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Unlocking India's Logistics Potential

The Value of Disaggregated Macroscopic Freight Flow Analysis

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Abstract

India is one of the fastest growing major economies. However, at 14 percent of gross domestic product, its logistics costs are high relative to the 8 to 10 percent that is typical of most advanced economies. High logistics costs and poor logistics performance impact the competitiveness of the economy on multiple levels: (1) firms deliver less competitive goods and services; (2) consumers pay more than peers for goods; and (3) the cost of achieving improvements in gross domestic product is excessive. The development of a national transport and logistics network to facilitate competitiveness and sustainable development and uplift rural regions will play an increasingly important role in shaping spatial organization in emerging economies. An element that is absent, yet critically important for national logistics issues in emerging economies, is sufficiently detailed freight-flow analysis to facilitate targeted infrastructure investments and enable transformational change to improve national logistics performance. This paper presents the results of a disaggregated macroscopic freight demand analysis developed for India through a hybrid approach, calibrating the modeled input-output matrix and resulting freight flows with data where available. Data was obtained from multiple sources, such as agricultural statistics, national enterprise surveys, a financial performance database of Indian companies, population statistics, and transportation statistics from rail, inland waterways transport, highways, and ports. The model provides evidence for decision making on several levels. Aggregating freight flows enables planners to identify gaps in critical infrastructure and logistics chains. Disaggregated flows support decisions on the location of logistics clusters, maximizing the potential of multimodal transport systems, and designing the distribution and storage networks that underpin the economy.

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Produced by the Research Support Team

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Introduction

India has had steady economic growth since 2014, reporting 7.6% GDP growth for the 2015/16 fiscal year (Forbes, 2016). Despite a few shocks in 2016-2017, the projections are for above 7% growth in the medium term. The growth is ascribed largely to an increase in private consumption due to a growing middle class, and significant public investment in the Indian economy (World Bank, 2016a and 2017). The Government of India forecasts economic growth of 7-10% per annum over the next 20 years. Efficient freight transport is one of the key enablers to sustain these economic growth rates (Müller et al., 2012).

However, in 2015, logistics costs in India were estimated at 14% of GDP (Kumar and Shah, 2016), compared to North America's 8% and Europe's 9-10% in 2015 (Armstrong and Associates Inc., 2017). Total freight traffic is expected to grow at 9.7% per annum to reach over 13 trillion tonne-kilometers (tonne-km) in 2031/32 from about 2 trillion tonne-km in 2011/12. A balanced modal share is critical to supporting national logistics, which will underpin the economy and associated freight volumes. The National Transport Policy Development Committee (2014) estimated that the modal share of rail and road needs to shift from 35:65 in 2016/17 to 50:50 by 2031/32. Under an optimistic scenario where rail and road excel in their respective areas of domain competence, i.e., rail serving the medium and long-distance (above 300 km) high-volume traffic, and road transport serving low volume short-distance traffic in a complementary role, rail and road shares could reach 52% and 49%, respectively (Planning Commission, 2008 [Chapter-XI]). Nonetheless, to achieve this scenario the public sector and policy makers would have to make targeted evidence-based decisions for rail and a burgeoning inland waterway transport (IWT), to play an important role in servicing freight transport demand, reducing transport costs and mitigating the environmental impacts of freight transport (Kallas, 2011; Woodburn and Whiteing, 2012; Sanchez-Triana et al., 2013).

However, recent analysis cautioned that, without intervention, India's freight rail market share could decline to 25% in 2020 from 36% in 2009, compared to an almost 50% rail share in China and 40% in the United States, similar continent-size nations. Under this scenario, waste caused by poor logistics infrastructure will increase from US$45 billion (equivalent to 4.3% of GDP in 2009), to US$140 billion or more than 5% of the GDP in 2020. However, if logistics challenges are addressed in an integrated and coordinated manner, rail share could move towards the 50% targets mentioned above (McKinsey, 2010).

Achieving this modal shift will require four major interventions:

1) Building the right network and ensuring freight flows on the right mode, comprising an integrated network of high-density long-distance corridors (rail and waterways), medium-distance rail and road connectors, and efficient last-mile links;
2) Creating enablers to maximize the efficient use of the network, which includes developing logistics hubs and focusing on skills development;
3) Extracting more from existing assets, for example through increasing carrying capacity; and
4) Increasing the investment allocation to rail to more than 50% of total road/rail spending, with large sums spent on building high-density traffic corridors, connectors and last-mile links.

Some of the above interventions are already underway. To realize these transformational changes, India's National Transport Development Policy estimated the average annual transport infrastructure investment to amount to US$114 billion by 2032 (Makwana, 2016). One of the enablers of optimal allocation of these resources is access to consistent, reliable, disaggregated freight-flow information to quantify the efficiency and capacity of the logistics network over the intermediate and long term, thereby enabling the management of transport as a strategic national resource (Tavasszy & De Jong, 2014).

The objective of this working paper is to report on the development of a disaggregated freight-flow model for India. This model was developed as part of engagement between the World Bank and Government of India on national logistics. The model provides a sectoral and regional disaggregated quantification of total national freight flows and related costs to (1) improve the understanding of the national freight-flow landscape and facilitate evidence-based policy formulation and investment prioritization, (2) establish intermodal freight potential along the country's most dense freight corridor, the Eastern Corridor, and (3) identify and prioritize logistics improvement and cost saving interventions for rail, road and ports on the Eastern Corridor.

Freight flows are a natural and important part of logistics, which is defined as an integrative and systemic support function, applying trade-offs to determine optimal cost levels in the provision of the transport and storage of goods to address the time and place discrepancy between supply and demand for conforming to customer requirements (Lummus et al., 2001). Transport plays an important part in logistics and for all three of the economies that will be referenced in this report, the United States, South Africa and India; it constitutes more than 50% of logistics costs (64% in the case of the United States [AT Kearny, 2017] and 58% in the case of South Africa [Havenga, et. al. 2016]). The work in this report focuses on transport, but the context within a logistics system for further study should not be ignored.

The next section contains a critical review of literature which provides an overview of India's freight logistics environment, highlighting the exponential growth in transport sector investments planned across all modes. These investment plans are however not underpinned by a current disaggregated macroscopic freight demand model to facilitate the optimal allocation of limited resources to support India's growth trajectory. The macroeconomic relevance of disaggregated macroscopic freight demand modeling is therefore discussed. This is followed by an overview of the development of freight demand models to inform the methodology to develop India's freight demand model (FDM), which is subsequently described. Next, the results of India's FDM are presented, firstly providing an aggregate overview of the Indian freight transport environment, followed by a description of the Eastern Corridor, including the identification of logistics cost savings potential on this corridor. The paper concludes with a summary and the identification of next steps.

Overview of India's freight logistics environment

India is the 18th largest export economy in the world (with exports amounting to $292 billion in 2014) and the 13th largest import economy (with imports amounting to $421 billion in 2014). Between 2009 and 2014, exports increased at an annualized rate of 12%, from $165 billion to $292 billion. Over the same period, imports increased at an annualized rate of 11%, from $249 billion to $421 billion (The Observatory of Economic Complexity, 2015).

The optimistic growth outlook of 7-10% per annum over the next 20 years by the Government of India is, in part, predicated on improvements in the business environment. According the 2018 '*Doing Business*' report, India improved from 134th in 2015 to 100th in 2018. The *Global Competitiveness Index* published by the World Economic Forum (2015-16) reflects a similar trend. In the 2015-2016 report, India jumped 16 ranks to 55th place (although it still ranks seven places lower than in 2007). Per the report, this dramatic reversal is largely attributed to the pro-business and pro-growth initiatives by the Government of India. An ambitious reform agenda based on a series of high-impact initiatives ranging from access to electricity and sanitation to smart cities and transport infrastructure modernization has formed the backbone for economic recovery and social reforms (World Bank, 2016c). This range of reforms is necessary to support growth, as the Indian economy is classified as being in the first stage of economic development, i.e., being factor-driven and competing mainly on unskilled labor and natural resources (World Economic Forum, 2015-16). Stage 2 of economic development is efficiency-driven, followed by stage 3, which is innovation-driven.

This is also evident in India's manufacturing sector contribution to GDP, which is relatively low among its Asian peers, as shown in Figure 1. To boost the manufacturing sector, the Government of India launched the '*Make in India'* initiative with the goal to reposition India as a global hub for low cost and high value manufacturing. The campaign aims to facilitate investment, foster innovation, enhance skills development, protect intellectual property, and build best-in-class manufacturing infrastructure in India (Vision AIS, 2015). The National Manufacturing Policy is targeting at least 25% contribution to the GDP from the manufacturing sector by 2022 from the current contribution of 17%. To achieve this target, it is estimated that the manufacturing sector needs to grow at 15% CAGR over a period of 7 years starting in 2016. If implemented successfully, *Make in India* will form an important backbone of economic growth going forward and requires, *inter alia*, highly effective and efficient logistics services (Kumar and Shah, 2016; Makwana, 2016).

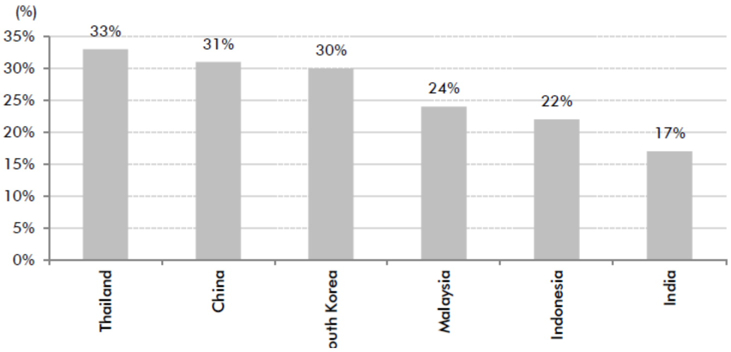

Figure 1: India's manufacturing sector contribution to GDP is the lowest amongst Asian peers (Makwana, 2016)

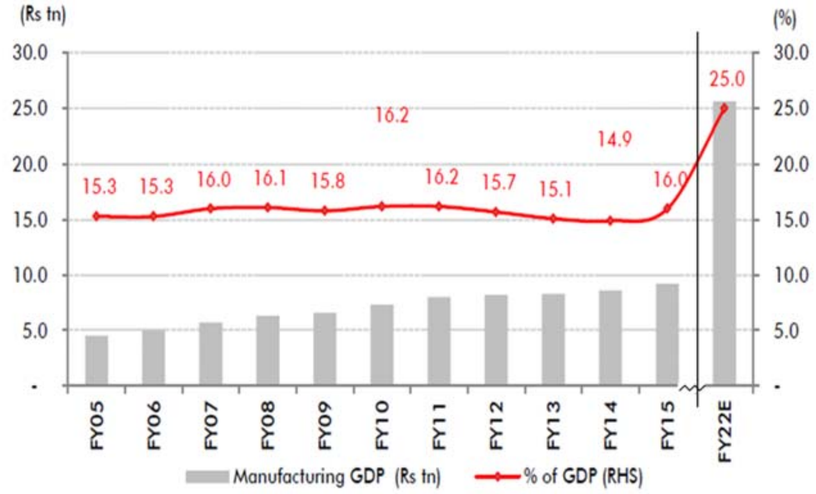

Figure 2: India's manufacturing sector – 10-year trend (2005-2015) vs. "Make in India" projection (2022) (Makwana, 2016)

India is however still positioned in the growth stage of the logistics lifecycle where supply chain services are typically managed in-house with functional service providers contracted for distinct elements of the supply chain, without the benefits of supply chain integration and optimization (Phillip Capital, 2016). The penetration of organized firms in India's logistics industry is estimated at 10-12% as compared to more than 50% in the United States and 30-40% in Europe (Makwana, 2016).

Since the inception of the World Bank's Logistics Performance Index (LPI) in 2007 up to 2014, the LPI reflected challenges in India's logistics, its rank falling from 39th (out of 150 countries) in the world in 2007 to 54th (out of 160 countries) in 2014, and its score unchanged. The most pertinent challenges were reported in the areas of infrastructure, customs and logistics competence. In the latest LPI India has however turned around its trajectory impressively by ranking 35th (out of 160 countries) in 2016, with an 11% improvement on its 2014 score (World Bank, 2016d) as shown in Figure 3.

LPI for India	Rank	Score
2007	39	3.07
2010	47	3.12
2012	46	3.08
2014	54	3.08
2016	35	3.42

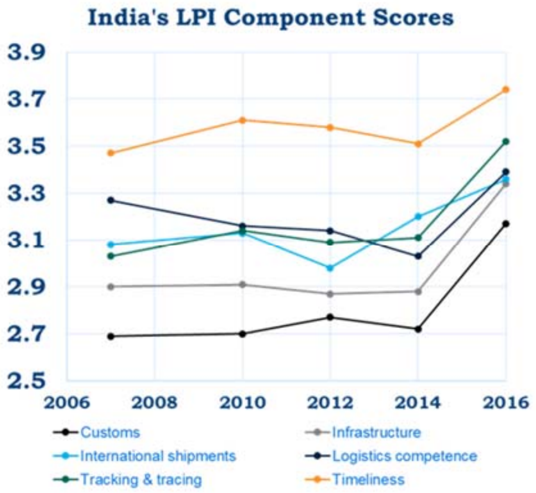

Figure 3: India's LPI performance history (total and components) (World Bank, 2016e)

However, the LPI measures performance at key international gateways and not logistics connectivity and performance in the hinterland (World Bank, 2016d). The promising LPI results therefore do not necessarily echo the full scale of surface logistics challenges in India where a fragmented road freight industry and saturated freight rail capacity constrain economic development efforts (Das, 2014).

The remainder of this section provides a modal overview of India's transport sector i.e. road and rail, ports, and coastal shipping and IWT. This discussion is a necessary precursor to a deeper analysis of national logistics.

a) Road and rail

The history of transport infrastructure development in India was predicated on a British colonial strategy to transform the colonial economy into a source of cheap raw materials and a market for manufactured British goods. Freight rates supported this process as port-oriented traffic was highly subsidized at the cost of inland traffic. This resulted in a significant primary, a weak secondary, and a bloated tertiary economy and led to the emergence of an essentially centrifugal system oriented towards ports which impacted node development and resulted in a multiplicity of rail gauges and distorted freight policies. Railway pricing worked on the principle of “what the traffic can bear” rather than “cost of service”, resulting in cross-subsidization from high-value to low-value traffic to support government policies. The growth in road transport, with a concomitant shift of high-value traffic to road, curbed this practice, increasing losses for the railway as low-value goods were transported below-cost on rail. Increasing losses, in turn, curtailed investments, further impacting rail’s ability to serve its customers (Raza and Aggarwal, 1986). The steady shift of freight from rail to road is depicted in Figure 4.

