in ports for coastal shipping is not fully applicable to foreign-flagged vessels converted to coastal vessels. Delays at ports further add up to the lead time and also increase the uncertainty. This is a matter of concern for the LSP as the auto-manufacturers are eagerly awaiting cargo delivery to the dealers.

Despite facing all of the above challenges, the LSP has reported substantial savings in outbound logistics costs, which has caught the attention of auto-manufacturers. In the initial phase, they are able to attract some business, especially for long-distance cargo. One of the major concerns shared by the LSP 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 have the potential to grow as a strong alternative logistics option. It offers the advantages of lower transportation cost, reduced environmental emissions, and decongestion of existing road and rail infrastructure. The ro-ro shipping would be financially sustainable only at a certain scale of operations. Apart from the scale in terms of cargo availability, several other supporting mechanisms would still be required to develop this system. The following section presents an analysis based on mathematical programming to investigate the economically feasible development of coastal ro-ro intermodal shipping as an alternative to road transportation.

4. Methodology and data analysis

In this study, we develop an optimization model to study the cost viability of intermodal coastal shipping mode of distribution in conjunction with regular mode of distribution via roadways. We develop this model from the point of view of the LSP managing outbound logistics of the auto-manufacturer. We consider a scenario where the LSP is managing the outbound logistics of the entire cargo of the auto-manufacturer. Two modal options are considered: road based mode, directly from the production facility to the dealers using car-carrier trucks, and another option is coastal ro-ro shipping based intermodal delivery. Analysing these competing options jointly helps in comparing the road based mode with coastal shipping based mode. The model would attempt to answer the following question:

under what conditions would coastal shipping be a viable alternative to road based alternative for the entire outbound automotive deliveries of the auto-manufacturer?

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. Nearby ports, connecting the same city area, are considered as one: namely Mumbai and JNPT, and Chennai and Ennore. Figure 1 demonstrates important ports in India and two route options, ROUTE-1 and ROUTE-2. The first one starts at Chennai and stops at Tuticorin, Mumbai, and Kandla before coming back to Chennai. The later starts at Chennai and covers eastern India by serving the ports Paradip and Kolkata, before returning to the origin. The ports have been chosen based on the availability of adequate facilities for handling automobile cargo and hinterland connectivity. Several different route options consisting of the visits to subsets of the chosen ports are generated. All the possible shipping routes originate and end at the port of Chennai.

The auto-manufacturer has a set of customer locations. A customer location is defined as a group of dealers within a city or a district. Two alternative transportation modes are considered for distribution- one considers the direct, production facility-to-dealer using inland trucking, and other using intermodal network consisting of coastal shipping as an intermediate part. We assume a set of ships are available for service, which consists of different types of vessels in terms of capacity and cost characteristics. A ship may or may not be used in the planning horizon. Since this is a viability study aiming at strategic level decision making, a 12 period model, each period consisting of 30 days is considered. In a single period, a ship may serve a certain number of voyages across a trade route by loading vehicles at the first port of each route, which is Chennai. The same vessel discharges cargo at subsequent ports along the same route.

It is assumed that the required first mile deliveries are made as per the requirements of loading at the first port. A customer location may be served by the nearest port, which could be a part of some of the trade routes being served. The objective of the study is to decide on the trade routes to be used, numbers of different vessel types to be selected and the distribution pattern for each customer, while minimizing the total cost of inland transportation and intermodal transportation. Most previous studies of this type consider given freight rates for shipping transportation, but we consider overall costs from the point of view of the LSP.

4.1. Mathematical model formulation

In this section, we present the mathematical model used for analyzing the problem. All notations and symbols used in the model are described in the following subsection followed by the mixed-integer linear programming formulation.

