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The potential of Vizhinjam Port as a regional hub: a network analysis : a feasibility analysis from a network perspective

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THE POTENTIAL OF VIZHINJAM PORT AS A REGIONAL HUB –A NETWORK ANALYSIS

A feasibility analysis from a Network perspective

By

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DECLARATION

I certify that all the material in this dissertation that is not my own work has ben identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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ABSTRACT

Title of Dissertation: The potential of Vizhinjam Port as Regional Hub: A Network Analysis

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This paper explores and analyzes the south Asian maritime network to assess the potential of the Vizhinjam transshipment port in India from a network perspective. Port research has been going through a transitory phase as research topics have moved away from purely geographical and operation to an increasingly interdisciplinary approach. The spatial arrangement of port and port networks have risen to prominence for researchers in the last decade. Although European and East-Asian networks have been extensively discussed, research on the South Asian network structure remain scarce. This study fills the gap by examining the South Asian port network by using the social network analysis (SNA) approach. The weekly liner service schedule of all the members in the three major alliance operating in the South Asian, Middle Eastern and Indian Ocean region was collated and investigated using SNA principles on the Gephi open-source software.

On the whole, the south Asian network mimics the global network. The network analysis from a graph theoretical approach posits the scale-free nature of the system and the presence of clusters highlight the small-world characteristics of the network. Furthermore, the Indian port sector was studied, its performance and the current policy inputs discussed. Privatization can be seen to have improved performance owing to more competitiveness due to financial freedom in a dynamic liner market. A feasibility study using sensitivity analysis was also performed considering the estimated capacity of the Vizhinjam transshipment port. Multiple permutation of port linkages based on berth capacity were used to assess the optimum outcome. The analysis highlights the feasibility of the port on both the neutral and positive stance owing to its spatial and physical characteristic as seen by the change in the network structure upon Vizhinjam's introduction in the system. A small-world approach, where by connection to central ports was seen viable but a feeder line bundling configuration along the Indian ocean and Indian east-west coast region was found to be the optimal solution due to its proximity to major routes and deep draft. The conclusion discusses the holistic view of the south Asian network and the benefits of privatization and policy changes on Indian ports, especially Vizhinjam.

Key Words: Network Analysis, Vizhinjam Port, Feasibility Study, South Asian port network

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LIST OF ABBREVIATION

APSEZ	Adani Ports and Special Economic Zone Limited
BOT	Build-Operate-Transfer
CMA-CGM	Compagnie Maritime d'Affrètement - Compagnie Générale Maritime
COSCO	China Ocean Shipping Compnay
CSIL	Center for Industrial Studies
DBFOT	Design-Build-Finance-Operate-transfer
DP	Dubai Port
FAL	French Asia Line
FDI	Foreign Direct Investment
GAIL	Gas Authority of India
GoI	Government of India
GSC	Global Supply Chain
ICD	Inland Container Depot
ICTT	International Container Transhipment Terminal
JNPT	Jawaharlal Nehru Port Trust
MSC	Mediterranean Shipping Company
NMDP	National Maritime Develpoment Program
ONGC	Oil and Natural Gas Corporation Limited
PPP	Public-Private Partnership
PTP	Pelabuhan Tanjung Pelepas
SEZ	Special Economic Zone
SNA	Social Network Analysis
SWOT	Strength Weakness Opportunities Threats
TEU	Twenty-Foot Equivalent Unite
UASC	United Arab Shipping Company
ULCV	Ultra Large Container Vessel
UNCTAD	United Nations Conference on Trade and Development
UNESCO	United Nations Educational, Scientific and Cultural Organization
VISL	Vizhinjam International Seaport Limited

Chapter One - Introduction

1.1 Background

The outbreak of globalization, began centuries ago. Colonization and discovery voyages supplemented this process. Globalization as seen today was instigated particularly by the invention of containers. But unlike the trade imbalance perspective which explorers voyaged for, colonial states looked to capitalize on the low cost of production perspective something which has been further harnessed by the current global economy. The spatial separation of production from the consumption with added services to the overall supply chain function at cheaper locations owing to containerization, has led to the evolution of a complex maritime based logistical system and the emergence of ports as a crucial element in the form of a gateway for trade. The continual growth in world trade has not only transformed shipping but also ports. The increasing competition to meet the global market demands has intensified inter-port competition, changing the function of ports and accelerating the evolution process. Evolution ports to hubs of trade, has developed an intricate system intervened with accessibility and centrality. These hubs are characterized with strong links between cities with long standing maritime infrastructure supplement by a system of railways and canals. There is also an emergence of economic zones around major ports highlighting a shift from colonial to a modern economy-based change.

Ports in the last couple of decades have been subject to increasing pressure from its customers, shipping lines and shippers due to the tertiary nature of their demand. Being capital intensive projects, ports to remain sustainable both economically and environmentally, there is a need to enhance performance, service quality and network position (Ducruet, 2013). The enhancement of these activities are a subject that attracts interest for not only researchers or students but also economists, policy makers, governments, engineers to name a few. But it seen that each step or advancement in transportation and logistics led to the downfall of intermediate trade location as intermodalism and technological advancements (like megaships) render them redundant. It increases the role of centrality of bigger ports or their accessibility in an era of mega ships. The role of ports has also been redefined as a result of these logistical integration, expansion and evolution of more complex distribution structures (Lee, Song, Ducruet, 2008). The shift of dominance of eastern ports like Singapore, Hong Kong, as compared to the traditional ports like Rotterdam, London, New York was a result of globalization aided by containerization and a changed supply chain structures. These ports also highlight the symbiotic relationship of ports with urban development and economic prowess. The added complexities of today's global supply chain in conjunction with economic inequality has led to shipping via ports becoming a crucial building block in development of many city and countries (Dwarkesh & Salim, 2015). This evolution of ports from a traditional centre of transport to a dynamic centre of commerce and growth has been altered by globalization. The last decade has seen a further shift of ports from metropolis to suburban areas (like Shenzhen, Ningbo, JNPT, Mundra) as a result of differential port and city planning, in line with Barkes (1986) port decentralization concept in his five-phase model.

1.2 Problem Identification

Trade and economy complement each other. The transportation revolution as discussed by Lee, Song and Ducruet highlighted the contribution of containerization and intermodalism to economic changes in the past (2008). Rich dividends earned from investments on port infrastructure by nations like Singapore, Belgium in the past and China, Vietnam, Malaysia, Indonesia recently supplement this argument. Ports, in an increasingly competitive global market, have become the catalyst of promoting economic activities (Clarke, Dollar & Micco, 2004; Weiss, 1990; Ng, Yang, Cahoo & Lee, 2016 et al). With a long coastline, close proximity to the the trade routes presents an abundance of opportunities for the Indian sub-continent, which has so far failed to capitalize it well as compared to some of its counterparts like China and Srilanka.

With economic relevance of ports increasing, ports by functioning as nodal point attract logistical (like in case of Singapore) and industrial (like east coast China, Vietnam, Thailand) activities creating a large number of jobs (Dwarkish & Salim, 2015). But a ports' significance in the shipping network is dependent on various micro and macro economic factors. This dissertation examines the network structure of the Asian, Middle-Eastern and East-African (Indian ocean region) port network with respect to the Vizhinjam port in the Indian Sub-continent. The Vizhinjam International Seaport is located at the southern tip of Kerala, India. This analysis aims to assess the viability of the multimillion-dollar project in the current logistical ecosystem. We therefore aim to focus on investigating liner trade routes using vessels schedules to assess the project feasibility from a network perspective in conjunction traditional port efficiency and hinterland perspective which would be further discussed in the following section. The study would thus compare the connectivity of all the competitive ports by analysing centrality measure and evaluating the current performance standard, of ports and local logistic system, and policies to evaluate the system holistically.

1.3 Research Objective

The purpose of the study is to understand the relationships between the ports by identifying the structure of the system of ports in the south Asian region (we would include the middle-east and Indian ocean regions as well). Consequently, analysing these infrastructural characteristics to evaluate links in the network configuration and to perform sensitivity analysis according to the estimated operational capacity of Vizhijam to lure traffic away from Colombo, the immediate competitor in terms of ability to handle vessel capacity exceeding 12,000 TEUs and more importantly trans-shipment cargo. In the last decade, considerable research has been conducted on the shipping network on a comparative as well as feasibility basis. Despite a huge bank of data and analytical research, focusing on the global and regional patterns in containerized shipping, fairly small pool of research focuses on the Indian peninsula which is set to become one of the largest economies and consumer base in the future (Panigarh & Pradhan, 2012). This dissertation apart from adding to the current literature aims to add a new perspective for port infrastructure developers and government alike to understand shipping liner demands from a network perspective in inter-port relationships with respect to port competition and complementarity, especially when developing transhipping ports. The research for the dissertation would aim to achieve the following objectives:

- Understanding the current liner network in South Asia through network analysis and evaluate the significance of the neighbouring competitive ports namely, Colombo, Kochi, Mundra and Mumbai-JNPT, from a network centrality and closeness perspective.

- Understanding the correlation between draft and traffic characteristics to their network characteristics via regression analysis of port performance parameters with centrality coefficients as dependent factors.

- Estimating Vizhinjam ports' expected centrality based on the parameters of the port, currently under-construction highlighting the market potential of the project.

- Reviewing micro and macro economic factors influence port operations and competitiveness.

1.4 Research Methodology

With the feasibility of a port depending on both sea-side and land-side factors, the dissertation aims to dwell into the sea-side factors like liner network structure, port systems and port centrality. Research on the network structure, which still remains scarce is the cornerstone of this project. To understand the shipping network, we would investigate the connectivity of the case ports from the perspective of social network analysis(SNA), a branch of sociology which studies collection of individuals and the linkages among them. The linkages in our research would be the connection between various ports via container liner routes. For modelling networks, SNA uses graph theory, algebra and statistics (Wasserman & Faust, 1999). Hence we would develop a network model on graph theory and analyse various features of this network using algebra and statistics procured from the port of calls schedule of liner under the new alliances. By relating various actors (in this case, ports) into networks we can define competition, their complementarity and more importantly analyse the network structure and its behaviour. Under this perspective, the elemental factor that determine the success of a port would be its strategic location in the network. The dependencies among the ports can be measured with structural variables like centrality measures, which hypothesize that port do not function independently but rather influence each other. The computation for the same would be done using the software called - Gephi, a network analysis software which has been previously used for mapping networks in social context like Facebook and Twitter.

1.5 Dissertation Structure

We organize the remainder of this dissertation into the 6 chapters. Chapter 2 would provide a literature review on containerization and development of Indian ports. The pedagogic flow of the chapter begins from historical background of port before dwelling into container shipping networks, port hierarchy and selection criteria. Consequently, we introduce the scope of the Indian port in the south Asian port system. This would be followed by discussing the port performance and the current logistical ecosystems. We shall also discuss the current public private partnerships (PPP) in India and their performance as Vizhinjam is a PPP project. In chapter 3, we introduce the various ports to be considered under the study and analyse the Vizhinjam International Seaport Limited Project. We would further discuss network principles describing the mechanism of network analysis. Chapter 4 would explain the evolution of SNA in geographical theory and methodology used to apply social network analysis as a tool, together with basic concepts of networks terminology, structural and locational properties. Chapter 5 would showcase the application of SNA on the selected ports. Data collection and preparation for using in Gephi would be discussed before dwelling into the the structure around the Indian sub-continent, network analysis and some rudimentary causes shall be discussed. Following network analysis, we shall present the result of the sensitivity analysis on Vizhinjam before dwelling into feasibility analysis. The Section 6 would posit the challenges to fulfil the potential of Vizhinjam Transhipment terminal and discuss the logistical and governance challenges of the port development project. The concluding section would discuss the research outcomes, recommendations and scope for further research in network analysis and port development assessments.

Chapter Two - Ports as cornerstone of economic growth

2.1 Historical Background

The Indian maritime history dates back to the 3rd millennium BCE when the Mesopotamians begin trade with the Harappan civilization via sea routes marking the beginning of the evolution of shipping. Indus-port city of Lothal in present day Gujarat, India, proves the prominence of sea-trade in the Indian sub-continent (UNESCO,2017). The sheltered coastal sea routes proved a safer option over land trade for maritime trade to develop in the Babylon-Mesopotamia-Harappan region. The commodity and vessel trade with Swahilis late in the first millennium CE, discussed by Pollard & kinyera also highlights the naval presence of Indians (Pollard & Kinyera, 2017). Over the centuries, the evolution of sea trade moved westward, as succinctly pointed out by Stopford in his westline analogy (2009).

The rise of Greek shipping in the Mediterranean followed by roman empire's widespread establishment of trade networks connected Europe to Asia (Stopford,2009). The emergence of Venice and the Hansetic sea trade routes in the 1st millennium CE was a result of increased prosperity of Europe. Empires became richer by trade and stronger by conquest. Though the Chinese were said to be technically more advance, the 15th century ban on ship construction paved the way for maritime dominance to European explorers which would dominate shipping for the next 5 centuries. The exploration of Portuguese and Spanish explorers was the cornerstone of evolution of trade and evolution of port cities as a result of new emerging markets. The emergence of London, Antwerp, Hamburg epitomizes the evolution of ports as trade centres based on exploratory or colonial voyages in America and Asia (Stopford, 2009). Colonized states too prospered. Colonial Port cities like Hong-Kong Bombay, Calcutta, Cochin all developed into major port cities most of which have been quaintly renamed to Mumbai, Kolkata and Kochi respectively in the post-independence era. Technology was another major factor which led to evolution of ports. The unitization of cargo and invention of telegraph led to a series of changes. With better knowledge of cargo demand, and advent of steamship let to reduce warehousing and increase speed of cargo movement (Alderton,1999).

Containerization paved way for Asian ports like Singapore, Kobe, Hong Kong to rise to prominence. Globalisation supplemented by information technology fastened the process, with Asian nations becoming major producers of commodities backed by cheap labour and innocuous labour policies. The advent of megaships with increased draft and intermodalism lead to a new wave of changes. Physical properties of ships along with spatial characteristic of port started taking precedence over functionality as ports like Gioia Tauro, Algeciras, Dubai with very little transit cargo become major transhipment hubs owing to their deep drafts and value-added services (Alderton, 1999). Though there have been studies on evolution of ports, which would be discussed later, changes like containerization, evolution of megaships and the policies by government to adapt to these changes in the dynamic maritime ecosystem have been at the heart of port development.

2.2 Containerization

The shipping industry has been transformed by the expansion of trade, integration of different modes of transport and technological advancement. Containerization, for one has been herald as the lynchpin of globalization. But in the grand scheme of things, the adaption of containers and the assimilation of intermodal transport infrastructure in the years after Malcom Mclean envisioned this pioneering concept opened the true potential of containers. Add to this the production of components and goods across the world, especially in the developing economics as pointed out by Gereffi led to the establishment of global supply chains(GSCs) (1996). Transportation in a global supply chain put shipping in the forefront of the global economic system. It was a vector for growth in production and distribution, facilitating a shift from a push to pull logistics (Rodrigue and Notteboom, 2008). Acting as a bridge between different geographical and economical regions the maritime sector became the proponent of growth and economic change (Ng and Wilmsmeier, 2012; Rodrigue and Notteboom, 2009; Lee, Song & Ducruet, 2008; Notteboom & Winkelsmans, 2010 et al). The transport revolution subsequently changed the roles of seaports (hereafter referred as ports) from an interface between sea and land to an integrated element of the global supply chain as a consequence of intermodalism and logistic integration (Robinson, 2002). The evolution of containers brought about not only sea-based changes like ship design, liner routes along with economic changes but also significantly affected port infrastructure and operational practises. This phase of transformation of the maritime sector witnessed a significant increase in the research works particularly in operation, planning, governance and most recently sustainability in both shipping and ports sector (Lau, Ng, Fu & Li, 2013; Ducruet & Ng, 2014).

It seemed that the tendency for ship operators to develop maritime logistics and supply chains during the 1990s had raised the popularity of general transport and logistics journals, especially the logistical ones (Lau et al, 2013). Container shipping is closely linked to the port network and vice-versa and play a crucial role in port development owing to the disintegration of production and cross border integration of world trade in the last few decades. Out of the 202 authors who published container shipping papers in 1967-2012, only 28 did not come from institutions based in East Asia, Europe and North America – among them four from Africa, seven from the Middle East, 14 from Oceania and three from South America (Lau et al, 2013).

This highlights lack of container shipping research by Indian institutes even though it's one of the largest economy boasting a more than 7,000 km coastline (Kumar, Pathak, Pednekar, Raju, & Gowthaman, 2006).

2.3 Ports

Port studies have been predominantly centred around geographic papers. Pioneers like Rimmer, Hayuth, Taaffe et al envisaged port evolution models based on growth and development of corridors which had a deeply amalgamated geographical ideology. The early studies on ports were specific to geographic importance (Like Hoyle 1967, 1968; Taaffe 1963, Fleming & Hayuth, 1994) but as shipping evolved, the focus also moved to an array of topics which were based on surveys and discussions, based on an area of choice to specific interconnected issues like economics, port city relations and ports as gateways (Bird, 1980; Hoyle, 1989; Slack, 1989) apart from the traditional approaches on port growth and importance. The emergences of the 'Asian tigers' saw a shift to research on Asian ports. The rise of competition has led to a more applied and interdisciplinary approach to research. The feasibility assessment of mega-containers ship by Cullinane and Khanna (1999) has fostered a paradigm shift witnessed by the rise of transhipment hubs. With every port striving to become a hub, an intuitive question arises - is it necessary? To be able to answer this, a more structural research on maritime networks with nodes and port links not only on global but also regional level is necessary. Containerization has significantly changed port operation models and competition amongst seaports (Cullinane & Song, 2006). A port's management solely based on terminal infrastructure does not attract clients, and port operators have to make major decision on hinterland development to reduce overall transport and logistic costs to ensure sustained growth (Notteboom & Winkelmans, 2010; Oliver & Slack, 2006). From a port development perspective also, strong international connections and analysis of both sea and land based factors is essential to ensure feasibility of a port development project.

2.4 Evolution of Container Ports

The constantly evolving network of ports today call for an increased competition, where ports try to, as suggested by Notteboom and Rodrigue, focus on inland terminals and multimodal networks to preserve their attractiveness and to fully exploit potential of economies of scale against their rival ports (2005). Port operators today need to compare their port with distant ports on various key performance indicators to identify best practices for the purpose of learning and implementing efficient practises. The 1990s saw the emergence of transhipment hubs, which have been well documented. A lot of research have been performed on the evolution of megaports in an era of mega -containerships (Robinson, 2002; Ng, 2006; Baird, 2007). Frémont and Ducruet discussed the emergence of transhipment and regional port development and competitiveness (2005). With the examples of Busan, they highlighted the importance of physical, economical and bureaucratic function of ports and the need for port to adapt to the constantly changing maritime demand. Ports have become a key component of the logistical chain and therefore their operation and development are directly affected by economic variables. The direct correlation with quantifiable factors like network and spatial characteristics, operational services variables as well as qualitative factors like policy and governance affect ports' growth rate as pointed out by Sanchez et al (2003). The recent trend of asymmetrical growth of ports and cities has further declined growth rates of ports as scope for expansions is reduced(Lee, Ducruet & Song, 2003). Sanchez et al also highlighted the reduction of cost and improvement in efficiency amongst other factors that mark the success of a port and its growth in the future. The advent of intermodalism and megaships largely affected the economics of international trade, with hub port rendering smaller ports redundant with cargo being moved to hub ports via inland transport corridors or feeder systems to large ports accessible by large ships to capitalizing on the economies of scale.

Container ports today can be divided into three categories: hub port, trunk port and feeder port, and the main criterion needed to be called a hub port is not throughput cargo rate but transhipment cargo rate (Huang, 2008 as cited in Nam & Song, 2011). A more subjective definition in terms of ship-to-ship transfer, the hub port is conceived as a pure transhipment port with the sole purpose of transfer goods from one ship to another. Under this perspective, the elemental function of the port is to reduce cargo handling time during ship transfer and all other logistical infrastructure like warehousing, packaging et al are vital but secondary or less important. This transfer efficiency is based on three intra-port aspects which are: berth handling, yard storage and intra-terminal transport and the overlapping network of the port to ensure efficient transhipment. So in a perfect transhipment hub, mother and feeder ship should be capable of docking fairly close to each other to minimize cargo handling time. Paradoxically, however, the type of development that has taken place in some ports has led to the opposite results: terminals have been built at considerable distance from one another because of the lack of available space and increased application of hub and spoke system by liner companies (Foschi,2003).

Another fundamental factor that determine the success of port (also as a hub to some extent) is strategic location while other factors like large capacity of port area, port facility's capabilities and operation efficiency also affect port network and growth. Government's role in policies, laws, economic zone development also plays a crucial role (Nam & Song, 2011). The growing share of containerized cargo tonnage is a strong indicator of the need of increased integration of Indian ports, as ports are internationally considered the centre of multimodal transport. The preposition of this study is in line with the extensive research of Nam & Song (2011), which proposes that, "hub ports (in particular, container ports) should be examined with not only their container throughputs in terms of Twenty-Foot Equivalent Units (TEU) but also their connections with shipping lines in the inter- and intra-region." So the viability study of Vizhinjam port would have to focus on these qualitative and quantitative factors.

One must also understand the role of the ports as junction between sea transport and land transport which can be viewed from two perspectives – The user's perspective and the operator's perspective. From the stand point of users of the ports - shipping liners, forwarders and shippers, the attractiveness of a port, as per the research by Yuen, Zhang & Cheung on East Asian Port competitiveness highlight the location and costs of port, custom and regulations, services, cargo handling facility and hinterland as the major decision making factors (2012). The effect of hinterland conditions on the supply chain system to smoothen the logistical needs of the users is therefore important aspect for port operators to consider as the attractiveness of a port is dictated by the weakest link in this chain. This is justified by the fact that, port of Dubai, Colombo, Tenjung Pelepas and Port Klang in Malaysia are better positioned for trade than any of the Indian ports. The low connectivity and delay in cargo handling deterring shippers to move to other ports in the continent (World Bank, 2013).

Port governance has also changed. The last few decades have witnessed a shift in port management from government to private due to restrictive labour practices and centralized government structure which was slow to react in market fluctuation and most importantly to reduce risk by undertaking joint ventures (Port reform Toolkit, 2007). This led to changes in administration structure of ports, which can be broadly divided into 4 models, where operational responsibilities are taken up by either port authority or outsourced to a private firm or a partnership. The scenario in port management today involves, the public sector acting as planner, facilitator and regulator while ensuring access to hinterland properties, whereas the private sector acts as service provider, operator, and sometimes also as developer together with public sector (Brooks, 2004).

Type	Infrastructure	Superstructure	Port labor	Other functions
Public service port	Public	Public	Public	Majority public
Tool port	Public	Public	Private	Public/private
Landlord port	Public	Private	Private	Public/private
Private service port	Private	Private	Private	Majority public

Figure 1 Basic Port Management Models

Source: World Bank - Port Reform Toolkit 2007

2.5 Correlation of port and economy

Port are the harbingers of change, they have a positive influence on development of surrounding areas (Ferrari & Musso, 2011). The medieval ports were the centres of trade whilst industrialization saw the colonial era ports become the epicentre of economic activities with road and rail networks focusing on moving goods to port. They served as a catalyst to change. As port hinterlands evolved into special economic zone, port moved from an old venetian markets places to industrial zones like in Shenzhen (Wang & Ng, 2011). An historical analysis of major cities in the world would highlight the correlation of ports and shipping activities to economic growth of surrounding areas. Ports have evolved differently in different regions in the world; while the western ports followed Hoyle's port city model, Asian ports have followed a consolidated model posited by Lee, Song & Ducruet (2008). But the effect of port on regional and national economy in both the cases can not be undermined. A Port being the dense intersections connecting hinterland to foreland, play a crucial role economic growth and competitiveness of a country (Dwarkish & Salim, 2015). Port efficiency, which would be discussed in a later section, affects transportation cost and in turn the growth rate (Sanchez et al, 2003).

Ports are more than a sea-land interface, it's a function, a set of activities that provides impetus for four types of industries. Firstly, the port-specific industries like stevedoring, port services (like bunkering). Secondly, port-related activities that include firms involving in shipping activities like import-export firms, provision or store suppliers and lastly port-induced activities like manufacturing industry and other industry that aid maritime trade like banks, legal firms, brokers and commodities trading firms (Yochum & Agarwal,1988, 1987). Ports also help directly or indirectly generate employment. Good example is the Port of Hamburg. The port of Hamburg more than 150,000 jobs in the Hamburg and Hanseatic city region supporting more than quarter of a million people and generating a gross domestic product of 12.6 Billion euros in 2010 (Dwarkish & Salim, 2015).

The pioneering social network analysis by Zhao, Wall and Stavropoulos to understand the foreign direct investment (FDI) network characteristics of port cities and non-port cities supplements the above arguments. The result of the study of top 10 FDI destinations showed port cities attracted a high degree of FDI compared to non-port city (2017). It is also worth noting London and New York where previously port cities which developed on Hoyle's port city model and are in the hinterland of major ports (Felixstowe, Newark respectively). Though major investments were centred around megaports like Singapore and Hong Kong, the study also highlighted the ability of smaller ports (Mumbai, Dubai, Los Angeles) in the port network being positioned higher in the FDI network as compared to some other larger ports, especially Asian port cities (Zhao, Wall & Stavropoulos, 2017). This shows the significant influence of port and hinterland development on the economic growth and prosperity of port-cities. Furthermore, as Wilmsmeier and Sanchez (2010) pointed out, increased frequency of vessel calls provides incentives to invest as result of reduced transportation costs. This could be analyzed by studying the position of port, (in our case Vizhinjam) in the port network to understand its connectivity further helping the authorities and governments in the grand scheme of things.

2.6 Introduction to maritime Networks

Half a century ago, the French geographer Perpillou suggested that ports and maritime transport form a constellation highlighting a perspective of coexisting substructures and systems (1959). No further attempts were made to dwell into the subject. The application of network theories on ports was set out by the induction of cluster theory and interconnection of industrial clusters envisaged by Porter and containerization leading to formation of shipping service networks (1998). The globalized economy marked by complex supply chains led to a lot of discussion on spatial glocalization and an ever growing liner network. The concept of port systems were seminal works by Taaffe, Ducruet and Notteboom. This in turn led to network theories as initially discussed by Robinson (1976), Hayuth(1981), Fleming and Hayuth (1994), Slack and Wang(2002) et al as branch of spatial changes in port infrastructure , being further analysed by contemporary geographers like Ducruet, Notteboom and Ng. Notteboom and Ducruet evaluated the liner shipping route to develop the first network structure of ports using graph theory (2012). They also pointed out the influence of shipping network and port choices on the container throughput of the port as port connectivity is likely to influence the number of port of calls and thereby its performance as a whole as well (2012). The tendency to deploy larger ships and reduction of port of calls are steps to reap the benefits of economy of scale in today's competitive market as posited by Kowalczyk (2012). Network analysis with significant focus on physical and operational feature of ports is therefore essential to access the feasibility. The increasing focus on transhipment cargo and the reduced number of calls as highlighted by Dwarkesh and Salim puts a push effect on ports (2015). Global hubs and maritime transport corridors, manifested by high capacity liner services with the advent of megaships, can be located at close spatial distance to underdeveloped and peripheral nodes (Wilmsmeier & Sanchez, 2012).