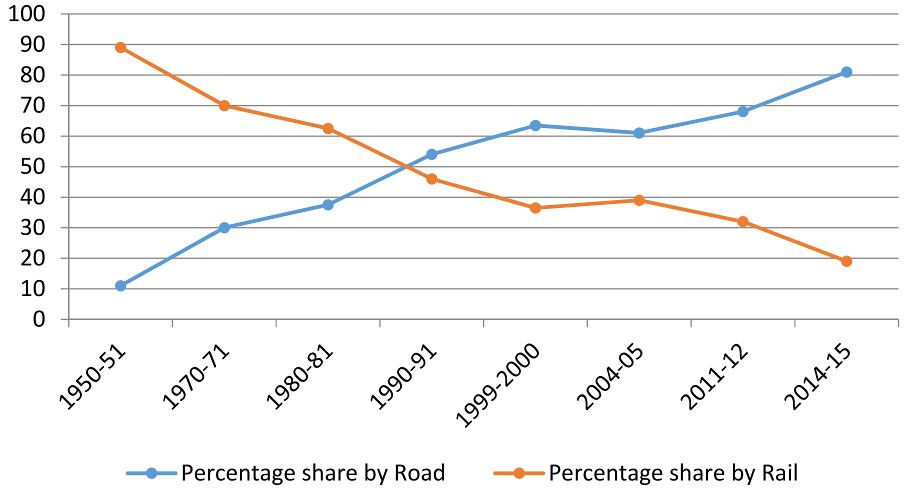

Figure 4: Indian road freight traffic surpassed rail freight traffic since the late 1980s (National Transport Policy Development Committee, 2013, updated with results from India freight demand model)

Total road length in India increased from approximately 0.4 million km in 1951 to 4.8 million km in 2012, while the total length of national highways increased from 22,000 km to 77,000 km, a 3.5-fold increase (Central Statistics Office, 2014). This century alone, road length (state and national) has grown by almost 35%, compared to growth in rail track length of less than 5%, as shown in Figure 5 (Makwana, 2016).

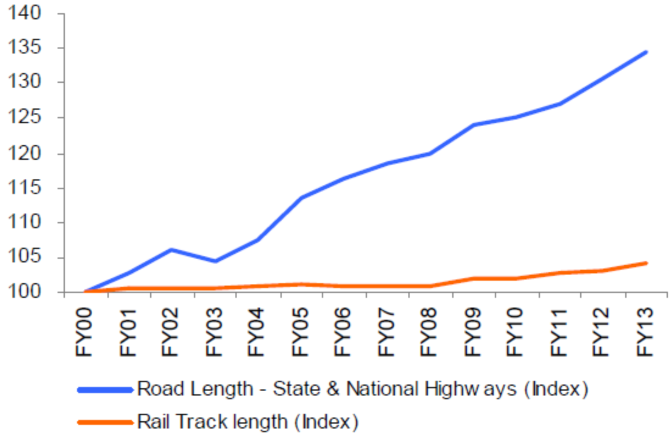

Figure 5: Growth in road length vs. rail track length (Kumar and Shah, 2016)

On an aggregate level, in the past six decades, rail freight loading has grown by 1,344% and passenger kilometers by 1,642%, while railway capacity, measured in route-kilometers, has grown by only 23% (Phillip Capital, 2016). The Indian Railways' (IR) major rail lines link the four metropolitan cities of Delhi, Mumbai, Chennai and Kolkata and its two diagonals (Delhi-Chennai and Mumbai-Howrah), adding up to a total route length of 10,122 km (16% of total route length), and carrying more than 52% of the passenger traffic and 58% of revenue earning freight traffic of IR. The existing trunk routes of Kolkata-Delhi on the Eastern Corridor and Mumbai-Delhi on the Western Corridor are highly saturated, with line capacity utilization varying between 115% and 150%. The lack of investment in and high saturation levels of rail are compounded by capacity conflicts, with passenger services receiving higher priority, also evidenced by the cross-subsidization of passengers by freight shown in Figure 6.

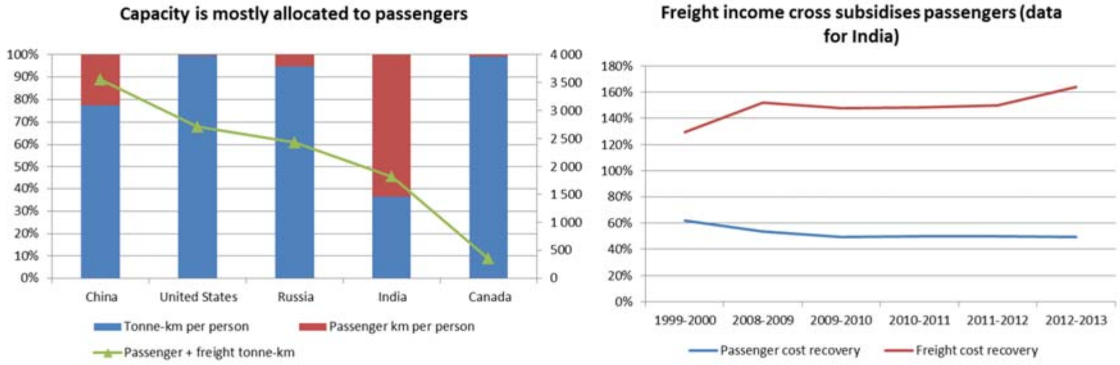

Figure 6: Rail capacity and cost recovery challenges in India

Given the poor state of rail and the associated regulatory environment, a highly-fragmented trucking industry emerged. Seventy-seven percent of truck owners have a fleet size of five vehicles or less. In addition, there are approximately 5,000 intermediaries in the freight industry. Intense competition resulted in low freight rates and limited regulation resulted in overloading, causing early aging of vehicles, vehicle breakdowns and damage to roads. In addition, trucks are involved in 30% of road accidents due to a lack of skilled drivers. In addition, the Government of India heavily subsidizes diesel, in effect promoting a shift of freight to road (Council of Supply Chain Management Professionals, 2009). Inner-city congestion is also a debilitating feature of India’s freight distribution landscape (Kumar and Shah, 2016).

To address these challenges, Government of India launched the *National Highways Development Program* in 2001. The first phase of the project involved the construction of the roads connecting the ‘Golden Quadrilateral’, the 5,800-km highway connecting the four major metropolitan areas, via four- and six-lane roads (cities of New Delhi, Mumbai, Kolkata and Chennai). By 2013, the Government of India had invested $5.6 billion in this project. The second phase entails the construction of the North-South and East-West corridors (Asturias et al., 2016). The project seems highly successful with districts along the Golden Quadrilateral doubling the new output of young firms, growth of new manufacturing firm entrants and an overall growth in Indian manufacturing of between 15% and 19%. (Ghani et al., 2014).

In addition to substantial increases in investments starting in 2000, Indian Railways have also committed to an exponential investment increase up to 2020 (see Figure). Out of six dedicated freight corridors (DFCs) planned in a phased manner, two corridors (Eastern and Western) are scheduled to be fully commissioned by FY18-19. The Eastern DFC will run from Ludhiana in Punjab to Dankuni near Kolkata (1,839km) and the Western DFC will stretch from Jawaharlal Nehru Port Trust (JNPT) near Mumbai to Dadri in Delhi (1,534 km). The phasing of corridors is synchronized with the most-saturated sections on the Mumbai-Delhi and Delhi-Kolkata rail links (Philip Capital, 2016). It is envisioned that the DFCs will be used exclusively for freight trains, leaving the existing lines free for passenger trains (Makwana, 2016). The vision is that improved performance on the DFCs will be supported by high-speed movement and double-stacking, in turn reducing investment requirements in wagons, and increasing turnaround times (Kumar and Shah, 2016; Makwana, 2016).

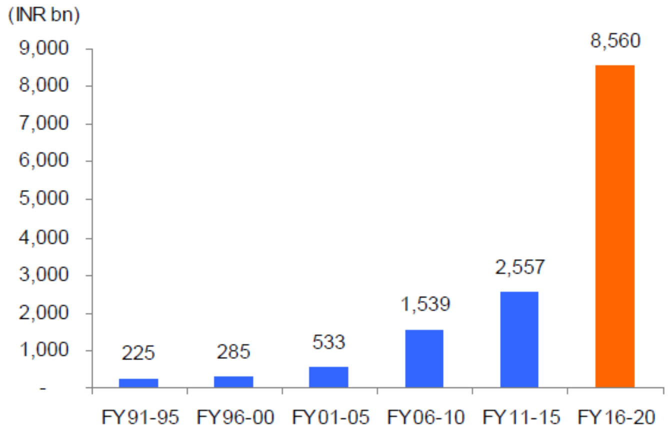

Figure 7: Exponential increase in investments by the Indian Railways (Kumar and Shah, 2016)

An efficient port system will further unlock the value of corridor investments.

Ports

The capacity of India's 12 major ports almost doubled between 2006 and 2015 to 890 mt, yet capacity utilization declined, mainly due to a slowdown in cargo traffic growth led by both global and domestic factors, infrastructure bottlenecks and a shift in traffic to minor ports. Trade cargo at the almost 200 minor ports (with a combined capacity of approximately 690 mt) increased at a CAGR of 13% over the past decade (versus the overall trade CAGR of 7%) and it accounted for nearly 45% of the total maritime trade in 2015 (refer to Figure8) (Kumar and Shah, 2016).

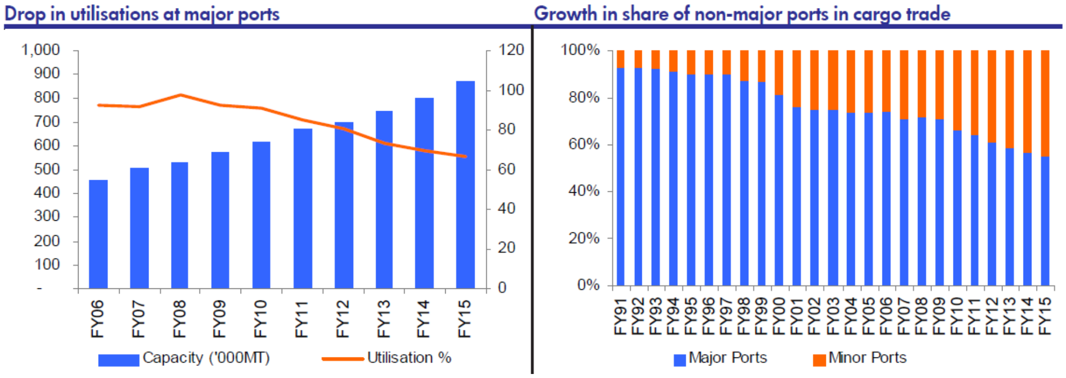

Figure 8: Traffic from India's major ports are increasingly pilfering to minor ports (Kumar and Shah, 2016)

Containers handled at major ports doubled between 2005 and 2015, and another 50% growth is expected between 2016 and 2020. This is partly attributable to the high import demand driven by increased domestic consumption. Break-bulk cargo (rice, maize, glass, granite, garnet sand, soya, cement and flowers) is also increasingly transported in containers due to handling efficiencies and reduction in losses and damages. This increased containerization supports the rationale for investments in corridors and freight logistics hubs. Minor ports' share of container cargo has however also outpaced the growth at major ports due to infrastructure constraints at major ports. The flattening in container throughput at major ports is depicted in Figure9 (Kumar and Shah, 2016; Philip Capital, 2016).

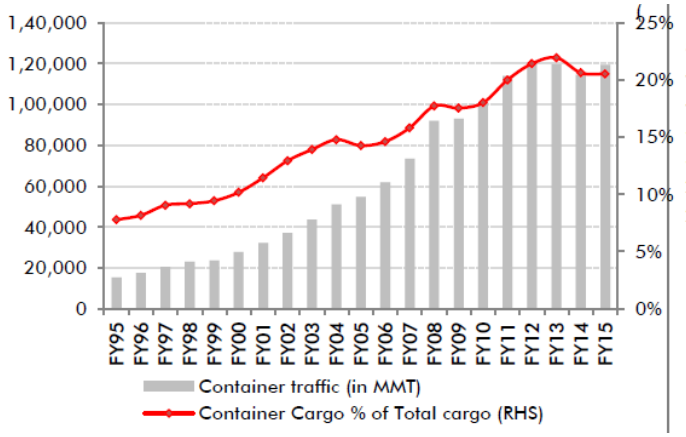

Figure 9: Trend in container volumes at major ports (Makwana, 2016)

Most of India's container traffic is concentrated along West-Coast oriented export/import (Exim) routes, with 70% of the volumes handled at the three West-Coast ports of JNPT, Mundra and Pipavav. Penetration on domestic routes contributes only 20% to India's overall container rail traffic (Kumar and Shah, 2016, Herrera Dappe and Suárez-Alemán 2016).

Furthermore, an increased demand for temperature-controlled logistics (i.e. reefer containers) due to higher consumption of perishable items, growth in pharmaceuticals, and an increasing number of niche and high-end products that require cold chain services such as the ready-to-cook and ready-to-eat meals required by retail and quick-service-restaurants, means that India's temperature-controlled logistics industry is estimated to grow at 15-20% each year for the next 3-5 years (Kumar and Shah, 2016; Philip Capital, 2016). This is on the back of a significant growth of cold-storage capacity in India since the turn of the century (refer to Figure 0). The bulk of future investment is expected to go towards the development of container and coal-handling capacity on the east coast and container-handling capacity on the west coast. The ports on the east coast, however, require more attention due to longer ship turnaround times and low container market share relative to natural hinterland demand (Herrera Dappe and Suárez-Alemán, 2016).

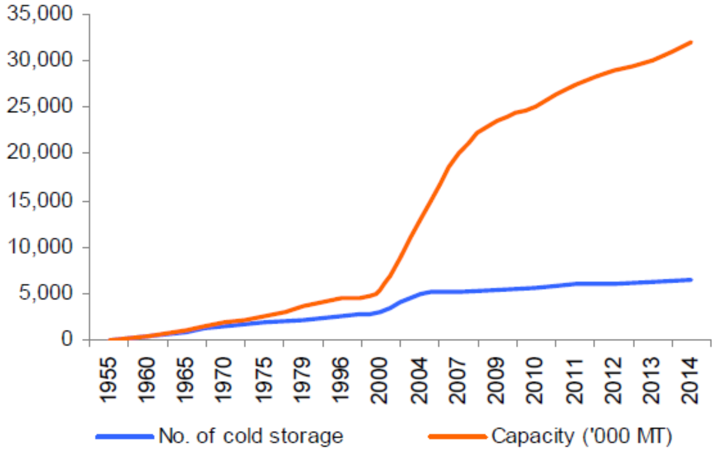

Figure 10: Growth of cold storage in India (Kumar and Shah, 2016)

Port, road and rail congestion challenges are exacerbated by the fact that India is not taking advantage of its coastal shipping and IWT opportunities.

