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Developing a Disaggregated National Freight Flow Model for India

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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 is important for shaping spatial organization in emerging economies. However, most emerging economies lack sufficiently detailed freight flow analysis to facilitate targeted infrastructure investments and evidence to make interventions that improve national logistics performance. This paper presents the results of a disaggregated macroscopic freight flow 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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1. Introduction

India has had steady economic growth since 2014 reporting 7.6% GDP growth for the 2015/16 fiscal year (Forbes, 2016). Despite the 'twin shocks' of demonetization and GST introduction in 2016-2017, the projections are for above 7% growth in the medium term with an acceleration to 7.4% at end of FY17/18. India's growth is ascribed largely to an increase in private consumption due to a growing middle class, and significant public investment in the economy (World Bank, 2016a and 2018). 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, logistics costs in India are estimated at 14% of GDP, compared to North America's 8% and Europe's 9-10%. Like many emerging economies, policy makers in India struggle to access detailed and comprehensive analytics and data which could allow for better understanding of spatial and commodity characteristics of freight transport. Such insight is needed to facilitate targeted investments and efficiency initiatives over the medium and long term to enable management of transport as a strategic national resource (Tavasszy & De Jong, 2014). Most analyses and studies pointed to poor quality of infrastructure, dysfunctional trucking sector, port efficiencies or customs procedures as binding constraints. Nevertheless, it is challenging to use these studies to make targeted decisions without making several assumptions about the macro-logistics impact. Such analyses are typically based on existing economic and logistics performance indicators, including the World Banks' Logistics Performance Index (LPI), World Development Indicators (WDI) and World Economic Forum (WEF).

This paper reports on 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 sectorally and regionally disaggregated quantification of total national freight flows and related costs to (1) improve 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.

2. The Value of Disaggregated Macroscopic Freight Flows

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, urbanisation, 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 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 internalisation to enable both suppliers and consumers to make full cost trade-offs in their purchasing and logistics decisionmaking 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 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 modelling 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 USA the *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 modelling 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 policy making 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 they reflect the regional structure of the economy. Tavasszy and De Jong (2014) reiterated that ideally, freight flow modelling 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 modelling with the broader economy, geographically as well as functionally (Tavasszy, 2006).

Four decades ago, Van Es (1977) described the purpose of national freight modelling based on key outcomes, namely to:

- Inform policy measures to (1) improve transport infrastructure, (2) enable optimal modal competition and (3) facilitate impact analyses of various transport policy alternatives;
- Estimate the composition of future freight transport demand to inform modal and investment requirements and enable cost-benefit analyses for infrastructure investment decisions (e.g. modes, hubs and ports); and
- In the long run, leverage the understanding of future requirements and subsequent infrastructure investments to influence the spatial location of production and demand patterns.

These outcomes have been echoed recently by Banomyong et al. (2008), Tavasszy and De Jong (2014) and De Jong et al. (2016).

To develop multi-commodity, multi-regional national freight models, an econometric modelling approach is required (Havenga and Simpson, 2018). Such econometric models attempt to identify and analyse cause-and-effect and correlative relationships between total freight demand and its drivers. The need for these models has been understood for decades, but the practical application has been lagging.

Kresge and Roberts (1971) emphasized the importance of coupling the macroeconomic environment, industrial production, final demand and freight transport on a network in a freight demand model. Van Es (1977) described the key outputs of such a model as volume and geographical composition of domestic and international transport by commodity group, the current and estimated share per transport mode for different scenarios, and the capacity per mode. Fosgerau and Kveiborg (2004) showed that estimating future freight transport requirements from aggregate production led to overestimation of transport growth due to the economic shift to less transport intensive industries. This supports sectoral disaggregation in national freight models to improve the accuracy of transport volume estimates and forecasts.

In the main, there are two approaches to develop spatially and sectorally disaggregated freight-flow data required for these models: a survey approach and a demand-side approach.