In a competitive market from the user perspective, ports have become an integral part of shipping company strategy. Their operational as well as geographical properties are crucial factors in the liner network planning, especially in terms of transhipment hubs. The evolution being triggered from an economic standpoint but spatial importance remains essential even though port centralities have not changed much in the last two decades (Ducruet and Notteboom, 2012). Firat Bolat in his Phd dissertation applied network principles to assess the feasibility of Turkish ports in the Bosporus region (2015). He approached feasibility using network analysis in two ways, namely, port connectivity and port collaboration. Competitiveness & collaboration of ports was determined using independent pairs based on a one to one analysis of each port in the Bosporus port system individually. This was different and more focused approach than the network analysis of Ducruet and Notteboom which focused on a global network based on liner vessel movement data from Lloydslist. They highlighted the correlation of centrality to container throughputs and posited the high betweenness of certain ports rather than their degree to connectivity (2008). No research exists on the south Asian region. Furthermore, out of all research on port economics, operation, management have increased in the last few decades, very few of these studies have been by Indians, even though the geographical and economical significance of the country (Lau et al, 2013). The lack of network understanding from an Indian port system perspective leaves numerous question unanswered. This puts port developers in a handicap, when developing strategies and policy to compete at the global level.

2.7 Development of Indian port system

With a coastline extending over 7,500km (Kumar et al, 2006), the Indian peninsula lies strategically close to two major shipping routes, namely, east-west route and the Suez Canal route. Being one of the fastest developing economies in the world, the need for India to enter the global shipping industry has been long awaited. Historically, Asia especially India and China were a major part of the silk route. Amongst the largest exporters of spices and linen, they were the cornerstone of Eurasian trade. The British colonial influence on the country manifested in development of port cities like Mumbai, Chennai and Kolkata, which moved good from the western, southern and eastern hinterland respectively to be shipped to England (Kosambi & Brush, 1988). But a depleted fleet and almost decimated shipbuilding industry as result of colonial rules, saw India struggle to recover in the post-independence era (Kumar, 2012). The cargo flow though, through Indians ports have increased steadily in the last half of the century. Mumbai, Kolkata, Chennai, Mormugoa, Kochi and Vizag all being older than century, handle a significant low amount of cargo compared to other global ports. There is also a significant difference in throughput of ports on each coast as can be seen below, owing to historical growth and geographic position to both hinterland and foreland like Europe

(Behera,2016). India today has 12 major ports and more than 150 non-major ports, just more than 20 of those can handle containerized cargo.

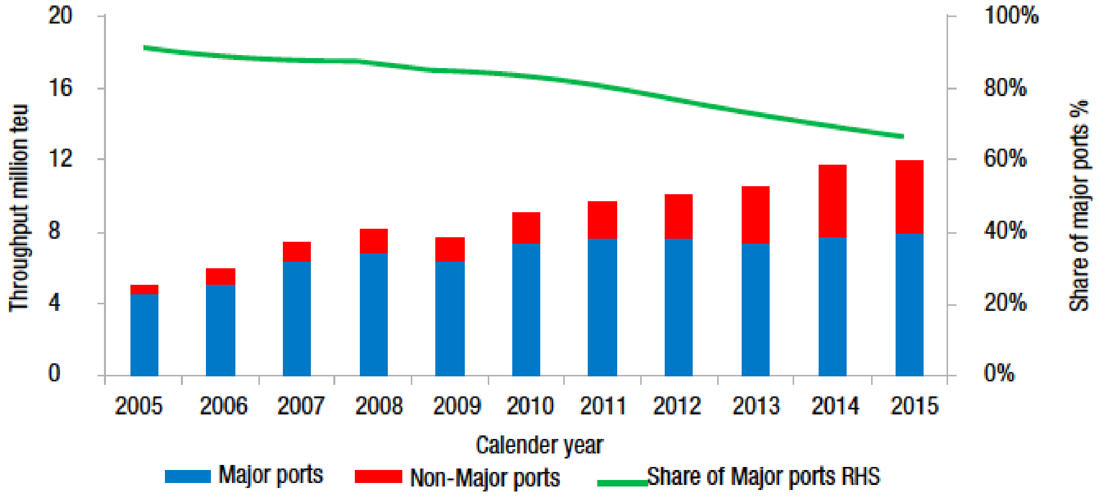

Figure 2 Container traffic growth in India along with decline share of major ports as per Indian Container Market Report

(Source: Behara, 2016)

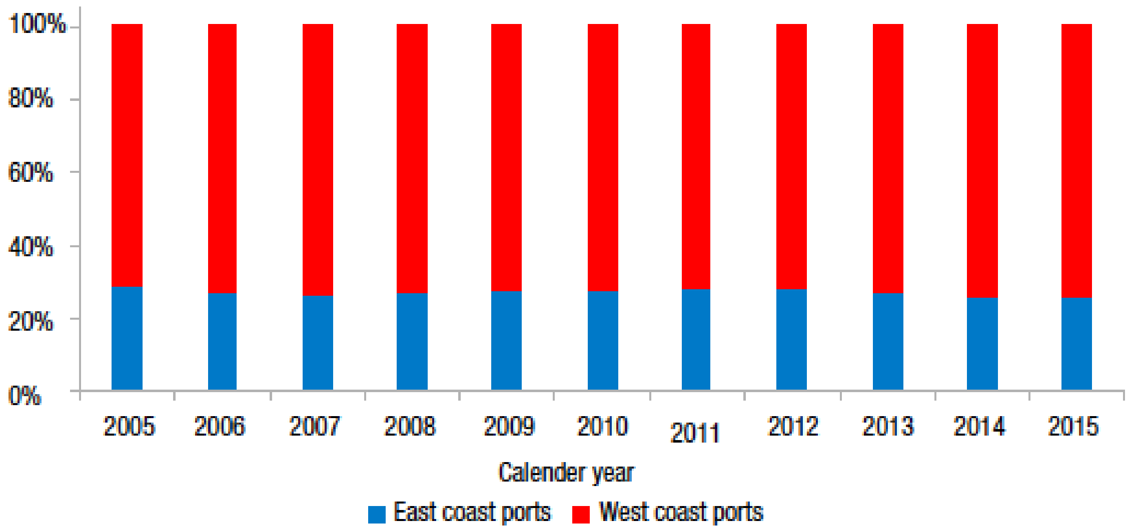

Figure 3 Share of containers handled at west coast and east coast ports

(Source: Behara, 2016)

The emergence of port infrastructure as a major factor in economic growth in today's global logistic ecosystem coupled with the inefficiencies of port and logistical infrastructure, has forced the government to increase investment in transport and port infrastructure. This resulted in the government opening the sector to private investment. In the present scenario, Asia has become one of the largest consumer and producer of finished goods. As the United Nations Conference of Trade and Development (UNCTAD) Review of maritime transport

(2016) states, "Developing countries remained key world importers and exporters in 2015 and have consolidated their position as suppliers of raw materials, while also strengthening their position as large sources of consumer demand and main players in globalized manufacturing process." A SWOT Analysis of the Indian shipping sector highlights the judicial shortcomings along with under investment in the maritime sector in comparison to other major seaborne trading nations as a major weakness. Swift development in China, Srilanka, Dubai and inefficient port handling has severely impeded India's potential.

The container traffic in India is set to grow being driven by

- Growing International trade
- Penetration of containerisation
- Development Hub and feeder service structure
- Presence of huge market and service industry

The figure below highlights the distribution of ports along with throughput in India. The throughput and draft of each of the ports are mentioned in the Table 1.

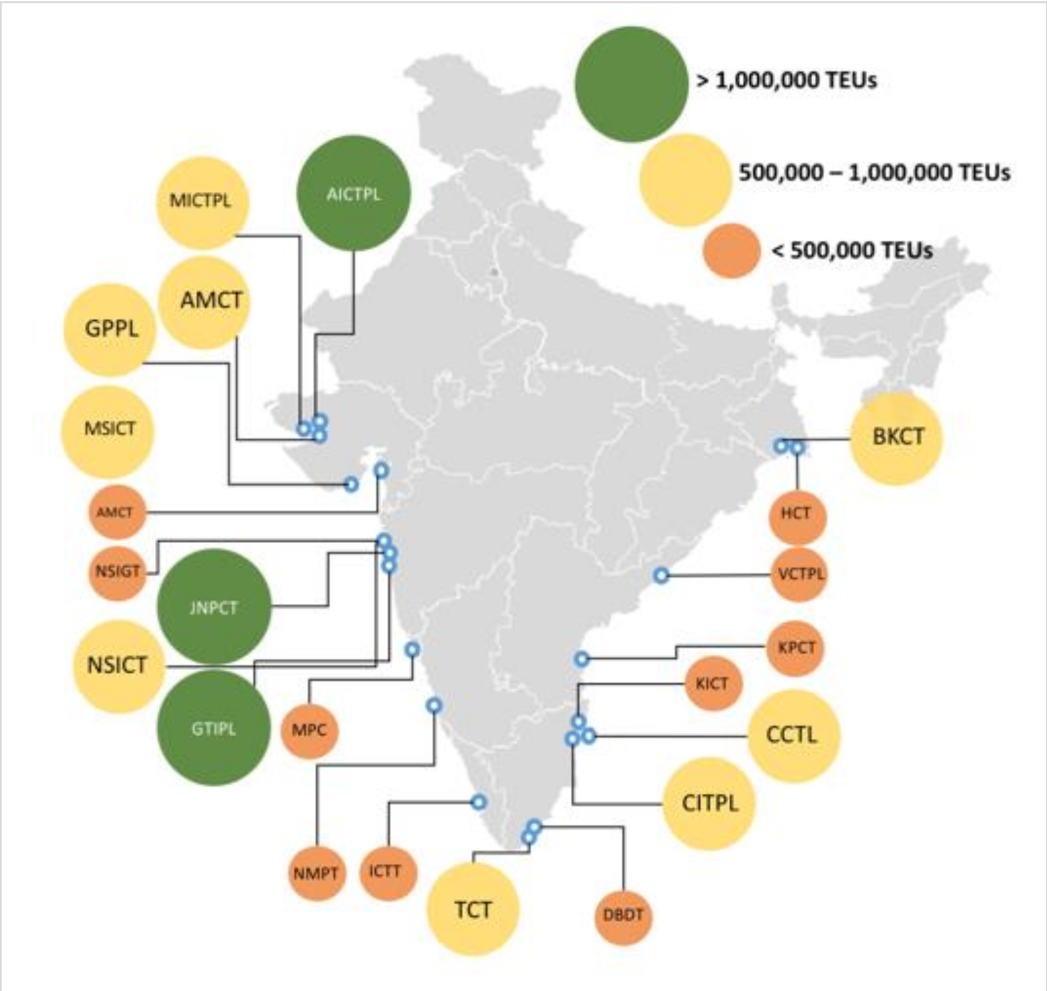

Figure 4 Distribution on Indian Container handling port according to throughput 2015-16 as adopted from the Indian Conatiner Market Report 2016.

(Source: Behera, 2016)

2.8 Current performance of Indian Ports

15 of the top 20 container ports in the world are in Asia, mostly China with exception of Singapore, Dubai and Malaysian ports (UNCTAD, 2016). The figure 5 highlights the current TEU handling capacity of the world's top 10 ports as adapted from UNCTAD compared to Indian ports as reported in the annual report from ministry of shipping, Government of India (2016). India doesn't have any major ports neither in terms of container handling nor with the overall tonnage capacity in the world's top 20 list.

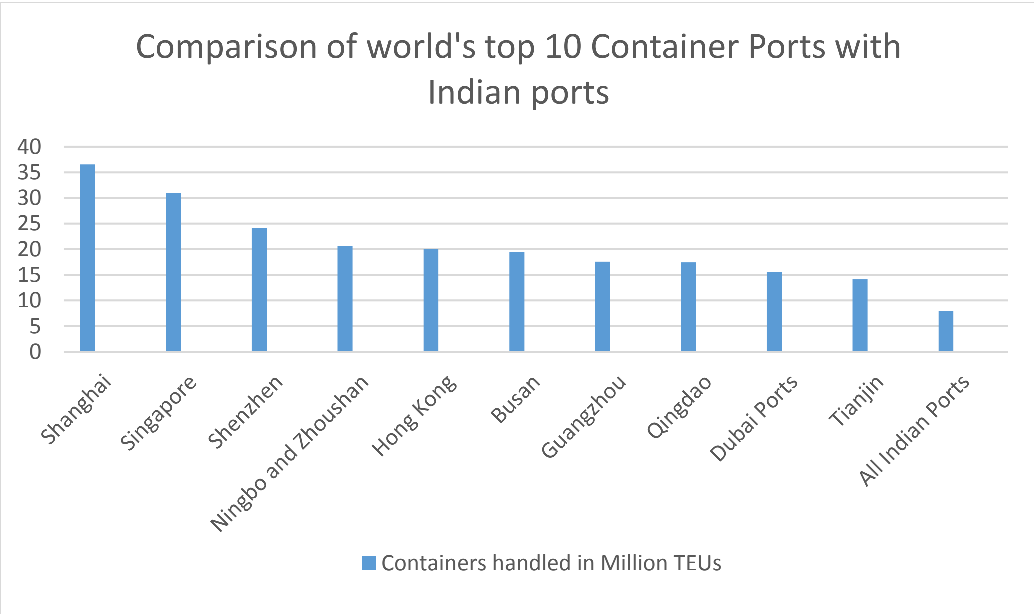

Figure 5. Comparison of world's top 10 Container port with Indian ports as adapted from the UNCTAD annual report and Ministry of shipping, government of India annual report.

(Source: UNCTAD 2016 and Ministry of Shipping, Government of India (2016))

As a result of this most Indian ports are still being visited by feeder vessels, directly elongating the supply chain in turn affecting cost and transport time for cargos for shippers (Dasgupta & Sinha, 2016). The last decade has seen the cargo traffic double as a result of the economic growth witnessed by the nation. The expansion of the manufacturing sector and the increase demand on the back of growing purchasing power, has led to this rise in trade. This directly has affected the expansion of the port and maritime sector in India. With growing trade volume, moving in-out and through India, liner connectivity between trading partners like Europe, Asia and South-East Asia seeks particular attention. Container trade which was traditionally handled by major ports like Mumbai, Chennai is facing stiff competition by the evident growth in cargo handling by non-major ports like Mundra Port. Modernization and improved operational practises has also reduced turnaround time for ships to 2.14 days according to ministry of shipping (2016), but inland logistical delay still upsets shippers. The efficiency of the logistic system to connect ports to hinterland was also a weak link in the overall transport logistic chain, as seen by the Maersk case study of India (Jensen, Olsen & Westergaard-Kabelmann, 2016). The operators of today's ports know, the key to success is a complex process involving the needs of the user for logistical efficiency, technological changes, socio-economic factors, spatial characteristics and global demand of trade.

Table 1 Port Throughput and Growth Rate

Abbreviation	Port Name	Throughput (TEUs)	Growth Rate	Coast	Rank	Draft
GTIPL	APM Terminals Mumbai - Gateway Terminal India	1 860 283	Low	West	1	14
JNPCT	Jawaharlal Nehru Port Container Terminal	1 429 277	Low	West	2	14
AICTPL	Adani International Container Terminal	1 073 728	High	West	3	16
NSICT	DP World - Nhava Seva Intl. Container Terminal	999 680	Low	West	4	14
MICTPL	DP World - Mundra Intl. Container Terminal	985 627	Low	West	5	14
AMCT	Adani Mundra Container Terminal	936 599	High	West	6	14.5
CCTL	Chennai Container Terminal - DP World	867 549	Medium	East	7	14.5
CITPL	PSA's Chennai International Terminal	695 611	Low	East	8	13.4
GPPL	APM Terminals Pipavav - Gujarat Pipavav Port Ltd	694 612	Low	West	9	15.5
BKCT	Bharat Kolkata Container Terminal	577 000	Medium	East	10	14.5
TCT	PSA Sical Tuticorin Container Terminal	510 000	Low	East	11	8.5
ICTT	Vallarpadam Intl. Container Transhipment Terminal	429 000	High	West	12	10.9
AHCT	Adani Hazira Container Terminal	301 755	High	West	13	14.5
VCTPL	Visakha Container Terminal	293 000	High	East	14	13
NSIGT	Nhava Seva India Gateway Terminal	202 328	High	West	15	16.5
KPCT	Krishnapatnam Port Container Terminal	118 623	High	East	16	13.5
KICT	Kattupalli International Container Terminal	115 227	High	East	17	14
DBGT	Dakshin Bharat Gateway Terminal	110 000	High	East	18	12.8
JNPT-SWB	JNPT - Shallow Drought Berth	107 288	High	West	19	10
HICT	Haldia International Container Terminal	85 000	Low	East	20	8.5
NMPT	New Mangalore Port - (Containers)	76 000	High	West	21	7.6
MPC	Mormugao Port - Containers	17 292	High	West	22	14.4

(Source: Behera, 2016)

Shipping is an important indicator of both commodity and services of country. With cargo handling capacity of India ports currently more than 19 million TEUs, India is taking a lot of efforts to improve the infrastructure and efficiency at the ports, trying to bring it at par with some of the other ports around the world (Behera, 2016). India currently operates via 12 major ports spread across the east-west coast with several non-major ports being modernized and developed under the Sagarmala Programme and the national maritime development programme (NMDP 2010-2020). JNPT, Chennai (Major) and Mundra (Non-Major) currently handle 75% of the container traffic in lieu of developed SEZs in the hinterland, but other ports are improving capacity as India aims to boost trade (Ministry of shipping, 2016). Currently India like most Asian countries has a heterogenic mix of port regionalization, where some ports systems showcase interconnection and concentration (phase 5-6) with high traffic density while others are scattered ports (phase 1-2) with cross hinterland captured but low traffic owing to political issues as seen according to the works of Rodrigue & Notteboom (2010).

As per the report by Drewry Shipping Consultants, there are as many as 247 listed CFS's and ICD's in India. Most of these are located closer to the ports. This demonstrates the dependency on port based facilities as the primary point for containerisation and clearing cargo. Inland penetration of containers is a major issue. The presence of several bottlenecks as result of bureaucracy and irregular development of intermodal transport system (road and rail) leads to longer container turnaround and lack of last mile connectivity, which stall the growth of ports and shipping. Vessel handling capacity owing to draft restrictions also affect Indian shipper's chances of ripping the benefit of economy of scales and the lack of transhipment ports in India adds a cost penalty (World Bank, 2013). Apart from developing deep draft ports, there is a need to address the following issues to help improve overall logistical performance of ports:

1. Hub and feeder operation along both coasts
2. Connectivity between inland depot and container freight stations
3. Intermodal connectivity at ports
4. Inland connectivity within ports on both coast
5. Development of special economic zones to enhance ports operation as a value adding node in the global market.

Given the recent changes in cabotage laws provides Vizhinjam port with a large market and ample opportunity to build on the hub-feeder system. Adani logistics Ltd at Mundra has shown efficiency levels at par with global standards. Adani ports and Special economic zone limited (APSEZ) also has joint ventures with major shipping lines at Mundra, this puts Vizhinjam port in a suitable position to explore the opportunities in the current global market.

2.9 Indian Infrastructure policy

Ports are infrastructural undertakings usually requiring heavy investment. As mentioned before, they have an economic multiplier effect on their surrounding regions and are the centre of many socio-economic activities ranging from leisure bases to industrial and energy supply bases (Alderton,1999). As an important part of a nation's transport infrastructure, ports must be part of the national transport plan. Historically, ports in India have not been under much focus but have come into emphasis recently as a result of numerous reports of logistical fallacies and public infrastructural shortcomings. Studies by the World Bank (2013) and major shipping companies (Like Maersk, 2016) have highlighted the inadequacies of the system. The effects of performance of ports adding to the increased cost for exporters and importers has become far too obvious lately (Ghosh & Be, 2015). But ports aren't the only one to be blamed, other factors like lack of integrated transport network, obsolete facilities, poor work practices have stalled growth of Indian ports. With import and export of merchandise steadily growing, there is a need to upgrade the overall national transport infrastructure (World Bank, 2013).

Since 1996, private participation in public infrastructure has been encouraged by the Government of India (hereafter GoI), on a build, operate and transfer basis (Lakshmanan, 2008). Major companies like Maersk, CMA-CGM, Adani group have invested in ports and terminals, but implementation remains sluggish owing to the risk and heavy bureaucratic challenges. But the increasing in cargo handling in privately managed and joint venture project at non-major ports, as highlighted below, shows the growing advantage of PPP projects.

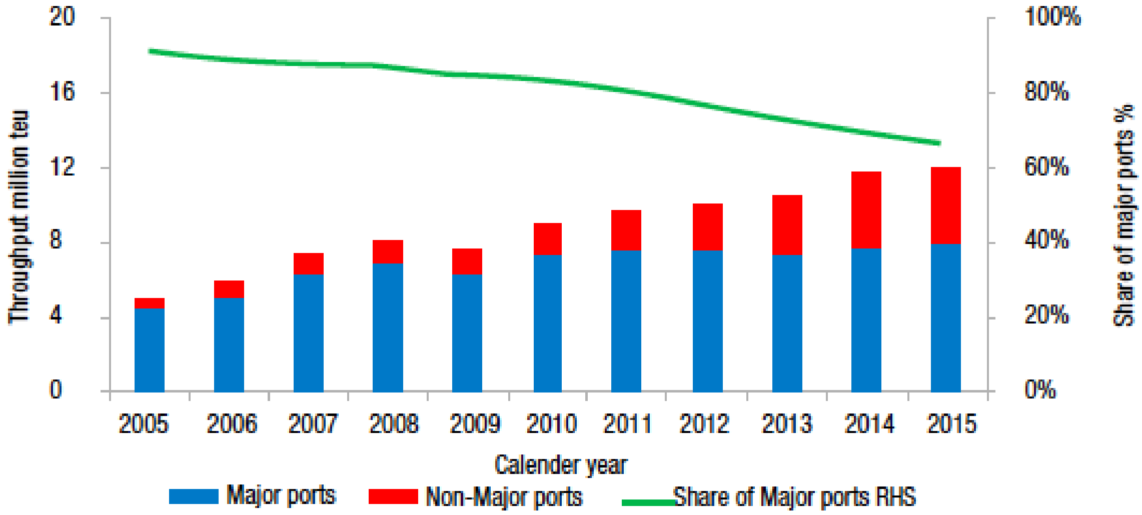

Figure 6 Increase in throughput at Non-major ports as per Indian Container Market Report

(Source: Behera, 2016)

India is yet to harness the full potential of an efficient policy framework of liberalization and deregulation, corporatization and private sector participation which have worked worldwide (World Bank,2013). Privatization in the last two decades has attracted few international investments due to the FDI policies and have mostly been undertaken by public sector undertakings (like GAIL, ONGC et al) (Lakshmanan, 2008; Raghuram & Gangwar, 2007). Add to this a large focus on developing the telecom sector which comprised of more than 40% of the total investment in India at the cost of transport infrastructure has seen India becoming an IT powerhouse but an infrastructural nightmare. The 12th Plan period by the GoI planning commission aims to reduce the infrastructural deficit. Through NMDP and Sagarmela project, GoI has been addressing the challenges of capacity building, efficiency improvement, accessibility and modal switching optimization along with improving environment, safety and almost non-existent integrated regulatory practises. With around 95% (by volume) and 70% (by value) of global merchandize trade conducted via sea, the above stated challenges need to be addressed quickly to maintain the current economic growth rate. Only JNPT (100%) and Kandla(95%) were able to achieve the targeted traffic projections out of more than 20 container port. Kochi and Ennore being the lowest, highlight the need to focus on infrastructure development and developing integrated policies in the southern states as shown by Ng & Gujjar with the case study of Indian southern hinterland(2012). It is worth mentioning the correlation in high efficiency and private sector involvement in JPNT. The incoherency in national infrastructure and port development is also a key issue to be addressed. A port logistical cluster system as developed by China (Wang & Slack (2004), Monios & Wilmsmeier(2013), Monios & Wang(2013), Kim (2017) et al), the freight village concept in Italy and the development of ports like Gioia Tauro could all be used to draw lessons. There is a urgent need to address the challenge of ability to handle the current fleet of megaships and the hinterland connectivity of Indian ports. With a logistic performance index score of 3.42, ranked 35th, India has a lot of scope to improve (World Bank, 2017). The accessibility of hinterland and intermodal connectivity would be crucial for ports development.

Chapter Three - The Asian Port Network

3.1 Vizhinjam international seaport limited Project

The Vizhinjam International Seaport Limited (VISL) is the special purpose government company, developing the deep water greenfield port at Vizhinjam. Adani ports and special economic zone limited (Hereafter, APSEZ) is developing the port under Design, Build, Finance, Operate and Transfer (DBFOT) model scheduled to be completed in 3 phases first of which is to be completed by December 2019. AECOM, India was in charge of the planning of the port project. The Final master plan was submitted in 2014 and no further changes or revised reports have been published, so the remainder of the research on the feasibility of this project would be based on the plans and productivity estimated according to the Integrated Port Master Plan Report.

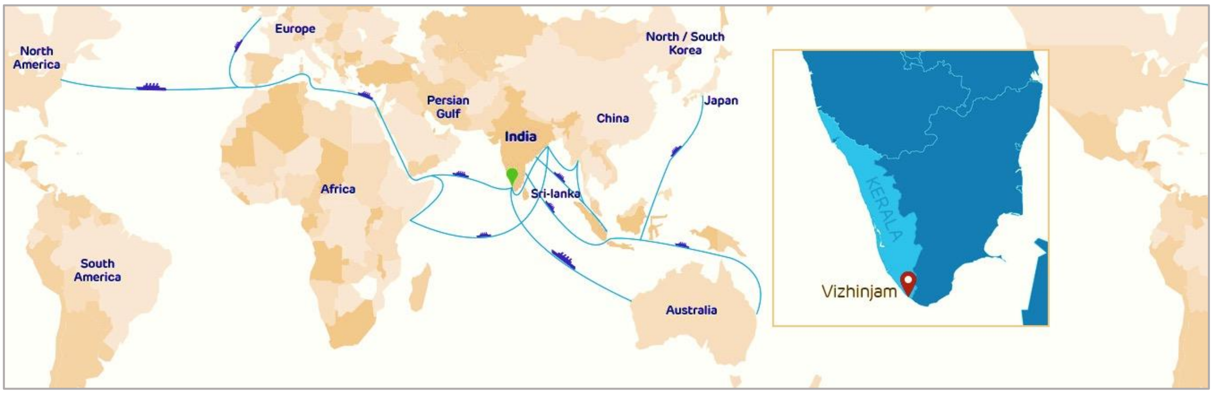

Figure 7 Geographical position of Vizhinjam Port

(Source : Adani Ports, 2017)

The proposed project is a greenfield project aimed to develop Vizhinjam International Deepwater Multipurpose Seaport. First of it's kind, the port with its deepwater draft of 20m would be capable of handling the largest fleet of vessel currently operating in the world. The project must also be noted is based on the projections of the Drewry report of 2010 submitted to AECOM (AECOM, 2014).