Coastal shipping and Inland Waterways Transport (IWT)

India has a long coastline spanning 7,500 km, forming one of the largest peninsulas in the world, yet coastal shipping accounts for less than 6% of total domestic freight movement, even though direct transport costs are three-fold less than road transport (Philip Capital, 2016). To address this, 10 coastal economic regions are to be developed, each covering 300-500 km of coastline. The Government of India is targeting a five-fold increase in coastal shipping volumes by 2025 (IWAI, 2017).

IWT is considered the most cost-effective mode of transport, both due to efficiency per liter of fuel consumed, as well as a load capacity eight times that of rail and 27 times that of road (see Figure 11).

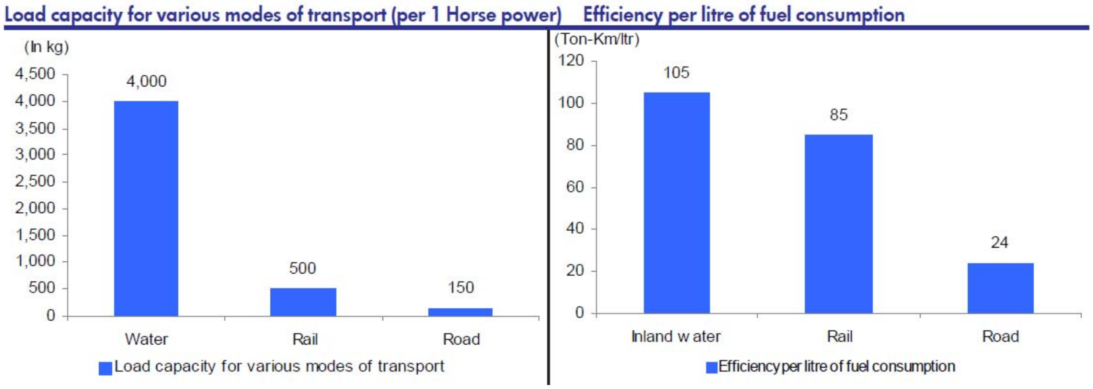

Figure 11: Efficiency of water transport compared to rail and road (Kumar and Shah, 2016)

India has almost 14,500 km of navigable inland waterways, of which 5,200 km are major rivers and 500 km are canals suitable for mechanized crafts. Following independence, India took nearly 40 years to set up the Inland Waterways Authority of India (IWAI), created in 1986. Up to 2015, the Government of India spent only US$200 million on inland waterways transport. This compares poorly to China's US$15 billion expenditure in the last five years alone, and Germany's annual budget of €15 billion in

2014. As shown in Table 1, India has five declared National Waterways, of which three are operational, with freight market share of 0.7%. The ambition of the government is to increase this several fold and unlock the full potential of IWT.

Table 1: India's declared National Waterways (IWAI 2017)

National waterway	Location	Stretch (km)
NW 1	Ganga-Bhagirathi-Hooghly river system from Allahabad to Haldia	1620
NW 2	Brahmaputra river from Sadiya to Dhubri	891
NW 3	West Coast Canal from Kottappuram to Kollam along with Champakara and Udyogmandal canals	205
NW 4	Godavari & Krishna rivers & Canals between Kakinada and Puducherry	1095
NW 5	Brahmani river & Mahanadi delta system along with East Coast Canal	623

In March 2016, Government of India declared its ambition to develop an additional 106 inland waterways to be National Waterways. To back this ambition, specific programs and investment plans have been made to develop IWT infrastructure while private stakeholders are expected to invest approximately US$10 billion in barges and other operational assets (Phillip Capital, 2016). As a priority, IWAI is developing NW-1, from Haldia port in West Bengal to Allahabad in Uttar Pradesh with support from the World Bank (IWAI 2017). Initially, bulk commodities such as coal can be targeted for more efficient transportation (Singh, 2015) contributing to road decongestion and freeing up rail capacity. Other bulk commodities and food can follow soon, leading to further decongestion, cost savings and a decrease in environmental and accident-related externality costs (Gupta, 2016).

Integration of Modal Plans

The integration of the port, IWT and coastal shipping investment initiatives is managed through Sagarmala, the flagship program of India's Ministry of Shipping. This program was introduced to boost port-led development and is a testament to the Government of India's ambition to further open India to trade. Sagarmala anchors the port-led development ambition on four key pillars, namely port modernization, port connectivity improvement, port-led industrial growth and development of coastal communities (Government of India, 2015). Sagarmala has identified three areas of urgent intervention required if the Indian port sector is to realize the ideal of port-led development namely: policy and institutional interventions, port infrastructure expansion and upgrades and efficiency of land-side evacuation through better hinterland connectivity by integrating rail, road and IWT (Mitra et al., 2016).

The success of the road, rail and port integration hinges on integration with logistics hubs. India already has more than 200 functional dry ports, which primarily provide customs clearance services, while also enabling the storage and consolidation of goods. There are more than 30 operators around JNPT alone with a total annual capacity of 3 million TEUs operating at only 50-60% utilization on average (Kumar and Shah, 2016). CONCOR (the largest container train operator in India with an ExIm market share of nearly 75%) is developing five Multi-Modal Logistics Parks (MMLPs) along the Western DFC. Indian Railways produced a private freight terminal policy and investment program in 2011 to increase efficient evacuation of trains and enhance its freight income through providing additional warehousing space and a reduction in the amount of handling/transportation for the customer (Kumar and Shah, 2016). The current hubs are however not being developed within the context of an overarching national freight transport strategy and taking cognizance of modal shift and consolidation opportunities.

Three decades ago, Raza and Aggarwal (1986) noted the paradox that while, following independence, the Government of India recognized balanced regional development as a key policy objective, in the early 1980s effective national economic planning was still being pursued without statistics on inter-regional interdependencies demonstrated through freight flows. This has remained a challenge, as one-off modeling initiatives typically precede freight transport and logistics, without an overarching freight-flow strategy providing national context and enabling annual tracking of key indicators. In 2007, a major study was conducted on logistics and it identified several shortcomings in logistics-related policy dialogue: (1) inadequacy of updated data on modal freight flows, (2) the time lapse since similar previous studies (1978 and 1986), and (3) the major changes in the economy impacting demand-supply linkages, freight flow volumes, flow patterns and modal options. Almost a decade has passed since that study and, unfortunately, these exact reasons pertain to the need for the activity discussed in this paper. For example, consider spatial development options for Uttar Pradesh. A recent study by Mehta et al (2014) suggests that the key criteria for locating logistics hubs include availability of land and fiscal space and government capacity to implement these investments, which are needed to spread the effects of trunk infrastructure. In the absence of detailed and disaggregated analysis, it would be difficult to quantify the trade-offs or decide policy options that affect logistics. In the next section, the macroeconomic relevance of disaggregated macroscopic freight-flow analysis is discussed.

The Macroeconomic Relevance of Disaggregated Macroscopic Freight Flows

Background

Transport forms part of the so-called network industries, which provide services and infrastructure of general economic interest. These industries have a significant impact on national and regional competitiveness as they typically contribute a significant portion of GDP and employment, while impacting the success of other industries (Commission of the European Communities, 2002). Globally, unabated population growth, urbanization, and resulting increased consumption is expected to intensify pressure on transportation services (Ivanova, 2014), exacerbated by the global reality that transportation infrastructure is approaching capacity levels (Müller et al., 2012). Significant changes on both the supply and demand-side of logistics could however impact these trajectories. On the supply side, disruptive technologies such as driverless trucks, drone delivery (Van Meldert and De Boeck, 2016; Connolly and Coughlin, 2017) and the physical internet - an analogy with the electronic internet to unitize shipments into globally standardized ‘packets’ and optimize routing through portals- could transform the supply landscape significantly (Crainic and Montreuil, 2015). On the demand side, alternative business models including a departure from just-in-time business practices, a return to more localized consumption, recycling at source and additive manufacturing, have the potential to reduce the demand for logistics and interrupt the growth trajectory of freight transport (European Parliament, 2010; Attaran, 2017).

The network industries are however also characterized by several market distortions such as scale economies and externalities and are therefore typically subject to some form of regulation (Commission of the European Communities, 2002). Ultimately, this should include total cost internalization to enable both suppliers and consumers to make full cost trade-offs in their purchasing and logistics decision making to support the scale of change that is made possible through technological developments (Sustainable Aotearoa New Zealand, 2009). The latter is important as the stock of transport infrastructure has been identified as the main explanatory factor for the level of transport costs (Ivanova, 2014), leading to an argument that higher-quality road infrastructure reduces transit times which negates the negative effects of generalized transportation costs on trade flows (Arbués and Baños, 2016). Currently this argument is possible because the price signal fails as the full ecological and social impacts of freight activity are not accounted for in transport costs (Lewis and Conaty, 2012).

Macroscopic freight demand modeling will be a key enabler for the management of transport and logistics as a macroeconomic production factor within this changing landscape as logistics- and connectivity-related interventions are estimated to have the highest potential to reduce trade costs and to boost global value chain integration (World Bank, 2016d). This thinking is beginning to take root in national logistics policy. For example, in preparing the U.S. *National Freight Strategic Plan,* understanding of major freight flows was considered a key input for informed planning (US Department of Transportation, 2015).

According to Ivanova (2014), existing empirical literature on freight demand modeling focuses on aggregate trade flows and ignores the differences between various commodities and region pairs in terms of the impact of transport costs on trade patterns and volumes. This aggregated approach does not allow for making policy-relevant conclusions related to particular industries and commodities and diminishes the usefulness to macro-econometric analysis. Three decades ago Raza and Aggarwal (1986) understood that aggregate freight-flow analysis does not reflect the diversities of and the disparities in either the production or consumption processes, nor can it reflect the regional structure of the economy. Tavasszy and De Jong (2014) reiterated that, ideally, freight flow modeling should commence from economic linkages, as freight transport is an outcome of these interactions. De Vries et al. (2012) highlighted that analyses of structural change in developing countries are constrained by the lack of detailed sector data, obscuring a proper assessment of the role of structural transformation in driving aggregate productivity growth through resource allocation to value-added industries. A more in-depth understanding of the freight transport market presupposes access to reliable, disaggregated freight-flow information (Lyk-Jensen 2011). Disaggregation is required on *inter alia* commodity flows and geography, and an increased linking of freight modeling with the broader economy, geographically as well as functionally (Tavasszy, 2006).

The relevance of spatial and sectoral disaggregation in macroscopic freight demand modeling is threefold (informed by Ludlow, 2011):

- Macroeconomic planning and policy applications to *inter alia* assess the health and changing structure of the economy at the national and regional level over time, to conduct sector and regional analysis and to direct spatial planning;
- Macro logistics planning and policy applications to assess transportation demand, engineer an optimal modal balance, identify economic impacts of transportation network investments and support macroeconomic growth through directing capital investments; and
- Mesoscopic applications to target investments and logistics solution development for specific industries or geographies.

These are discussed in turn below using specific examples from the United States and South Africa, the two countries with the longest running time series of freight volume and cost data.

Macroeconomic Planning and Policy applications

The efficient movement of freight within and through a region is vital to its growth and economic development. An understanding of commodity-level freight flows allows for the assessment of the demand for specific transportation facilities and services (Mesenbourg, 2011) and supports a region's infrastructure investment decisions (Harris and Anderson, 2011). In the United States, results from the Commodity Flow Survey (CFS) are for example applied to explore the feasibility of dedicated truck lanes on the Interstate 70 corridor connecting Indiana, Illinois, Missouri and Ohio (refer Figure 12). The

CFS flow summaries and map outputs allow the visualization of directional proportional flows in terms of value and tonnage, by commodity, mode, and combinations thereof. This information is utilized to quantify the need, capacity, and sustainability of developing and maintaining a successful dedicated truck lane system (Digre et al., 2011). In addition, knowledge regarding bi-directional flows can inform decisions by logistics service providers regarding dedicated truck fleets for certain industries (Panchalavarapu, 2010).

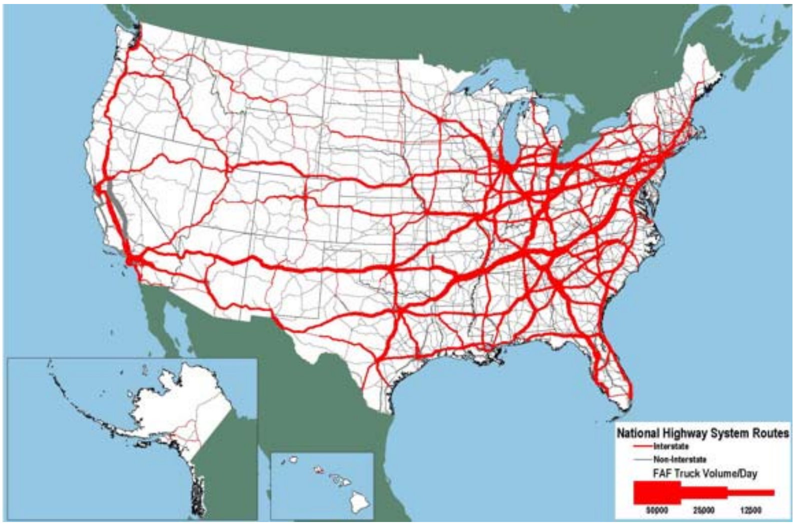

Figure 12: Map of USA freight flows (US Department of Transportation, 2007)

South Africa's freight demand model provided the core database for a national corridor performance measurement system that was developed to inform transport network efficiency and to improve the performance of strategic corridors (Department of Public Enterprises, 2016; Havenga et al., 2015).

Furthermore, commodity flow matrices facilitate investigating economic relationships by providing a measure of the extent to which industries in different regions are linked and creating an understanding of how policies and investments in one region impact linked regions (Zhang et al. 2003; Schwarm et al., 2006; Richard Paling Consulting, 2008). It also informs the role of shared regional logistics infrastructure (such as road corridors) in supporting the economy of surrounding regions and communities and how the infrastructure links to outlying regions.