First, a survey approach involves estimating the characteristics of the total freight market through analyses of the responses to a commodity-flow questionnaire distributed to a representative sample of freight logistics stakeholders, combined with other data sources. A limited number of countries (e.g. the USA and Sweden) conduct regular commodity flow surveys (CFS) as the basis for their freight demand models. The most well-known freight demand models are SAMGODS (the Swedish model) and the Norwegian model, which both use the Swedish CFSs conducted in 2001, 2004/2005 and 2009. The models for mode and shipment size choice that are being developed for the European model TRANS-TOOLS3 use both the CFS 2007 from Sweden and the ECHO survey from France (conducted in 2004) as databases for freight flow estimation (De Jong et al., 2016).The United States CFS is conducted every 5 years, the latest data is for 2012 with the 2017 CFS being conducted in 2018 (United States Census Bureau, 2018). Comprehensive CFSs are extremely resource intensive and still require significant analysis post-survey to estimate the total freight market. In addition, survey-based research suffers from several recognized challenges, such as sampling biases and non- or partial responses (Kockelman et al., 2009), as well data continuity challenges due to time lapses between surveys and changes in scope (Bergquist et al., 2016).

Second, a demand-side approach develops freight flows based on interactions between supply and demand as informed by the macroeconomic input-output (I-O) model, which describes interdependencies between industries in terms of intermediate inputs, driven by developments in final household demand (Marcos and Martos, 2012). 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, i.e. market equilibrium, expanded to multiregional or spatial I-O models in the 1950s (Ivanova, 2014). The growth in international and cross-border trade in the latter part of the 20th century peaked interest in the spatial disaggregation of national accounts to improve planning. This led to a growth in the adoption of I-O analysis for planning, forecasting and general impact analyses; especially in emerging countries (countries such as Brazil, China, Nepal and the Philippines developed I-O models for these purposes). There are also developments within I-O modelling to enable the incorporation of a wide array of spatial and sectoral data to reduce uncertainty and improve applications, so-called hybrid I-O models (Lahr, 2016). Müller et al. (2015) (for Germany), Alises and Vassallo (2016) (for Spain and the UK) and Lin et al. (2016) for Singapore confirmed the use of I-O models (or subsets thereof) to improve the understanding of the link between economic activity and freight transport.

3. Methodology for Developing the Freight Model for India

The overarching process and key data sources for the freight flow model are captured in Figure 1.

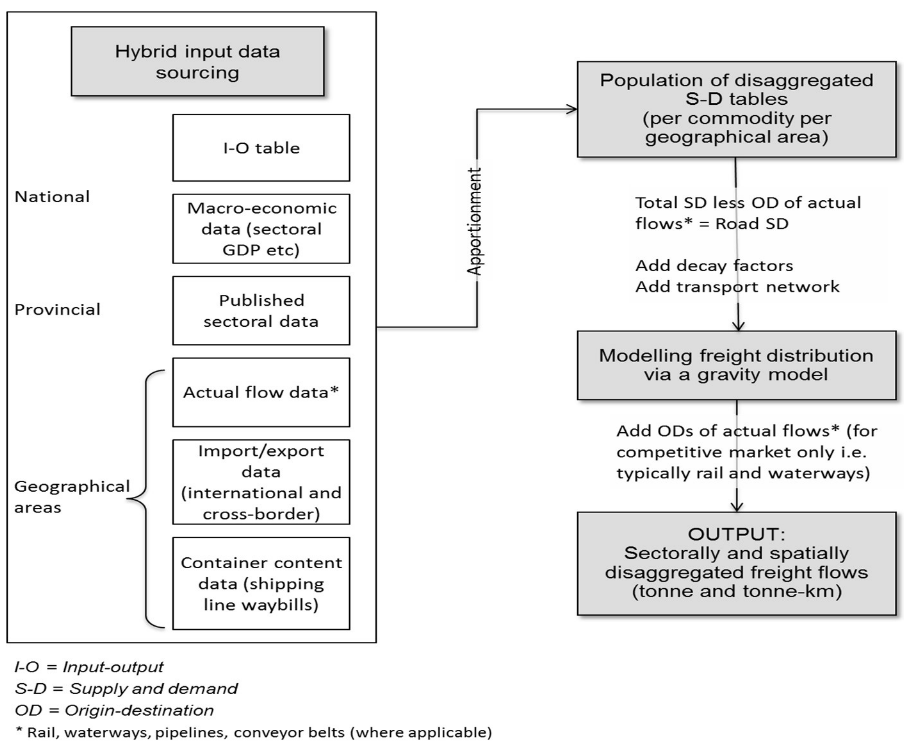

Figure 1: Key data sources and process detail of the National Freight Flow Model

One of the primary goals of the modelling is to have standardized outputs which can be improved or continuously updated. These standard outputs are supply and demand data, which result in freight flows with the primary parameters of origin, destination, commodity, volume and transport mode. The primary steps are the gathering and development of actual and modelled commodity-level data, disaggregating this data to supply and demand per geographical district, and modelling freight flows between origins (supply) and destinations (demand). Not all data will be available, however, the intent is to develop the supply-and-demand tables based on the hybrid approach as described below, utilizing the specific datasets which are generally available in most countries.