4.1.1. Notations

Indices

k	customer location
v	ship type

t	time period
r	shipping trade route for delivery
i	port

Sets

$\mathcal{K}$	set of all customer locations of the auto-manufacturer
$\mathcal{K}_i$	set of all customer locations served by port i
$\mathcal{V}$	set of available ship types
$\mathcal{R}_v$	set of all shipping routes that can be served by the ship type v
$\mathcal{P}$	set of unloading ports
$\mathcal{P}_r$	set of unloading ports along route r
$\mathcal{T}$	Set of time periods (i.e. months) in the planning horizon, $\{0, 1, 2, 3, ..., \lvert\mathcal{T}\rvert\}$

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 the 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 to the LSP (VCS), while the ship is sailing along with fixed cost of using each port (VCP) along the route, but excludes the variable cost of loading/discharging at the ports.
C_i^{VH}	Variable per unit cost of loading/discharging the automobiles at the port i
C_k^{T}	Direct trucking cost between the production facility and customer location k
C^{OT}	Inland transportation cost between the production facility and the origin port
C_{ik}^{KT}	Inland transportation cost between port i and customer location k
D_{kt}	Estimated demand in number of automobiles at customer location k in time period t
T_{vr}	Number of days to complete a voyage on route r by a ship of type v (starting at the origin port and till it is back to the origin port)
$\bar{Q}_v$	Maximum carrying capacity of ship type v in units of automobiles
$\bar{T}$	Number of days in a single time period
T^{OT}	Truck travel time from the production facility to the origin port
T_k^{KT}	Truck travel time from the production facility to customer location k, directly
T_{vri}^{S}	Shipping time from the origin port to port i with a ship 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 customer location k

Decision variables

f^T_{kt}	Number of automobile units transported through the direct truck delivery mode to customer location k in time period t from the production facility
f^S_{ikt}	Number of automobile units of the last mile delivery made from the port i to customer location k in time period t
u_v	Number of ships of type v used in the planning horizon
y_{vrt}	Number of voyages served by ships of type v on route r in time period t
q^L_{vrt}	Number of automobile units loaded at the origin port of route r in time period t by ship type v
q^U_{ivrt}	Number of automobile units unloaded at port i of route r in time period t by a ship of type v

The variables u_v and y_{vrt} are integer variables, while the rest of the variables are considered continuous due to their considerable size.

4.1.2. 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 a type, v, to be used in the planning horizon, u_v. The ship type v may serve a certain number of voyages of route r in time period t, y_{vrt}. These decision variables represent the liner route design, fleet sizing and fleet deployment part of the strategic problem. The value of y_{vrt} suggests whether a route is selected for service in a time period and also the frequency of voyages served by a particular ship type on this route. The options available for ship types and routes are decided apriori. The fleet deployment along the different selected routes provides the necessary capacity for intermodal shipments of automobiles from the origin port to the different discharge ports.

The other set of related variables determines the exact shipment allocations between the origin and destination nodes in each time periods, across the direct road and coastal shipping based modes. Figure 2 represents the two modal options of coastal and direct truck delivery. The origin is the auto-manufacturer's production facility, and the destination is a customer location, k. Demand faced by a customer location k in time period t, D_{kt} may be served by two options. A part of the total demand is met by delivering f^T_{kt} units of automobiles using the direct truck delivery mode. The remaining demand is catered to by shipping f^S_{ikt} units of automobiles from port i to customer location k. This port belongs to a route being served by a ship deployed for the coastal shipping operation in the given time period t. To cater to the port requirements for making final deliveries as above, a ship v must load q^L_{vrt} units of automobiles from the origin port and discharge q^U_{ivrt} units of automobiles at port i. It must be ensured that demand is always met, ship capacities are not exceeded and the overall transport capacity available in a period is dependent on the ship types deployed. Next, we present the mathematical formulation of the problem.