Regional commodity flow matrices result in a deep understanding of the economic and industrial base of a region; a prerequisite for estimating future freight flows since the sectoral impact of changes in economic conditions, and the concomitant impact on freight transport demand, can be modeled more accurately (Harris and Anderson, 2011; Mesenbourg, 2011; Lawson et al., 2011). This can also facilitate proposals regarding re-localization, i.e. a move by businesses to return economic activities closer to their local markets to reduce production risks and transport costs (North, 2010). In the longer term, these efforts could lead to more sustainable transport demand. Commodity-level input-output modeling and resulting freight flows also allow for validation of data against economic and production data from other sources on a very detailed level, improving the accuracy of the freight flows and enabling the refinement of other sources where applicable. Given the scale and relative permanency of large-scale infrastructure investments in a resource-challenged world, the benefit of improved accuracy is evident (Havenga, 2007).

Through this process, infrastructure spending and policy initiatives can be better informed, industrial clusters developed in the correct spatial context, and other bottlenecks and issues can be addressed within the context of the total national freight-flow landscape.

Macro Logistics Planning and Policy applications

Commodity-level data enable an understanding of current modal shares, the sustainability of future freight flows given the current trajectories, and where to target modal shift given commodity characteristics.

Zhang et al. (2003) reported on the development of a methodology, based on the CFS data, to systematically estimate state-wide truck travel demand using the state of Mississippi as a case study. The first step is a detailed commodity flow data analysis including modes and origin-destinations, which facilitates conversion of road flows into truck trips by using average density of freight and average load per truck to estimate the composition of different truck types carrying different commodity groups. One of the objectives is to identify and prioritize intermodal infrastructure opportunities given that highway networks are experiencing severe congestion - with concomitant externality costs - while other inland transportation modes are underutilized. Feasibility studies for the development of intermodal technologies are enhanced through the availability of commodity-level data, since specific industries and freight owners can be targeted per route.

Similarly, the State of Alabama used the CFS to develop a state-wide model that showed the possible impact of new relocated industries and the movement of their goods on the state's existing transportation infrastructure. Understanding the total character of freight movements along a corridor – its prevalent commodities and potential safety and operational constraints – facilitates the identification of potential options for shifting commodities to alternate modes of transport to alleviate congestion (Anderson and Harris, 2011).

In South Africa, the segmentation enabled by the country's disaggregated macroscopic FDM informed the development of a domestic intermodal strategy (Havenga et al., 2012) and allowed for confidential input to the national rail policy to change the thrust of rail policy away from one that is focused only on institutional reform and increasing clarity towards one that encourages development and investment (Smith, 2012). The externality cost extension to the transport cost component of South Africa's logistics cost model is providing ongoing input to national and international discussions on logistics' contribution to sustainability, as well as providing inputs to carbon taxation (Havenga, 2010 and 2015). Outputs from the South African freight demand model also played a pivotal role in directing large-scale infrastructure investments, notably the rail and port capital investment programs, with the intent of creating capacity ahead of demand (Havenga, 2012; Transnet, 2015).

The inclusion of imports and exports in spatial disaggregation unlocks analysis of the advantages of supply chain coordination and the elimination of trade barriers for cross-border and international trade. Reducing delays at South Africa's two major inland border posts can reduce the costs related to these delays by 55% due to reduced buffer stock required at the destination site, reduced costs of carrying inventory, and reduced vehicle utilization losses (Havenga et al., 2013). Havenga et al. (2016) showed that, for international trade, documentation costs and induced transport costs due to truck and ship standing times are approximately equal to direct port charges. These costs are at least in part avoidable and can be addressed through improved port efficiencies and collaboration between the ports, industry, and the South African Revenue Services.

The inclusion of rural areas in spatial disaggregation allows for detailed analysis which points to opportunities for a revival of rail branch lines in South Africa, which will reduce transport costs and externality charges in rural areas and increase equitable access to the core transport network. The research also expounds the single-network characteristic of South Africa's railroad, based on density requirements, relative to the size of the network (Simpson and Havenga, 2010).

In sum, the benefits of understanding macro-logistics facilitates decisions and discussions beyond transport and allow policy makers to focus on impacts of national logistics in a way that would not otherwise be possible. As can be seen from the case studies in the United States and South Africa the evidence can provide a basis for decisions with transformational impact. The challenge for emerging economies is that the research and application of macro-logistics are still in their infancy.

Mesoscopic Applications targeting Industries or Geographies

Commodity-level freight-flow analysis enables a more robust linking of freight activity with underlying economic activity, such as the increase in high-value, low-weight products which informs modal, service and transport technology requirements (Mesenbourg, 2011; Lawson et al., 2011).

Production of low-value bulk commodities, such as grain or coal, generates a transport demand disproportionate to their value (Transportation Research Board, 1997). In New Zealand, the *National Freight Demand Study* showed that almost 60% of the total freight transport demand consists of the movement of relatively low value commodities such as liquid milk, aggregate, timber and wood chips. For these goods, transport costs can represent a high proportion of the delivered costs. Minimizing the transport costs is therefore an essential part of keeping the overall logistics costs low and, for items which are converted into exports ensuring that these are competitive on world markets (Richard Paling Consulting, 2008).

For most commodity groups, the relationship between the value of output (in monetary terms) and transport volumes changes over time. These changes may be due to changes in the mix of commodities being produced within a given commodity group or changes in the average real value per ton of major products within the group (Transportation Research Board, 1997). In the United States, the Commodity Flow Survey (CFS) has allowed policy makers and researchers to understand how the growth in demand for higher value and time-sensitive commodities has affected the transportation system by driving growth in trucking (Ludlow, 2011). For example, from 1999 to 2009 the percentage of electronic commerce sales in the retail sector increased sevenfold from 0.6% of total retail sales in 1999 to 4.1% in 2009. In manufacturing, e-commerce shipments increased from 18% of total manufacturing shipments in 2000, to 39% in 2008 (Mesenbourg, 2011; Lawson et al., 2011). The CFS is also being applied to understand the impact of increasing globalization on furniture industry supply chains with U.S. furniture imports having grown 108% and exports increasing 41% from 1999 to 2007. The commodity forecasts and predicted flows will enhance understanding of the underlying global and domestic furniture supply chain requirements (Liu and Tolliver, 2011).

In South Africa, the commodity-level segmentation within the national freight demand model enabled the identification of palletizable fast moving consumer goods for the domestic intermodal business case. More than half of South Africa's potential intermodal freight moves on the country's two most-dense freight corridors. Building three intermodal terminals to connect the three major industrial hubs – Gauteng, Durban and Cape Town – could enable modal shift to rail, increasing rail densities and thereby reducing logistics costs - including externalities - for the identified intermodal freight flows on these two corridors by two-thirds (Havenga et al., 2012).

An understanding of the transportation of hazardous materials allows objective evaluation of the safety risks involved. Understanding the geographical flows of these commodities facilitates policy-making, alleviates public safety concerns by providing data for conducting risk analyses and security assessments, and identifies emergency response and preparedness requirements (Duych, 2011).

The relevance of spatial and sectoral flows in macroscopic freight demand analysis is clear. In the next section, an overview of the development of freight demand models is provided to inform the methodology to develop India's FDM.

Background to Macroscopic Freight Demand Modeling

Transportation demand modeling was formalized within urban passenger transportation planning during the 1960s with the development of the sequential four-step model. The four steps refer to trip generation, trip distribution, mode choice and route assignment (De Jong et al., 2004).

Walter et al. (1998) expanded this approach and include freight modeling in their approach based on the premise that passenger flow models rely on socioeconomic factors rather than profit maximization which is often the case with freight which requires a mathematical optimizing algorithm. They highlight the problems associated with the absence of intercity data and propose and develop an approach to develop an investment analysis model that integrates regional input-output models, spatial interaction models, cost-benefit analysis and geographic information systems. Ortuzer and Willumsen (2011) admit that a large part of their seminal work is around passengers with a strong urban emphasis even though freight movement, and especially road haulage, is an important source of congestion, noise and other traffic problems. They maintain that policy options are limited, but that freight demand modeling can play an important role in developing countries where exports and market access for underdeveloped areas are important.

Specific characteristics of the freight transport industry therefore render freight transport demand modeling more challenging from a methodological point of view than passenger transport demand modeling. These include (De Jong et al., 2004; Müller et al., 2012; Ivanova, 2014):

- The heterogeneity of freight (from parcel deliveries with many stops to single bulk shipments of hundreds of thousands of tonnes) and the heterogeneity of geographies;
- The diversity of stakeholders (freight owners, customers, freight forwarders, logistics service providers, government and communities) and components (technology, infrastructure, fixed- and moving assets) within freight supply chains requiring coordination and integration. These lead to complex relationships and, frequently, conflicting requirements.

This is compounded by the mega scale and extended lifespan of freight transportation infrastructure such as railways and ports (Rodrigue, 2016). In addition, specific modeling requirements impact the freight modeling process. According to Müller et al., 2012, the requirements include:

- Modeling and tracking the link between freight transport and final consumption (often proxied by GDP growth);
- Accurate conversion of trade values to trade volumes (the majority of economic data is published in monetary terms);
- The choice of vehicle type as impacted by cost sensitivities and freight requirements; and
- Ability to link modal interaction, mainly rail, road and waterways, as well as the interaction with passenger capacity requirements.

The complexity induced by these characteristics and requirements is the main reason why the development of freight transport modeling has been lagging the development of passenger transport modeling. The basic premise is however straightforward: The spatial patterns of production and consumption generate freight transportation flows to meet the needs of end consumers (Ivanova, 2014). This translates into the following four-step approach for freight demand modeling (De Jong et al., 2004):

- Production and attraction – Estimating the spatial distribution of economic activities, i.e. spatially-disaggregated supply (origin) and demand (destination) of commodities and shifts in this spatial distribution over time as the economy responds to policies, macro- and microeconomic trends. The output dimension is origin and destination tables in tonnes. In intermediate stages of the production and attraction models, the dimension could be monetary units (trade flows).
- Distribution – Modeling volumetric freight flows between origins and destinations (cells of the OD matrix).
- Modal split – The allocation of the volumetric freight flows to modes (e.g. road, rail and IWT).
- Assignment – The modal flows are converted to vehicle-units and assigned to networks (ideally, incorporating both truck flows and passenger cars on road networks).[1]

There are essentially three methodologies available for developing freight supply and demand data: a demand-side approach, a supply-side approach and a survey approach (Havenga and Pienaar, 2012b).

A demand-side approach addresses the geographical disparity between supply and demand through flow-modeling techniques and modality assumptions. It is based on the macroeconomic input-output (I-O) model of the economy which describes the interdependencies between industries in terms of intermediate inputs, driven by the developments in final household demand. The country-level multi-sectoral I-O framework was developed by Leontief (1986) in the 1930s, based on the theory of Keynes who postulated that production is determined by consumption, so-called market equilibrium, expanded to multiregional or spatial I-O models by Chenery, Isard and Moses in the 1950s allowing for the calculation of inter-regional trade (Ivanova, 2014). It requires voluminous disaggregated economic data but renders a deep understanding of freight-flow patterns and resulting demand for logistics infrastructure. The demand-side approach therefore has the potential to provide the most comprehensive information but is only possible if adequate data and funding are available (Transportation Research Board, 1997).

A supply-side approach collects data regarding actual transportation activity on each mode of transportation and constructs a network view of the supply of freight transportation infrastructure. Typically, road freight volumes, due to its fragmented nature, are modeled based on truck counts at weighbridges and counting stations, while actual rail and port data are mostly available through agreements with incumbents. The supply-side approach is the most cost-effective option but does not provide detailed O-D data or commodity visibility.

A survey approach entails the distribution of a questionnaire to a sample of freight logistics stakeholders and, through statistical analysis of the responses, the characteristics of the total freight market are estimated. The strength of the survey approach is that it can elucidate industry dynamics to explain freight flow trends and anomalies. Questionnaire-based surveys however tend to underperform due to sampling biases and non- or partial responses (Kockelman et al., 2009), and present reporting challenges due to confidentiality requirements (Zhang, 2003; Richard Paling Consulting, 2008; Harris and Anderson, 2011). In addition, surveys are often once-off endeavors with limited repeatability due to time lapses and changes in scope, and fail to provide systemic logistics

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[1] Very few models conclude with converting tonnages flows to vehicle-units and assigning this to the transport network. Currently this falls outside the scope of the India FDM.

observations, impacting their macroeconomic effectiveness (Havenga and Pienaar, 2012b; Bergquist et al., 2016).

There are numerous national and international freight transportation models discussed in the literature, for example the Italian national model, the REGARD model in Norway, the Walloon Region freight model in Belgium, the SCENES European model system for passengers and freight, the Dutch TEM-II and SMILE models, as well as the Swedish SAMGODS model (De Jong et al., 2004; Müller et al., 2012; Ivanova, 2014). The lack of a standardized modeling approach is attributable to limited methodological and calibration details being made available publicly, the challenges involved in the estimation of freight demand given that reliable data on freight volumes are scarce and fragmented, and data availability is different for each geography modeled, as well as the variety of objectives driving freight demand modeling which give rise to models that are context-specific, hampering the transferability of models (Mommens et al., 2017).

To improve the continuity and application of its country-level FDM, the chosen approach for India's model is a demand-side model due to the comprehensive nature and resulting application possibilities of demand-side modeling. The spatial and sectoral disaggregation is enabled through utilization of hybrid input data i.e. actual and modeled data, to improve accuracy. The model outline is discussed below.

Methodology for developing the India Freight Demand Model (FDM)

The underlying driver of the India FDM is sufficient disaggregation of the national transportable economy on a spatial and sectoral level, followed by flow generation via gravity modeling, to enable detailed analysis on all the core components of the national freight system.