3.2 Civil engineering features

The first phase of port is envisaged over 33 hectares. The port is designed to accommodate 2 berths with a quay length of 800 meters with an estimated port capacity of 900,000 TEUs. The plans are based on the model vessel of 12,500+ TEU capacity. The port has a natural draft of 18m which would allow for vessels with capacity exceeding 18,000+ TEUs to berth as well. The port would also have a cruise berth for leisure and a liquid berth to allow for bunkering operations. The container yard in phase 1 would have 5,600 TEU ground slot for storage with utility route designed taking into consideration, expansion and port upgradation options.

The following phases of expansion would aim to increase port capacity to 3,350,000 TEUs with quay length of 2000m and 5 berths and TEU ground slots of 18,200 by 2044. A phase by phase growth is given in the following table

Table 2 Vizhinjam Expansion Plan

Vizhinjam Port Development						
Phase	Annual Capacity	Quay Length (m)	Quay Length Added	No. of Quay Cranes	Total no. of Berths	Terminal Area Addition
Phase 1	900,000	800	800	8	2	33
Phase 2	1,800,000	1200	400	12	3	16
Phase 3	3,3500,000	2000	800	20	5	30

(Source: AECOM, 2014)

3.3 Adani Ports and Special Economic Zones Limited (APSEZ)

The largest port operator in India, the Adani groups subsidiary, APSEZ is currently operating ports and terminals in 10 locations, across the western and eastern seaboard (Adani Ports, 2017). With a pan-India presence and investments on international port management projects in Australia and Malaysia, APSEZ has been increasing their participation in the port sector. The growth in throughout of Mundra port is a testament to their performance as a port manager. The Adani group also the largest private container train link operator. This also provides APSEZ an added advantage of the possibility of developing intra-port intermodal connections.

The 2013 report by world shipping council on trade estimated more than 28.3m TEUs being traded between Asia and Europe via the East-west trade route. This includes an area covering East-Asia, Asia, middle-east, Mediterranean and Europe. Based on the model vessel capacity at any given time, there would be about 2,270 vessel traversing on east west routes. This account 99 services between Europe and far-east Asia, based on Drewry 2013 container forecast (AECOM, 2014). This highlights the vast opportunity the strategic location present, but various other factors affect the ports ability to capture the market involving all the users. The figure below highlights the approximate deviation from the Suez routes and its deviation from some of the major ports including Vizhinjam (yellow).

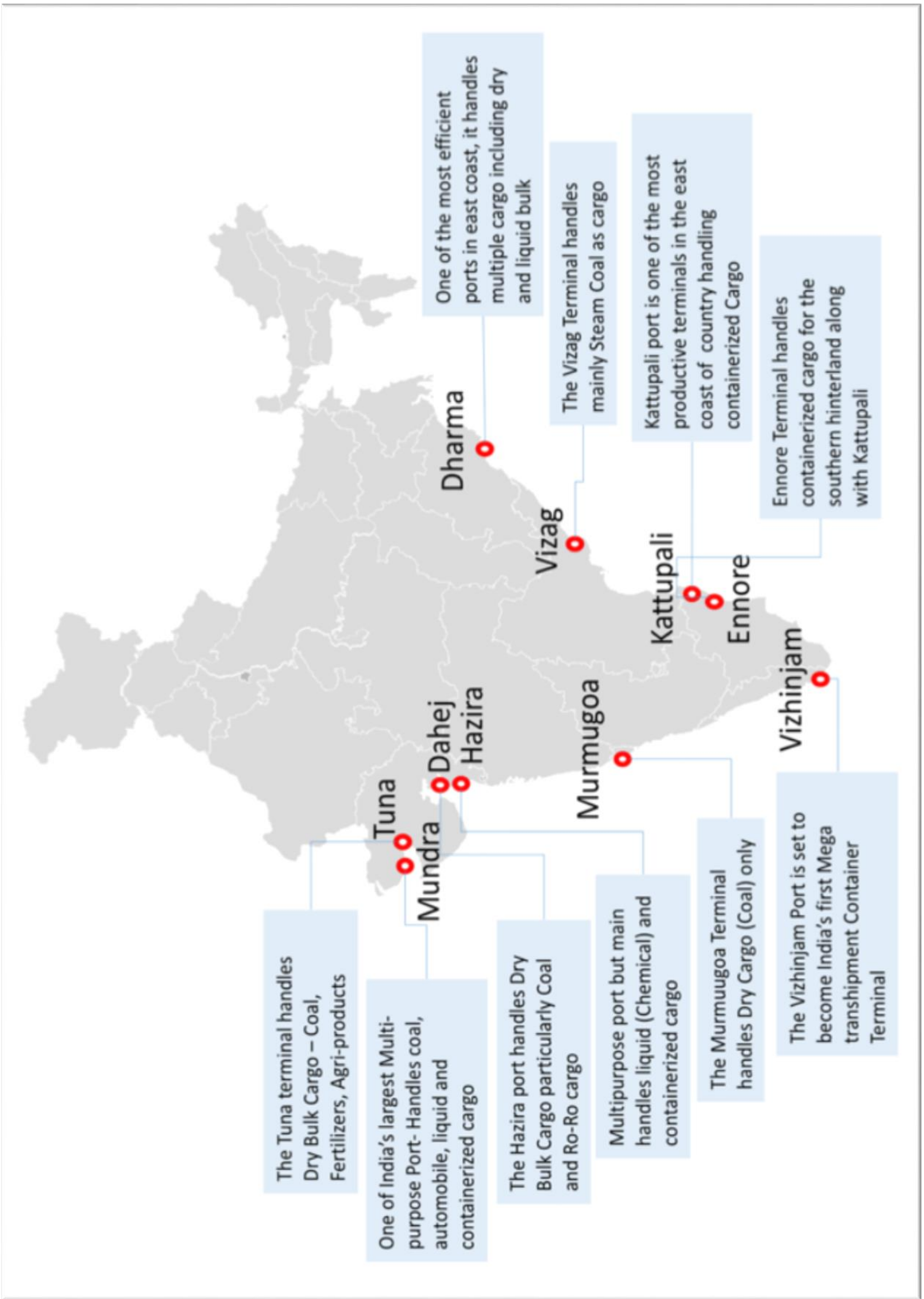

Figure 8 APSEZ managed ports across India

(Source: Adani Ports, 2017)

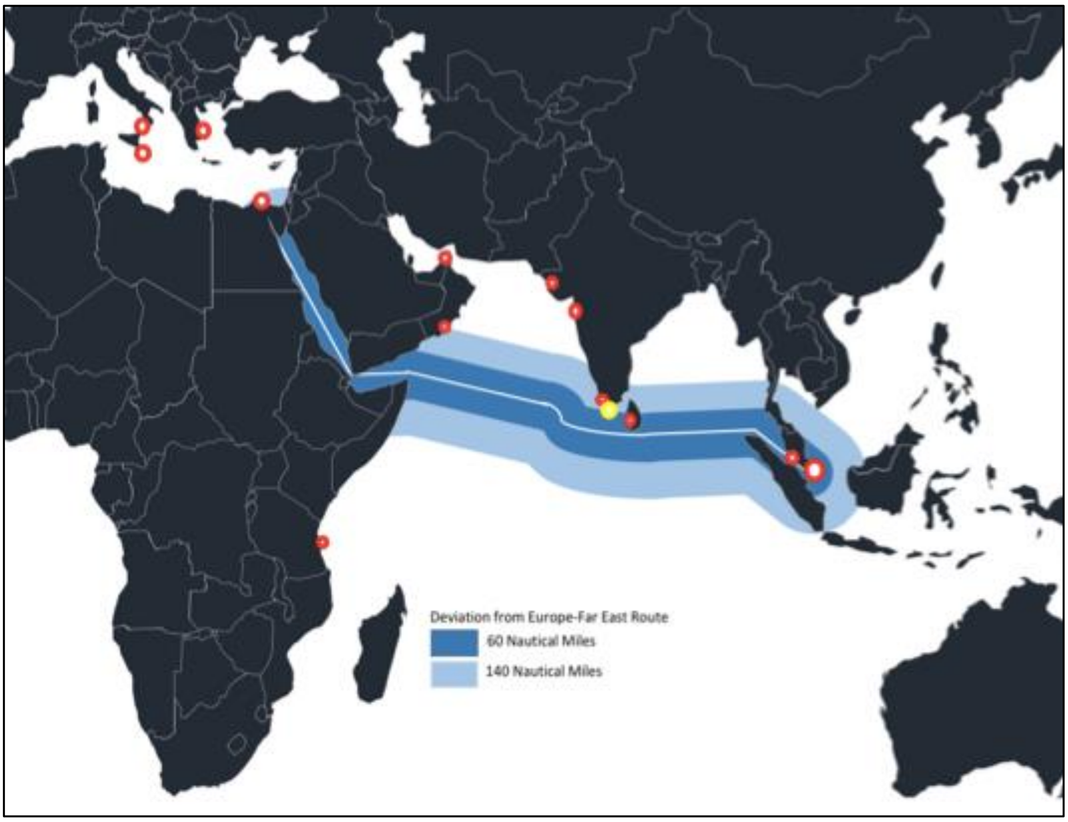

Figure 9 Deviation from Europe-Far East Routes

(Source: Author, 2017)

A comparison of VISL with some of the major port along the east-west trade route are given in the table for a preliminary benchmarking before we proceed to the network analysis of the port network. The annual throughput, quay length, number of cranes, terminal area along with the draft are provided below.

Table 3 Port comparison in the Research Area

Port	Throupghput (Million TEUs)	Quay Length (in Meters)	No. of Berths	Maximum Draft (in Meters)	No. of Quay crane	Terminal Area (in Ha)
Singapore	30.9	19170	62	18	223	744
Jebel Ali	14.77	5060	26	17	87	87
Port Klang	13.17	7929	30	17.5	93	257
Pelepas	8.28	5040	14	18	57	189
Colombo	5.73	2692	11	18	27	75
Mumbai	4.52	2337	6	14	27	135
Khor Fakkan	4.33	2000	6	14	20	70
Jeddah	3.96	1700	5	15	11	60
Salalah	3.33	2200	6	18	25	476
Mundra	3.32	2704	8	16	31	72.8
Chennai	1.5	2292	7	14	18	96
Kochi	0.43	600	2	14.5	4	40
Tuticorin	0.5	379	1	10.9	3	10
Kolkata	0.42	1244	7	8.5	15	22
Vizhinjam	0.9	800	2	20	8	33

Indian Ports

(Source: Adopted from various ports website by author)

3.4 Benchmarking and Analysis

The Asian port network have risen to prominence in the world trade as a result of growing trade in the form of merchandize trade from production rich south and south-east Asian countries like China, Vietnam, Taiwan, Indonesia, Bangladesh, Thailand along with India. The boom in trade and economy has lead to development of terminals and transhipment ports moving cargo to Europe and the Americas. The unavoidable importance of the maritime route can be attributed to the following factors:

- High density of maritime Traffic along the route
- Increase traffic of New panamax and ultra large container vessels (ULCV)
- High Population density providing market place
- Developing economies along the route providing cheap services including transhipment and manufacturing as a result of GSC
- Presence of multiple choke point

For the purpose of the study, we shall consider the major transhipment terminals along the east-west route as highlighted in the previous table. Ports on the east of Singapore are ignored for the simplicity purpose as almost all vessel on the east-west route call at Singapore or port of Klang before calling at one of the south Asian or Middle-east ports. The strategic location of Vizhinjam Port close to the international maritime trade route along with its deep draft put it in direct competition with some of the port in south Asia.

Some of the other deep draft port in the South Asian region are mentioned below.

- Port of Colombo
  Largest and busiest port in south Asia currently, the port of Colombo currently has three container terminals Jaya container terminal, South Asia Gateway Terminal and Unity Container Terminal. Present at the immediate vicinity of Vizhinjam, Colombo Ports could be directly affected by Vizhinjam ports' operation.

- Jebel Ali Port, Dubai
  The busiest port in the middle east is strategically located to cater to the transhipment needs of the Persian Gulf region. It makes the port an important nodal point in the system.

- Port of Salalah Oman

  One of the major ports located closest to the suez canal route, it becomes at imminenet point at the heart of the pacific rim providing opportunity to serve the middle-eastern, Indian and east african regions.

- JNPT - APM Gateway terminal Mumbai

  The largest and busiest port in India, it serves for transit and transhipment of the western region of Asian and the Indian sub-continent.

- Mundra Port

  The upcoming port in Gujarat, is also operated by the Adani ports (APSEZ). It registered the fastest growth rate in 2016 and its set to overtake Mumbai as the largest container port in India with the improved capacity to handle 5.5 million TEUs.

- Kochi Port

  Also situated in Kerala, the Vallarpadam and ICTT are domestic competitor of Vizhinjam and serve the same hinterland.

- PSA Singapore

  The largest collective port facility in the world, PSA operates Tanjong Pagar, Keppel, Brani and Pasir Panjang and Sembawang Wharves with 69 berths out of which 10 berths at Pasir Panjang are capable of handles the largest container vessels.

- Port of Klang

  Located at one of the busiest shipping lanes, Port of Klang which comprises of the north and the west port, is strategically located in the Malacca strait. A combined 29 berths and 16.6 million TEUs capacity makes Port of Klang a major transshipment hub.

- Jeddah Port

  Situated on the Red Sea, Jeddah like Port of Klang and Singapore is situated within 60 nautical miles from the Asia-Europe route. The Saudi port along with Damman and Jubail serve the middle-eastern and north African hinterland.

Apart from understanding the physical geographical and managerial aspects of shipping, it is also important to understand the decision-makers in the container global logistical chain to enhance performance. The chain comprises of freight owners that represent the demand for shipping, freight forwarders who decide optimal routes and seaport selection, either for transshipment or direct calls. This along with terminals operational characteristic and demand attracts liners companies. Research from various researchers have highlighted the following factors need to be considered for development and growth of a regional hub.

Table 4 Factors affecting competitiveness and attractive of regional hubs adapted from various research works

Factors affecting competitiveness and attractiveness of regional hub port
Physical Factors
Length of Quays to accommodate required ships
Drafts to handle loaded vessels at maximum draft
Terminal area and yard capacity to optimize cargo flow
Number of Quay Cranes to load and unload vessels
Gate operations to smooth cargo movement in and out of Port
Geographical Factors
Proximity of port to Major Shipping Lanes to minimize deviation
Network Position of the port to support hub-spoke services
Port-City spatial features
Access to Intermodal networks to ensure connectivity to hinterland
Presence of Market for cargo
Organizational and Managerial Factors
Information and Cargo Management Systems to ensure realtime data
Security and safety features of the port
Productivity of ports include congestion in and out of the port
Value added services offer by or around the port
Flexibility in operation to accommodate delays by shipper or vessels
Tariffs and taxes

(Source: Author; 2017)

All largely depend on connectivity of the port and its performance. Using Network analysis, we aim to address the connectivity of South Asian Ports whilst discussing the current policy structure and logistical infrastructure of the Indian sub-continent.

3.5 Application of Port Network Theory

Ports can be treated analogous to social networks, where each port is connected to another port via liner ship movements. There actions or policy reforms usual permeates to other ports and justify how one ports actions affect other ports similar to social networks. While the network of ports on European and east Asia have been well discussed in a number of studies, research on south Asian port network has been overlooked. The south Asian network analysis would help us identify the major actors in the network and their impact on other actors through their centrality measures. The network analysis also shines light on the sub-structures patterns and behavioural patterns of the systems. This would present opportunity to develop strategies to optimize the performance of the actors, namely the port under consideration - Vizhinjam, India. The strategic location of the port along the east-west and Suez trade route puts Vizhinjam in a favourable position and an analysis of the network would be essential for both the user and the operators of the port. Complementarily understanding of ports operational capabilities along with the overall logistical scenario in the hinterland would further help us understand the feasibility of the port in the future and supplement the findings for overall optimizations.

Chapter Four - Social Network Analysis as an Analytical Tool

4.1 Network Analysis in Concept and Practice

Social network analysis (SNA) is a branch of sociology which studies collections of individuals and the linkages among them. For modelling social networks, SNA uses data from graph theory, algebra, and statistics (Wasserman & Faust, 1999). The theory differs from other sociological and mathematical theory at the elemental level by focusing on context and the behaviour of relationships between the actors rather than their discrete rational individualistic behaviour. The network analysis encompasses theories and application from a relational perspective.

Networks simply put, are a collection of nodes or actors, tangibly or intangibly connected by relations like friendship or trade. The relation between nodes is called an Edge, Ties or Link depending on the motive of studies. While networks can be mapped subjectively drawing a link between every node individually to draw a graph, mathematically they are represented by an adjacency matrix (Newman, 2007), which is symmetrical when we do not consider the direction of the link (Wasserman & Faust,1999). The fundamental of SNA, which are associated with social behaviour, can also be used on inanimate systems like transport infrastructure, as well where each node would be a function (like ports, airports, ICDs). These nodes which are part of a systems or network would react to the operational action of other nodes analogous to the bullwhip effect in supply chains which is prominent in a cluster based network of present day supply chain. It is essential to understand that actors and their actions are contextual and interdependent. These links are viewed as systems that imposes constraints or present opportunities on the actors in the network (Wasserman & Faust, 1999). The aim of the chapter is to present the concepts of network and understand the coherent nature of the system as a whole along with individual attributes. This would help provide a picture other than an individual component's characteristics.

A network could be studied in many ways. One can analysis individual attributes of the nodes or explore type of relationship and effects of the relationship on the node. One could also study the patterns of connection between systems and gain valuable insights on the behaviour of the system (Newman, 2010). The network is represented as a set of node, '*n'* connected by links '*m'*. Attributes could be added to each node, while edges could have directional properties and weights to further add details to the network, akin to individual characteristics and strengthen of friendship between two people.

Every network has complexity owing to the various permutation and combinations with which each node can act with other nodes. These interactions can also be as a result of their own change in attributes. They have patterns which can be localized (Clustering) or skewed (Homophility) in the overall network and can be effected by positions of nodes and changing links between them. To better understand positions of nodes in the network, it is elemental to understand the characteristics of a node to cognize their influence on the network. In the Graph Theory, the measures of centrality are used to measure the importance of a node and also to rank nodes. For the research on south Asian ports, the following centrality measure would be vital to understand the features of the system.

Degree centrality – it captures the connectedness of a node. It highlights the position in the network and number of other nodes directly connected to a node. The degree of a node is the number of neighbours a node is connected. The degree centrality is an indicator of the connectedness of a node. For a graph with n nodes, the degree denoted for a node *i by* k_i*,* which is the sum of all the connection. So if a node A is connected to four nodes, its degree is 4, similarly the centrality of B is 3 and so on.

$$Ki = \sum_{j=1}^{n} Aij$$

$$Degree\ Centrality = \frac{Ki}{n-1}$$

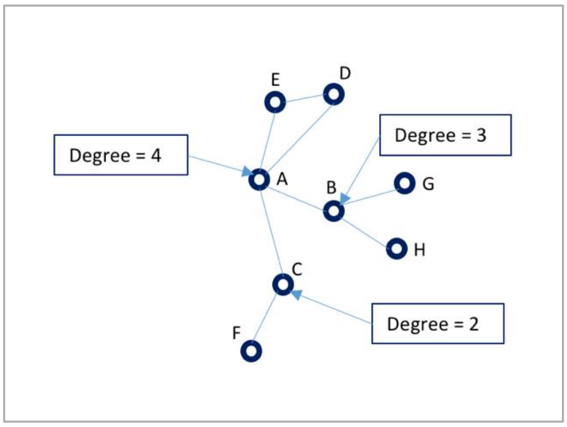

Figure 10 Node Degree Values of a Random Graph.

The degree highlights the position of a node in terms of connectivity. Another measure to define connectivity better is betweenness centrality. It highlights the importance of the node as a connector or intermediary to other components in the network. It measures the position of the node *k*, in the shortest path between two distinct node *i & j.* The node with high betweenness could be considered in crucial element to ensure flow of information or commodities (Wasserman & Faust, 1994). They act as gate keepers or connector. So betweenness of a node *k* is the number of shortest paths between *i* and *j* that *k* lies on (P_k(i,j)) compared to the number of shortest paths, that exist between *i* and *j* P(i,j).

$$C_b = \frac{Pk(i,j)}{P(i,j)}$$

$$Betweeness\ \ Centrality\ = \frac{Cb}{(n-1)(n-2)/2}$$

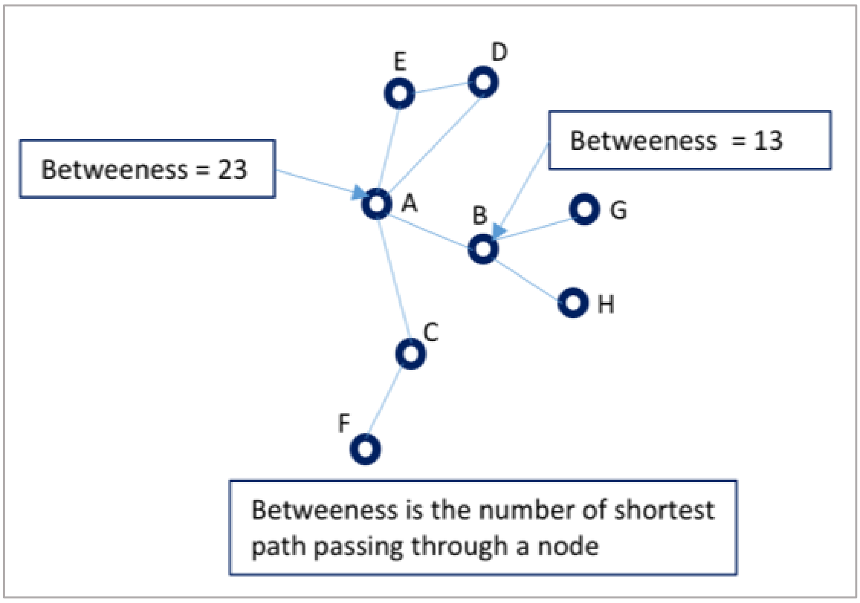

Figure 11 Betweeness values of Nodes in a Random Graph

The above mentioned measures of centrality highlight the position and not the influence of the node in the network. The Eigenvector centrality measure the centrality of the node i as a sum of the immediate neighbour's centrality. The centrality

$C_e = \sum_i k_{ij} C_d$

It's a natural extension of Degree centrality. Though centrality defines the connectedness of the node i, it would not be necessary that all node connected to i are equal. Eigenvector takes into account the importance of a node in a network would improved by been connected to other important node and vice versa. So instead of an unique degree as a result of connectedness, the eigenvector centrality provides nodes degree value proportional to the sum of the degree of its neighbours (Newman,2010). A node connected to an influential node would also be influential. It is particularly true in case of port networks, as port connected to global hub ports like Singapore, Rotterdam would have higher likelihood of attracting liner services and increase connectivity.

Another inherent aspect of networks is the natural division of nodes into groups or clusters which interact more within themselves. Clustering, one must understand captures the node's local cohesiveness by considering the formation of triplets in the community. In a social network concept, we often encounter friends who are acquainted to each other, similarly in shipping we have ports connect to each other via distinct links. This introduces an intuitive question as to if a node i is connected to two nodes j and k, what is the probability of j and k being connected? This helps us understand structural holes. We could find the pairs of neighbours of nodes i which are not connected with each other, this would indirectly indicate the opportunity for node i to control flow of information or commodities. This can be found using clustering coefficient of the node.

Clustering Coefficient, $C_i = \frac{\text{number of connected pair neighbours of node i}}{\text{total number of pairs of neighbours of node i}}$

Network analysis can also be used via visualization tools to determine the geographic spread of the network and highlight the polarization and nodal regions in the network. Modularity could be used to identify components and understand the quality of links within the partitions more efficiently and can be used to stabilize optimizing function of certain nodes. The Polarization could be measured using the clustering coefficient and finding major subgroups. By identifying cohesive sub-groups and major actor in it, we could devise a strategy to improve connectivity around these focal actors and thereby increasing the eigenvalue and connectivity and therefore improve the scope of viability. These characteristics complement the centrality indicators and indicate the influence of various nodes on the system as a whole.

4.2 Social Network Analysis as an Analytical Tool

SNA provides a workable model of networks which relates various actors into networks. The node attributes can then be assigned depending on the objective, to understand the network characteristics. This could then further provide a framework for collecting and analysing data useful for planning and monitoring changes in network activities (Wasserman & Faust, 1999). Network models based on graph theory provide valuable insights to analysts. The network diagrams help identify various network features like patterns, clustering and the implications of the relationship between different actors. Studies for quite sometime tried to analyse what are the mathematical, economical, political and social rules that govern formation and functioning of these networks. Network analysis have been used to study families ties of Medici (Padgett,1987), economic markets (Berkowitz, 1988) consensus and social influence (Friedkin and Cook, 1990), FDI in port-cities and non port-cities (Wall & Stavropoulos, 2017), Maritime networks (Ducruet & Notteboom, 2008) and have been used to predict epidemics, not only diseases but also social ideas, product adoption (Fowler & Christakis, 2010).

Though the metaphor of supply chain is borrowed from the idea of a chain from mechanics, in which every element is linked to the adjacent element, jointly providing strength with flexibility. The metaphor can transplant the chain idea into the sphere of shipping and ports (Mueller, Buergelt & Seidel-Lass, 2008). Ports being a crucial element of globalized trade, one would argue the metaphor of supply chain might be malapropos on ports logistics due to the lack of complete linearity in the chain and is often underlined with the presence of more expansive networks of ports and intermodalistic transport players. The chain in the maritime domain, is no more connected to two adjacent links but several other links which affect the efficiency and feasibility of the port. Under this perspective, the elemental factor that determine the success of port (also as a hub to some extent) strategic location and spatial characteristics of the port in the network. The social network analysis method explicitly focuses on the inter-relatedness of entities, in this case - Ports and provide methods to understand structural properties of networks (Wasserman & Faust,1999).

The notion of a network of relations linking entities or ties amongst them, has found wide expression throughout the social sciences, its application in shipping is enlightening. Recent researches largely being on the evolution and effects hubs on the network (Ducruet,2006 et al) and indicate the flow in network and their disproportionate importance (Newman,2010). The dependencies among the ports can be measured with structural variables, which hypothesize that functional characteristic of ports are not independently but rather influence each other. This measurement of system and its sub-structures, we hope would reveal patterns and relations that could be investigated to improve port connectivity and feasibility of future investment. The growing share of containerized cargo tonnage is a strong indicator of the need of increased integration of ports which are internationally considered the centre of multimodal transport.