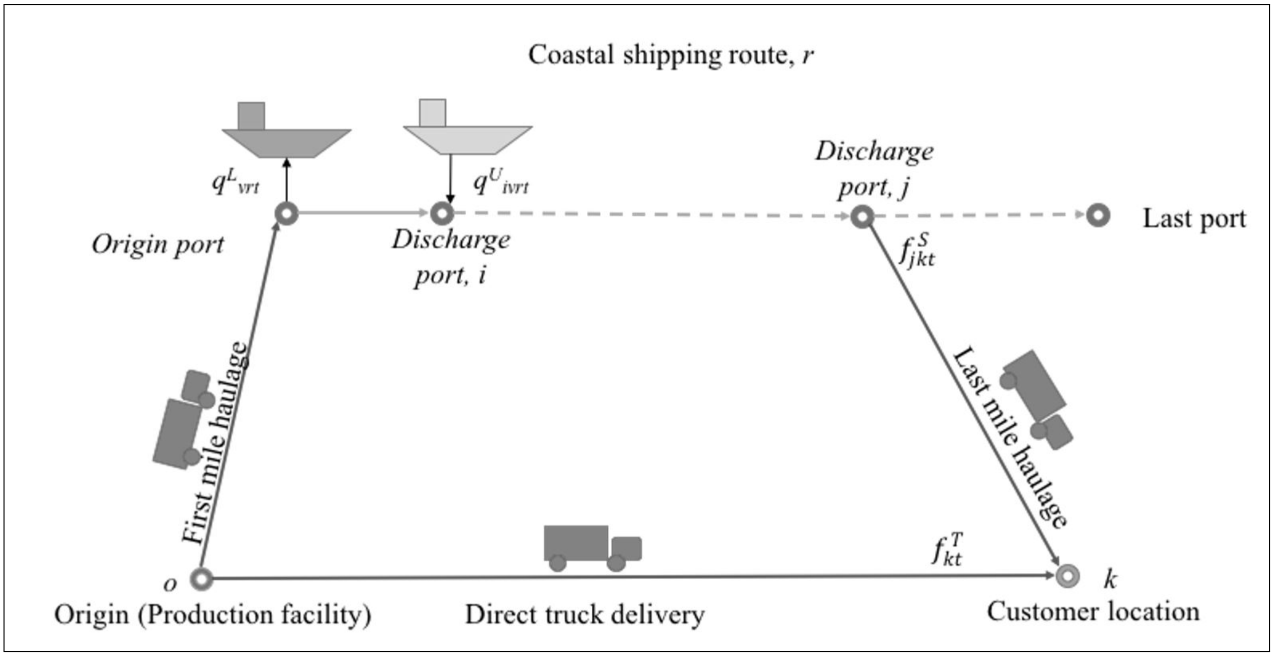

Figure 2: A diagrammatic representation of the multi-modal network

$$\begin{aligned} \textit{minimize} \quad z = \sum_{k\in\mathcal{K}}\sum_{t\in\mathcal{T}} C^T_k f^T_{kt} + \sum_{v\in\mathcal{V}} C^{FS}_v u_v + \sum_{v\in\mathcal{V}}\sum_{r\in\mathcal{R}_v}\sum_{t\in\mathcal{T}} C^{OT} q^L_{vrt} + \sum_{v\in\mathcal{V}}\sum_{r\in\mathcal{R}_v}\sum_{t\in\mathcal{T}} C^S_{vr} y_{vrt} \\ + \sum_{i\in\mathcal{P}}\sum_{k\in\mathcal{K}_i}\sum_{t\in\mathcal{T}} C^{KT}_{ik} f^S_{ikt} + \sum_{v\in\mathcal{V}}\sum_{r\in\mathcal{R}_v}\sum_{i\in\mathcal{P}_r}\sum_{t\in\mathcal{T}} C^{VH}_i q^U_{ivrt} \end{aligned} \tag{1}$$

Subject to

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

$$\sum_{v\in\mathcal{V}}\sum_{r\in\mathcal{R}_v} q^U_{ivrt} - \sum_{k\in\mathcal{K}_i} f^S_{ikt} = 0, \quad \forall i \in \mathcal{P}, t \in \mathcal{T}, \tag{3}$$

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

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

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

$$f^T_{kt} \geq 0, \quad \forall k \in \mathcal{K}, t \in \mathcal{T}, \tag{7}$$

$$q^L_{vrt} \geq 0, \quad \forall v \in \mathcal{V}, r \in \mathcal{R}_v, t \in \mathcal{T}, \tag{8}$$

$$f^S_{ikt} \geq 0, \quad \forall i \in \mathcal{P}, k \in \mathcal{K}_i, t \in \mathcal{T}, \tag{9}$$

$$q^U_{ivrt} \geq 0, \quad \forall v \in \mathcal{V}, r \in \mathcal{R}_v, i \in \mathcal{P}_r, t \in \mathcal{T}, \tag{10}$$

$$u_v \in Z^+, \quad \forall v \in \mathcal{V}, \tag{11}$$

$$y_{vrt} \in Z^+, \quad \forall v \in \mathcal{V}, r \in \mathcal{R}_v, t \in \mathcal{T}, \tag{12}$$