For India, the underlying driver of the freight flow model was to obtain a sufficient disaggregation of the national transportable economy on a spatial and sectoral level, followed by flow generation via gravity modelling, 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 was 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 modelling of some corridors.
4. Freight rail movements across India by commodity and Origin-Destination for all 55,000 rail stations provided by *Indian Railways*
5. Production volumes for agricultural and mining commodities per state or district
6. Previous nationwide O-D surveys carried out in 2007
7. Traffic counts from various stations owned by *National Highway Authority of India (NHAI)*
8. Industry reports for some key commodities

Supply and Demand per Commodity on a Geographical basis

Supply and demand on a geographical basis per commodity was 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 modelling 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 and 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 modelled 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 modelling 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 becomes 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 modelled data, resulting in improved disaggregated supply and demand tables. The same process was followed for known flows such as rail data. These were hardcoded, and the remainder modelled.

As shown in Table 1, 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, required infrastructure, policy and operations.

Table 1: 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

Cargo type	Commodities
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 is published in India. Where data was not available on a district level, secondary keys were used for apportionment. For example, to apportion private expenditure on motor vehicles, proxies such as population, employee and average income per district were used, while intermediate demand for coal was estimated from the production of electricity (based on the known location of coal-fired power stations). In certain cases, such as the production of maize, geographically disaggregated maize production data is available, however, for some agricultural crops data is only available per province. It 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 freight model 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 datasets 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 modelling 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, several national statistics bodies and trade gateways like ports and border crossings (Mommens et al., 2017). While none of these models utilize 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 modelling produces sufficient uncertainty of its own accord.

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

The input data for the flow modelling was 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 was modelled as road flows via a gravity model. Once the road flows per commodity for road transport were established, the known flows per commodity were added back to provide total flows that aggregated to the original total supply and demand tonnage, enabling modal analysis.

The most common 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

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 modelling, 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 homogenous 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).

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).

$$Tij = Ai.Bj.Oi.Dj\,f(Cij,ß) \qquad (3)$$

$$Ai = 1/(\Sigma j.Bj.Dj.f(Cij,ß)) \qquad (4)$$

$$Bj = 1/(\Sigma i.Ai.Oi.f(Cij,ß)) \qquad (5)$$

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)

f is the decay function where:
$f(Cij,ß) = \exp(-ß.Cij)$ in case of an exponential function
$f(Cij,ß) = Cij^{-ß}$ 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 enable 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:

$$\sum_j Tij = Oi \quad (6)$$

$$\sum_i Tij = Dj \quad (7)$$

For the India freight model, 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, it was 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 Africa were however available. At the outset of the South African gravity-modelling exercise, distance-decay parameters were developed informed by the decay parameter principles 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 different to that in India, such as sugar cane, which is transported very short distances in South Africa to one region, but long distances across 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 modelling was 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 depicts spatial relations such as distances, flows, travel times and travel costs (Utrecht University, 2013). Once freight flows had been modelled, they were aggregated to facilitate analysis and recommendations

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).

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

L = road line haul cost	*d = depreciation rate per tonne-km*
n = number of commodity groups	*c = cost of capital per tonne-km*
i = commodity grouping	*l = license fee and road tax per tonne-km*
p = number of typologies	*q = insurance per tonne-km*
j = typology	*e = driver fees per tonne-km*
s = number of routes	*f = fuel cost per tonne-km*
k = route	*m = maintenance and repair costs per tonne-km*
x = tonnes transported	
y = distance in kilometers	*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 travelled (y), describe the base of the formula.

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. The resulting parameters of the India freight model 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 (refer Table on page 6);
- 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 modelled 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.