The application of Social Network Analysis in the maritime sector in the South Asian domain, which lies along one of the busiest shipping lane of maritime trade, would help understand the cluster of major trading ports. This would not only highlight the exchange of commodities and goods but also interdependency of the different actors (ports). The objective isn’t to instigate a paradigm shift but to engage in productive research and speculation in order to come up with a more refined perspective to analyse feasibility of ports in south Asia from the network prospective. This we believe would then be further reviewed on a macroeconomic level in the future to assess relationship between countries or on a microeconomic level as done by Mueller et al on supply chain systems. This study also aims add to the extensive research done on the shipping sector in India and help major parties namely, government, terminal operators, infrastructure developers, shipping companies, logistic companies alike make better decision.

Chapter Five - Application of Social Network Analysis to South Asian Ports

5.1 Container Shipping Data Analysis

The last two decades has witness a continuous growth in containerization and throughput of ports. The increase in containerization and concentration of cargo on certain ports can be seen from port statistics of the past. There have been significant changes in the global port systems, with new ports rising to prominence in the liner shipping network. It's a complex system comprising a byzantine combination of door to door services coupled with line bundling, pendulum and hub-spoke movement of containers. Container shipping lines preordain port selection and therefore influence port hierarchy and annual throughput (Ducruet & Notteboom, 2012). One of the most important route in container shipping is the Europe – Far east route (Drewry, 2017). Passing through the Indian ocean, shipping lines observe a fixed route selecting a few regional ports of call in South Asia. Representing more than 60% of maritime trade moving along the east-west route The growth, feasibility and competition amongst south Asian ports have predominantly been analysed from an operational perspective like throughput, berth optimization and other container statistics, a network perspective to analyse spatial efficiency was conducted in this study. The limited draft of port and the advent of ultra large container ships is likely to affect the average number of port calls per loop and port selection. This would increase port competition and is likely to change the current network dynamics of south Asian ports especially the transhipment hubs which remain redundant due to lack to transit cargo. But lower deviation costs add a centrality and intermediacy factor to these port (Fleming & Hayuth, 1994; Ducruet & Notteboom, 2012). As traffic flow is a result of route and port selection by main players in the chain, network cost and performance becomes crucial (Ducruet & Notteboom, 2012). Some ports have a strong hierarchical presence as a result of service variables and liner service networks. To understand the network, we analysed the vessel movement.

5.2 Data Source

The methodology to analyse liner networks in South Asia is determined by inter-port connection between South Asian-Middle Eastern-East African Ports. The highlighted area in the following figure defines the area under research. Any connections between ports outside this area have been ignored.

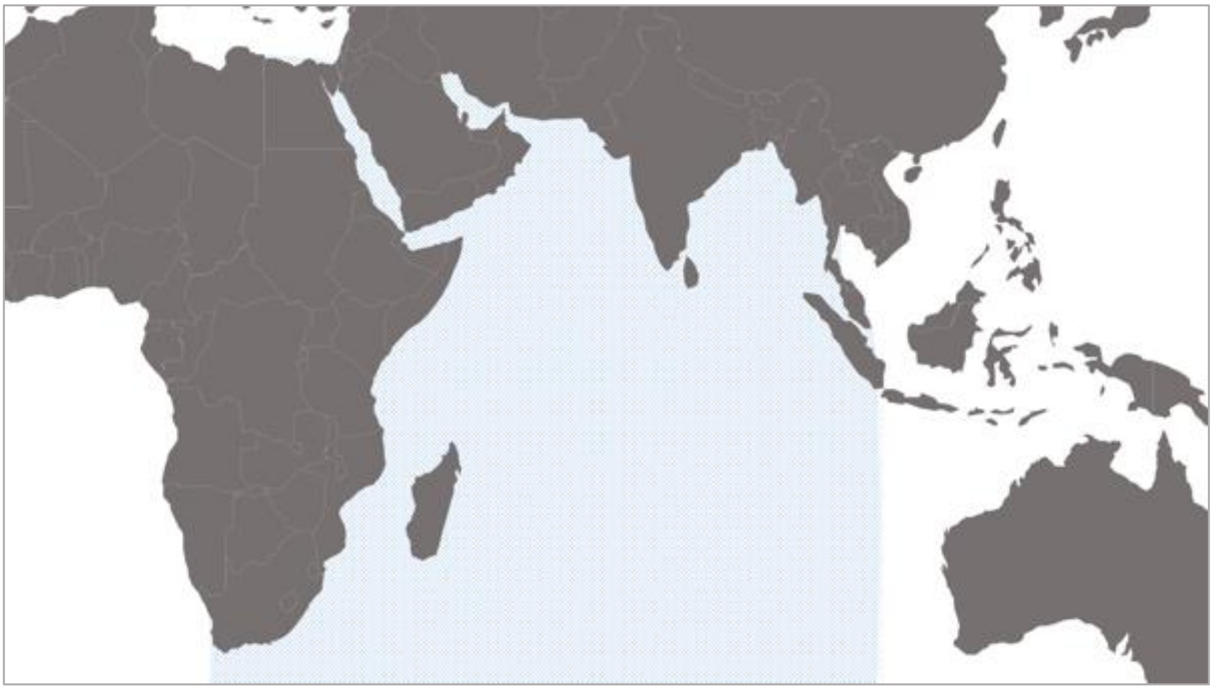

Figure 12 - Area under research

(Source: Author,2017)

Following the April, 2017 reshuffling of shipping alliance, the current three alliances namely, 2M, THE Alliance and Ocean Alliance together represent 77.2% of the world container capacity. The data for the research comprise of vessel movement in the Suez and Europe-Far East routes along with the secondary feeder route of the liner companies in the three alliances and UASC-Hapag Lloyd on a weekly call basis. The ports were considered as the nodes and the vessel movement between these ports as the edges in the analysis. For the in-depth analysis of port competition from a network perspective both Liner schedule data along with port attributes like draft were included.

Vessel movement for the first week of September 2017 were chosen from the route network of each individual member of the alliance, thus ensuring capture the operation of the alliances as a whole. The links were considered to be undirected and equally weighted for the ease of calculation and due to lack of deployed vessel capacity information for all companies and routes. To classify deployed vessel capacity, ports (nodes) were given the attribute of draft to estimate vessel size. The inter-port connection only within the research area (South Asian, Middle Eastern and African Ports) were considered and any direct connection with port west of Said and East of Singapore were ignored to understand interaction between South Asian ports and the major transhipment hubs in the extremities.

5.3 Gephi - Network Analysis Software

Gephi is an open-source graph and network analysis software suitable to work with complex data. It provides dynamic network visualization tools to elucidate large network to help understand the system better. Its high quality layout algorithms, data filtering option make the software flexible and user-friendly which could be used to plot inherently complex network graph articulately. Design features also allow to manipulate graph design to enhance visually interactive understanding. Data collect were exported to Gephi in two list, namely Nodes list indicating the distinct ports in the network and the Edge list indicating the interaction (in the form of vessel movement) between nodes (ports).

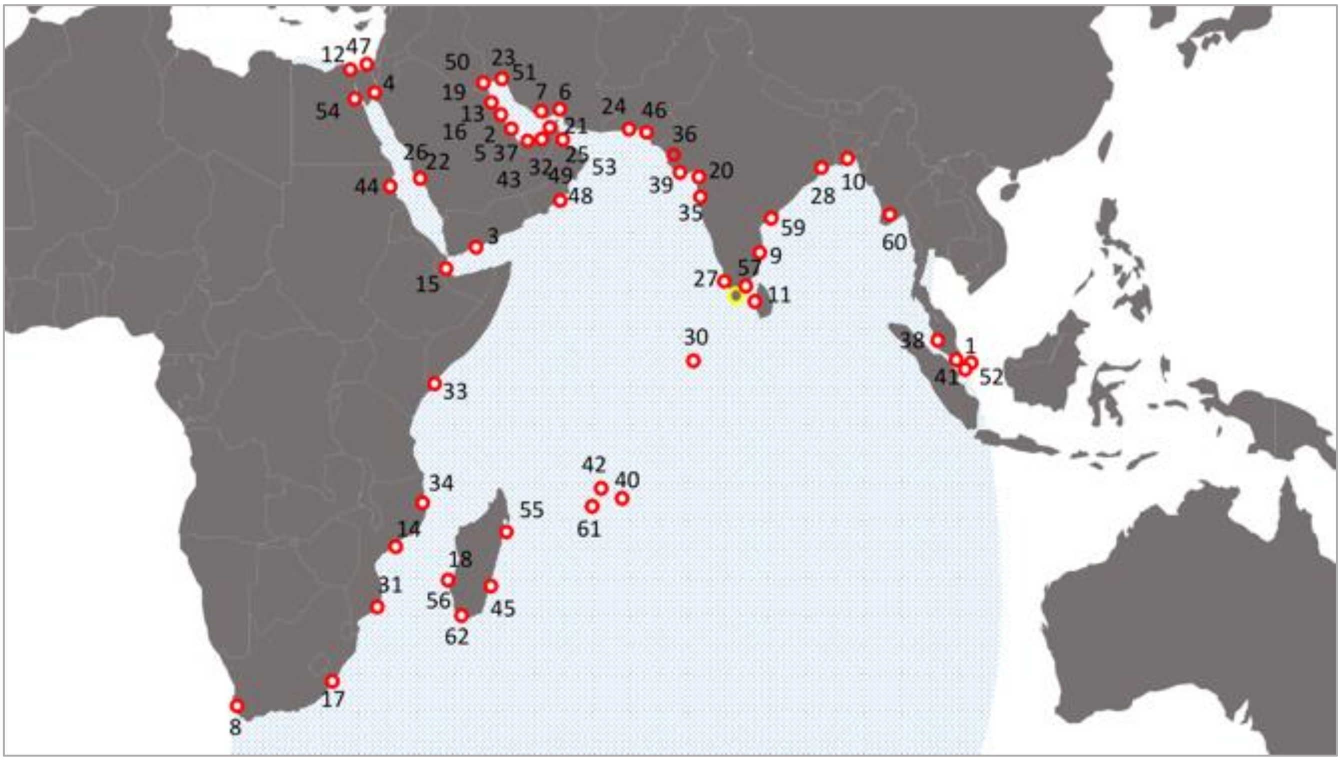

Figure 13 Node list

(Note : Ports considered in the Research based on Liner Schedules in September, 2017.
Yellow Point is for new port – Vizhinjam)
(Source: Author, 2017)

5.4 Regional Network Characteristics

To study the structure of a network it must be visualized to gain insights obscured by raw stacked data. We used Gephi to visualize data. The network charts were investigated based on the centrality measures, modularity and the clustering coefficient.

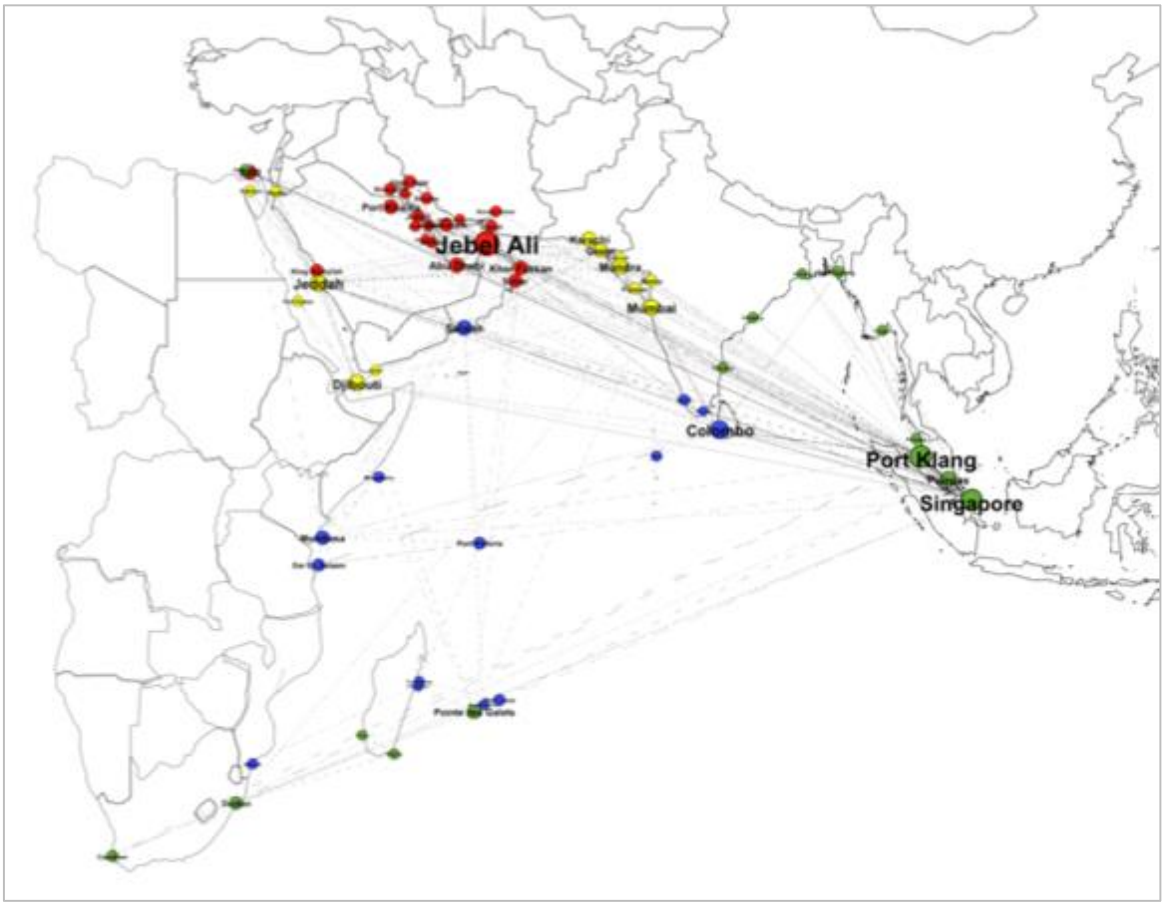

Figure 14 South Asian Port Network

(Note: Each color represents different Clusters)
(Source: Author, 2017)

Table 5 - Topological feature of south Asian maritime network

Index	Measure	Value
Network Size	No. of Nodes	62
	No. of Edges	857
	Maximum Degree	32
	Average Degree	6.677
	Diameter	5
Small-World	Average Clustering Coefficient	0.512
	Modularity	0.327
Efficiency	Average Path length	2.417

(Source: Author, 2017)

The topological properties of the port network are highlighted in the network graph and overview table. The south Asian region, which is subset of the global maritime network was investigated from graph theoretic approach. The data collected from the liner companies generated 62 individual ports of calls (Nodes) in their networks, creating 857 links weekly. The links are shown as weighted in the graph (indicated by thicker lines) as an in-built function of Gephi and does not affect centrality calculations. It is based on the number of interaction between two pair of ports by all the liners per week. The network's degree distribution highlights the scale-free properties of the network. The clustering coefficient of undirected weighted network was 0.512 with an average path length was 2.417 similar to the global network features (Ducruet & Notteboom, 2012). This indicates the small-world characteristics of the network. This analysis on the network was complemented by performing the modularity algorithm which measures the density of links within a port cluster/community comparing it to the inter cluster links. The positive yet low modularity highlighted the existence of overlapping clusters as seen by the presence of few ports on two clusters. It indicated the system is divided in four communities with slight overlapping as a result of overlying feeder network, line bundling network in those regions in order to increase frequency on the weekly basis. Middle-east with its market and south-southeast Asia as manufacturing further polarize the South Asian network. The deployment megaships can be seen by the convergence to their cluster hub like Jebel Ali, Colombo, Singapore and Jeddah. Unlike the global maritime network, the regional maritime network considered only intra-regional vessel movement and port of calls, the port hierarchy is slightly different from expected.

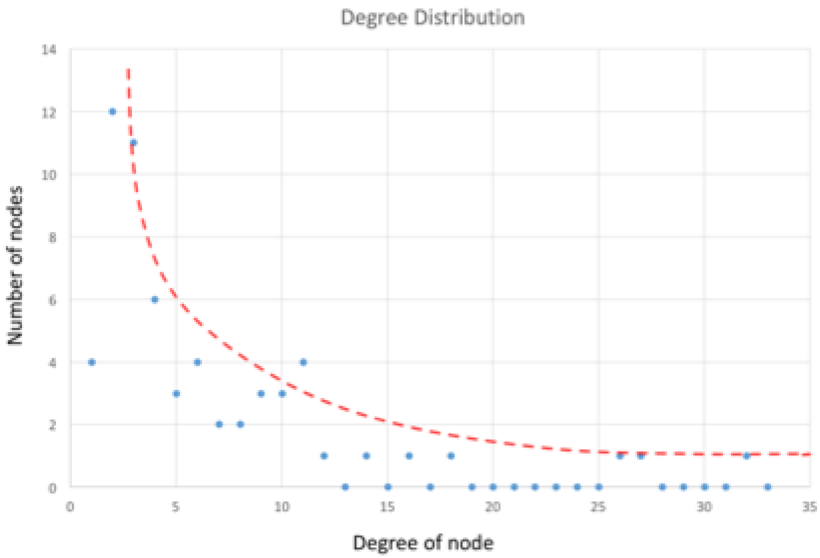

Figure 15 Degree Distribution of South Asian Port Network

(Source: Author, 2017)

5.5 Port hierarchy in Network

The dominance of certain ports is clearly visible, with Singapore, Jebel Ali and Port Klang leading the pack due to their sheer size and capacity. But Jebel Ali is the most connected port in the South Asia region (Degree, Ki = 32), this is partly because of the omission of any links between port within the South Asian area of research and ports outside it. Its also partly because of the intricate Persian Gulf and Arabian sea feeder and line bundling networks centring on Jebel Ali, the largest transhipment hub in the Persian Gulf. The presence in the straits, a point of congestion on the east-west route also puts certain ports in an ideal location for transhipment as seen with the high centrality measures of Jeddah, Djibouti in the Suez, Jebel Ali, Khor Fakkan in the Persian Gulf region and Singapore, Klang, PTP in the Malacca Strait.

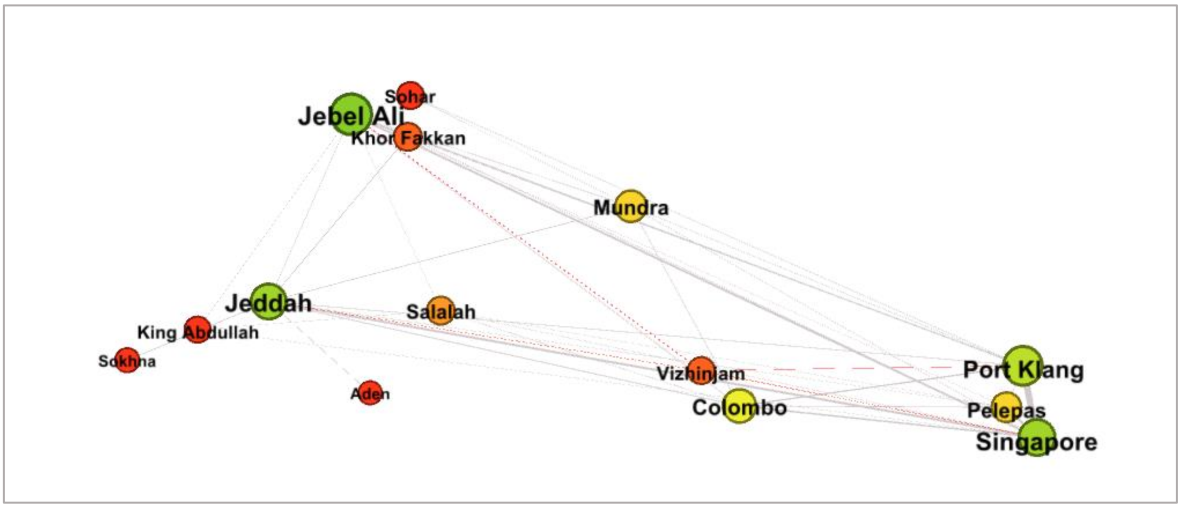

Figure 16 Port network of ports which can handle Megaships >18,000 TEU

Note: Capacity based on vessel draft
(Source: Author, 2017)

The deep draft of the ports and a dense network of smaller feeder network add to the centrality of these ports. It mimics a two-mode network with pockets of nodal regions being seen with the system pivoting around Colombo, the core regions being split between middle-east – East Africa and south-east Asia. Geographical proximity to markets and production hubs delineate the strong concentration in those areas. This is due to low cargo or cargo-related services generated in the south Asian sub-continent (Indian - Srilanka - Pakistan – Bangladesh). The frequency of port calls calls is highest in Singapore, Port Klang and Colombo in South Asia due to their proximity to the trunk routes which minimizes deviation costs and the ability to berth megaships along with large port areas that promote transhipment activities.

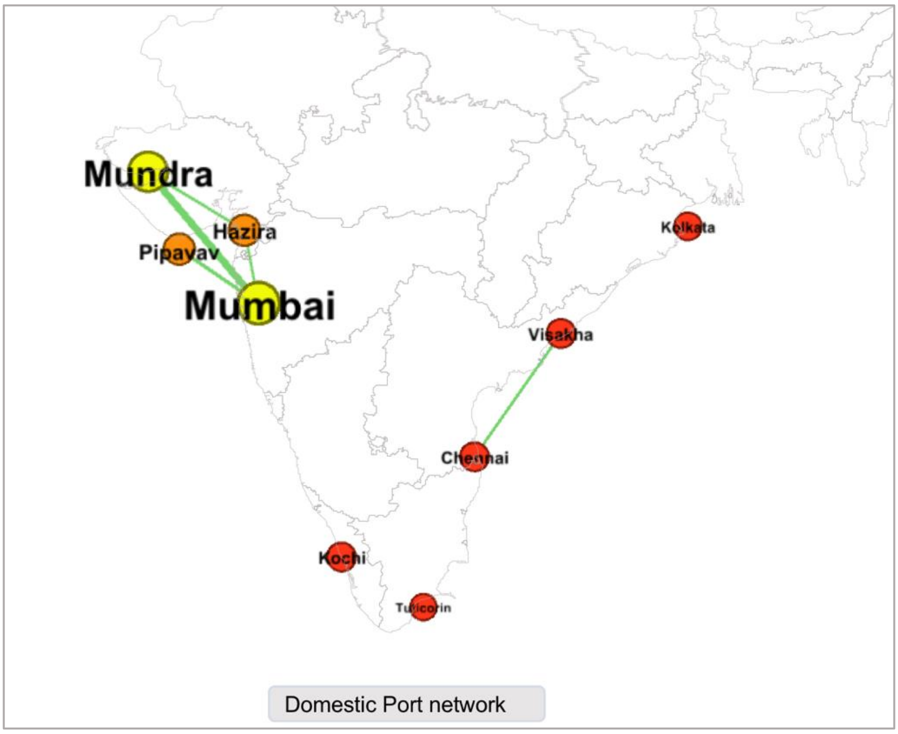

Figure 17 Indian Port Network based on network analysis

(Source: Author, 2017)

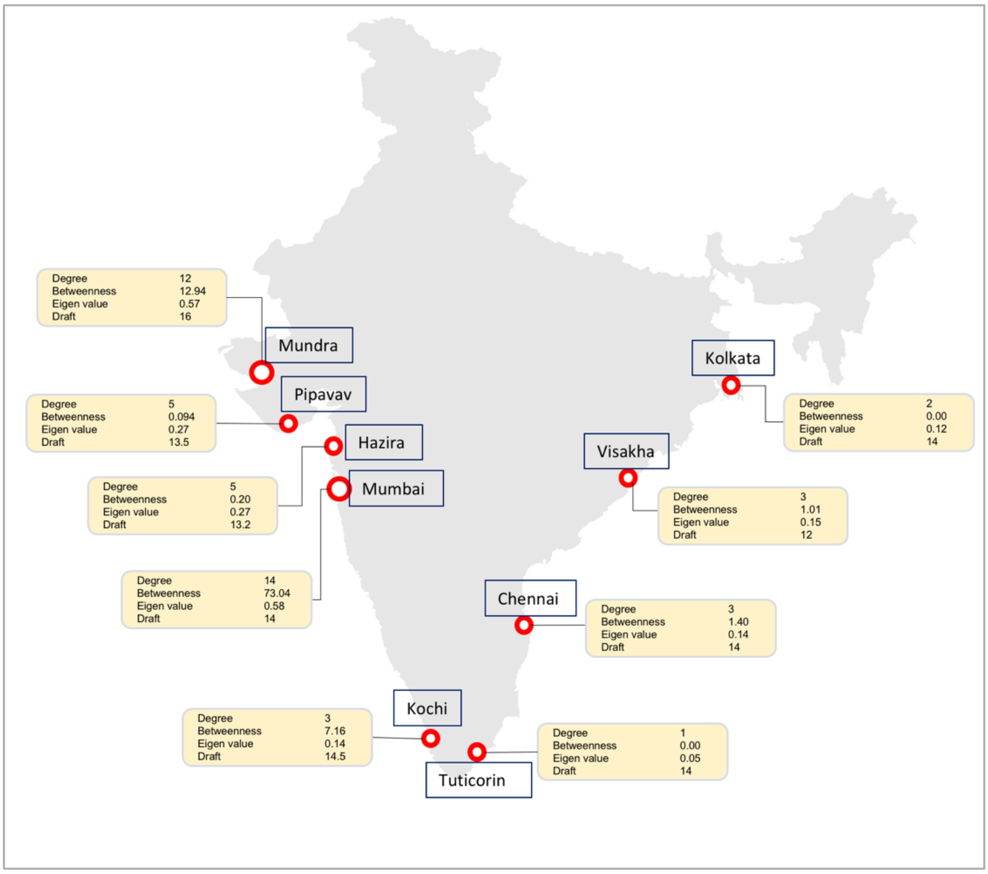

Figure 18 Centrality measures of Indian ports in the network

(Source: Author, 2017)

The degree distribution of the Indian subcontinent confirms the correlation of throughput to degree of ports. The absence of certain Indian ports can be attributed to lack of port of calls from major carriers and the presence of intra-regional feeder systems.

5.6 Sensitivity Analysis

Having mapped the network, we can see the significant nodal ports and their hierarchy. The feasibility of the transhipment terminal in Vizhinjam would depend on its ability to utilize the constructed capacity by attracting services from within the network and new markets. Considering the berth capacity of the port compared to other ports we calculated the vessel calls Vizhinjam port would attract on a weekly basis. Based on the 25 lifts per minute estimated capacity in the first phase, along with 2 berths on an 800-meter-long quay, with 8 cranes, the Vizhinjam port is expected to hand 3 Main liner and 5 Feeder calls weekly at 100% berth utilization. We performed a sensitivity analysis taking the estimated service capacity as the datum, along with an over as well as under confident scenario. The Vizhinjam port owing to it strategic location, could be connected to all the major ports in the Indian ocean region on a pendulum service or line bundling service. Weekly routes based on the operational capacity were tried with different sets of ports and formed network features analysed. A method of trial and error was tried on every permutation of linkages between Vizhinjam and ports with a degree of higher then 7, this was followed by filtering based on centrality measures. The connection was then checked for feasible application, as some connection made little economic sense. Another drawback to this method was the constrains limited links to direct links only. Furthermore, it can be seen connection with any of the Indian ocean port, invariably makes Vizhijam a pivotal node provided it is connected to other cluster's central nodes, this highlights the opportunity to explore African feeder market along with domestic feeder services. Due to lack of any major port, Mogadishu and Djibouti are the only competitors in the region and draft constraints restricts their growth to feeder networks only unlike Vizhinjam. Linkage with Jebel Ali and Singapore is crucial for Vizhinjam as they affect both network measures and market opportunity.