The objective function (1) minimizes the total cost of shipping automobiles from the production facility to all the customer locations in the planning horizon. The first term is the cost of direct truck deliveries made from the origin to all the customer locations. The second term is the fixed cost of chartering vessels in the planning horizon. The third term is the cost of performing first-mile transportation by trucks from the production facility to the origin port for automobiles delivered through the coastal intermodal transportation. The fourth term calculates the total variable cost of operating ships along the selected routes together with the fixed cost of using ports along each served route. The fifth term calculates the total cost of last-mile trucking from delivery ports to respective customer locations for all the automobiles delivered through the coastal intermodal shipping. The last term calculates the total variable cost incurred from the port operations. Constraints (2) ensure that the number of automobiles loaded at the first port of a route in time period t is equal to the sum of numbers discharged at subsequent ports of the same route in the same time period. Constraints (3) ensure that the number of automobiles discharged at port i in the time period t is equal to the number of final distribution made to the nearby customer locations from the same port. Constraints (4) are demand fulfillment conditions at each customer location for each time period. Constraints (5) restrict the total automobiles carried by coastal shipping to the total maritime transportation capacity available. Constraints (6) relate the number of ships of each type to the maximum possible number of voyages feasible for that ship along various routes. Constraints (7) – (10) impose non-negativity conditions on four sets of decision variables. Integrality conditions for the integer decision variables are given in the constraints (11) and (12).

4.1.3. Lead time performance

Lead time of automobile delivery is an important consideration in the study of coastal shipping for automotive logistics. The results of the above mixed-integer linear programming model ((1) - (12)) are used to derive the measures of overall lead time performance of the maritime logistics system. Weighted average lead time of all automobile unit shipments from the production facility to the customer locations are derived.

$$WALT_T = \frac{\sum_{k\in\mathcal{K}} \sum_{t\in\mathcal{T}} D_{kt} T_k^{KT}}{\sum_{k\in\mathcal{K}} \sum_{t\in\mathcal{T}} D_{kt}} \tag{13}$$

Equation (13) gives the weighted average lead time of all the automobile shipments using only the direct trucking delivery option (WALT$_T$).

$$WALT_C = \frac{\sum_{i\in\mathcal{P}} \sum_{k\in\mathcal{K}_i} \sum_{t\in\mathcal{T}} (T^{OT} + \sum_{v\in\mathcal{V}} \sum_{r\in\mathcal{R}_v} y_{vrt} T^S_{vri} + \sum_{v\in\mathcal{V}} \sum_{r\in\mathcal{R}_v} y_{vrt} T^P_{vri} + T^T_{ik}) f^S_{ikt}}{\sum_{i\in\mathcal{P}} \sum_{k\in\mathcal{K}_i} \sum_{t\in\mathcal{T}} f^S_{ikt}} \tag{14}$$

Equation (14) gives the weighted average lead time of all the automobile shipments through coastal intermodal delivery option, $WALT_C$. The values of all the decision variables are derived from the mixed-integer linear programming model results.

4.2. Data estimation

Data were estimated from a real scenario faced by the LSP managing coastal intermodal shipping for the auto-manufacturer. The model requires data related to exact customer locations, distances between origin and different nodes in the logistics network, monthly demand at each customer location, available route options, options for ro-ro ship types, truck freight rates between each origin-destination pair in the road network, all fixed and variable costs associated with hiring and operating ships, and port charges applicable to coastal ro-ro ships.

In India, a car dealer is associated with a single auto-manufacturer. The auto manufacturers website lists the names and addresses of all its dealers located in India. Exact locations of each dealer were tabulated from the published data. Dealers within the same district or city block are identified as one customer location. A total of 261 customer locations were identified for the auto-manufacturer. Online mapping applications (Google Maps, 2017) are used to record the road distance between the origin and each customer location. 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, 2017b; Capitaline, 2017). Data sources on automotive sales in India publish data

Table 1: A small subset of estimated district-wise annual sales data

District	State	Automobile annualsales (units)	Auto-manufacturer to district (km)
A	Bihar	42	1980
B	Uttar Pradesh	433	1997
C	Maharashtra	43	1168
D	Rajasthan	1679	2274

Table 2: Month-wise sales estimate of districts

District	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
A	3	3	3	4	4	4	4	4	3	4	3	3
B	35	35	35	36	41	37	37	36	35	38	35	34
C	3	3	3	4	4	4	4	4	3	4	3	3
D	135	134	135	140	161	143	143	139	136	146	135	132

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 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. Table 2 shows a small portion of the estimated yearly sales of each district and its distance from the auto-manufacturer's plant. Table 3 presents a snapshot of estimated, district-wise sales data of the auto-manufacturer, month wise.