Data collection

The depth of data available in India is immense yet dispersed, therefore giving rise to the typical onerous data cleaning and data integration challenges demanded by heterogeneous data sources. The following data was received from various sources and agencies in India:

1. Economic data from the Prowess Database that specified intermediate demand, mining and agricultural production, and beneficiation of products at specific locations throughout India over multiple years.
2. Handbook of horticultural statistics from the Ministry of Agricultural Statistics, and mining statistics from the Ministry of Mines.
3. Import and export data per commodity for all ports in India. This included import and export data per port for major commodities. For some ports import and export data - from ports such as the Kolkata Dock System (KDS) – were more detailed on a commodity level, described origin-destination states and specified whether freight was containerized or not. Having access to hinterland ODs is not common, and this provided valuable input into modeling of some corridors.
4. Freight rail movements on commodity and OD level
5. Production volumes for agricultural and mining commodities per state or district
6. Industry reports for some key commodities

Supply and Demand per Commodity on a Geographical basis

Supply and demand on a geographical basis per commodity is determined as per equations 1 and 2 below.

$$Total\ demand = Intermediate\ domestic\ demand + Final\ domestic\ demand + Exports \quad (1)$$

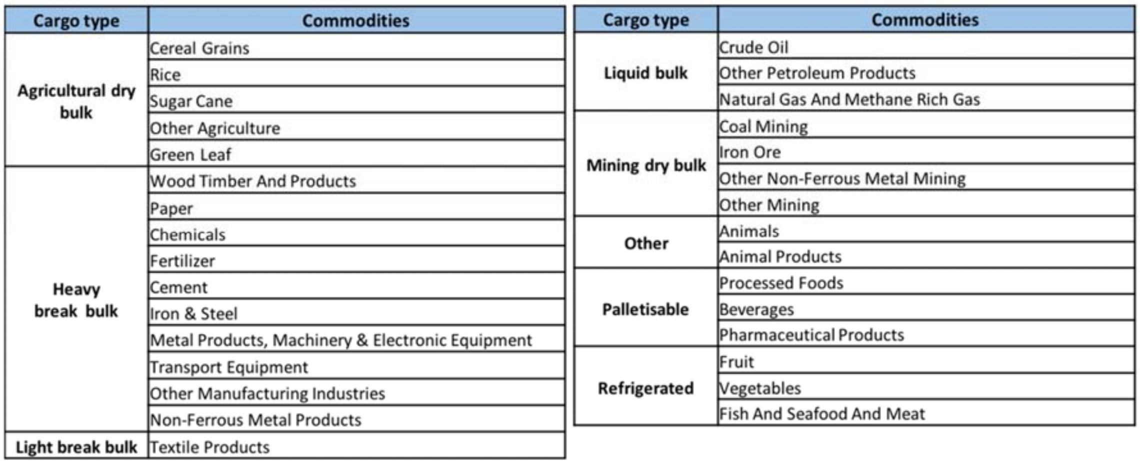
$$Total\ supply = Production + Imports \quad (2)$$

Total supply equals total demand which corresponds to the market equilibrium condition (Ivanova, 2014). The modeling of total supply and demand addresses a concern raised by Lyk-Jensen (2011) that freight traffic forecasting typically does not adequately incorporate international trade flows.

An official spatially disaggregated I-O table was not available for the Indian economy, thus final supply and demand tables had to be constructed (the tables are therefore referred to as supply and demand tables, not I-O tables, as the upstream and downstream interdependencies are not automated). The model is a hybrid, dependent on actual and modeled data, but differs from many other models in that the main inputs are actual data, while the overall supply and demand balance is maintained, implying modeling of unknown data points. In the case of India, the latter refers mainly to final regional consumption data, as well as the regionalization of aggregate data. Actual data is hardcoded in the supply and demand tables, which is much more reliable and useful than an assumption-based disaggregation. For example, if new data on totals or regional supply and/or demand elements become known, the supply and demand tables are updated and rebalanced (the same holds true for district-level data, import and export data). Discussions with key players were also conducted for gathering spatially disaggregated actual data for larger commodities. The key was to rebalance both the aggregate and regional supply and demand tables when actual data replaced modeled data, resulting in improved disaggregated supply and demand tables. The same process is followed for flows where known flows (such as rail data) are hardcoded and the remainder modeled.

The sectoral disaggregation is informed by existing classification protocols. Following a number of iterations in the 1970s and 1980s to standardize data collection and reporting, the Annual Survey of Industries Commodity Classification scheme (ASICC) was developed in India in the late 1990s while maintaining linkages with the Standard International Trade Classification (SITC) which is maintained by the United Nations Statistics Division, and the Harmonized System (HS) which is maintained by the World Customs Organization (South Asian Association for Regional Cooperation, 2006). The final commodity group list for the India FDM maintains the link with the HS classification, informed by the practicality of data availability. As shown in Table 2, the model contains data for 31 commodity groups (to identify specific supply chains and to understand cost drivers) grouped into 8 cargo types (to identify logistic solution criteria and to identify required infrastructure, policy and operations).

Table 2: Cargo types and commodities in India's freight demand model



Cargo type	Commodities
Agricultural dry bulk	Cereal Grains
	Rice
	Sugar Cane
	Other Agriculture
	Green Leaf
Heavy break bulk	Wood Timber And Products
	Paper
	Chemicals
	Fertilizer
	Cement
	Iron & Steel
	Metal Products, Machinery & Electronic Equipment
	Transport Equipment
	Other Manufacturing Industries
	Non-Ferrous Metal Products
Light break bulk	Textile Products
Liquid bulk	Crude Oil
	Other Petroleum Products
	Natural Gas And Methane Rich Gas
Mining dry bulk	Coal Mining
	Iron Ore
	Other Non-Ferrous Metal Mining
	Other Mining
Other	Animals
	Animal Products
Palletisable	Processed Foods
	Beverages
	Pharmaceutical Products
Refrigerated	Fruit
	Vegetables
	Fish And Seafood And Meat

To apportion national supply and demand to the districts in India various methods were required. Districts are the smallest available geographical unit on which some data are published in India. Where data was not available on a district level, secondary keys were used for apportionment. For example, to apportion private consumption expenditure on motor vehicles, keys such as population, employee and average income per district were used, while intermediate demand for coal is estimated from the production of electricity (based on the known location of coal-fired power stations). In certain cases, such as for instance the production of maize, geographically disaggregated maize production data is available, however, for some agricultural crops data are only available per province. They could be disaggregated based on land area per district and number of employees in the agricultural sector per district. The biggest data challenge in the India FDM source data was with geographical names as there is no standard naming convention, resulting in manual processing of thousands of records to correlate data between sources.

This hybrid approach is in line with the Norwegian freight model, which uses the Norwegian CFS as a platform, supplemented with other available data sets and updated with more recent data as available (Hovi et al., 2013). The hybrid approach also echoes the aim of the German freight model which is to enable national freight traffic modeling for all surface transport modes with best utilization of national statistics, vehicle owner surveys and national I-O tables (Müller et al., 2012). The Belgian disaggregated freight model utilizes input data constructed from the annual national transport survey, a number of national statistics bodies and trade gateways like ports and border crossings (Mommens et al., 2017). While none of these models utilizes spatially disaggregated I-O models to determine freight flows, they acknowledge the importance of strengthening freight demand analysis to the extent possible with actual data, as disaggregated freight demand modeling produces sufficient uncertainty of its own accord.

Once the final supply and demand tables per commodity and district are created, freight flows are modeled to match demand with supply using a gravity-modeling technique.

Gravity Model

The estimation of flows per commodity is based on a gravity modeling approach using the volumetric spatially disaggregated supply and demand tables.

The input data for the flow modeling is created by subtracting the origin and destination data of known flows (rail freight for all of India, and other known freight flows for which an inland origin or destination is known) from the supply (origin) and demand (destination) values, the balance of supply and demand data are modeled as road flows via a gravity model. Once the road flows per commodity for road transport has been established, the known flows per commodity are added back to provide total flows that aggregated to the original total supply and demand tonnage, enabling modal analysis.

The most commonly used method applied in the distribution step is the gravity model (Ivanova, 2014; Arbués and Baños, 2016). Müller et al. (2012) confirmed that complex national and international freight transportation models that offer a holistic overview of transportation demand typically employ some type of gravity model to explain the trip distribution step. Inspired by Newton's law of universal gravitation, the gravity model is based on the notion that bilateral trade flows are directly proportional to the volumes of supply and demand of the regions under consideration and inversely proportional to a measure of transport resistance. The function describing the attraction value between origins and destinations within a certain distance is called a distance decay function (Smith, 1970). The decay parameter determines the slope of the decay function. Raza and Aggarwal (1986: 114) highlighted the relationship between distance and freight flows in one of the first comprehensive freight-flow analyses for India. Figure 13 shows statistically significant inverse correlation between rail flows and distance, while the coefficient of determination (which indicates the proportion of explained variance) for all commodities except industrial products are above 50%, indicating that variations in the volume of inter-regional freight flows are mainly due to the friction of distance.

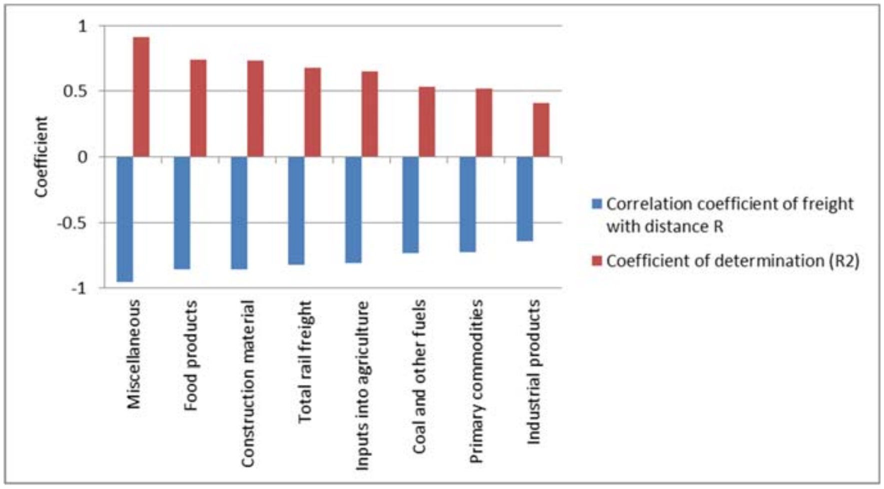


Figure 13: Interdependence of rail freight flows and distance (Raza and Aggarwal, 1986: 114)

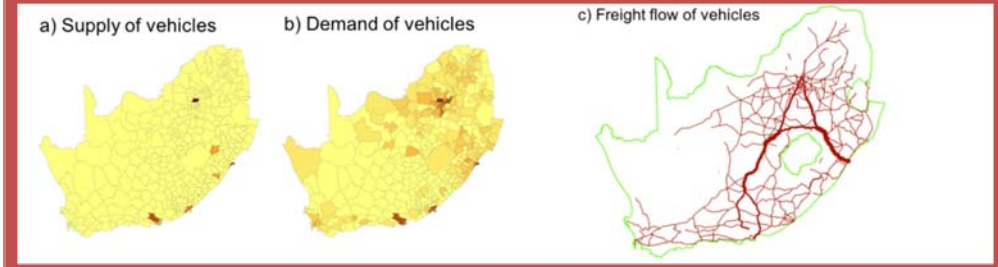
Figure 13 also highlights that distance decay rates vary from one commodity to another based on its nature and utility. Low value, bulk commodities generating a transport demand disproportionate to their value tend to have a sharp rate of decay, while for higher-value commodities the impact of distance is smaller, suggesting low decay parameters (UK Department for Transport, 2002). These commodity characteristics translate into two distance decay functions applied in gravity modeling, namely (de Jong and Van der Vaart, 2010):

- An exponential function which represents the quickly declining distance decay, i.e. with very little or no long-distance flows (mostly used for bulk commodities or homogeneous goods); and

- A power function which represents the more gradually declining distance decay with high flows over short distances, but considerable longer distance flows (mostly used for manufactured and end-use agriculture commodities, i.e. heterogeneous agglomerations).

Exhibit 1: Selecting an appropriate decay function – the example of motor vehicles in South Africa

Figure a) below illustrates the supply of vehicles in South Africa. Vehicles are imported or assembled by a small number of facilities near the ports on the east coast and further north in Gauteng, the industrial center of the country – these facilities are manufacturer-specific. Demand occurs in the areas where high concentrations of middle- and upper-class consumers reside (Figure b). Selecting an exponential decay function will result in supply meeting the closest demand. However, as the choice of vehicle brand and model is important to the consumer, a power decay function is selected to ensure that the resulting flows mimic the reality of vehicle deliveries in South Africa (i.e. that all motor vehicle brands are supplied to all demand areas in South Africa) (Figure c)


a) Supply of vehicles
b) Demand of vehicles
c) Freight flow of vehicles

Travel time or travel distance or a more complex generalized transportation cost function combining actual costs and the opportunity costs of travel time are often used as measures of transportation resistance (Bates, 2008). In developing economies, data sources are frequently disparate and covert, there is limited data on freight flows, and therefore limited data on transportation and logistics costs. In these cases, it is not possible to utilize transportation costs as a resistance factor to determine disaggregated freight flows, as freight flows are a key input into developing disaggregated cost models. Distance is therefore the most commonly available measure of resistance, as distance is an objective readily available variable. Road cost components, such as diesel consumption and truck wear-and-tear, also typically have a linear relationship with distance, rendering distance an appropriate transportation resistance factor (Martinez-Zarzoso and Nowak-Lehmann, 2007; Giuliano et al., 2013).

The above parameters are operationalized in a gravity model as per Equations (3), (4) and (5) (de Jong and Van der Vaart, 2010).

$$T_{ij} = A_i.B_j.O_i.D_j f(C_{ij},\beta) \tag{3}$$

$$A_i = 1/(\Sigma_j.B_j.D_j.f(C_{ij},\beta)) \tag{4}$$

$$B_j = 1/(\Sigma_i.A_i.O_i.f(C_{ij},\beta)) \tag{5}$$

Where:

Tij = the estimated volume of freight flows between origin i and destination j

Ai = the balancing factor for origin i that ensures compliance to Oi

Bj = the balancing factor for destination j that ensures compliance to Dj

Oi = the constraint value for origin i (i.e. total supply)

Dj = the constraint value for destination j (i.e. total demand)

ƒ is the decay function where:

ƒ(Cij,ß) = exp(-ß.Cij) in case of an exponential function

ƒ(Cij,ß) = $Cij^{-ß}$ in case of a power function

where:

Cij = the distance between origin i and destination j (the resistance measure)

ß = the decay parameter

The availability of both supply and demand data enables the use of a doubly-constrained gravity model (de Jong and Van der Vaart, 2010) where total flows from a district (the origin) equal the total supply from that district, while flows to a district (the destination) equal the total demand at that district. This ensures adherence to the market equilibrium condition where total supply equals total demand (Ivanova, 2014).

Equations (4) and (5) above hold for a doubly-constrained gravity model if the constraint equations (6) and (7) below are satisfied through an iterative procedure:

$$\sum_j Tij = Oi \tag{6}$$

$$\sum_i Tij = Dj \tag{7}$$

For the India FDM, the road distance matrix was used to determine the flow data for the non-rail component of freight. A detailed national road network was constructed. This allowed road travel times to be estimated between the various origins and destinations, penalized for the type of road. A lower resistance was given to national roads, so freight collates towards these highways, the logic being assumed improved travel time on highways. This refers to Cij in Equations 3 to 5, which typically refers to distance, but can be adjusted based on estimated travel time or costs. For the India FDM, it is adjusted by ranking roads through reducing the travel distance for highways and increasing the travel distance for rural roads.