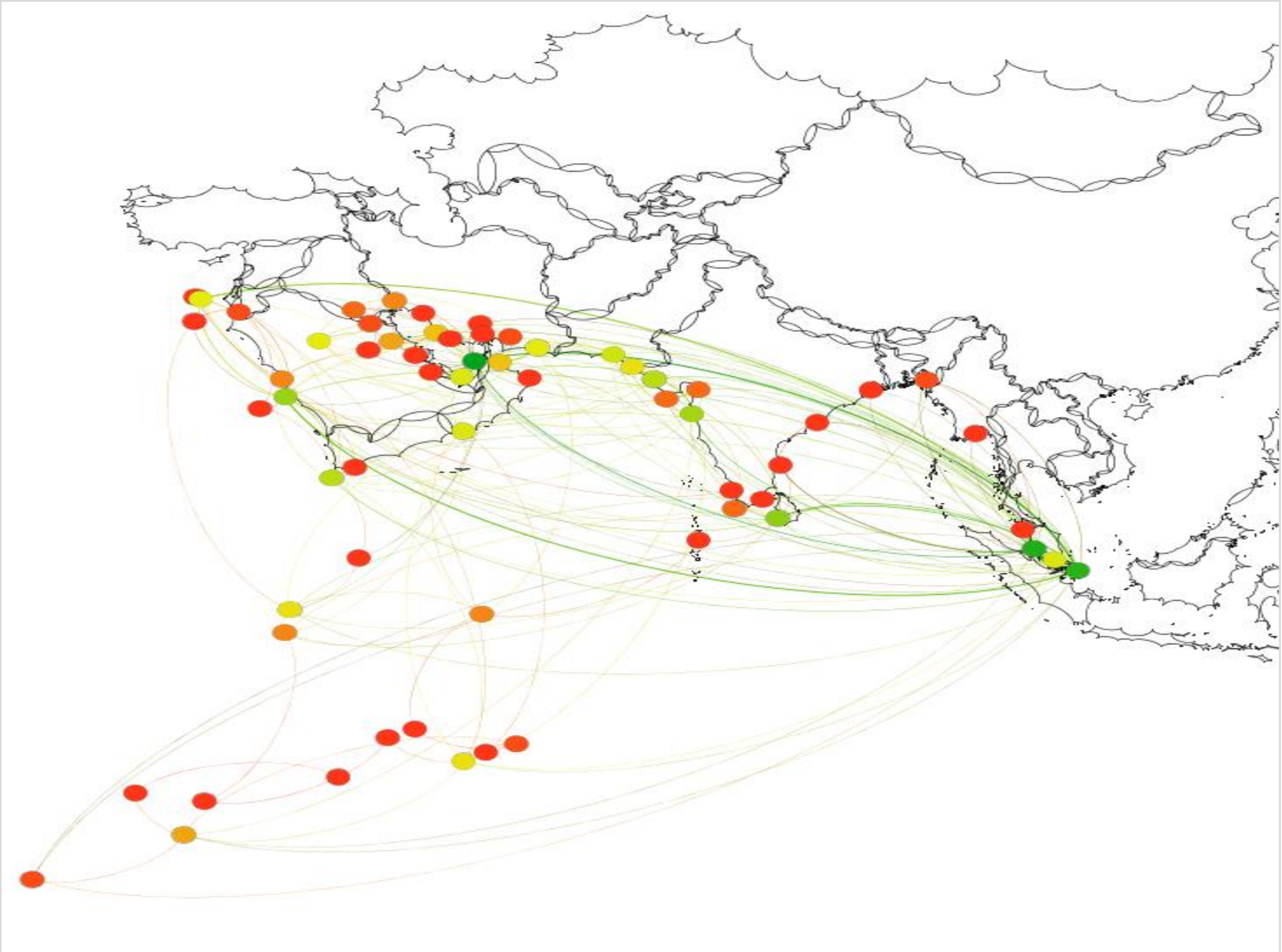

Figure 19 South Asian maritime network including Vizhinjam optimum forecast

(Source: Author, 2017)

Considering that at the current berth and operation specification, at most 2 mother and 3 feeder vessel service could be accommodated at 65% berth utilization as estimate by AECOM(2014). Different link combinations result in different patterns, but considering the goal of transhipment and the expected availability transit cargo, certain ports along the Suez route and East-west route were give preferences. The increase in number of clusters upon connection with focal points in each of the present clusters, highlights feeder network development opportunities. Line bundling services in Indian ocean region and west cost point towards the ability of Vizhinjam to mimic Colombo in the network. This is confirmed by the increase in modularity and clustering coefficient of the system highlighting community formation with less transitivity. Deeper draft compared to some of the central ports in the network also highlights unexplored opportunity as mentioned previously.

5.7 Feasibility Analysis

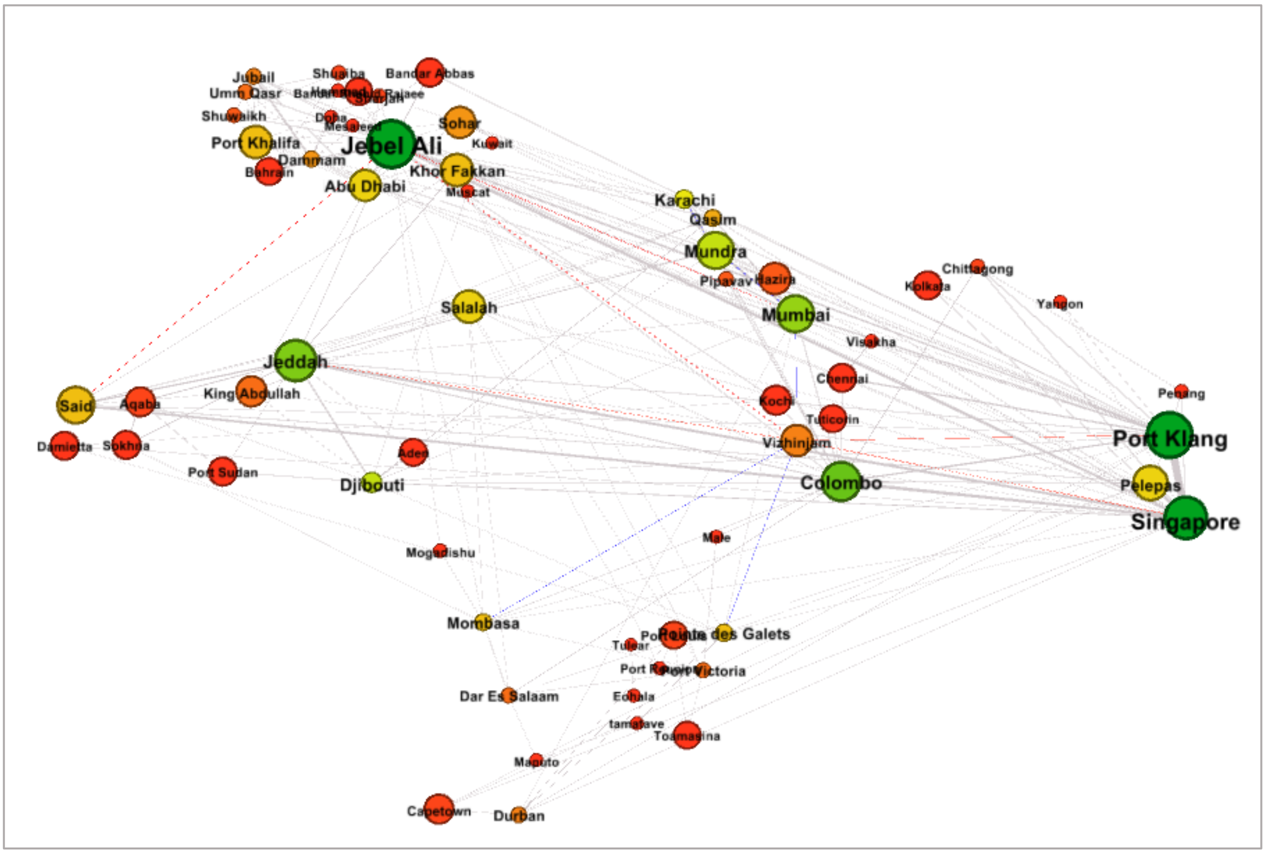

Figure 20 Port network including Vizhinjam.

(Note: Green nodes have highest degree of connection and red the least and Size highlights betweenness of the nodes)
(Source: Author, 2017)

The port physical features allow it to harbour the biggest ships currently in service. The central location also would ensure the port feature on shipping liner network provided it could match performance standard required for efficient operation of liner fleet. But considering the current container shipping scenario where ships are growing in size and exceeding 20,000 TEUs, port's infrastructure would most likely come under strains. The presence of 2 berths with a quay length of 800m would allow simultaneous operation of 2 vessels (One ULCV and One New Panamax). One mother -feeder pair simultaneously. This would lower transhipment cost owing to reduced dwell time on simultaneous feeder-mother berthing. The introduction of the ports and services change the structure of the network as described in the previous section. Depending on the ports performance a notable change in the structure of clusters and the density within clusters is seen as tested by the modularity change in the system. The juxtaposing of this with centrality measures highlight the potential of the port in the long run but it would be subject to various commercial and logistical factor in the hinterland and forelands. There could be seen the ability of Vizhinjam to assimilate into present clusters without changing the structure of the network by staying connected to central nodes. There is also a possibility of increasing the number of cluster by connecting to feeder networks. These options highlight the potential of Vizhinjam from a network perspective, but the viability of the project would depend on many of the factors discussed in figure 10. Though the physical characteristics can be used for benchmarking, the network changes are affected by liner preferences which depend on other variables.

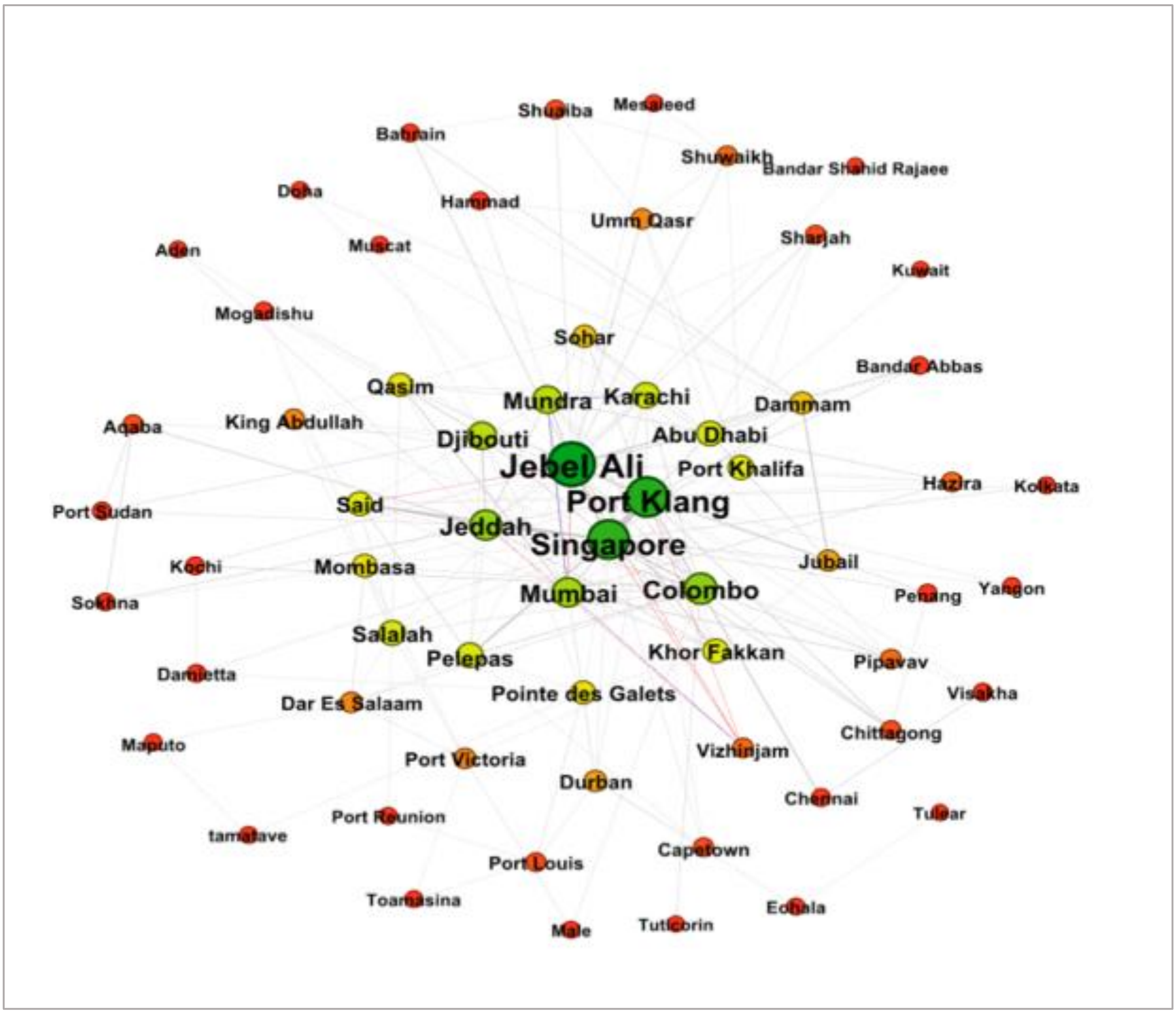

Figure 21 Degree Centrality Based South Asian Port Network

(Source: Author, 2017)

The current capacity of Vizhinjam puts it in a suitable position in the network placing it higher than most of the existing ports, but it still remains connected to few ports due to berth capacity. This masks Vizhinjam's strategically significant position and ability to operate as a transhipment hub to a certain extend. But for a greenfield project, this estimated network feature is a positive step which in all likelihood be complemented by APSEZ's ability to ensure world class standards and a well defined network of APSEZ ports and terminals.

Chapter Six - Discussion

6.1 Role of Vizhinjam International Seaport Terminal

Understanding the network properties was essential to recognize how the system operates and behaves but other parameters need to be considered to access the viability of certain nodes and their affects on the system. With around 95% of the country's trade by volume and 70% by value being carried via ships, ports are crucial to the India's economy (IBEF, 2017). With more than 1600 million metric tonne of cargo handled in its 12 major and 64 minor ports, the need to increase capacity is paramount. A lack of deep port for mother vessels to berth has significantly affected the Indian customer. The added logistical costs as a result of lack of direct calls and a domestic transhipment port has been long identified. The transhipment of containers via foreign ports like Colombo, Singapore is at a great cost of loss traffic at Indian ports and increased cost for shippers. Indian cargo constituting 48% of the transhipped cargo at Colombo embodies the dire need for capacity building especially in the form of a major transhipment port (Kurup, 2017). Perhaps the development of Vizhinjam International Seaport Terminal under the government's priority area as a transhipment hub is a pragmatic and important step to improve the Indian maritime sector. With Chinese investments into Colombo and Hambantota which have similar network characteristics, the urgency to develop Vizhinjam is vital (BBC,2017).

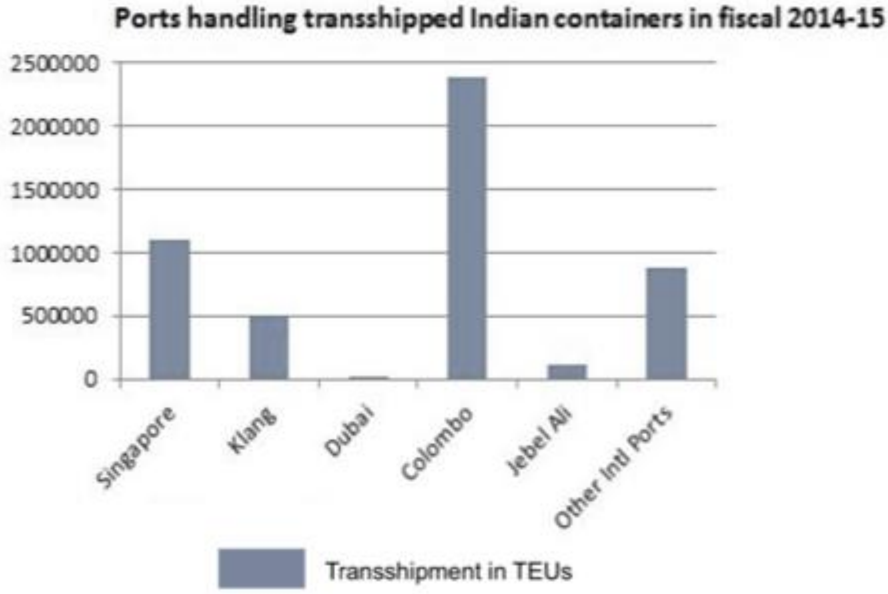

Figure 22 Ports handling Indian transshipment cargo

(Source: Ministry of Shipping, 2015)

But the rush to build transhipment hub should be done cautiously. Vallarpadam - Kochi, was Kerala's attempt to break through the transhipment market. With DP world operating the terminals on a BOT model, the port still couldn't attract mother vessels with cargo throughput remaining less than 500,000 TEUs (Ministry of Shipping, 2016). Lower draft, unionization and tariff related issue further bogged down its growth. Unlike Vallarpadam - Kochi, Vizhinjam International Seaport Terminal is a greenfield project. The public private sector partnership on the DBFOT basis with Adani Ports offers ample opportunity. Adani Ports are the leading private sector port developer and operator in India. They currently operate 10 ports and terminals across the Indian coastline, Mundra being the largest and amongst the fastest growing container ports in the country. With the project on schedule, the role of Vizhinjam would initially be to secure Indian transhipment cargo. The port with is deep basin and planned operational machinery can host the largest vessels in the world from day one. The presence of large hinterland albeit overlapping would complement the transhipment cargo. The central location at the southern tip would also cater to the east-west coast and the can act as gateway connecting regional network to the global network. The proximity to major routes, natural deep draft and the availability of gateway cargo from the southern hinterland would make Vizhinjam sustainable transhipment hub.

6.2 Challenges

Port growth is a function of liner network, which aims to meet the growing global supply chain demands at the optimum operational cost and customer requirements, in terms of accessibility, service time and frequency (Ducruet & Notteboom, 2012). With major liner shipping companies operating with inland logistic providers to provide door-to door service, hinterland activity also become a crucial decision making factor. The Vizhinjam port development project even with its central location is subject to some challenges.

1. Network positioning - The authorities need to attract major shipping lines to call at Vizhinjam. In the complex global supply chain multiple parties starting from shipper to liner operator and port operator play roles in the port selection process. CMA-CGM and MSC operating joint ventures with the Adani ports is a positive sign but the low designed berth capacity would shift focus to the next challenge.
2. Performance and Reliability - "Shipping lines require reliable ports and will sail their ships elsewhere if a port is not reliable", said Cecilia Eckelmann Battistello, managing director of Contship Italia, Gioia Tauro's operator (CISL, 2012) following a drop in Gioia Tauro's throughput after the withdraw of Maersk line from calling at the port (CISL, 2012). The phase one would furnish 800m of quay accommodating 2 berths and container capacity of 900,000. In ensuring maximum capacity utilization and schedule

reliability, productivity of the terminals would need to be better or at least at par with Colombo and other major ports to ensure quick turnaround. Mundra port operates at an average turnaround time of 0.8days with 30 lifts per hour with capacity utilization factor of 82.6% (Behara, 2016) highlighting operating efficiency of Adani ports. Mundra and Vizhinjam have similar quay dimensions (810m and 800m respectively) which allows APSEZ to implement a similar process flow.

3. Geographic location - Apart from closeness to shipping lanes and destination markets, connection to intermodal networks also play a crucial role in port development (CISL,2012). The challenge to integrate different modes of transport to improve hinterland connectivity would be crucial to the growth of Vizhinjam port. With 4 ports vying for the same hinterland, inland penetration and connectivity would play a crucial role in increasing throughput and attracting customers.
4. Value creation - Value added services like packing, assembly or presence of special economic zones around port make ports attractive. The lack of space around Vizhinjam and the allocation of 37 hectare of land as SEZ could be a deterrent when compared to ports like Mumbai, Mundra, Colombo and Singapore with larger allocated areas for the same.
5. Logistical Infrastructure - As per the world bank, India ranked 35th in the logistical performance index, lower than many of India's Asian counterparts. The added lead time coupled with unreliable services usually leads to increase in cost for shipper. The shared hinterland which offers multiple gateways to add options for shippers requirement is nullify due to political and bureaucratic redtapes which affect port growth and efficient logistics (Ng & Gujjar, 2009).

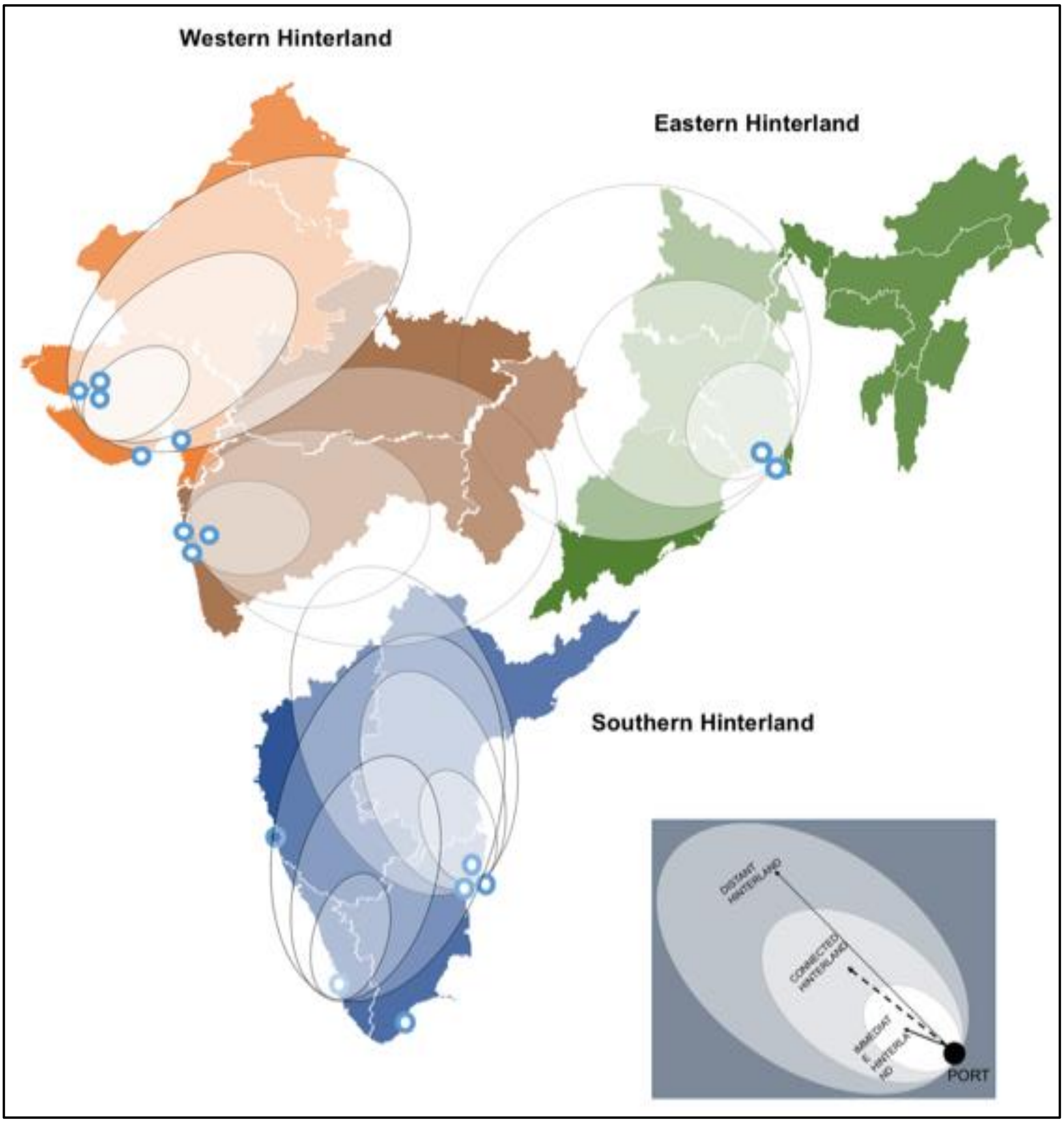

Figure 23 Indian Hinterland Concentration around ports

(Source: Author, 2017)

6.3 Opportunities and Future Scope

The emergence of ports as a network of terminals, have seen ports become an interface between transport and economic geography. This is further supplemented by the rise of port operating transnational corporations (Oliver & Slack, 2006). Institutional changes are a vital element that determines the strategic choices that affect growth of ports and the last two decades has witness considerable changes in the Indian Maritime sector. Liberalization of foreign investment schemes and taxation laws under the national maritime development program have guised into opportunities for firms like Maersk, DP-world, Adani Ports et al to capture a fairly under-developed sector in India. The development of the international

container transhipment terminal at Kochi and now Vizhinjam is a result of those changes. But to be competitive in the global arena, there is a need for policy inputs as well as suitable conditions to foster business performance to reduce cost (Porter,1990).
Port reforms initiatives have been important, considering the lack of commercial orientation needed to compete with global ports. Firstly, the loosening of cabotage laws was a positive move in reducing transhipment cost of major deep harbour ports to cater to mother vessels. This not only reduced transhipment volume moving to ports abroad but also ensured growth of domestic ports. Shippers would also benefit as a result of reduce cost and exploit economy of scales of vessel operating on the main trade routes. Secondly, 100% FDI in ports on BOT basis has given autonomy to port operators to be competitive. Financial and infrastructural development decisions previously need to be approved by central government, delaying decision making significantly in a highly dynamic market (Panigrahi & Pradhan, 2012). It also led to skill and technology upgradation, a fundamental requirement of a partially modernized sector, this improved port efficient and instilled competitiveness in turn increasing productivity of ports. The success of greenfield port projects depends on collaboration between various institutions like the government at the national and the state level, transport ministry including railways, airways and service providers. The government also needs to ensure industrial and infrastructural development goes together in tandem with port development to maximize the synergies. The current participation of an increasing number parties and the growth rate of privately operated ports highlight the success of policy changes made in the recent year, but further synergies are required to ensure consistent growth. There is a strong need for coordination at the national, regional as well as local level to optimize the growth opportunity for Vizhinjam and improving overall logistics for smooth business development reducing transportation cost for shippers.