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. All the trucking rates in USD between different pairs of locations were estimated using this model.

$$Freight\ Rate\ (20t\ Full\ Truck\ Load) = 185.69 + 1.46\ \times\ Distance\ (km) \tag{15}$$

All trade route options were considered with Chennai as the origin port. All combinations of ports are considered as route options keeping the geographical sequences into consideration. A total of 2047 route options were generated using a computer code for generating combinations as subsets of all ports.

Ship options were chosen from the currently available ro-ro ships in the international market. We chose a subset of

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

ships types having varied characteristics in terms of capacity, speed, etc. We surveyed technical managers of a large ro-ro shipping company and requested them to provide us a list of vessels of different sizes and other characteristics. Large vessels were considered unsuitable for coastal shipping after discussions with logistics managers involved in coastal shipping of automobiles in India. These specific ships are considered as ship types in this study, assuming that this sample represents the available ship types in the international market. Table 3 present the ship types 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). Port charges in India for ro-ro ships are one of the highest in the world. This would be particularly disadvantageous for an upcoming market, where ro-ro vessels would have to run partially laden in many voyages. For the considered ship types, Table 3 presents the estimates related to ship capacities in terms of CEU (Car Equivalent Units), ship sizes in terms of GRT, average ship speeds in knots, variable cost of running the ships at sea (VCS), variable cost of ships' port stay (VCP), fixed costs of hiring ships (FCS) are based on data estimates shared by the logistics firm. VCS consists of 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. Relationship between the above cost components and the cost terms used in the mathematical model are presented in the section 4.1. The logistics firm time-charters the ro-ro ship from a shipping company. The shipping company is responsible for operating the ship. Thus, the costs considered include the margins charged by the shipping company to the logistics company.

Table 3: Ship 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

4.3. Data analysis

The mathematical model presented in Section 4.1.2 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 one scenario, only direct

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

trucking mode was considered and in the other, both coastal shipping and direct trucking options are considered as modal options. Sensitivity analysis of the second scenario is carried out on various cost parameters. Table 4 presents the two scenarios tested under various configurations. 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 3. Configurations 3 - 22 are derived by individually reducing the various cost components from the original cost estimates, as shown in columns 2-3 of the Table 4.

Table 4: computational results for different configurations

Config.	**Reduction in per unit shipping cost considered under the three categories (%)**			**Comp. time**[4] **(sec)**	**Opt. objective (mill. USD)**	**Reduction from Config. 1 (%)**	**Share of coastal shipping (%)**	**Ship types used (number of ships deployed)**	$WALT_C$ **(days)**
	FCS	VCS	VCP						
1	-	-	-	1	109	0	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	10.0	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)	8.5
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	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	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

[4]Computational time includes model build-up and solution time to optimality.