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 India, truck flow data was used on a case-by-case basis, such as comparing traffic around Varanasi on the Delhi-Kolkata corridor with the modelling 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.
- After twelve months of fine tuning, the results from modelling show 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.

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). In the absence of average $/ton values this table could not 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. 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.

4. Application of the National Freight Flow Model and Discussion

From the model, it is evident that the Indian economy generates 4.6 billion tons of freight shipments - 21.9% agricultural, 38.7% mining and 39.4% manufacturing related commodities - resulting in a transport task of 3.1 trillion ton-km at a cost of US$130.0 billion. When expressing ton-km requirements in terms of GDP (i.e. how much is contributed to the GDP by moving a ton of freight one kilometer), India emerges as amongst the least productive of 41 countries for which this measure could be calculated, with a conversion ratio of around one US$/ton-km, compared to the top two (Norway and Switzerland) delivering above US$20/ton-km and the top 12 countries all above US$10/ton-km (Havenga et al., 2012; ton-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 2 and highlights 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.

India's national freight flows resulting from the supply and demand interaction highlights the dense, quadrilateral concentration of freight flows, with the highest density evident on the Eastern Corridor. Dense corridors and long transport distances are ideal markets for intermodal freight transport solutions (Yevdokimov, 2000; Slack, 2016). The approach adopted allows for this level of disaggregation for all 31 aggregate commodity groupings identified in this study. With reference to modal segmentation, 70% of India's transport task in ton-km is on road. Rail delivers almost a third of the transport task in ton-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 500km, which is higher than the 300km from which intermodal traffic is regarded as feasible (Kallas, 2011; Sanchez-Triana et al, 2013). Therefore, this seems to be a sizeable opportunity for modal shift. Corridor flows generate a disproportionately high amount of transport activity due to the long distances travelled. Just over a quarter of the freight tons transported utilizes India's major freight corridors, but 56% of the transport task in ton-km are on corridors. 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.