In a doubly-constrained spatial interaction model where both the origins and destinations are known but the derived freight flows over the transport network are unknown, the problem is essentially confined to the estimation of a suitable decay parameter. In terms of actual flows, only rail freight-flow information is available (which in most instances accounted for only a small market share); the distance decay parameter could therefore not be derived (for all commodities) from actual data. Decay parameters utilized in other gravity models are also typically not published, these could therefore not be used as a starting point, as commodities tend to exhibit similar distribution characteristics. Decay parameters for the South African FDM were however available. At the outset of the South African gravity-modeling exercise, distance-decay parameters were developed informed by the decay parameter principles discussed above as well as known flows such as rail flows and large industry flows.

The ‘best-fitting’ distance decay parameters were subsequently selected. These decay factors have been fine-tuned over a period of 10 years. Annual application and interaction with industry have proven the accuracy of these decay factors to model commodity-flow behavior. These decay factors were utilized as a starting point, informed by known rail and port flows in India, and fine-tuned through iterative application of the gravity model. However, the freight flow behavior of some commodities in South Africa is completely different to in India, such as sugar cane, which is transported very short distances in South Africa to one region, but long distances across the country in India. The best-fitting decay factors were used based upon multiple tests of various decay factors to determine the best overall fit in line with partially known data and inputs from local stakeholders.

The UK Department for Transport (2002) also stated that, lacking freight-flow data from which to estimate the parameters, developers iteratively adjust the coefficients to match observed counts and vehicle miles of travel estimates by truck type and if not available, using analyst judgement. A distance-decay parameter is developed for each commodity group individually to account for the varying nature and utility of the commodity, as discussed above.

The gravity modeling is done using software called FlowMap® which was developed in 1990 at Utrecht University. The cost-effective and user-friendly software was initially targeted towards use in developing countries’ spatial planning and has been applied successfully in South Africa for various spatial planning purposes since 2000, when the Professional Edition was released. FlowMap® expands typical GIS functionality to allow for the management and analysis of data that depict spatial relations such as distances, flows, travel times and travel costs (Utrecht University, 2013).

The convergence criterion must also be set in FlowMap®. This determines how well the number of trips that to be estimated from the origins and to the destinations has to equal the set variables for the origin and destination constraints respectively. The convergence criterion also determines how well the MTL that is to be estimated has to equal the distance as was set above (de Jong and Van der Vaart, 2010). This is the required accuracy of fit between the modeled data results and the input parameters.

Typologies

Once freight flows have been modeled, they are aggregated to facilitate analysis and recommendations. A succinct view of national freight flows can be obtained through aggregation into two key freight-flow typologies for India, each with unique transportation characteristics. Firstly, corridor flows occur over long distances between major cities. Due to the high freight density on corridors, these flows provide ideal opportunities for economies of scale and consolidation. Rail transportation is generally the most efficient and suited mode for this type of flow, although countries with navigable river systems (such as some countries in Europe) have had major successes in returning high-volume freight to inland waterways (Inland Navigation Europe, 2016). Secondly, there are those flows that are neither urban nor corridor flows and are labeled ‘other’. Typified by broad distributions of origins and destinations outside the cities, medium to long distances and low freight densities, flows of this nature are the most difficult to optimize and can be suited to either road or rail (these flows are mainly in rural areas). [2]

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[2] A third typology, urban freight flows (freight traveling within major cities), typically travel short distances, and are more affected by congestion and therefore better suited to smaller road vehicles. Due to the nature of demand-side modeling, the latter is not modeled, as urban freight mostly refers to the ”last leg” of transport, in effect a double-count of traffic that has already been measured as a supply-and-demand flow, and includes collections, deliveries, distributions and redistributions.

To define the corridors used during the aggregation of OD-level flows, a graphical depiction of the total road network was superimposed with a simple map of the highways, and roads classified as being either highways or regional roads. For the corridor aggregation, the major cities and the catchment areas surrounding the cities were identified as the core catchment due to the high densities involved, while outlying areas were identified as the wider catchment due to lower densities: flows from a core to a core were defined as corridor Class 1 and are flows from a single origin to a single destination, flows from a core to a wider catchment areas are defined as corridor Class 2, and flows from wider catchment areas to wider catchment areas are defined as corridor Class 3. The difference between Class 3 and the 'other' typology is that Class 3 flows still flow along the corridor and can therefore be easily consolidated with other corridor flows.

Modeling Transport Costs

With a complete database of freight flows, transport costs are calculated in a similarly disaggregated fashion. Actual rail and waterway tariff data were received from the respective operators. Road tariffs (costs) were calculated as per equation (8).

$$L = \sum_{i=1}^{n} \sum_{j=1}^{p} \sum_{k=1}^{s} xy_{ijk} \left[(d + c + l + q + e + f + m + z)_{ijk} + t_k \right] \tag{8}$$

L = road line haul cost

n = number of commodity groups

i = commodity grouping

p = number of typologies

j = typology

s = number of routes

k = route

x = tonnes transported

y = distance in kilometers

d = depreciation rate per tonne-km

c = cost of capital per tonne-km

l = license fee and road tax per tonne-km

q = insurance per tonne-km

e = driver fees per tonne-km

f = fuel cost per tonne-km

m = maintenance and repair costs per tonne-km

z = tire wear cost per tonne-km

t = toll fees per tonne-km

This equation involves the summation of all the different cost elements of road transport within a typology on a specific route. The different cost elements of road transport are determined by vehicle type; this, in turn, is determined by the commodity type, typology and route of travel. The commodity's 'preferred' vehicle type will change with changes in each of these variables. Once the vehicle type and volume are known, the cost elements can be assigned according to equation (8), above. The core drivers of transport costs, i.e. weight in tonnes (x) and distance traveled (y), describe the base of the formula.

It is however important for logistics infrastructure and efficiency planning and will be modeled based on freight flows developed from truck counts in subsequent phases of the project.

The cost elements are primarily influenced by:

- **Asset type:** Vehicle type, condition and fuel-efficiency.
- **Utilization:** Load factor, workdays per year, kilometers per year, driver hours and other labor regulation
- **Nature of trip:** Long-haul or short haul, road condition, altitude and terrain.
- **Financing terms:** Interest rate, depreciation parameters.

Data regarding the cost elements and their drivers were sourced from multiple industry reports and workshops with organized trucking bodies in Delhi and Kolkata.

Adding a transport cost layer to the India FDM enables robust cost-benefit modeling of various scenarios investigated to improve the performance of the Eastern Corridor. (This could be expanded to total logistics costs in future revisions of the model.)

Final Model Parameters

The resulting parameters of the India FDM are:

- Freight flows between 672 geographical areas: 637 districts within India, 30 of India's ports and 5 neighboring countries (Bangladesh, Bhutan, Myanmar, Nepal and Pakistan);
- For 31 commodity groups grouped into 8 cargo types
- On the three inland modes (road, rail and IWT), as well as crude oil in pipelines;
- Aggregated per typology namely corridor and rural freight;
- Identifying mode suitability for rail-friendly freight and waterway-friendly freight; and
- Adding actual railway and waterway transport costs and estimating costs for nine road cost drivers to enable cost-benefit analysis.

The result of this process is a database of about 4 million unique freight flows, to which transport costs of known flows are added and estimated for modeled flows. Each unique flow specifies how many tonnes of a specific commodity were transported between a specific origin-destination district pair during a year and on which mode (road/rail). Each record further differentiates whether this was domestic, import or export freight and calculates the tonne-km associated with that freight flow.

The modeling framework and outputs of the India FDM addresses the unique characteristics and requirements of freight demand modeling, discussed in the literature survey as follows:

- The heterogeneity of freight transport is addressed through commodity and spatial disaggregation and allows for policy-relevant conclusions for specific industries and geographical areas;
- Mapping the national freight flow landscape while enabling mesoscopic applications (due to the level of disaggregation), aids prioritization towards collaborative long-term goals, aiding the diversity of stakeholders to align conflicting requirements;
- The linkages between freight transport, the broader economy and final consumption studied through the development of disaggregated supply and demand tables;
- The challenges with the conversion of trade data in monetary terms to trade volumes largely circumvented through developing the bottom-up supply and demand tables in volume terms from all available sources;
- The choice of vehicle type is included in the transport cost model to account for cost sensitivities and the requirements of specific commodity groups;
- The modal interaction between rail, road and waterways is a core component of the model;
- The regionalization of supply and demand is facilitated through the development of disaggregated supply and demand tables commencing from the most granular spatial disaggregation at which

national data is available, namely districts. The bottom-up data gathering process facilitates the correlation of the disaggregated data with available aggregates.

Model Validation

- Given the lack of an established I-O model in India, available data, desktop research and interviews with industry experts and logistics service providers were utilized to construct and refine supply and demand tables.
- Truck counts are a relatively cost-effective tool to estimate aggregate freight flows and are therefore often used as a validation method for verification of modelled flows (Zhang et al., 2003; Richard Paling Consulting, 2008). In South Africa, for example, a robust national freight flow model (NFFM) was developed that translates the truck counts by the South African National Roads Agency into tonnages (Havenga and Pienaar, 2012a), and the NFFM and South Africa's spatial freight demand model are used for cross-validation purposes. Truck flow data for India was used on a case-by-case basis, such as comparing traffic around Varanasi on the Delhi-Kolkata corridor with the FDM results, and these comparisons were favorable. A next step would be the translation of total truck count data into freight flows for cross-validation purposes.
- Following project approval of the India FDM based on initial estimates of freight logistics cost reduction opportunities on the Eastern Corridor, twelve months' subsequent research and fine-tuning of the model shows remarkable alignment with initial estimates on an aggregate level. This is in line with experiences for example in Norway where, following numerous model refinements, the overall macro distribution in the new model version was quite similar to that obtained in the former version (Hovi, et al., 2013). However, the refined disaggregated models enable a better description and fit to mesoscopic applications, therefore improving validity and applicability to industry, regional or typology-level transport challenges, as well as enabling targeted infrastructure investments. This confirms the usefulness of two different levels of freight transport modeling to increase the accuracy of the forecasts and the range of policy applications of the models:
    - A fast (low-resolution) policy analysis model which includes a wide range of factors but limited detail, to aid with initial screening and comparison of policy alternatives ('first order approximations'); and
    - A detailed (high-resolution) forecasting model which analyzes limited factors in a lot of depth for estimates at a mesoscopic level (e.g. industry, region, typology or network) and to provide inputs for project evaluation.

  The reasoning behind this is to address the diverse information needs of the numerous stakeholders, to minimize cost by using the policy-analysis model for prioritizing options, and to improve accuracy by using the detailed model when long-term, high-cost decisions are required (De Jong, Gunn, & Walker, 2004). These principles can be utilized going forward.

Research Constraints

- A national I-O table for India has been developed as part of the World I-O database (funded by the European Commission).[3] In the absence of average \$/ton values this table cannot be converted to tonnage terms. The project team is endeavoring to develop such values for the I-O table to serve as a macroscopic validation since the World I-O database is not regionally disaggregated.

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[3] Refer http://www.wiod.org/new_site/database/niots.htm.

Conversion of I-O outputs to tonnes using $/tonne ratios is a key source of vulnerability in spatial I-O modeling. These ratios can be developed from export data but is highly unlikely to be correct for domestic movements (UK Department for Transport (2002)).

- Disaggregation into 672 geographical areas implies onerous data requirements, the viability and necessity of such detailed disaggregation will become more distinct as the model matures.
- The interaction with passenger capacity requirements is important from infrastructure and spatial planning points of view, and methods to include this need to be considered.
- Logistics behavioral modeling – making the trade-offs between transport and inventory holding explicit by including warehouse locations in OD tables as an interim demand point is an important addition to spatial flow patterns, impacts the costs of freight movements and infrastructure usage, and aids the understanding of the impact of freight policies. The Dutch SMILE model was the first aggregate freight model to account for the routing of flows through distribution centers, and therefore also consolidation possibilities (Tavasszy, 2006). The aggregate-disaggregate-aggregate (ADA) modeling approach in Scandinavia also made joint logistic and transport choices within the constraint of total logistics cost (Comi, Donnelly, & Russo, 2014). This type of extension needs to be considered in future.

Results and Discussion

India's Total Freight-flow Market Space

The Indian economy generates 4.6 billion tonnes of freight shipments - 21.9% agricultural, 38.7% mining and 39.4% manufacturing related commodities - resulting in a transport task of 3.1 trillion tonne-km at a cost of US$130.0 billion. When expressing tonne-km requirements in terms of GDP (i.e. how much is contributed to the GDP by moving a tonne of freight one kilometer), India emerges as among the least productive of 41 countries for which this measure could be calculated, with a conversion ratio of around one US$/tonne-km, compared to the top two (Norway and Switzerland) delivering above US$20/tonne-km and the top 12 countries all above US$10/tonne-km (Havenga et al., 2012; tonne-km for India obtained from the India FDM described in this paper). Transport is therefore a strategic resource requiring national attention.

The supply and demand on a district level that give rise to this transport task is illustrated in Figure 14 for all of South Africa. The same process was followed for India, which highlighted a high supply and demand density on the central east and west coasts, but pockets of density throughout the country, providing a challenge to cost-effective transport solutions.

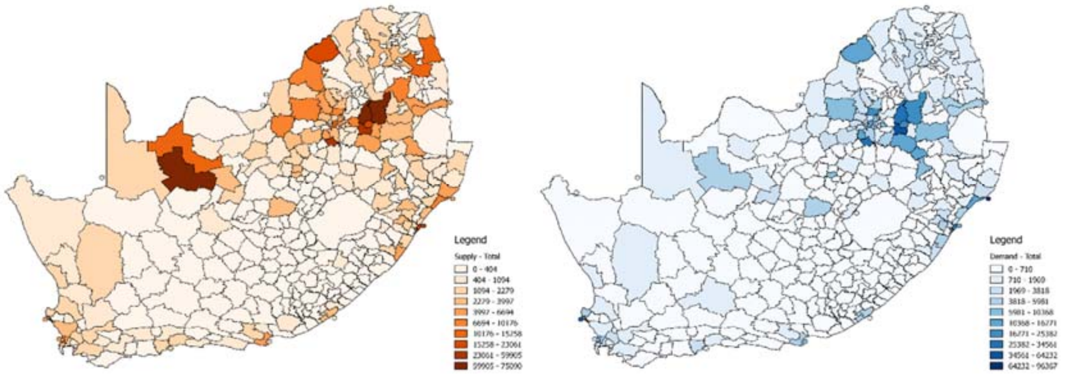


Figure 14: Total supply and demand in South Africa for all commodities (tonnes 2015)

India’s national freight flows resulting from the supply and demand interaction highlight the dense, quadrilateral concentration of freight flows, with the highest density evident on the Eastern Corridor (discussed in more detail in subsequent sections). Dense corridors and long transport distances are ideal markets for intermodal freight transport solutions (Yevdokimov, 2000; Slack, 2016).