20	50	0	20	8,468	89	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

4.3.1. Model results

Table 4 presents the computational results for various configurations under the two scenarios. Scenario 1 calculates the total cost of the outbound distribution of cars using direct truck delivery mode. The total cost to deliver 431,272 cars in a year comes out to be USD 109 million, which is equivalent to USD 254 per car on average. The multimodal coastal shipping delivery options are tested in scenario 2, under successive reductions in different cost parameters. 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 ships of type 4 need to be employed for the planning horizon. Under the existing cost structure, large ships are suggested. Successive reductions in the fixed cost of shipping are tested in configurations 3 – 6. A gradual cost reduction of 9.3% – 10% is seen 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%. 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%. 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 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 fixed shipping cost. Sharp reductions in 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 cost, 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 4. An increase in the share of coastal shipping, with the reduction in operating costs, also tends to improve the lead time performance of the coastal shipping. This is because of the spread in port usage in coastal shipping based distribution. Analysis on port usage suggests that for the configurations 2 and 7 to 13, which represent no change in distribution plan and coastal share from the configuration 2, Kolkata and Mundra emerge as the two discharge ports being used, with an equal share in the distribution. Kolkata is a major port in the eastern part of India, with a major portion of the eastern and north eastern parts of India connected to it through roads. Similarly, Mundra is a port in the western state of Gujrat, with major parts of the western and north western part of India connected to it. Thus, the current scenario calls for the usage of farthest ports from the origin to be used as the main discharge ports in the coastal shipping service. Configurations 3, 4 and 14 suggest the addition of one more port, Paradip, on the eastern coast of India. Further reductions in costs as presented in the remaining configurations suggest 5 to 8 discharge ports, spread across the coastline from the Eastern to the Western part of the country, to be used for the coastal distribution. 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. Details of important routes with associated ports, ship types, voyage frequencies, delivery share in coastal shipping mode, are illustrated. The major routes suggested in the coastal shipping mode consist of single discharge ports.

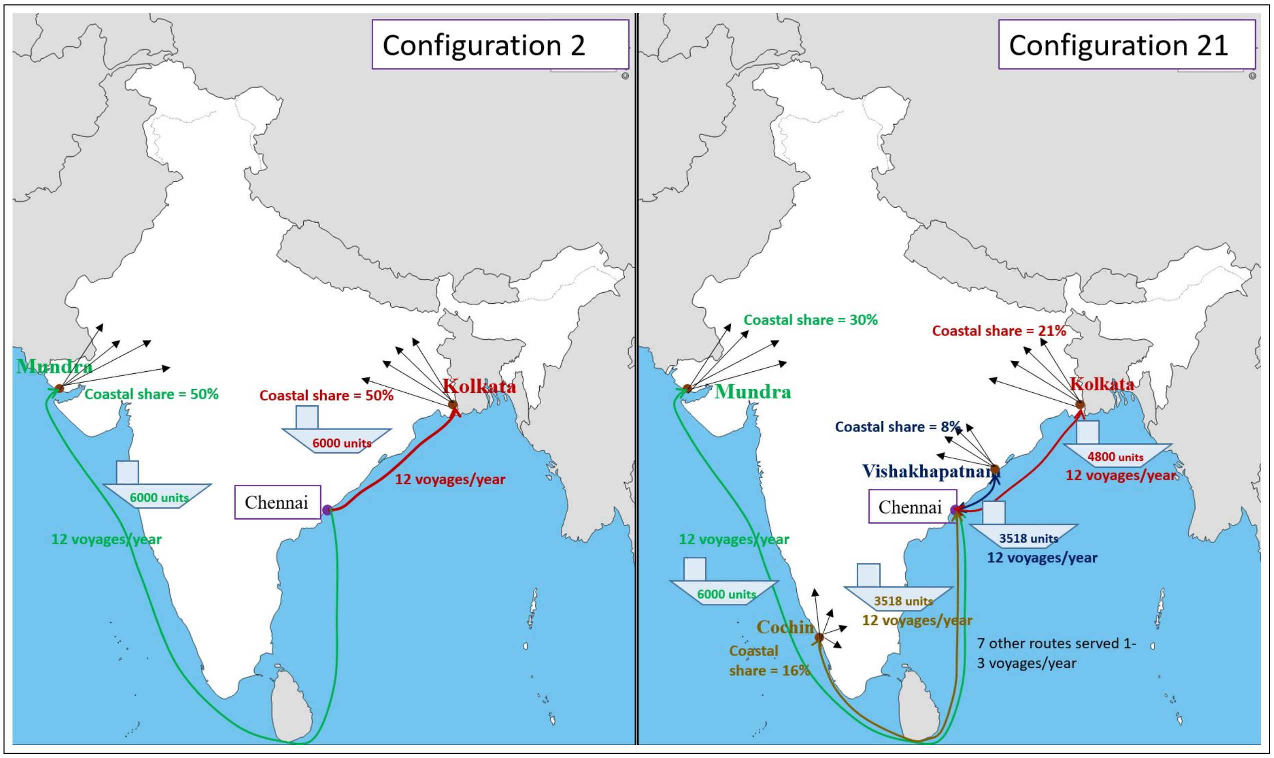

Figure 3: Coastal intermodal network characteristics for two extreme configurations