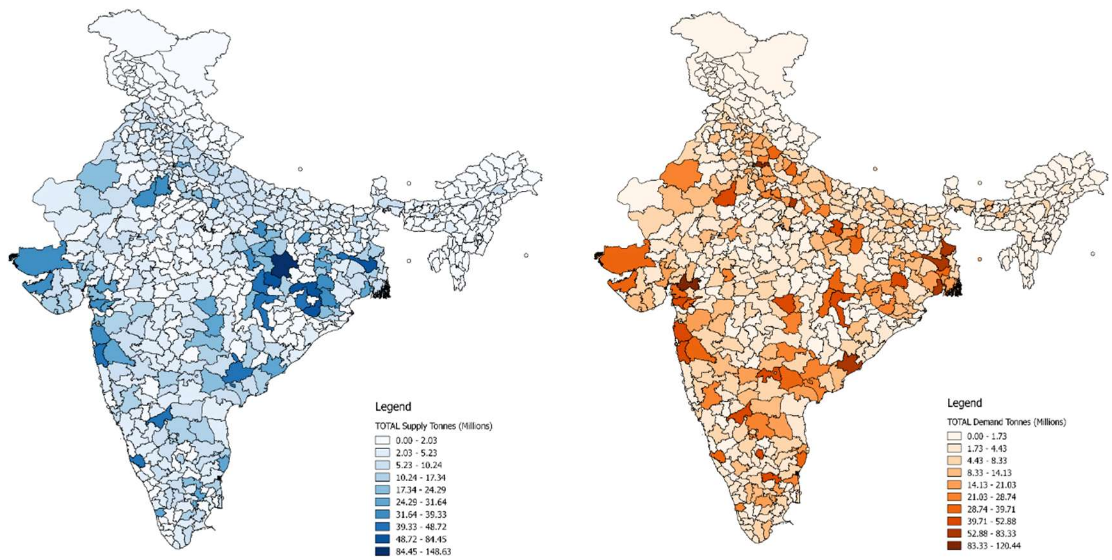

Figure 2: Total supply and demand for all commodities in India

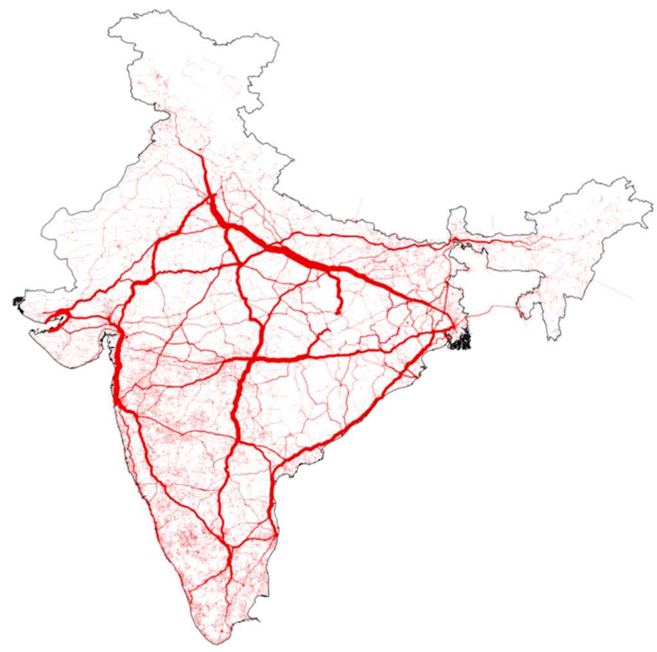

Figure 3: Total freight flows for all commodities in India

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 road. Integration poses a more complex problem. Although rail is cheaper per ton-km, the total supply chain cost may be higher when using rail if the user must 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.

The above issues were the subject of further analysis on the Eastern Corridor which was identified as a key focus area of the study, representing 19% of total corridor ton-km in India, and 24% of total tons transported. Like the modal split in the rest of India, most this freight is on road (refer 2). In contrast to aggregated national freight flows, the rail market share of tons transported and the transport task (ton-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 2: Road and rail freight on the Eastern Corridor

Mode	Tons		Ton-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 Export-Import (ExIm) traffic (refer Table ***3***3). In its current form, it is mostly a domestic corridor and a large portion of ExIm freight that should use Kolkata port system rather uses remote ports towards the West due to efficiency and capacity challenges.

Table 3: ExIm and domestic split of freight for the Eastern Corridor

Flow types	Tons		Ton-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. This is confirmed by the ATD of imports and exports through Kolkata which are on the lower end when compared to the other commercial ports (refer Figure 4).