The development of regional port system serving different hinterland with State-Center government co-operation along with infrastructure development would also help channelize domestic cargo to maritime transportation system. This would also improve the chances of growth for the Vizhinjam transshipment port. There is also an urgent need to ensure competitiveness via technological upgrade, policy changes and talent development to facilitate blending of local and foreign investment into the maritime sector to suit the future requirements of the Indian economy. The current transition to industry 4.0 present Vizhinjam opportunity to incorporate essential digital infrastructure in development of the port and get head of the curve. The current National Maritime Development Program's policy changes have encouraged growth, but the sector still remains premature and a need for collaborative vision is essential albeit the success of some recent projects. There are certain logistical and commercial uncertainties like intermodal connectivity, hinterland development, value creation, that need to be focused on (Ng & Gujjar, 2009). Establishment of distribution centers, warehouses and other logistical platforms is essential to support container ports (Panigrahi & Pradhan, 2012). Though the deep draft allows Vizhinjam ample opportunities, these factors should be address in order to secure distinct advantage as a transshipment port.

Chapter Seven – Conclusions

7.1 Summary

In the current global logistical and supply chain dynamics, ports have evolved from gateway points in trade to value creating nodes. Today ports are socio-economical, technological and commercial hubs in the logistical network facilitating trade. The network of ports in an ever expanding market is intricate and understanding its characteristics provide valuable insights. This dissertation provides an analysis of the South Asian port network. It examines the structure of the network and provides the hierarchy of ports in the South Asia, Middle East and Indian Ocean region. There are 4 partially overlapping clusters in the structure of the network highlighting the small-world features of the network. Each cluster being focused on a specific market zone. The analysis further underlines the significance of ports like Jebel Ali, Jeddah and Colombo in the South Asian system. The regression analysis of the port throughput and centrality measure with draft does not emphasizes on the importance of draft as a factor affecting port's relative position in the system due to the advent of megaships. The outcome maybe affected due to small data set, but it aptly points out deeper draft does not does not guarantee more cargo. Other external factors and operational efficiency is crucial for port growth. The presence of few highly connected ports characterized by a degree distribution albeit in a small data set posit the scale free nature of the system. It also points out the dire lack of intra-port connection in India and urgent need for a major transshipment port in India. Mumbai and Mundra are the most central ports in country. The network analysis is supplemented by the throughput analysis. Major part of both ports are privately operated. Vessel call at both ports in 19 services highlighting large number line bundling services, putting both port on the feeder network. The analysis which was based on liner vessel call schedule also lighted the choice of only one port of call in South Asian ports by most carriers deploying megaships (Like Maersk, MSC, COSCO).

Contemporary container shipping which is characterized by the ever increasing vessel capacity, new alliances have had considerable affect on the network of port. This can be seen in the regional distribution of services by specific alliances and reduced port call in trunk routes like the FAL or Asia-Europe services with maximum of 4 port calls in the region. The large number of feeder service also stress the draft constraint on bigger vessel, which could have been used on line bundling services instead of operating on a hub-spoke system. The need to improve coverage and service frequency along with assimilation of the fleet of mega ships into the network system has intensified inter-port competition, highlighting the need for ports to sustain and improve facilities including infrastructure to maintain attractiveness to the users. There is also high connection between hub ports, on an average, more than 30% of the connection of hubs are with other hub ports. The overarching dependence of Indian western ports on Jebel Ali and Colombo while eastern ports rely on Port Klang, Pelepas and Singapore confirms the need for transshipment hub from a network perspective. The large number of links between the hub ports in the network passing close to Vizhinjam presents a lot of opportunities. Analysis of each cluster individually also highlight the centrality of Colombo in the Indian ocean and Djibouti in African region and Jebel Ali in the middle-east. It must be noted that Singapore's prominence is underrated when we analysis the south Asian network on liner schedule due to omission of links outside the research area. On a global scale the relative position of Singapore is much higher compared to other ports in the south Asian network but within the network Jebel Ali remains most centrally connected port in the South Asian network.

The sensitivity test of Vizhinjam based on the estimated capacity of the port after completion of phase I shows positive result, from a network perspective. The introduction of Vizhinjam into the system changes various features of the network depending on the services to be deployed via Vizhinjam. The test based on a maximum of 5 calls for week at 65% utilization, of various combinations of Mother-feeder vessel with various ports shows an increase in the number of cluster in the system, highlighting the possibility of forming a feeder network with multiple regions in the system. This argument is confirmed with an increase in the clustering coefficient of the system when Vizhinjam is connected to central ports in each cluster. Connection to Suez and Singapore along with feeder line bundling network from west coast ports and Indian ocean regions increase the modularity and reduces clustering coefficient signifying the possibility for pendulum operations with Vizhinjam as pivot. This could be used as a good selling point to infuse post panamax vessels into pendulum and line bundling routes to absorb overcapacity and increase vessel calls. Colombo also largely operates on a similar configuration with line bundling operation of new panamax vessel, but the scope for Vizhinjam to developed could be attributed to the Indian market and availability of a larger hinterland for production and value creation. Ventures with MSC and CMA-CGM (members of two different alliances) in Mundra port provide unique opportunity for APSEZ to expand the loyalty at Vizhinjam as both liners have strong presence in Middle East and Indian Ocean regions. Though the network analysis of Vizhinjam present multiple permutations of links and positioning options, the viability of the project would largely depend on the operational efficiency of the port. With port like Mumbai, Mundra in the west and Chennai in the east already serving as gateway ports, transit from the same hinterland and transshipment would mean VISL would also need to develop hinterland infrastructure including economics zones and intermodal connectivity which play an elemental role in hub port selection.

7.2 Limitation and Further Research

Network research opens up several interesting queries for further investigation. As mentioned before, the relative position of ports (especially ports at both extremities due to their likely connection with other outside our research region) would change when considering global liner network and derive network measures for the south Asian region. Port selection for network analysis which were based on author's selection can be changed according to liner company and customer requirement, therefore adding a limitation to the research. Other attributes apart from draft of ports which were not included, like berth capacity, crane speed et al could have added multiple dimensions in the network analysis and provide a better analysis. Directed links could be included along with vessel capacity to assess the traffic flow and link weight to provide a more in-depth understand of container flow. Topology aspects and orthodromic distance between ports would also be included with operational cost to add the liner's perspective to the analysis. Inclusion of intermodal networks could also be added to incorporate inland penetration. The effects of networks on policy and vice versa also provoke rationalizing as policies play a crucial role in the development and growth of a port. The research could hence dwell into further in the future.

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Appendix

Appendix A - Node List for SNA

NODE ID	NAME	LABEL	NODE ID	NAME	LABEL
1	Pelepas	Pelepas	32	Mesaieed	Mesaieed
2	Abu Dhabi	Abu Dhabi	33	Mogadishu	Mogadishu
3	Aden	Aden	34	Mombasa	Mombasa
4	Aqaba	Aqaba	35	Mumbai	Mumbai
5	Bahrain	Bahrain	36	Mundra	Mundra
6	Bandar Abbas	Bandar Abbas	37	Muscat	Muscat
7	Bandar Shahid Rajaee	Bandar Shahid Rajaee	38	Penang	Penang
8	Capetown	Capetown	39	Pipavav	Pipavav
9	Chennai	Chennai	40	Pointe des Galets	Pointe des Galets
10	Chittagong	Chittagong	41	Port Klang	Port Klang
11	Colombo	Colombo	42	Port Louis	Port Louis
12	Damietta	Damietta	43	Port Khalifa	Port Khalifa
13	Dammam	Dammam	44	Port Sudan	Port Sudan
14	Dar Es Salaam	Dar Es Salaam	45	Port Victoria	Port Victoria
15	Djibouti	Djibouti	46	Qasim	Qasim
16	Doha	Doha	47	Said	Said
17	Durban	Durban	48	Salalah	Salalah
18	Eohala	Eohala	49	Sharjah	Sharjah
19	Hammad	Hammad	50	Shuaiba	Shuaiba
20	Hazira	Hazira	51	Shuwaikh	Shuwaikh
21	Jebel Ali	Jebel Ali	52	Singapore	Singapore
22	Jeddah	Jeddah	53	Sohar	Sohar
23	Jubail	Jubail	54	Sokhna	Sokhna
24	Karachi	Karachi	55	tamatave	tamatave
25	Khor Fakkan	Khor Fakkan	56	Tulear	Tulear
26	King Abdullah	King Abdullah	57	Tuticorin	Tuticorin
27	Kochi	Kochi	58	Umm Qasr	Umm Qasr
28	Kolkata	Kolkata	59	Visakha	Visakha
29	Kuwait	Kuwait	60	Yangon	Yangon
30	Male	Male	61	Port Reunion	Port Reunion
31	Maputo	Maputo	62	Toamasina	Toamasina

Appendix B1 Edge list of south Asian Port Network

Link ID	Source	Target		Link ID	Source	Target		Link ID	Source	Target
1	Tanjung	Colombo		39	Pointe des G	Port Louis		77	Jebel Ali	Shuaiba
2	Colombo	Said		40	Dar es Salaar	Mombasa		78	Shuaiba	Umm Qasr
3	Tanjung	Said		41	Mombasa	Sokhna		79	Umm Qasr	Abu Dhabi
4	Tanjung	Said		42	Port Louis	Pointe des Galets		80	Abu Dhabi	Sharjah
5	Tanjung	Said		43	Kuwait	Abu Dhabi		81	Sharjah	Sohar
6	Said	Singapore		44	Abu Dhabi	Muscat		82	Sohar	Qasim
7	Said	Singapore		45	Muscat	Djibouti		83	Qasim	Mundra
8	Singapore	Said		46	Djibouti	Mogadishu		84	Mundra	Mumbai
9	Singapore	Said		47	Mogadishu	Mombasa		85	Mumbai	Khalifa
10	Said	Salalah		48	Mombasa	Dar es Salaam		86	Sohar	Karachi
11	Salalah	Colombo		49	Dar es Salaar	Maputo		87	Karachi	Mundra
12	Colombo	Singapore		50	Singapore	Jeddah		88	Mundra	Sohar
13	Said	Singapore		51	Singapore	Jebel Ali		89	Jebel Ali	Abu Dhabi
14	Said	Singapore		52	Singapore	Colombo		90	Abu Dhabi	Khalifa
15	Said	Tanjung		53	Colombo	Jeddah		91	Khalifa	Sharjah
16	Singapore	Said		54	Singapore	Damietta		92	Sharjah	Jebel Ali
17	Salalah	Singapore		55	Singapore	Jeddah		93	Khalifa	Jebel Ali
18	Said	King Abdullah		56	Singapore	Jeddah		94	Jebel Ali	Shuaiba
19	King Abdulla	Jebel Ali		57	Singapore	Klang		95	Shuaiba	Umm Qasr
20	Jebel Ali	Singapore		58	Klang	Jebel Ali		96	Umm Qasr	Khalifa
21	Singapore	Said		59	Jebel Ali	Damman		97	Jebel Ali	Mundra
22	Said	King Abdullah		60	Damman	Jubail		98	Mundra	Mumbai
23	King Abdulla	Salalah		61	Jubail	Abu Dhabi		99	Mumbai	Qasim
24	Salalah	Tanjung		62	damman	jubail		100	Qasim	Jeddah
25	Singapore	King Abdullah		63	Jubail	Jebel Ali		101	Jeddah	Colombo
26	King Abdulla	Jebel Ali		64	Jebel Ali	Jeddah		102	Colombo	Singapore
27	Jebel Ali	Singapore		65	Jeddah	Jebel Ali		103	Singapore	Colombo
28	Tanjung	Colombo		66	Jebel Ali	Qasim		104	Colombo	Jeddah
29	Salalah	Colombo		67	Qasim	Mundra		105	Singapore	Damietta
30	Colombo	Singapore		68	Mundra	Mumbai		106	Damietta	Singapore
31	Salalah	Jebel Ali		69	Qasim	Mundra		107	Singapore	Jeddah
32	Singapore	Salalah		70	Mundra	Hazira		108	Jeddah	Singapore
33	Salalah	Said		71	Hazira	Mumbai		109	Singapore	Jeddah
34	Said	Singapore		72	Mumbai	Jeddah		110	Jeddah	Singapore
35	Said	Salalah		73	Jeddah	Djibouti		111	Jeddah	Khor Fakkan
36	Salalah	Colombo		74	Djibouti	King Abdullah		112	Khor Fakkan	Jebel Ali
37	Colombo	Singapore		75	King Abdulla	Qasim		113	Jebel Ali	Qasim
38	Djibouti	Pointe des Galets		76	Khalifa	Jebel Ali		114	Qasim	Mumbai

Appendix B2 Edge list of south Asian port network

Link ID	Source	Target		Link ID	Source	Target		Link ID	Source	Target
115	Mumbai	Mundra		153	Mundra	Sohar		191	Chittagong	Klang
116	Mundra	Jeddah		154	Hazira	Jebel Ali		192	Klang	Chittagong
117	Jeddah	Djibouti		155	Jebel Ali	Khor Fakkan		193	Jeddah	Colombo
118	Djibouti	Qasim		156	Singapore	Klang		194	Colombo	Singapore
119	Qasim	Mumbai		157	Klang	Chennai		195	Khor Fakkan	Jebel Ali
120	Mumbai	Hazira		158	Chennai	Colombo		196	Jebel Ali	Qasim
121	Hazira	Mundra		159	Colombo	Cochin		197	Qasim	Mumbai
122	Mumbai	Jeddah		160	Cochin	Damietta		198	Mumbai	Mundra
123	Khor Fakkan	Jebel Ali		161	Damietta	Pointe des Galets		199	Mundra	Jeddah
124	Jebel Ali	Dammam		162	Klang	Durban		200	Jeddah	Khor Fakkan
125	Dammam	Jubail		163	Durban	Cape town		201	Qasim	Mumbai
126	Jubail	Khor Fakkan		164	Cape town	Singapore		202	Mumbai	Hazira
127	khor Fakkan	Jeddah		165	Jubail	Abu Dhabi		203	Hazira	Mundra
128	Jeddah	Khor Fakkan		166	Abu Dhabi	Klang		204	Mundra	Jeddah
129	Khor Fakkan	Jebel Ali		167	Klang	Singapore		205	Jeddah	Djibouti
130	Jebel Ali	Karachi		168	Singapore	Jebel Ali		206	Djibouti	Qasim
131	Karachi	Mundra		169	Jebel Ali	Dammam		207	Mundra	Colombo
132	Mundra	Mumbai		170	Dammam	Jubail		208	colombo	Singapore
133	Jeddah	Aden		171	Umm Qasr	Jebel Ali		209	Singapore	Klang
134	Aden	Djibouti		172	Jebel Ali	Klang		210	Klang	Colombo
135	Djibouti	Jeddah		173	Klang	Jebel Ali		211	Colombo	Jebel Ali
136	Sokhna	Aqaba		174	Jebel Ali	Umm Qasr		212	Jebel Ali	Karachi
137	Aqaba	Jeddah		175	Klang	Jebel Ali		213	Karachi	Mundra
138	Jeddah	Port of Sudan		176	Jebel Ali	Bandar Abbas		214	Singapore	Klang
139	Port of Suda	Jeddah		177	Bandar Abba	Klang		215	Klang	Mumbai
140	Jeddah	Sokhna		178	Klang	Singapore		216	Mumbai	Mundra
141	Shuwaikh	Jebel Ali		179	Pipavav	Colombo		217	Mundra	Karachi
142	Jebel Ali	Shuwaikh		180	Colombo	Klang		218	Singapore	Klang
143	Sohar	Khalifa		181	Klang	Singapore		219	Klang	Chennai
144	Khalifa	Shuwaikh		182	Singapore	Klang		220	Chennai	Klang
145	Shuwaikh	Umm Qasr		183	Klang	Mumbai		221	Klang	Singapore
146	Umm Qasr	Khalifa		184	Mumbai	Pipavav		222	Singapore	Klang
147	khalifa	Abu Dhabi		185	Klang	Mumbai		223	Klang	Mumbai
148	Abu Dhabi	Sharjah		186	Mumbai	Klang		224	Mumbai	Pipavav
149	Sharjah	Jebel Ali		187	Klang	Singapore		225	Pipavav	Colombo
150	Jebel Ali	Sohar		188	Chittagong	Singapore		226	Colombo	Klang
151	Sohar	Karachi		189	Singapore	Klang		227	Klang	Singapore
152	Karachi	Mundra		190	Klang	Chittagong		228	Singapore	Klang

Appendix B3 Edge list of south Asian port network

Link ID	Source	Target		Link ID	Source	Target		Link ID	Source	Target
229	Klang	Karachi		266	Singapore	Jebel Ali		303	Port Victoria	Male
230	Karachi	Mumbai		267	Singapore	Colombo		304	Male	Colombo
231	Mundra	Klang		268	Colombo	Jeddah		305	Colombo	Klang
232	Klang	Singapore		269	Singapore	Jeddah		306	Singapore	Klang
233	Singapore	Klang		270	Singapore	Jeddah		307	Klang	Jebel Ali
234	Klang	Mumbai		271	singapore	jebel Ali		308	Jebel Ali	Mogadishu
235	Mumbai	Pipavav		272	jebel Ali	Dammam		309	singapore	Colombo
236	Pipavav	Colombo		273	Dammam	Jubail		310	Colombo	Jebel Ali
237	Colombo	Klang		274	Jubail	Abu Dhabi		311	singapore	Khor Fakkan
238	Klang	Singapore		275	Abu Dhabi	Klang		312	Khor Fakkan	Jebel Ali
239	Singapore	Klang		276	Klang	Singapore		313	Jebel Ali	Abu Dhabi
240	Dammam	Jubail		277	Singapore	Klang		314	Abu Dhabi	Sohar
241	Jubail	Jebel Ali		278	Klang	jebel Ali		315	Sohar	Klang
242	Jebel Ali	Jeddah		279	jebel Ali	bandar abbas		316	klang	Singapore
243	Jeddah	Said		280	bandar abba	Klang		317	Singapore	Colombo
244	Said	Jeddah		281	Singapore	Klang		318	Colombo	Mumbai
245	Jeddah	Khor Fakkan		282	Klang	Jebel Ali		319	Mumbai	Pipavav
246	khor Fakkan	Jebel Ali		283	jebel Ali	bandar abbas		320	Pipavav	Colombo
247	Khor Fakkan	Jebel Ali		284	bandar abba	dammam		321	Colombo	Klang
248	Jebel Ali	Qasim		285	dammam	abu Dhabi		322	Klang	Singapore
249	Qasim	Mumbai		286	abu Dhabi	singapore		323	Singapore	Klang
250	Mumbai	Mundra		287	singapore	Kolkata		324	Klang	Karachi
251	Mundra	Jeddah		288	Kolkata	Klang		325	Karachi	Singapore
252	Jeddah	Said		289	Klang	Singapore		326	Singapore	Tanjung
253	Said	Jeddah		290	Singapore	Klang		327	Tanjung	Colombo
254	Jeddah	Khor Fakkan		291	klang	chennai		328	Mumbai	Mundra
255	Jebel Ali	Singapore		292	Chennai	Visakha		329	Mundra	Singapore
256	Singapore	Said		293	Visakha	singapore		330	Singapore	jebel Ali
257	Said	Klang		294	Singapore	Klang		331	Jebel Ali	Hamad
258	Singapore	Tanjung		295	Klang	Chennai		332	Hamad	Dammam
259	Tanjung	Said		296	Chennai	Klang		333	Dammam	Jubail
260	Jeddah	Tanjung		297	Klang	Singapore		334	Jubail	Singapore
261	Singapore	Said		298	Klang	Colombo		335	SIngapore	Jebel Ali
262	Said	Jeddah		299	Colombo	Male		336	Jebel Ali	Bahrain
263	Jeddah	Klang		300	Male	Port Victoria		337	Bahrain	Dammam
264	Khor Fakkan	Klang		301	Port Victoria	Dar Es Salaam		338	Dammam	Jubail
265	Singapore	Jeddah		302	Dar Es Salaar	Port Victoria		339	Jubail	klang

Appendix B4 Edge list of south Asian port network

Link ID	Source	Target	Link ID	Source	Target	Link ID	Source	Target
340	tanjung	Colombo	377	tamatave	Maputo	414	Singapore	Tanjung
341	Colombo	Jebel Ali	378	Tanjung	Pointe des Galets	415	Tanjung	Singapore
342	Jebel Ali	Bandar Abbas	379	Khor Fakkan	Karachi	416	Singapore	Said
343	Bandar Abba	Klang	380	Karachi	Mundra	417	Said	jeddah
344	Singapore	Jebel Ali	381	Mundra	Mumbai	418	Jeddah	Tanjung
345	Abu Dhabi	Dammam	382	Mumbai	Djibouti	419	Singapore	Said
346	Dammam	Singapore	383	Djibouti	Jeddah	420	Said	Khor Fakkan
347	Jebel Ali	Bandar Shahid Rajaee	384	Mumbai	Pointe des Galets	421	Khor Fakkan	Klang
348	Bandar Abba	Jebel Ali	385	Pointe des G	Durban	422	Singapore	Said
349	Mundra	Djibouti	386	Durban	Eohala	423	Said	Jeddah
350	Djibouti	Qasim	387	Eohala	Tulear	424	singapore	Said
351	Qasim	Mumbai	388	Mumbai	Khor Fakkan	425	Said	jebel Ali
352	Mumbai	Hazira	389	Jebel Ali	Mombasa	426	Jebel Ali	Klang
353	Hazira	Mundra	390	Mombasa	Port Victoria	427	Singapore	Said
354	Mundra	Jeddah	391	Mundra	jebel Ali	428	Said	Jeddah
355	Jeddah	Khor Fakkan	392	Hazira	Khalifa Port	429	Jeddah	Colombo
356	Khor Fakkan	Jebel Ali	393	Singapore	Djibouti	430	Colombo	Singapore
357	Jebel Ali	Qasim	394	Djibouti	Jeddah	431	Tanjung	Klang
358	Qasim	Mumbai	395	Jeddah	Aqaba	432	Klang	Said
359	Mumbai	Mundra	396	Aqaba	Port Sudan	433	Said	Tanjung
360	Khor Fakkan	Port Victoria	397	Port Sudan	Djibouti	434	Tanjung	Singapore
361	Kolkata	Singapore	398	Djibouti	Klang	435	Singapore	Said
362	Singapore	Klang	399	Tanjung	Singapore	436	Said	Jeddah
363	Klang	Kolkata	400	Singapore	Jeddah	437	Jeddah	Klang
364	Chittagong	Colombo	401	Jeddah	Sokhna	438	Singapore	Khor Fakkan
365	Colombo	Chittagong	402	Sokhna	Aqaba	439	Khor Fakkan	Jebel Ali
366	Chittagong	Singapore	403	Aqaba	Jeddah	440	Jebel Ali	Abu Dhabi
367	Klang	Chittagong	404	Jeddah	Singapore	441	Abu Dhabi	Sohar
368	Jebel Ali	Mundra	405	Singapore	Djibouti	442	Sohar	Klang
369	Mundra	Mumbai	406	Djibouti	Jeddah	443	Singapore	Jebel Ali
370	Mumbai	Durban	407	Jeddah	Sokhna	444	Doha	Dammam
371	Durban	Port Louis	408	Sokhna	Aqaba	445	Dammam	Jubail
372	Port Louis	Pointe des Galets	409	Aqaba	Djibouti	446	Jubail	Singapore
373	Pointe des G	Khor Fakkan	410	Djibouti	Singapore	447	Singapore	Jebel Ali
374	Khor Fakkan	Jebel Ali	411	Singapore	Said	448	Jebel Ali	Bahrain
375	Singapore	Pointe des Galets	412	Said	Klang	449	Bahrain	Dammam
376	Pointe des G	tamatave	413	Said	Colombo	450	Dammam	Jubail

Appendix B5 Edge list of south Asian port network

Link ID	Source	Target		Link ID	Source	Target		Link ID	Source	Target
451	Jubail	Klang		488	Jeddah	Aqaba		525	Cape Town	Klang
452	Tanjung	Colombo		489	Aqaba	Port Sudan		526	Klang	Singapore
453	Colombo	Jebel Ali		490	Port Sudan	Djibouti		527	Klang	Tanjung
454	Jebel Ali	Bandar Abbas		491	Jebel Ali	Umm Qasr		528	Tanjung	Singapore
455	Bandar abba	Klang		492	Umm Qasr	Jebel Ali		529	Singapore	Colombo
456	Singapore	Klang		493	Singapore	Klang		530	Colombo	Mombasa
457	Klang	Colombo		494	Klang	Colombo		531	Mombasa	Klang
458	Colombo	jebel Ali		495	Colombo	Karachi		532	Khor Fakkan	Klang
459	Jebel Ali	Karachi		496	Karachi	Mundra		533	Jeddah	Singapore
460	Karachi	Mundra		497	Mundra	Klang		534	Singapore	Klang
461	Mundra	Colombo		498	Singapore	Klang		535	Tanjung	Singapore
462	Colombo	Klang		499	Klang	Karachi		536	Qasim	Mumbai
463	Klang	Singapore		500	Karachi	Mundra		537	Mumbai	Hazira
464	Singapore	jebel Ali		501	Mundra	Colombo		538	Hazira	Mundra
465	Jebel Ali	Abu Dhabi		502	Colombo	Singapore		539	Mundra	Jeddah
466	Abu Dhabi	Dammam		503	Chennai	Visakha		540	Djibouti	Qasim
467	Dammam	Singapore		504	Visakha	Chennai		541	Singapore	Said
468	Singapore	Klang		505	Chennai	Colombo		542	Said	Jeddah
469	Klang	Mumbai		506	Colombo	Cochin		543	Jeddah	Klang
470	Mumbai	Mundra		507	Cochin	Jebel Ali		544	Singapore	Said
471	Mundra	Colombo		508	Jebel Ali	Cochin		545	Said	Jeddah
472	Colombo	Klang		509	Cochin	Colombo		546	Jeddah	Klang
473	Klang	Singapore		510	Colombo	Chennai		547	Khor Fakkan	Karachi
474	Singapore	Klang		511	Singapore	Klang		548	Karachi	Mundra
475	Klang	Colombo		512	Singapore	Tanjung		549	Mundra	Mumbai
476	Colombo	Mumbai		513	Tanjung	Klang		550	Mumbai	Djibouti
477	Mumbai	Klang		514	Klang	Colombo		551	Djibouti	Jeddah
478	Klang	Singapore		515	Colombo	Dar es Salaam		552	Jeddah	Said
479	Colombo	Chittagong		516	Dar Es Salaar	Colombo		553	Said	Khor Fakkan
480	Chittagong	Colombo		517	Colombo	Klang		554	Jebel Ali	Klang
481	Tanjung	Singapore		518	Klang	Tanjung		555	Jeddah	Colombo
482	Jeddah	Sokhna		519	Tanjung	Singapore		556	Colombo	Singapore
483	Sokhna	Aqaba		520	Singapore	Durban		557	Tanjung	Colombo
484	Aqaba	Jeddah		521	Durban	Singapore		558	Colombo	Jebel Ali
485	Jeddah	Singapore		522	Singapore	Klang		559	Jebel Ali	Bandar Abbas
486	Singapore	Djibouti		523	Klang	Durban		560	Bandar Abba	Klang
487	Djibouti	jeddah		524	Durban	Cape Town		561	Singapore	Khor Fakkan