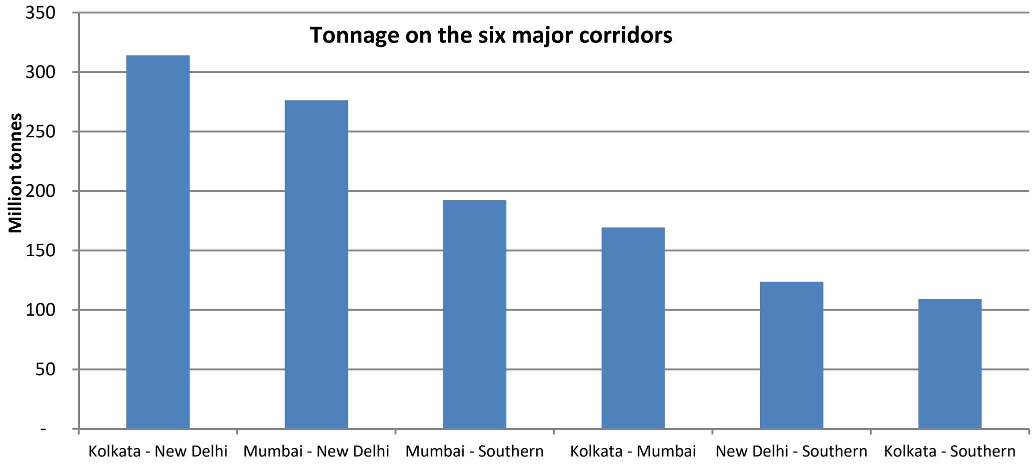


Figure 15: Tonnage on India’s six major corridors (2015)

The research approach allows for this level of disaggregation for all 31 aggregate commodity groupings identified in this study. As an example, Figure 16provides supply and demand detail for citrus in South Africa.

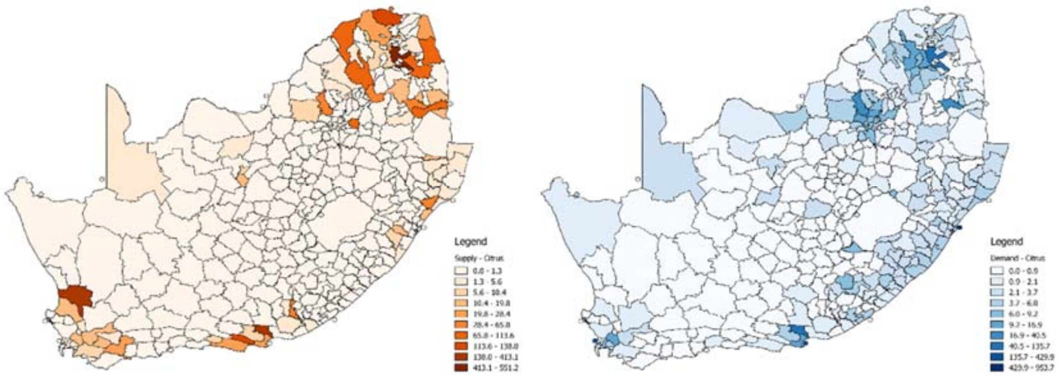


Figure 16: Total supply and demand for Citrus in South Africa (tonnage 2015)

The freight flows for Citrus relating to Figure 16 are depicted in Figure 17.

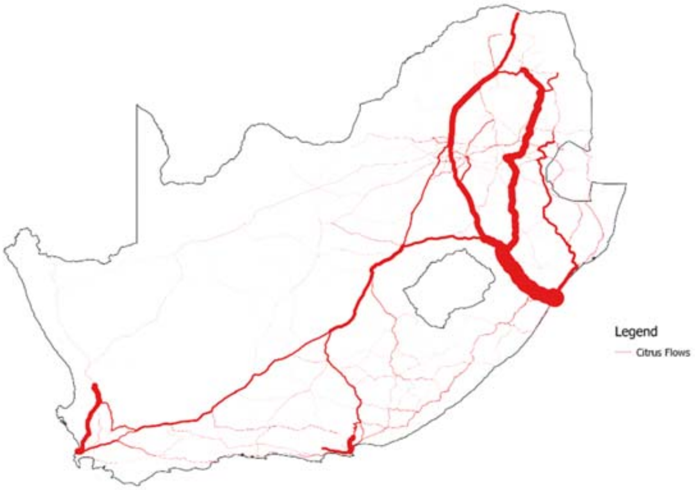


Figure 17: Total freight flows of Citrus in South Africa (tonnage 2015)

Segmentation

With reference to modal segmentation, 70% of India's transport task in tonne-km is on roads. Rail delivers almost a third of the transport task in tonne-km, equating to a quarter of freight shipments, while earning only a sixth of the transport cost in the economy. The average transport distance (ATD) on road is almost 500 km, which is higher than the 300 km from which intermodal traffic is regarded as feasible (Kallas, 2011; Sanchez-Triana et al, 2013). There therefore seems to be a sizeable opportunity for modal shift.

Corridor flows generate a disproportionately high amount of transport activity due to the long distances traveled. Just over a quarter of the freight tonnes transported utilizes India's major freight corridors, but 56% of the transport task in tonne-km are on corridors (refer Table 2). Addressing congestion and costs challenges on these major freight corridors is therefore a primary priority identified by this research. Rail is better suited to dense long-haul freight flows as it is more cost efficient, produces less emissions and congestion and reduces the rate of wear on highways significantly.

Table 2: Freight flows in India – typological segmentation (excluding urban and waterways)

Mode	**Tonnes**		**Tonne-km**		**Average distance**
	Millions	**%**	**Billions**	**%**	
Corridors	1 207	26%	1 712	56%	1 419
Other freight flows	3 440	74%	1 366	44%	397
Total	**4 647**		**3 078**		**662**

Corridor flows are dense, long-distance flows between major cities and provide ideal opportunities for economies of scale and consolidation utilizing rail and IWT. The 'other' typology is typified by broad distributions of origins and destinations outside of the cities, medium to long distances and low freight densities. Flows of this nature are the most difficult to optimize and can be suited to either road or rail (these flows are mainly in rural areas).

Three primary factors favor road as a mode-choice compared to rail, namely efficiency, infrastructure and lack of integration. Operational efficiency and a lack of high-performing infrastructure reduce the operational capacity of the rail line, making it difficult to compete with roads. Integration poses a more complex problem. Although rail is cheaper per tonne-km (refer Figure 18), the total supply chain cost may be higher when using rail if the user has to account for longer lead times and (current) unreliability. Rail is seldom the only mode of transport from origin to destination (the exception being pit-to-port operations). Therefore, for rail transport to be incorporated into an end-to-end transport solution requires the capability to switch freight at efficient intermodal terminals to a reliable rail service (both of which currently do not exist) to mitigate the additional handling costs and longer lead times.

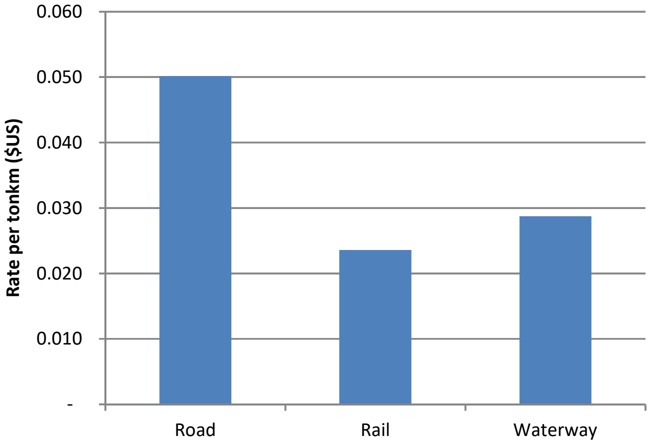


Figure 18: Rate comparisons for inland modes (Indian national average rates per mode for 2015)

Fuel is the major cost driver of road transport, contributing 51% of the overall road transport costs (Figure 19). The aging and under-maintained vehicle fleet is highly fuel-inefficient, a situation exacerbated by poor road conditions and severe congestion. Poor road conditions also wear tires quicker, adversely influencing this second largest road cost element. The fact that maintenance and repair and insurance are relatively low echoes the assessment of Kumar (2014) that the fragmented and informal nature of the trucking industry results in many operators who “drive under the radar” with unroadworthy, uninsured vehicles that are most likely also overloaded and unlicensed causing further damage to infrastructure. Apart from normalizing the road-rail modal split, improved road transport efficiency is high on the agenda.

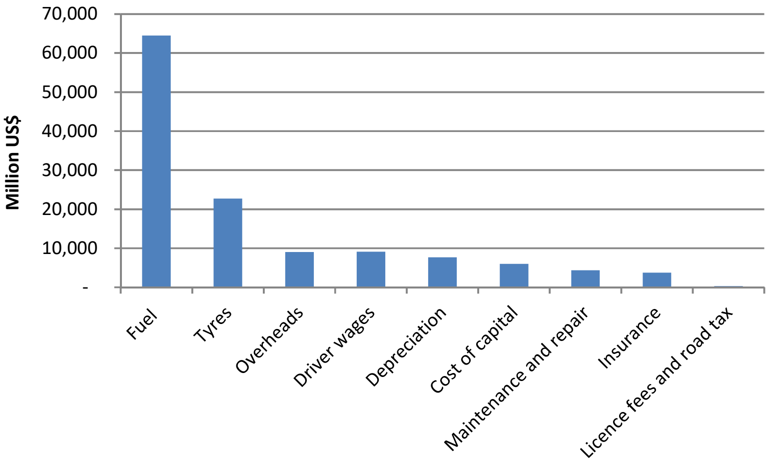


Figure 19: Road freight transport's cost drivers in India

The Eastern Corridor

The Eastern Corridor was identified as a key focus area of the study, representing 19% of total corridor tonne-km in India, and 24% of total tonnes transported. In the context of the national freight flow picture, this represents 6% of tonnage, 10% of transport activity and 8% of transport costs.

Similar to the modal split in the rest of India, most this freight is on roads (refer Table 3). In contrast to aggregated national freight flows, the rail market share of tonnes transported and the transport task (tonne-km) is almost equal, indicating long road transport distances and a relatively undeveloped rail sector, also illustrated by a relatively low-cost market share, i.e. mainly low-value commodities are transported on rail.

Table 3: Road and rail freight on the Eastern Corridor

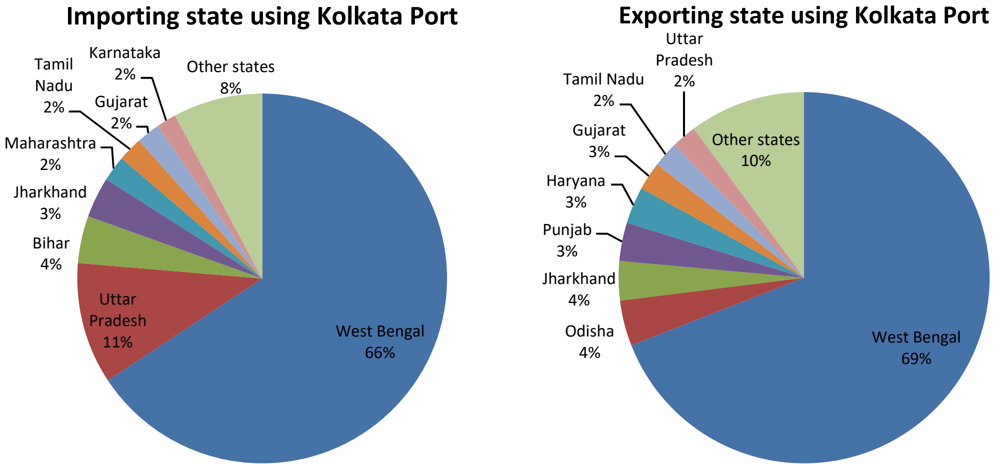
Mode	Tonnes		Tonne-kms		Average distance	Transport cost	
	Millions	%	Billions	%		US$ billion	%
Road	206.6	71%	224.3	70%	1,086	9.1	79%
Rail	83.6	29%	97.6	30%	1,167	2.5	21%
Total	**290.2**		**321.8**		**1,108**	**11.6**	

Almost none of the freight identified on the Eastern Corridor is ExIm traffic (refer Table 5:). It is, in its current form, mostly a domestic corridor, mainly since a large portion of ExIm freight that should use the Kolkata port system rather uses remote ports towards the West due to efficiency and capacity challenges.

Table 5: ExIm and domestic split of freight for the Eastern Corridor

Flow types	Tonnes		Tonne-kms		Average distance	Transport cost	
	Millions	%	Billions	%		US$ billion	%
Export	2.5	0.9%	3.8	1.2%	1,518	0.15	1.3%
Import	6.2	2.1%	8.5	2.6%	1,358	0.34	2.9%
Domestic	281.5	97.0%	309.6	96.2%	1,099	11.11	95.8%
Total	**290.2**		**321.8**		**1,108**	**11.60**	

The Kolkata port system does not operate as a hinterland port for the states along the corridor. The port is mainly a gateway port for West Bengal, with 66% of imports destined for West Bengal and 69% of exports originating in West Bengal. Capacity enhancements and improved connectivity should however provide a cheaper alternative for other states along the corridor.


Importing state using Kolkata Port

Exporting state using Kolkata Port

Figure 20: Imports and exports at the port of Kolkata, by state utilization

This is confirmed by the ATD of imports and exports through the Port of Kolkata which are on the lower end when compared to the other commercial ports (refer Figure 21).