5. Discussions

After more than two decades of efforts by the government to develop coastal shipping for intermodal shipping of specialized cargo like containers and ro-ro, India has witnessed a promising logistics initiative to ship finished automobiles using the coastal route. The policy analysis and study of the industry practice reveals that despite the currently existing bottlenecks, coastal shipping is a feasible mode of transportation in India. Auto-manufacturers are ready to accept the services as a viable alternative, and a few LSPs have demonstrated their capability to operate this mode of transportation. The most favorable policy of allowing foreign-flagged vessels for specialized cargo to serve Indian coast along with other monetary benefits have enabled this logistics initiative. 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 vessels, the absence of Indian tonnage in ro-ro, and infrastructural and procedural sustainability for scaling up the operations. Some of these problems need investments in terms of infrastructure development; like building dedicated facilities for handling ro-ro vessels to take care of congestion and high tides and development of Indian tonnage to enable smoothening of regulatory procedures at the ports and maintain flexibility of operations. With the growth in scale of operations, problems related to the availability of automobiles and associated services, like trucking and warehousing, will tend to subside as clients and partners will gain confidence in supporting this mode of delivery. The concern regarding higher delivery times can be offset by a high reduction in logistics cost from coastal shipping mode and reduction in environmental impact on modal shift. A growth in scale would also prompt the Indian ship-owners to buy ro-ro vessels and the port authorities to invest in additional infrastructure and simplifying operating and regulatory mechanisms. The next big question is how much cost reduction can be expected from the large-scale operation and to what extent this can be done.

The mathematical programming based analysis on outbound automotive delivery operations of a large auto-manufacturer in India through an active LSP presents alternative configurations and cost estimates for each. The results for configuration 2, corresponding to the current operations, suggest 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. The situation does not seem to improve much with reductions in individual costs components in terms of port charges and variable shipping costs, although a major reduction in fixed shipping costs could improve the share of coastal shipping. The current operations charter foreign-flagged ships from shipping companies on a short-term contract. These vessels need to be converted to Indian coastal ships by following certain regulatory requirements, like replacing at least half the crew with Indian nationals. A reduction in this cost component 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 charged seem to have a major impact. Port charges can be reduced by designing suitable tariff schemes for ro-ro vessels. Overall, the most important factors to enable large-scale operations are a high degree of support from clients in terms of business availability complemented by infrastructural and regulatory support from the relevant authorities. Lead time performance analysis suggests that the usage of coastal shipping mode would entail longer lead time for automobile delivery. So, an additional challenge is to accommodate the additional delays introduced by the alternative mode of delivery. A suggestion to improve delivery lead time performance is to operate storage areas at the discharge port terminals. Auto-manufacturers can maintain adequate inventory of automobiles to cater to the customer demand in the associated locations.

6. Conclusions

This study aims at analyzing the viability of coastal shipping as an alternative logistics option for the outbound logistics of finished automobiles. We have presented the case of an LSP managing the distribution of an important auto-manufacturer in India. The current state of the regulatory framework is presented along with various policy initiatives implemented by the government to enable coastal shipping, especially in reference to ro-ro ship operations. The challenges faced by the LSP in managing the operations are presented. Mathematical programming based analysis on estimated industry data suggests the potential cost reduction along with the optimal logistics system design and a mechanism to sustain large-scale operations.

The results and discussions show that the current infrastructural and regulatory framework is good enough to start and gradually scale up coastal shipping based intermodal distribution of finished automobiles. Almost two-thirds of automobile delivery can be shifted to the coastal shipping based logistics mode with potentially attractive cost reductions. The modal shift would also ensure a reduction in road congestion and other social costs associated with land-based delivery modes. High degree of support is required from the clients and other partners to scale up the coastal shipping operations in India. The data analysis also presents an optimal maritime logistic design in terms of route selections, vessel selection and deployment, and allocation of automobiles across various regions from each serving port. The rise in business will prompt all the stakeholders to participate even further by developing additional services and supporting mechanisms. Once the operations reach a certain scale, other initiatives like developing minor ports for handing coastal cargo can be implemented for further development.

Future work can consider inventory considerations at various locations along with transportation decisions to estimate storage terminal requirements at various locations.

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