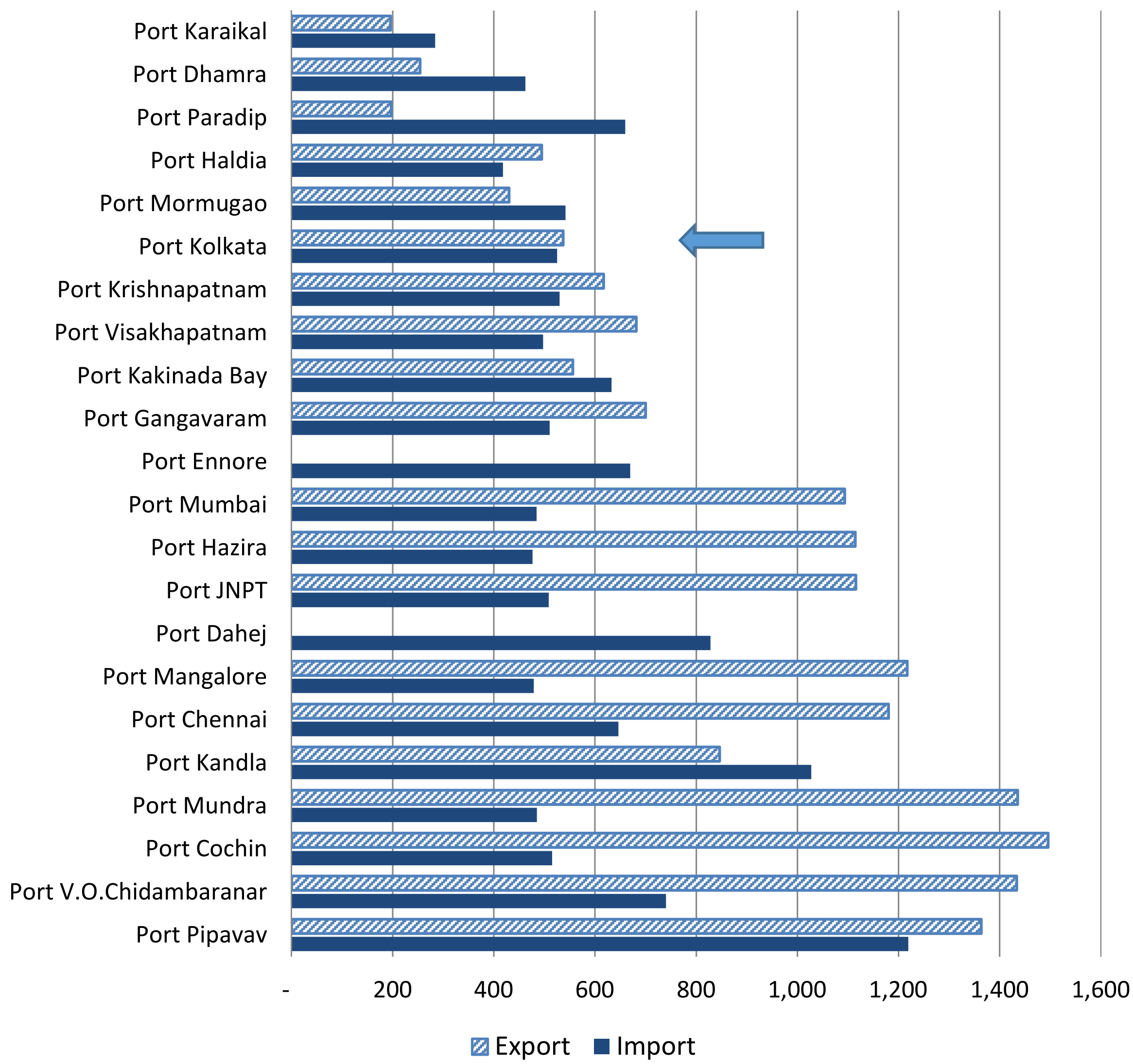

Figure 4: ATD of Kolkata port compared to India's other major ports

Table *4*4 compares the ATD of imports and exports for the seven states on 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 in 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

The Eastern Corridor transports 15.3 million tons of dense corridor freight and 280 million tons of freight with a wide catchment area. Further disaggregating the corridor flows, shows patterns of different cargo types on the Eastern Corridor as illustrated in Figure ***5***5. 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 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.