Appendix B6 Edge list of south Asian port network

Link ID	Source	Target		Link ID	Source	Target		Link ID	Source	Target
562	Khor Fakkan	Jebel Ali		599	Singapore	klang		636	Shuwaikh	Shuaiba
563	Jebel Ali	Abu Dhabi		600	Klang	Karachi		637	Shuaiba	Bahrain
564	Abu Dhabi	Sohar		601	Karachi	Qasim		638	Bahrain	Jebel Ali
565	Sohar	Klang		602	Qasim	Karachi		639	Jebel Ali	Shuwaikh
566	Klang	Singapore		603	Karachi	Singapore		640	Shuwaikh	Mesaieed
567	Singapore	Jebel Ali		604	Singapore	Tanjung		641	Mesaieed	Jebel Ali
568	Jebel Ali	Abu Dhabi		605	Tanjung	Colombo		642	Singapore	Klang
569	Abu Dhabi	Dammam		606	Colombo	Mumbai		643	Klang	Chennai
570	Dammam	Singapore		607	Mumbai	Mundra		644	Chennai	Klang
571	Singapore	Jebel Ali		608	Mundra	Singapore		645	Klang	Singapore
572	Jebel Ali	Bahrain		609	Singapore	Colombo		646	Singapore	Klang
573	Bahrain	Dammam		610	Colombo	Mumbai		647	Klang	Chennai
574	Dammam	Jubail		611	Mumbai	Pipavav		648	Chennai	Visakha
575	Jubail	Klang		612	Pipavav	Colombo		649	Visakha	Klang
576	Singapore	Klang		613	Colombo	Klang		650	KLang	SIngapore
577	Klang	Jebel Ali		614	Klang	Singapore		651	Jebel Ali	Mundra
578	Jebel Ali	Bandar Abbas		615	Singapore	Klang		652	Mundra	Jebel Ali
579	Bandar Abba	Dammam		616	Klang	Chennai		653	Jebel Ali	Mumbai
580	Dammam	Abu Dhabi		617	Chennai	Klang		654	Mumbai	Jebel Ali
581	Abu Dhabi	Singapore		618	Klang	Singapore		655	Tuticorin	Colombo
582	Singapore	Jebel Ali		619	Jeddah	Aden		656	Colombo	Tuticorin
583	Jebel Ali	Doha		620	Aden	Jeddah		657	Singapore	Kolkata
584	Doha	Dammam		621	Cochin	Colombo		658	Kolkata	Singapore
585	Dammam	Jubail		622	Colombo	Cochin		659	Karachi	Mumbai
586	Jubail	Singapore		623	Singapore	Chittagong		660	Mumbai	Mundra
587	Singapore	Djibouti		624	Chittagong	Singapore		661	Mundra	Said
588	Djibouti	Jeddah		625	Jebel Ali	Bahrain		662	Said	Jeddah
589	Jeddah	Aqaba		626	Bahrain	Jebel Ali		663	Jeddah	Karachi
590	Aqaba	Port Sudan		627	Shuwaikh	Jebel Ali		664	Singapore	Tanjung
591	Port Sudan	Djibouti		628	Jebel Ali	Shuwaikh		665	Klang	Singapore
592	Djibouti	Klang		629	Shuaiba	Jebel Ali		666	Khor Fakkan	Klang
593	Tanjung	Singapore		630	Jebel Ali	Shuaiba		667	Klang	Singapore
594	Singapore	Jeddah		631	Jebel Ali	Umm Qasar		668	Jeddah	Singapore
595	Jeddah	Sokhna		632	Umm Qasar	Jebel Ali		669	Jeddah	Colombo
596	Sokhna	Aqaba		633	Sharjah	Jebel Ali		670	Colombo	Singapore
597	Aqaba	Jeddah		634	Jebel Ali	Sharjah		671	Jebel Ali	Klang
598	Jeddah	Singapore		635	Jebel Ali	Shuwaikh		672	Singapore	Said

Appendix B7 Edge list of south Asian port network

Link ID	Source	Target	Link ID	Source	Target	Link ID	Source	Target
673	Said	Jeddah	710	Colombo	Chennai	747	Colombo	Mumbai
674	Jeddah	Klang	711	Singapore	Chittagong	748	Mumbai	Mundra
675	Jeddah	Singapore	712	Chittagong	Singapore	749	Mundra	Singapore
676	Singapore	Said	713	Chittagong	Klang	750	Singapore	Yangon
677	Said	Jeddah	714	Klang	Chittagong	751	Yangon	Klang
678	Jeddah	Klang	715	Chittagong	Penang	752	Klang	Singapore
679	Singapore	Khor Fakkan	716	Penang	Chittagong	753	Singapore	Jebel Ali
680	Khor Fakkan	Jebel Ali	717	Singapore	Penang	754	Jebel Ali	Dammam
681	Jebel Ali	Abu Dhabi	718	Penang	Singapore	755	Dammam	Jubail
682	Abu Dhabi	Sohar	719	Singapore	Klang	756	Jubail	Khalifa
683	Sohar	Klang	720	klang	Penang	757	Khalifa	Klang
684	Klang	Singapore	721	Penang	Klang	758	Klang	Singapore
685	Singapore	Jebel Ali	722	Klang	Singapore	759	Klang	Jebel Ali
686	Jebel Ali	Hammad	723	Singapore	Colombo	760	Jebel Ali	Hammad
687	Hammad	Dammam	724	Colombo	Mumbai	761	Hammad	Umm Qasr
688	Dammam	Jubail	725	Mumbai	Pipavav	762	Umm Qasr	Jebel Ali
689	Jubail	Singapore	726	Pipavav	Klang	763	Jebel Ali	Klang
690	Singapore	Jebel Ali	727	Klang	Singapore	764	Singapore	Klang
691	Jebel Ali	Bahrain	728	Tanjung	Singapore	765	Klang	Mumbai
692	Bahrain	Dammam	729	Singapore	Jeddah	766	Mumbai	Mundra
693	Dammam	Jubail	730	Jeddah	Sokhna	767	Mundra	Colombo
694	Jubail	Klang	731	Sokhna	Aqaba	768	Colombo	Klang
695	Singapore	Tanjung	732	Aqaba	Jeddah	769	Klang	Singapore
696	Tanjung	Jebel Ali	733	Jeddah	Singapore	770	Singapore	Karachi
697	Jebel Ali	Bandar Abbas	734	Singapore	Djibouti	771	Karachi	Mundra
698	Bandar Abba	Klang	735	Djibouti	Jeddah	772	Mundra	Klang
699	Singapore	Jebel Ali	736	Jeddah	Aqaba	773	Klang	Singapore
700	Jebel Ali	Abu Dhabi	737	Aqaba	Port Sudan	774	Singapore	Jeddah
701	Abu Dhabi	Dammam	738	Port Sudan	Djibouti	775	Jebel Ali	Singapore
702	Dammam	Singapore	739	Djibouti	Klang	776	Singapore	Colombo
703	Chennai	Visakha	740	Singapore	Karachi	777	Jeddah	Colombo
704	Visakha	Chennai	741	Karachi	Mundra	778	Colombo	Singapore
705	Chennai	Colombo	742	Mundra	Hazira	779	Klang	Chittagong
706	Colombo	Cochin	743	Hazira	Klang	780	Chittagong	Penang
707	Cochin	Jebel Ali	744	Klang	Singapore	781	Penang	Klang
708	Jebel Ali	Cochin	745	Singapore	Tanjung	782	Singapore	Jebel Ali
709	Cochin	Colombo	746	Tanjung	Colombo	783	Jebel Ali	Bahrain

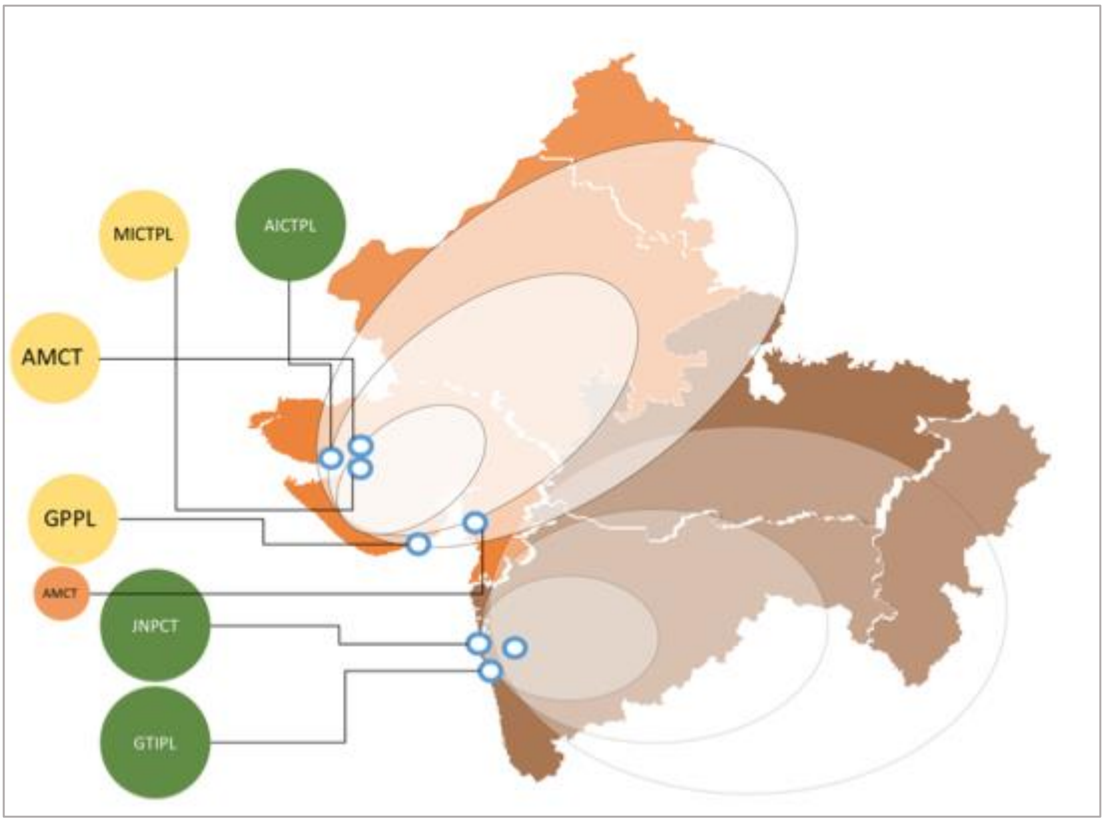
Appendix B8 Edge list of south Asian port network

Link ID	Source	Target		Link ID	Source	Target
784	Bahrain	Dammam		821	Mombasa	Colombo
785	Dammam	Jubail		822	Singapore	Penang
786	Jubail	Klang		823	Penang	Singapore
787	Singapore	Klang		824	Singapore	Jebel Ali
788	Klang	Penang		825	Jebel Ali	Dammam
789	Klang	Penang		826	Dammam	Jubail
790	Penang	Singapore		827	Jubail	Abu Dhabi
791	Singapore	Djibouti		828	Abu Dhabi	Klang
792	Djibouti	Jeddah		829	Klang	Singapore
793	Jeddah	Sokhna		830	Singapore	Klang
794	Sokhna	Aqaba		831	Klang	Mumbai
795	Aqaba	Djibouti		832	Mumbai	Pipavav
796	Djibouti	Singapore		833	Pipavav	Colombo
797	Klang	Singapore		834	Colombo	Klang
798	Singapore	Kolkata		835	Klang	Singapore
799	Kolkata	Klang		836	Singapore	Pipavav
800	Singapore	Klang		837	Pipavav	Karachi
801	Chittagong	Singapore		838	Karachi	Qasim
802	Singapore	Klang		839	Qasim	Mumbai
803	Klang	Mumbai		840	Mumbai	Colombo
804	Mumbai	Pipavav		841	Colombo	Klang
805	Pipavav	Colombo		842	Klang	Singapore
806	Colombo	Klang		843	Singapore	Klang
807	Klang	Singapore		844	Klang	Chennai
808	Singapore	Jeddah		845	Chennai	Klang
809	Singapore	Colombo		846	Klang	Singapore
810	Singapore	Jeddah		847	Singapore	Klang
811	Singapore	Jeddah		848	Klang	Chennai
812	Jeddah	Singapore		849	Chennai	Klang
813	Qasim	Mumbai		850	Klang	Singapore
814	Mumbai	Mundra		851	Chittagong	Colombo
815	Mundra	Jeddah		852	Colombo	Chittagong
816	Jeddah	Jebel Ali		853	Singapore	Klang
817	Jebel Ali	Qasim		854	Klang	Chittagong
818	Colombo	Dar Es Salaam		855	Chittagong	Singapore
819	Dar Es Salaar	Colombo		856	Tuticorin	Colombo
820	Colombo	Mombasa		857	Colombo	Tuticorin

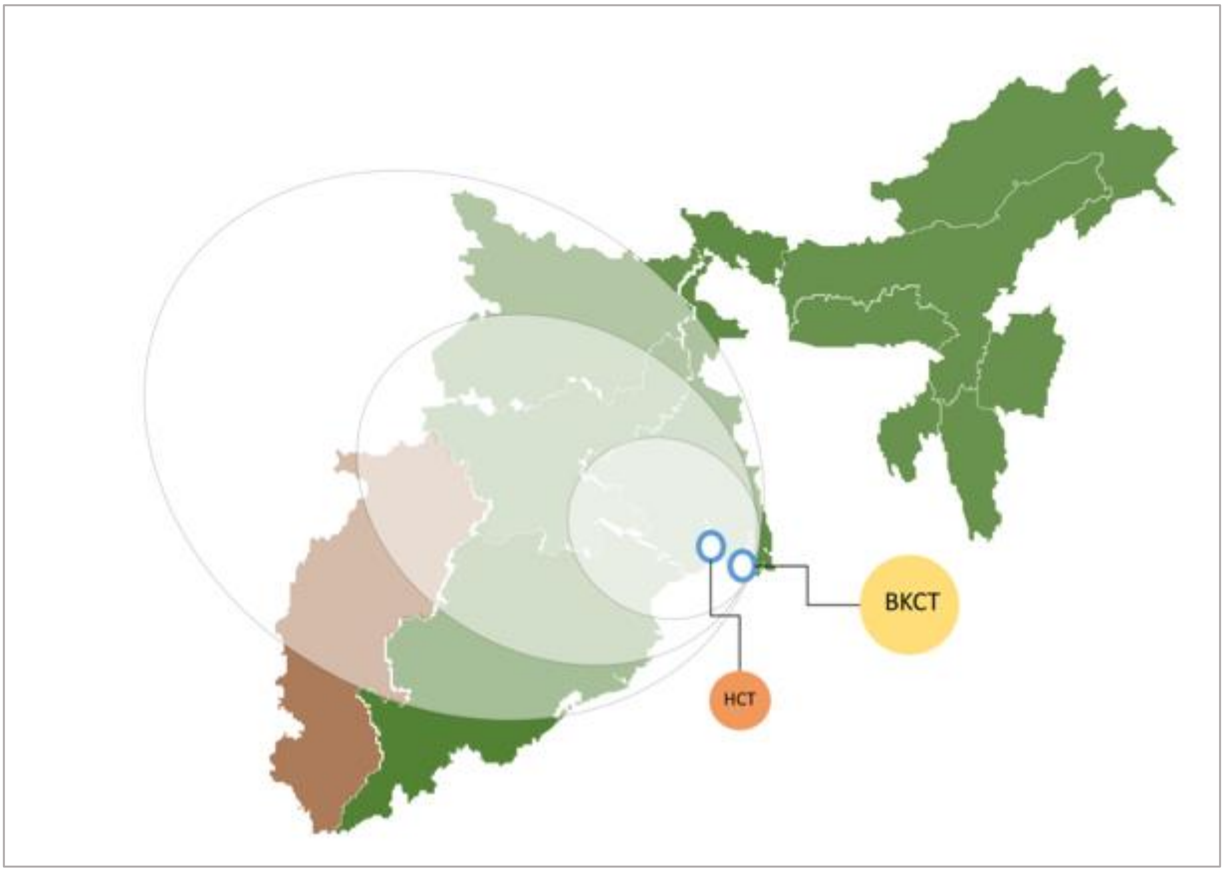
Appendix C - South Asian Region - Network Analysis Table

Node id	Label	Port Name	Degree	Betweeness Centrality	Eigen Centrality	Clustering Coefficient	Modularity Class	Closness Centrality	Eccentricity	Harmonic Closness Centrality	Weighted Degree	Triangles
1	Pelepas	Pelepas	11	49.250	0.507	0.509	1	0.526	4	0.578	45	28
2	Abu Dhabi	Abu Dhabi	11	100.902	0.402	0.364	3	0.473	4	0.545	34	20
3	Aden	Aden	2	0.000	0.091	1.000	0	0.363	5	0.395	4	1
4	Aqaba	Aqaba	4	2.062	0.121	0.667	0	0.370	5	0.414	22	4
5	Bahrain	Bahrain	3	0.500	0.123	0.667	3	0.394	5	0.436	14	2
6	Bandar Abbas	Bandar Abbas	3	0.325	0.176	0.667	3	0.430	4	0.467	17	2
7	Bandar Shahid Rajaee	Bandar Shahid Rajaee	1	0.000	0.078	0.000	3	0.389	5	0.420	1	0
8	Capetown	Capetown	4	1.050	0.204	0.833	1	0.424	3	0.462	6	5
9	Chennai	Chennai	3	1.403	0.141	0.667	1	0.404	4	0.441	26	2
10	Chittagong	Chittagong	4	1.403	0.209	0.833	1	0.421	4	0.462	25	5
11	Colombo	Colombo	18	193.640	0.670	0.320	2	0.545	4	0.627	120	49
12	Damietta	Damietta	3	5.202	0.114	0.333	1	0.404	4	0.439	5	1
13	Dammam	Dammam	8	23.365	0.277	0.357	3	0.459	4	0.518	44	10
14	Dar Es Salaam	Dar Es Salaam	6	54.666	0.192	0.467	2	0.407	5	0.462	13	7
15	Djibouti	Djibouti	14	111.312	0.482	0.264	0	0.477	4	0.561	45	24
16	Doha	Doha	2	0.000	0.105	1.000	3	0.391	5	0.428	3	1
17	Durban	Durban	7	147.050	0.259	0.333	1	0.445	3	0.497	10	7
18	Eohala	Eohala	2	60.000	0.035	0.000	1	0.313	4	0.342	2	0
19	Hammad	Hammad	3	0.333	0.127	0.667	3	0.394	5	0.436	6	2
20	Hazira	Hazira	5	0.200	0.271	0.900	0	0.442	4	0.488	14	9
21	Jebel Ali	Jebel Ali	32	562.648	1.000	0.192	3	0.629	4	0.745	150	95
22	Jeddah	Jeddah	16	142.974	0.650	0.425	0	0.530	4	0.608	114	51
23	Jubail	Jubail	7	3.201	0.350	0.714	3	0.466	4	0.516	34	15
24	Karachi	Karachi	11	9.942	0.535	0.673	0	0.504	4	0.564	35	37
25	Khor Fakkan	Khor Fakkan	10	48.500	0.471	0.511	3	0.508	4	0.561	36	23
26	King Abdullah	King Abdullah	6	3.571	0.295	0.667	3	0.477	4	0.518	8	10
27	Kochi	Kochi	3	7.167	0.147	0.333	2	0.424	5	0.462	12	1
28	Kolkata	Kolkata	2	0.000	0.139	1.000	1	0.401	4	0.433	8	1
29	Kuwait	Kuwait	1	0.000	0.035	0.000	3	0.323	5	0.349	1	0
30	Male	Male	2	2.022	0.072	0.000	2	0.367	5	0.399	4	0
31	Maputo	Maputo	2	3.383	0.033	0.000	2	0.302	5	0.333	2	0
32	Mesaieed	Mesaieed	2	0.000	0.098	1.000	3	0.391	5	0.428	2	1
33	Mogadishu	Mogadishu	3	1.883	0.152	0.333	2	0.430	5	0.466	3	1
34	Mombasa	Mombasa	9	70.512	0.379	0.389	2	0.500	4	0.551	14	14
35	Mumbai	Mumbai	14	73.041	0.584	0.440	0	0.540	3	0.601	73	40
36	Mundra	Mundra	12	12.941	0.574	0.621	0	0.504	4	0.571	67	41
37	Muscat	Muscat	2	1.797	0.076	0.000	0	0.365	5	0.401	2	0
38	Penang	Penang	3	0.000	0.160	1.000	1	0.404	4	0.441	13	3
39	Pipavav	Pipavav	5	0.091	0.278	0.900	0	0.427	4	0.473	18	9
40	Pointe des Galets	Pointe des Galets	9	110.827	0.299	0.278	1	0.469	3	0.527	11	10
41	Port Klang	Port Klang	27	299.648	0.916	0.234	1	0.610	3	0.708	207	82
42	Port Louis	Port Louis	4	24.853	0.077	0.167	2	0.349	4	0.393	6	1
43	Port Khalifa	Port Khalifa	10	21.162	0.375	0.467	3	0.466	4	0.534	13	21
44	Port Sudan	Port Sudan	3	0.000	0.108	1.000	0	0.365	5	0.404	12	3
45	Port Victoria	Port Victoria	6	51.008	0.151	0.200	2	0.386	5	0.442	8	3
46	Qasim	Qasim	9	10.146	0.392	0.556	0	0.466	4	0.526	33	20
47	Said	Said	10	5.198	0.504	0.689	3	0.504	4	0.559	57	31
48	Salalah	Salalah	11	93.567	0.423	0.418	2	0.508	4	0.567	17	23
49	Sharjah	Sharjah	4	0.000	0.177	1.000	3	0.401	5	0.450	8	6
50	Shuaiba	Shuaiba	4	1.000	0.136	0.667	3	0.396	5	0.445	8	4
51	Shuwaikh	Shuwaikh	5	1.833	0.165	0.600	3	0.399	5	0.453	10	6
52	Singapore	Singapore	26	330.309	0.883	0.228	1	0.616	3	0.705	252	74
53	Sohar	Sohar	8	7.194	0.354	0.607	3	0.452	4	0.514	16	17
54	Sokhna	Sokhna	3	3.005	0.100	0.333	0	0.370	5	0.408	15	1
55	tamatave	tamatave	2	10.004	0.040	0.000	2	0.326	4	0.357	2	0
56	Tulear	Tulear	1	0.000	0.011	0.000	1	0.239	5	0.257	1	0
57	Tuticorin	Tuticorin	1	0.000	0.053	0.000	2	0.355	5	0.380	4	0
58	Umm Qasr	Umm Qasr	6	5.333	0.200	0.533	3	0.407	5	0.466	14	8
59	Visakha	Visakha	3	1.010	0.156	0.667	1	0.404	4	0.441	8	2
60	Yangon	Yangon	2	0.000	0.139	1.000	1	0.401	4	0.433	2	1
61	Port Reunion	Port Reunion	2	3.586	0.051	0.000	2	0.355	4	0.383	2	0
62	Toamasina	Toamasina	2	2.980	0.034	0.000	2	0.300	5	0.334	2	0

Appendix D1 Hinterland - Western



Appendix D2 Hinterland - Eastern



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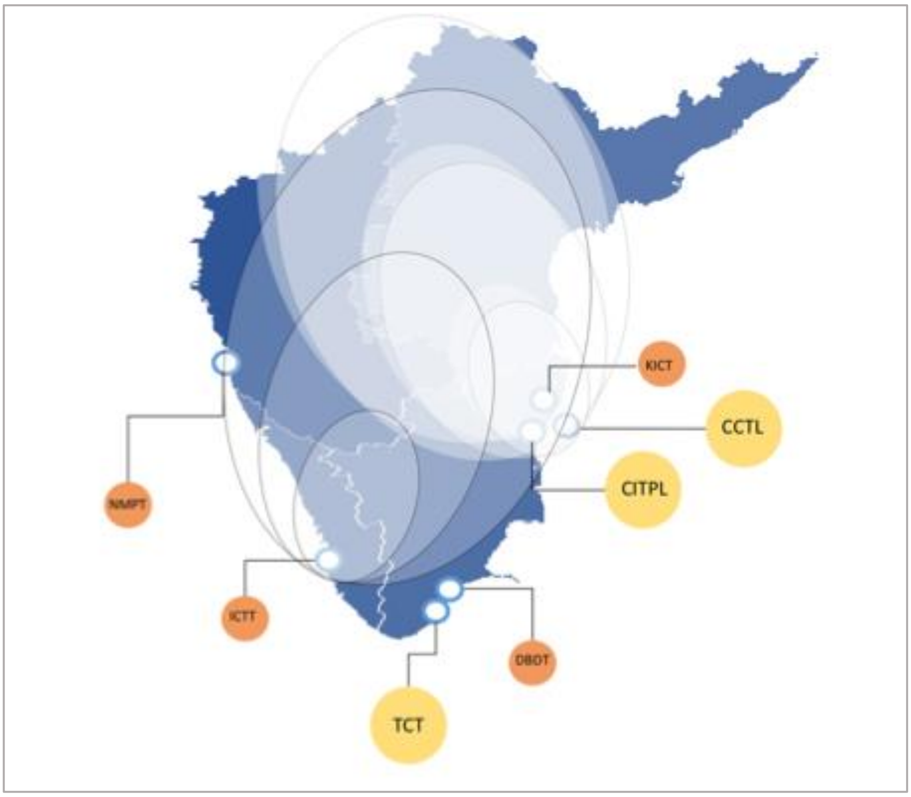
Appendix D3 Hinterland - Southern