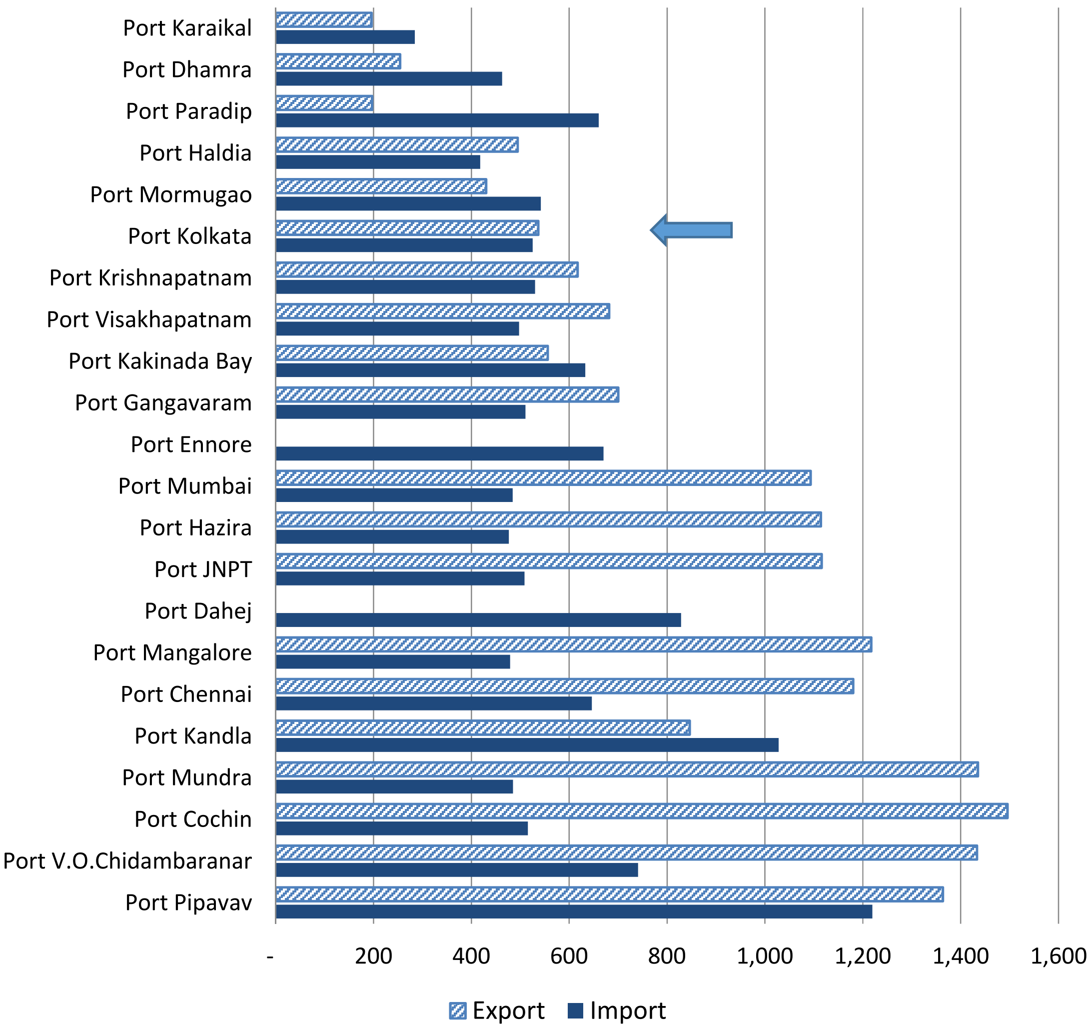


Figure 21: ATD of Kolkata port compared to India's other major ports

Table 4 compares the ATD of imports and exports for the seven states surrounding the Eastern Corridor compared to the average distance of that state to the Port of Kolkata. From the table, it is clear that from a distance point of view, most imports to and exports from the seven states should come through the Port of Kolkata. Furthermore, a large proportion of domestic freight between the states should also ideally make use of the Eastern Corridor as the most direct and efficient route.

Table 4: ATD of imports and exports to the seven states surrounding the Eastern Corridor, compared to the distance to the Port of Kolkata.

State	Current imports ATD	Current exports ATD	Average distance to Port of Kolkata
Bihar	1,268	1,520	1195
Haryana	1,405	1,499	1240
Jharkhand	680	1,041	948
NCT of Delhi	1,553	1,483	1464
Punjab	1,308	1,647	1750
Uttar Pradesh	1,493	1,452	1224
West Bengal	855	724	462

Disaggregating flows on the Eastern Corridor

The Eastern Corridor transports 15.3 million tonnes of Class 1 freight, 134.5 million tonnes of Class 2 freight and 140.4 million tonnes of freight between a wide catchment area and a wide catchment area.

Further disaggregating the corridor flows, one can consider the patterns of different cargo types on the Eastern Corridor as illustrated in Figure 22. When considering modal shift mining, dry bulk and heavy break bulk offer the greatest opportunities. These are dense flows along the corridor, offering economies of scale. The commodities themselves are also lower value, less time-sensitive commodities, making rail ideal. If the Port of Kolkata were to capture a greater portion of the hinterland imports and exports, an increase in palletizable and refrigerated flows could also be expected. Offering a competitive general freight rail service for this market segment would be a more ambitious goal that, if achieved, could further reduce logistics costs and congestion on the Eastern Corridor.

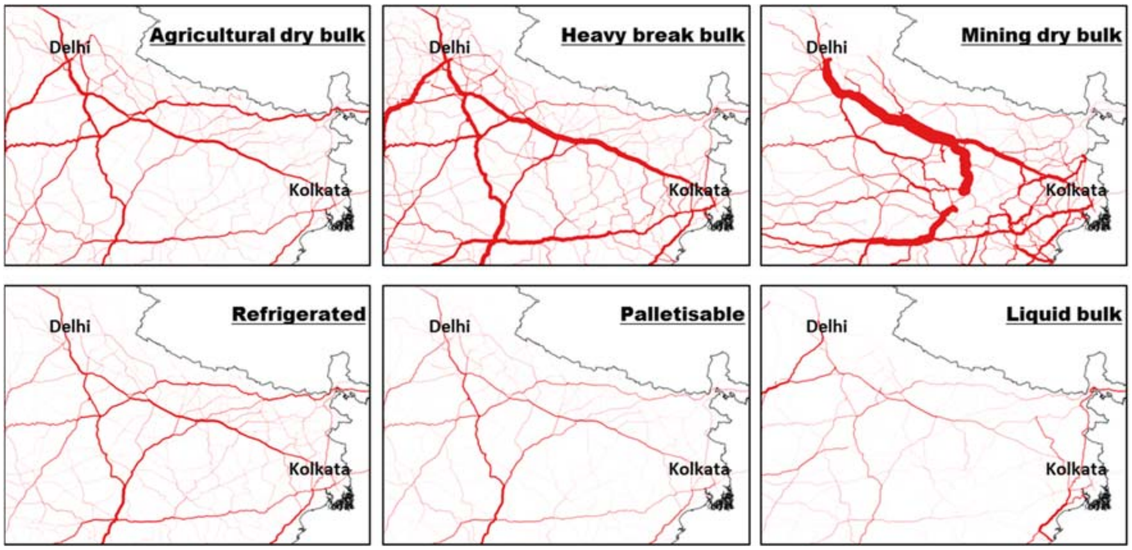


Figure 22: Freight flows according to cargo types on the Eastern Corridor

Applications of the FDM - Potential for modal shift on the Eastern Corridor

The current transport cost for the Eastern Corridor is US$11.6 billion (refer Table 5:). Initial results show that this can be reduced by US$1.6 billion if rail-friendly freight along the corridor is returned to rail, according to the current design, i.e. freight with origin-destination pairs along the corridor (refer Table 7:). Many of the freight flows currently using roads on the corridor are better suited to rail transportation (refer Figure 22). These flows are typically high-density, long-haul flows of less time-sensitive commodities that originate or are destined to locations close to the rail line. Specific reasons why these flows are not currently on rail relate to issues of efficiency and capacity on the Eastern Corridor rail line. Attracting these flows would require the rail line to commit and invest in the upgrade of its services and the design of a targeted commercial strategy. It has however become clear that a dedicated corridor focus can solve corridor capacity problems, but does not *per se* address problems with port limitations, connectivity or integrated logistics planning.

The Eastern Corridor has the potential to play a far more prominent role in unlocking logistics efficiencies and trade potential in the landlocked states north of West Bengal. It can also become a robust and prolific hinterland corridor for the two terminals of the Port of Kolkata to enable port-led development in the surrounding states. A key element of the proposal is to redesign the Eastern Corridor where it terminates in Kolkata by routing it via a logistics hub. Feasibility studies are required to determine the optimal location of a logistics hub. The logistics hub will require a high-volume, high-speed connection to the rail line at Dankuni, a high-volume, accessible truck terminal, and efficient intermodal transfer facilities. Capacity for other supply chain services such as storage, customs clearance and value-added services would also be beneficial but is not required right from the start. The logistics hub also needs to be connected to KDS directly, circumventing the city-center of Kolkata completely. A rail or inland waterways shuttle is suggested as a high-speed, high-volume solution. An accessible, high-speed connection from the logistics hub to HDC will also be necessary, but this may very well remain a road solution. If these conditions are met, a further US$2.1 billion of costs can be saved (these savings are detailed in Table 7:). Modal shift on the Eastern Corridor will therefore only contribute 44% of the total potential of $3.7 billion saving that can be achieved by an integrated corridor design.

Table 7: Eastern Corridor savings potential in US$ million – mainly related to improved utilization of rail and improved port system

Strategic objective	Intervention	Description	Dedicated freight corridor (US$ millions)	Logistics hub and dedicated link	
				(US$ millions)	%
Rail corridor solution	Modal shift within corridor	Rail-friendly freight on road shifts to rail (origin and destination are within the corridor)	**1,647**		**44%**
Kolkata as gateway for Uttar Pradesh, Jharkhand and Bihar	Hinterland port shift of rail-friendly freight	Freight that can use rail will shift to the closer port of Kolkata		**496**	**13%**
	Hinterland port shift of freight on road	Freight that cannot use rail (due to location of load points), but will shift exports away from Western ports due to the improved link and shorter distance		**868**	**23%**
Improve access and reduce congestion	Corridor-city link	Freight shifts from road to rail because it can more easily reach the port on rail		**549**	**15%**
	Kolkata city logistics improvement	The hub and link will also have a concomitant positive alleviation effect on inner-city congestion		**146**	**4%**
	Terminal-port link	Reduce current ExIm costs due to reduced congestion		**39**	**4%**
Total			**1,647**	**2,097**	

Applications of the FDM - Examples of Cost-Benefit analysis on the Eastern Corridor

The six interventions discussed above all relate to modal shifts, attracting freight to the port, and reducing congestion in and around Kolkata. The fact is that, despite these interventions most freight remains on road and exactly because of these interventions the road traffic on the Eastern Corridor will increase as more ExIm freight uses the corridor. Therefore, the systemic issues that plague road transport in India in general need also to be addressed. The versatility and detail of the India FDM allow the assessment of what the potential benefit could be on the Eastern Corridor resulting from road efficiency interventions. Although this study is only a prefeasibility analysis, it does not detail the cost/investment side of the cost-benefit analysis. The results, however, are real and illustrate how the model can be used.

In total, US$ 1.7 billion per annum could be saved through six systemic interventions listed in Table 8 Many of these interventions require industry-wide collaboration and/or costly infrastructure development – the cost and practicality of which also need to be taken into account.

Table 5: Examples of cost-benefit analysis – mostly relates to more efficient road transport, as well as road-rail collaboration

Intervention	**Mode**	**Rationale**	**Savings per annum (US$ millions)**
Improved training of truck drivers	Road	Will improve distance that trucks can be driven and fuel consumption	**271**
Add lanes to highways	Road	Will reduce congestion and therefore increase distances that trucks can be driven	**437**
Replace vehicles with a newer fleet[4]	Road	Improved fuel consumption	**-111**
Improve truck turnaround times in ports	Road	Trucks drive further	**25**
Eradicate state border post delays	Road and rail	Trucks drive further	**547**
Consolidate flows through improved collaboration	Road and rail	Reduce empty haul	**509**

Implications for Other Emerging Economies

The implications of this work for others emerging economies are important. Understanding freight flows in these spaces where efforts to increase exports and to gain access to underdeveloped areas is urgent, and facilitating the movement of goods has a major impact on economic development (Ortuzer and Willumsen, 2011). Understanding freight flows, specifically:

- Assists in the prioritization of infrastructure investments in fiscal-scarce environments;
- Assists in modal optimization, therefore reducing freight logistics costs;
- Assists with policy formulation, direction and prioritization to facilitate modal shift, private sector investments and spatial planning; and
- Aids identification of key development nodes.

Examples of these are developing in India, such as outlined in this report, and illustrated for South Africa and Sub-Saharan Africa.

Concluding remarks

The objective of this working paper is to report on the development of a disaggregated macroscopic FDM for India. This model is a sectorally and regionally disaggregated quantification of total national freight flows and related costs to (1) improve the understanding of the national freight-flow landscape and facilitate evidence-based policy formulation and investment prioritization, (2) establish intermodal freight potential along the country's most dense freight corridor, the Eastern Corridor and (3) identify

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[4] This saving will depend on the cost of new vehicles. With current information, it does not result in a positive answer to shift to newer vehicles. Some truckers have suggested that only the engines could be replaced and not the full bodies.

and prioritize logistics improvement- and cost saving interventions for rail, road and ports on the Eastern Corridor.

The Indian economy generates 4.6 billion tonnes of freight shipments, translating into a transport task of 3.1 trillion tonne-km at a cost of US$1,043.0 billion. When expressing tonne-km requirements in terms of GDP, India as one of the least productive of 41 countries for which this measure could be calculated, with a conversion ratio of around one US$ of GDP/tonne-km, compared to the top 12 countries, which generate above US$10 of GDP/tonne-km. Spatially challenged economies (i.e. economies with long transport distances between supply and demand areas, as well as to and from ports, such as the United States, the Russian Federation, China, India and South Africa) will work towards low costs per tonne-km to offset the reality of high demand.

Similar to many emerging economies with an infrastructure backlog, the majority (70%) of India's total transport task in tonne-km is on roads, while 60% of tonne-km is on long-distance corridors, underscoring the importance of a strategic corridor focus. Initial indications are that potential savings of US$3.7 billion can be achieved through the development of a dedicated freight corridor on the dense Eastern Corridor. This includes engineering a more optimal modal balance between road and rail and increasing port efficiencies, both of which will be supported by connections to a freight logistics hub.

The research and view of supply, demand and flows support the quadrilateral view of India's freight flows. It also, however, identifies new opportunities and insights. ExIm freight is important, but many of the freight logistics challenges relate to domestic freight. Both domestic and ExIm freight is poorly organized, however, the sheer volume of domestic freight causes major problems. Addressing ExIm issues in isolation will therefore have little effect, because the domestic freight will still create congestion. The Eastern Corridor is a case in point. Addressing the domestic freight challenges will not only create capacity for more ExIm freight along the corridor, it could also lead to ExIm freight on other corridors switching to the Eastern Corridor, reducing costs and relieving congestion at major ports and cities.

The benefits of the India FDM methodology to address freight transport related questions are:

- It is **comprehensive and allows for** quantitative analyses of an entire industry, commodity group, mode, state or country.
- It is **disaggregated and detailed** enough to execute targeted analyses on specific corridors and for single commodities and to conduct market share break points for different modes.
- It is **accurate** and be used as an input to calculate national logistics costs – with possibility of identifying the drivers - and even external costs in subsequent phases.

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