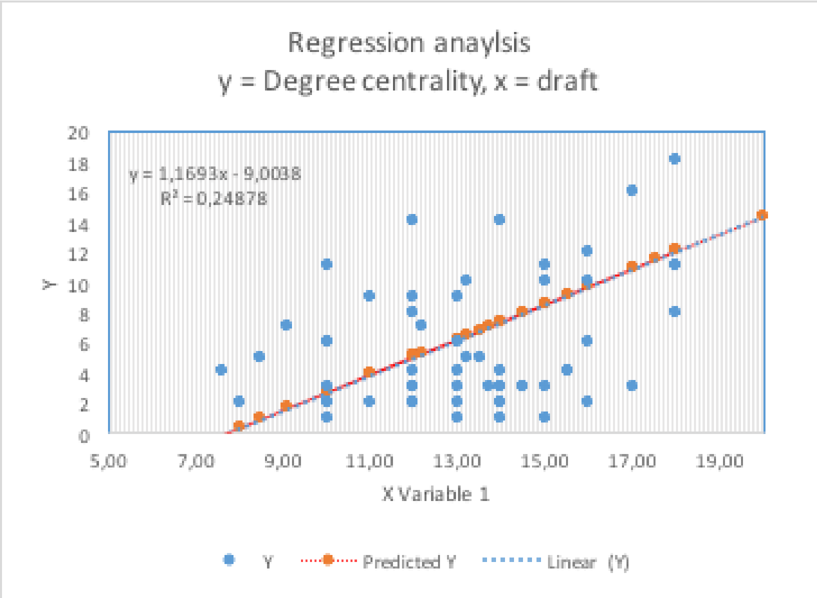


Appendix E Vizhinjam Traffic

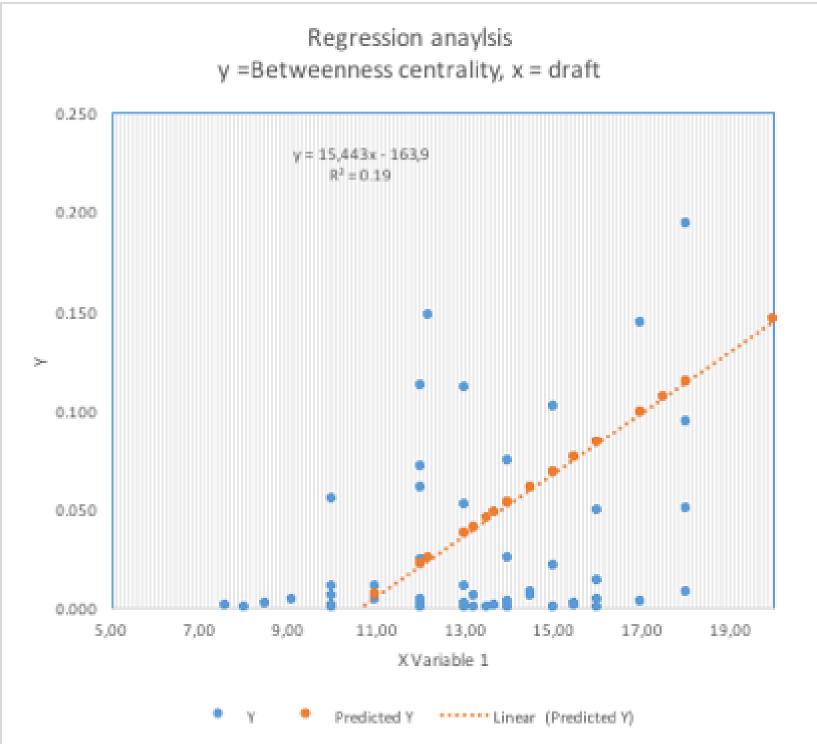
	Unit	Phase 1	Phase 2	Phase 3
		FY14-20	FY21-30	FY31-44
Container terminal				
Gateway Container Traffic	[TEU]	138,459	392,371	768,904
Transhipment container Traffic	[TEU]	683,798	1,292,842	2,054,545
Total	[TEU]	822,256	1,685,212	2,823,449
Vessel calls - main liners	[#]	156	312	520
Vessel calls - feeders	[#]	260	312	468
Multi-purpose terminal				
Fertiliser and FRM	[tons]	20,000	180,000	540,000
Timber	[tons]	24,000	91,000	104,000
Raw cashew (break-bulk)	[tons]	63,000	88,000	133,000
Total	[tons]	107,000	359,000	777,000
Vessel calls	[#]	n/a	n/a	n/a
Liquid terminal				
Petro-products	[tons]	159,000	518,000	1,051,000
Total	[tons]	159,000	518,000	1,051,000
Vessels calls	[#]	n/a	n/a	n/a
Cruise terminal				
Vessel calls	[#]	30	60	120

(Source: Forecast as per Drewry as citied in AECOM, 2014)

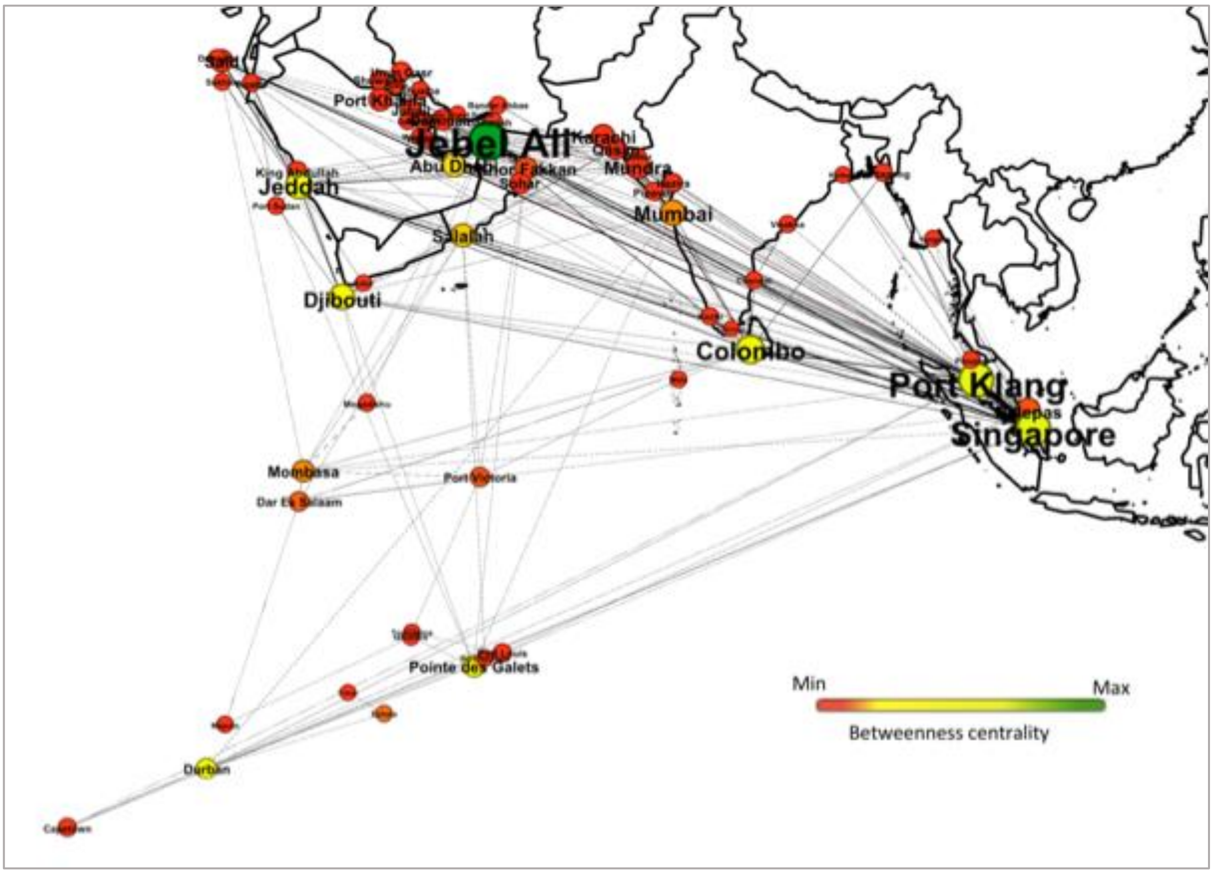
Appendix D Regression Analysis #1



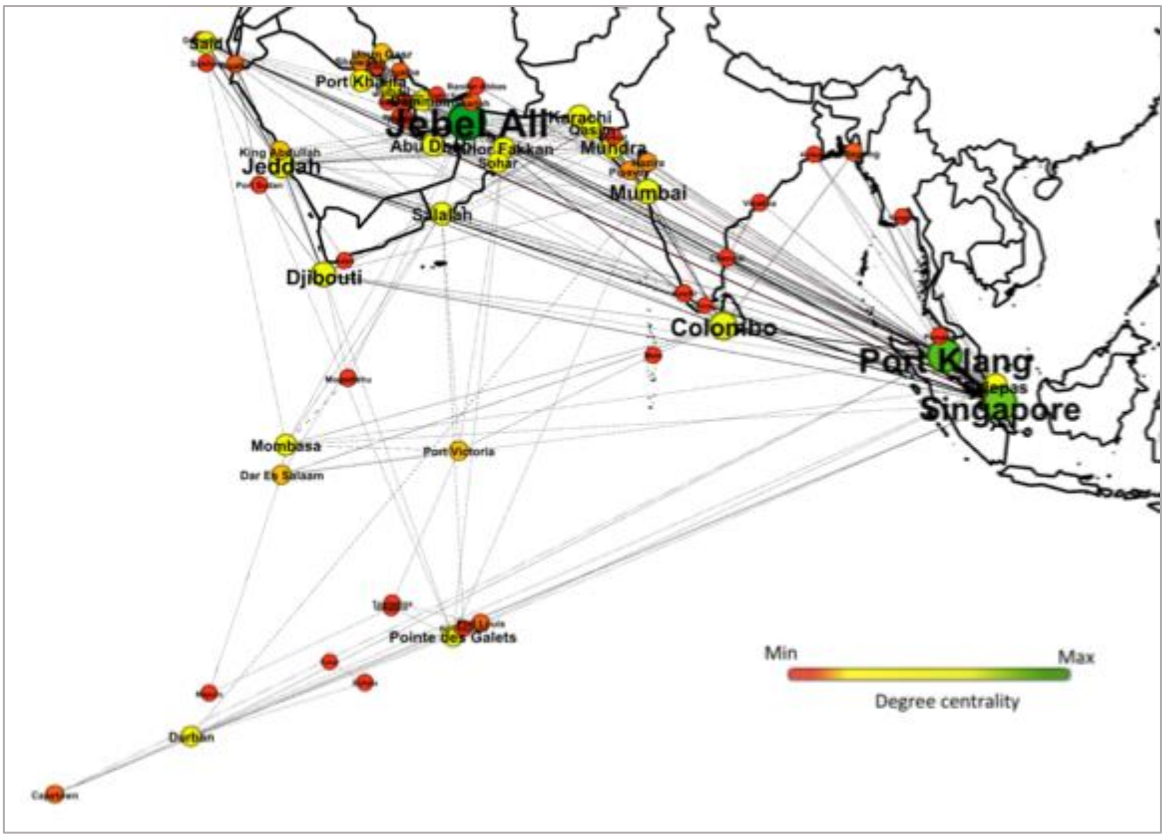
Appendix E Regression Analysis #2



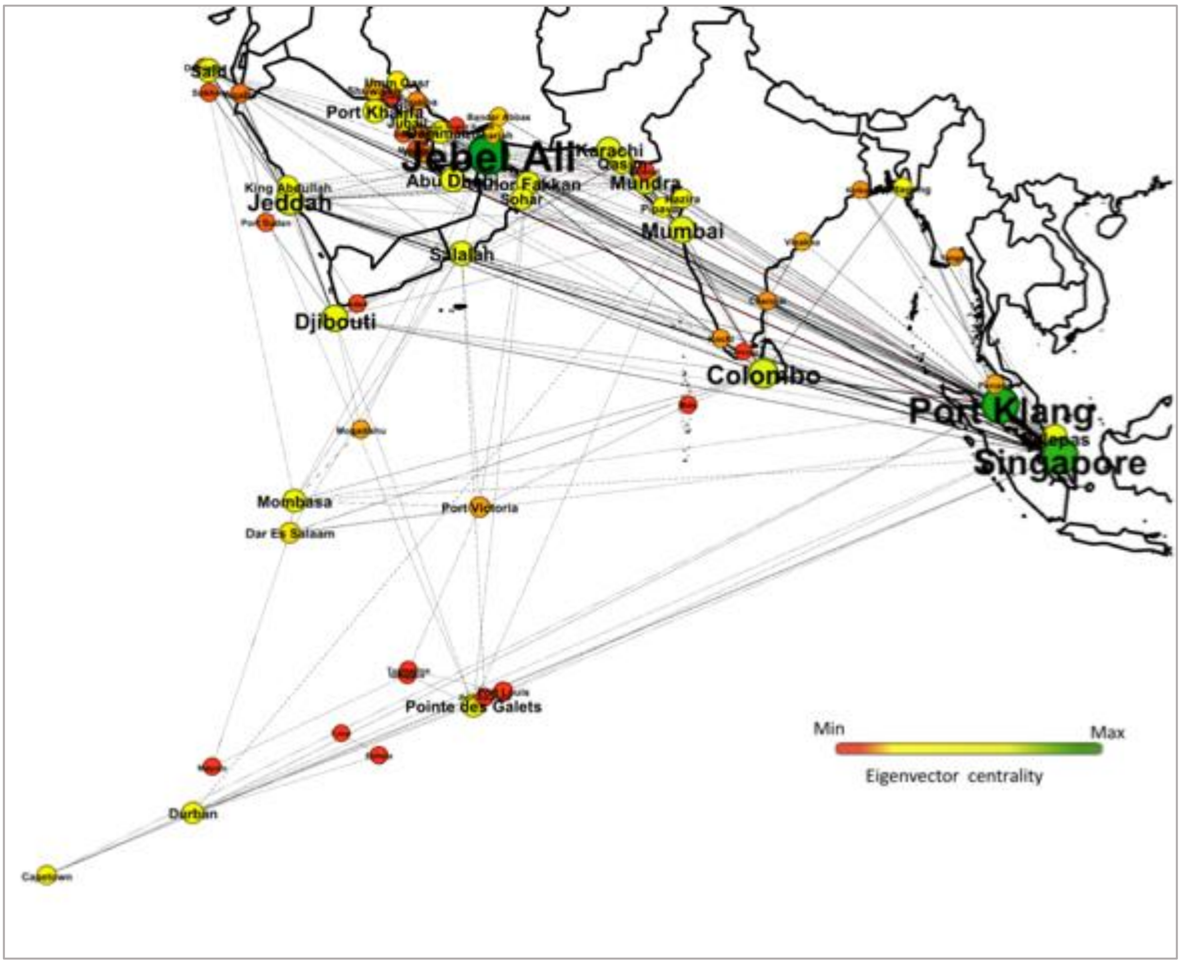
Appendix F Betweenness centrality of the current network



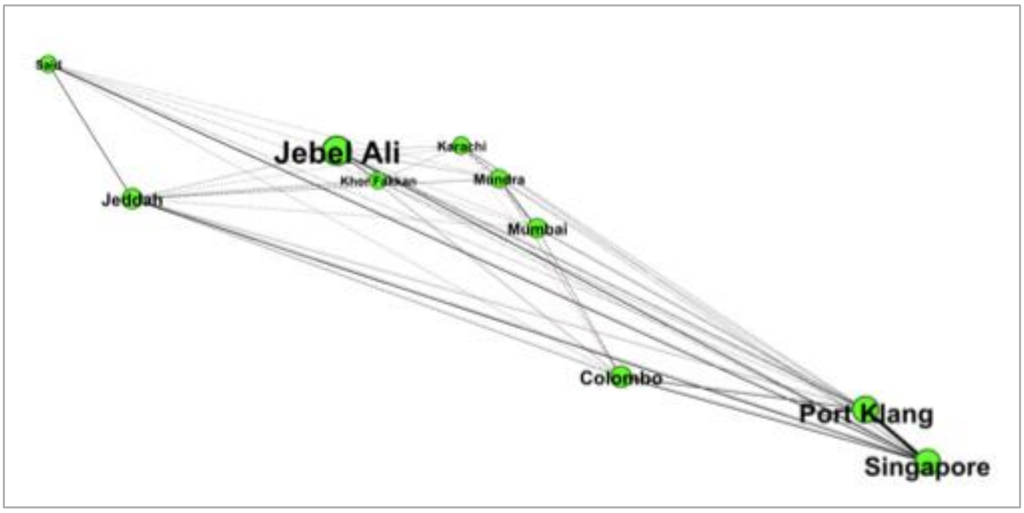
Appendix G Degree Centrality of the current network



Appendix H Eigenvector Centrality of the current network

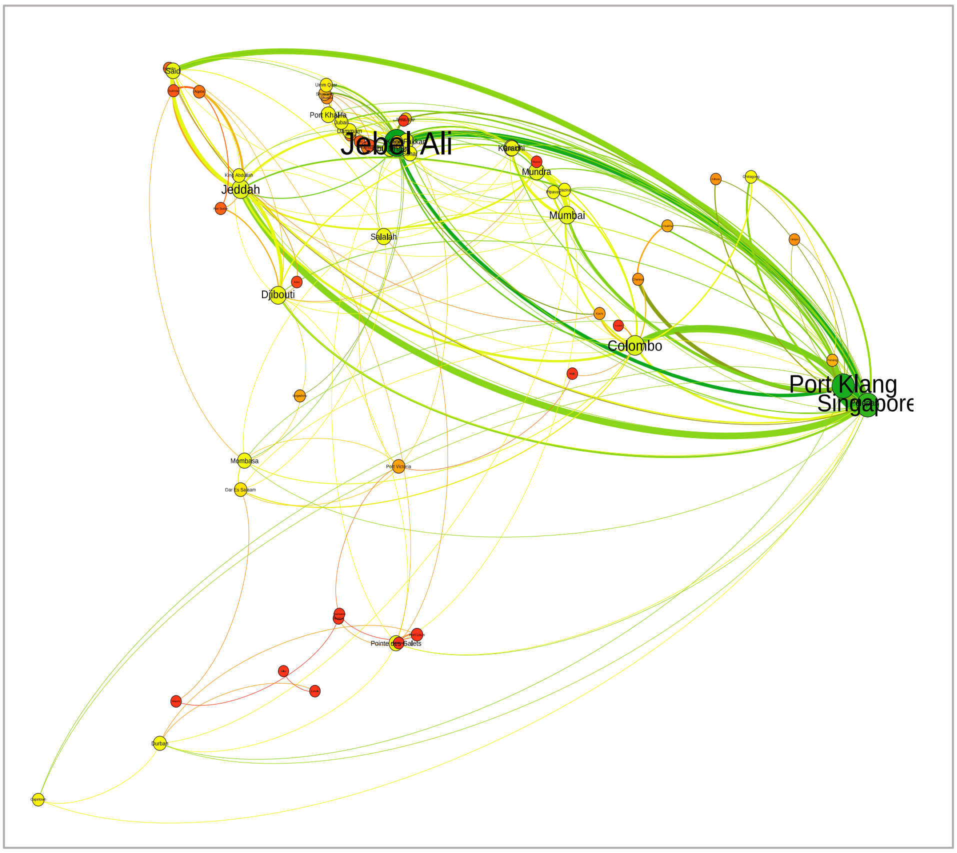


Appendix I K-core analysis to check maximal subset of the network in current network

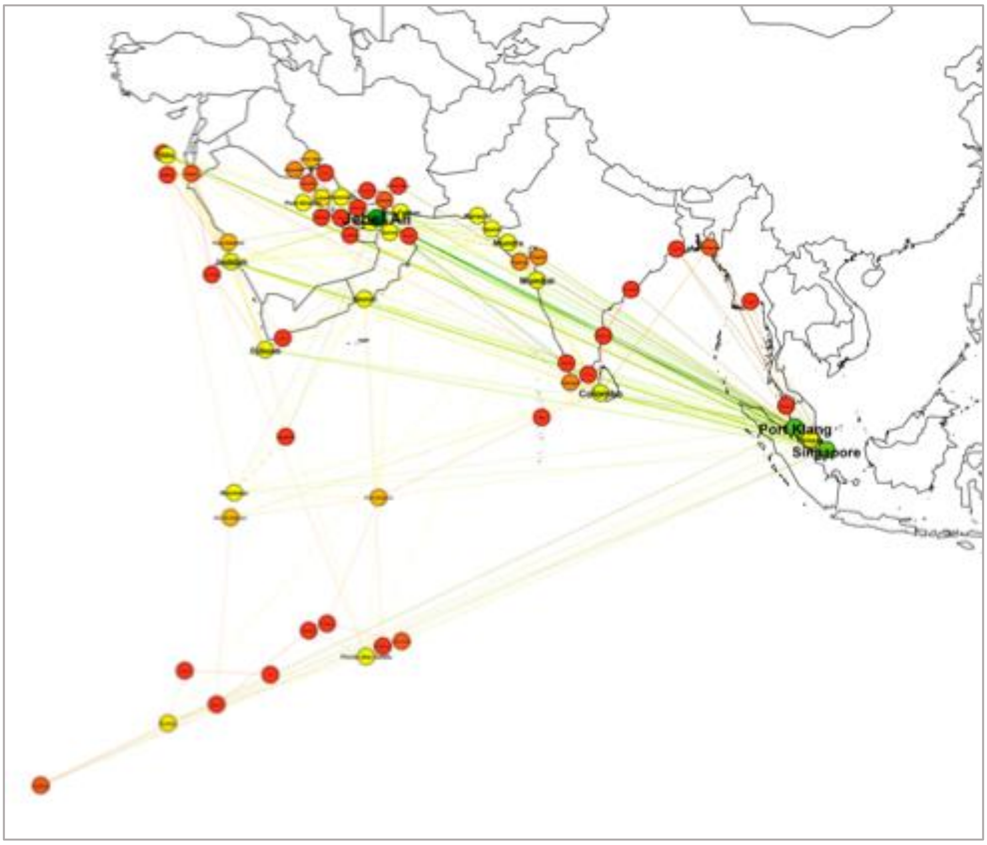


(Note: K-core defines the maximally connected sub-graph in the network. It highlights the networks most central nodes. The k-core filter operates by removing any node less than the value of k from the network to access the largest group. Here the k-core value was 7, so it shows the network of ports whose neighbors have degree at least equal to 7. Above this value, no group exists.)

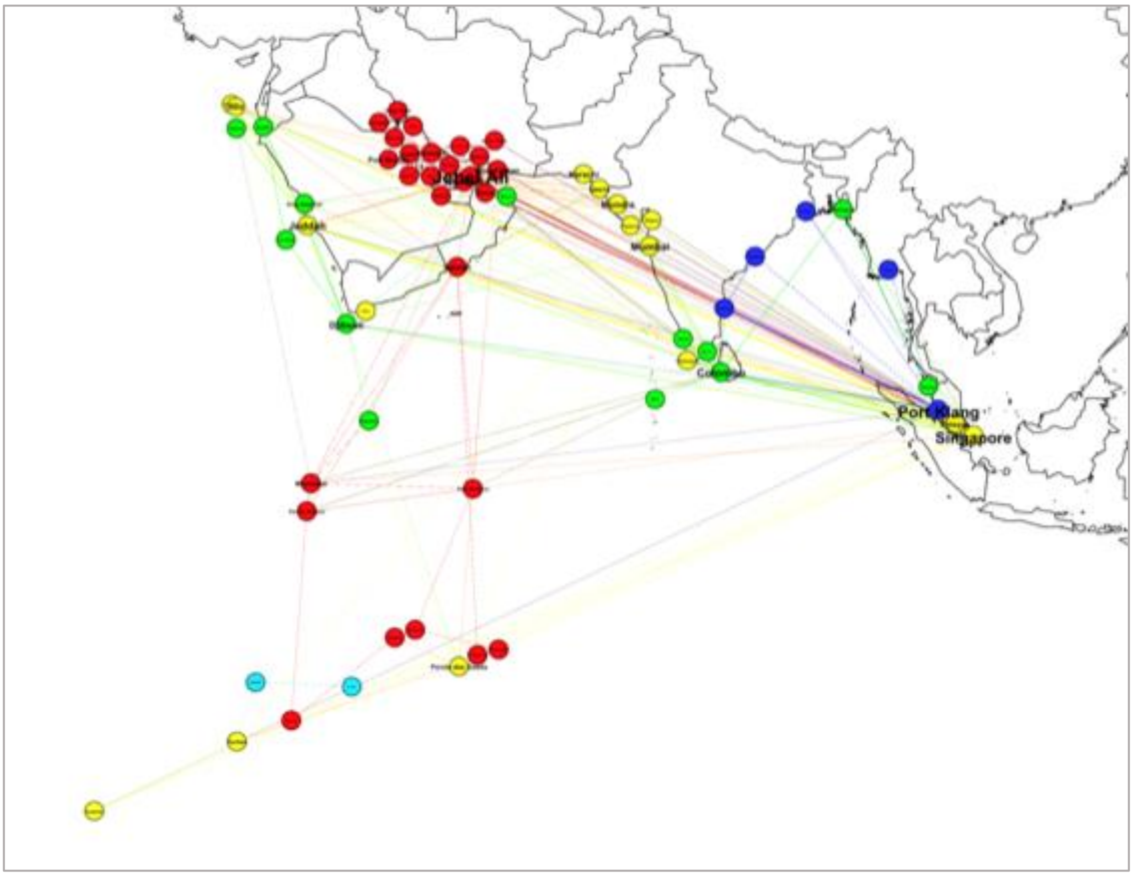
Appendix J Network Graph highlight service frequency between ports



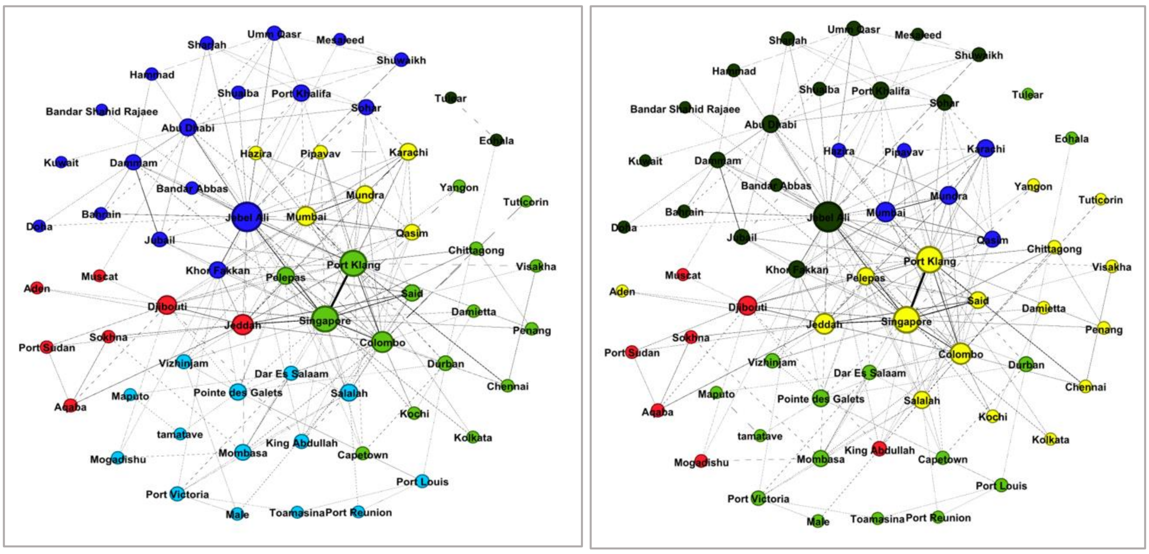
Appendix K Change in Degree with Vizhinjam's introduction



Appendix L1 Change in Modularity with Vizhinjam's introduction



Appendix L2 Addition of Vizhinjam to all central nodes in cluster



(Note: In case A/ B Vizhinjam degree = 6/7, betweenness centrality = 24.22/35.08 Eigen value = 0.28/0.66. It can be seen connection with any of the Indian ocean port, invariably makes Vizhijam a pivotal node if it is connected to other cluster's central nodes, this highlights the opportunity to explore African feeder market along with domestic feeder services)