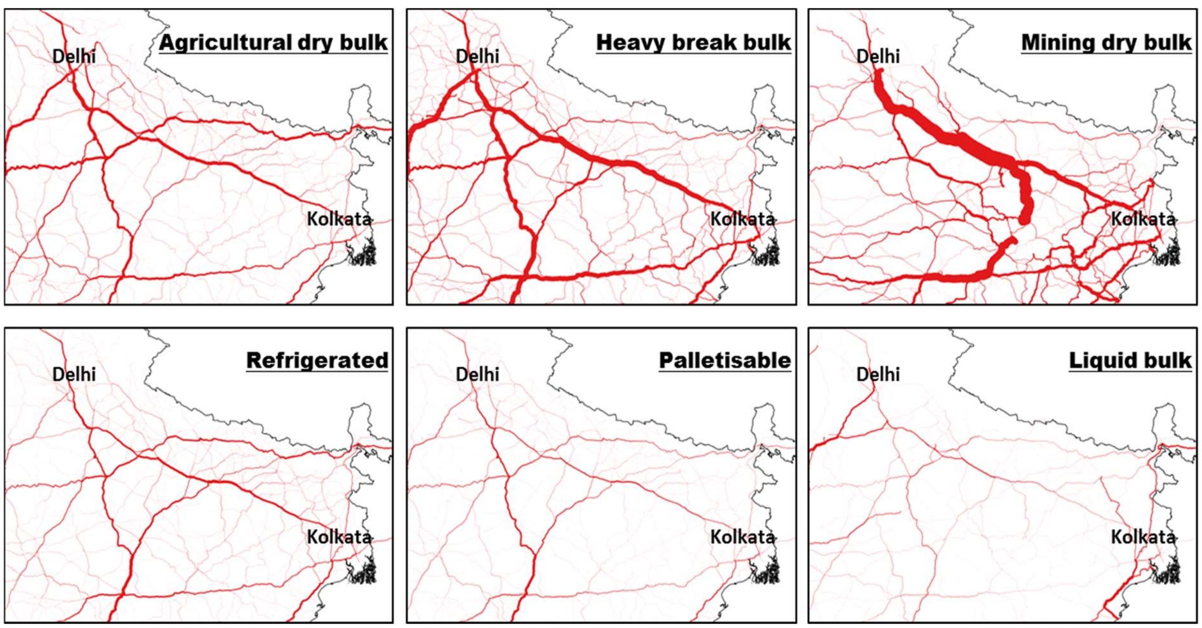

Figure 5: Freight flows according to cargo types on the Eastern Corridor

The current transport cost for the Eastern Corridor is US$11.6 billion (refer Table 3). Initial results show that this can be reduced by US$1.6bn 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). Many of the freight flows currently using road on the corridor are better suited to rail transportation. 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 railways 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 5). 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 5: 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**	

5. Implications of India National Freight analysis for other Emerging Economies

The implication of this work for emerging economies is important. Understanding freight flows in these spaces where efforts to increase exports and to gain access to underdeveloped areas are urgent, and facilitating the movement of goods have 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 the identification of key development nodes.

6. Concluding remarks

The objective of this paper is to report on the development of a disaggregated macroscopic freight flow model 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 and prioritize logistics improvement- and cost saving interventions for rail, road and ports on the Eastern Corridor.

The Indian economy generates 4.6 billion tons of freight shipments, translating into a transport task of 3.1 trillion ton-km at a cost of US$1043.0 billion. When expressing ton-km requirements in terms of GDP, India emerges as amongst the least productive of 41 countries for which this measure could be calculated, with a conversion ratio of around one US$GDP/ton-km, compared to the top 12 countries who generate above US$GDP10/ton-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 USA, Russia, China, India and South Africa) will work towards low costs per ton-km to offset the reality of high demand.

Like many developing countries with an infrastructure backlog, the majority (70%) of India's total transport task in ton-km is on road, while 60% of ton-km are 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 DFC 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.

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

- It is **comprehensive** enough to provide 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** enough to use as an input to calculating logistics costs and even external costs in subsequent phases.

References

Alises, A. and Vassallo, J.M. (2016), "The impact of the structure of the economy on the evolution of road freight transport: A macro analysis from an input-output approach", Transportation Research Procedia, Vol. 14, pp. 2870-2879, https://doi.org/10.1016/j.trpro.2016.05.404.

Arbués, P. and Baños, J.F. (2016), "A dynamic approach to road freight flows modeling in Spain", Transportation, Vol. 43 No.3, pp. 549-564.

Aritua, B., Havenga,J.H., Simpson, Z. and Chiew E.W.L. (2018). "Unlocking India's Logistics Potential : The Value of Disaggregated Macroscopic Freight Flow Analysis", Policy Research Working Paper No. 8337, World Bank, Washington, DC, https://openknowledge.worldbank.org/handle/10986/29371.

Banomyong, R., Cook, P. and Kent, P. (2008), "Formulating regional logistics development policy: the case of ASEAN", International Journal of Logistics Research & Applications, Vol 11 No. 5, pp. 359-379.

Bergquist, M., Bernhardsson, V., and Rosklint, E. (2016). "Report: Representation of the Swedish transport and logistics system in Samgods v.1.1.", available at: vti.diva-portal.org/smash/get/diva2:1034226/FULLTEXT01.pdf (accessed 29 November 2017).

Coto-Millán, P., Fernández, X.L., Pesquera, M.Á. & Agüeros, M. (2016), "Impact of logistics on technical efficiency of world production (2007–2012)", Networks and Spatial Economics, Vol. 16 No. 4, pp. 981–995, doi:10.1007/s11067-015-9306-6.

Da Silva, M.A.V. and de Almeida D'Agosto, M. (2013), "A model to estimate the origin–destination matrix for soybean exportation in Brazil", Journal of Transport Geography, Vol. 26 (January), pp.97-107.

De Jong, G., Tavasszy, L., Bates, J., Grønland, S.E., Huber, S., Kleven, O., Lange, P., Ottemöller, O. and Schmorak, N. (2016), "The issues in modelling freight transport at the national level", Case Studies on Transport Policy, Vol. 4 No. 1, pp. 13-21.

De Jong, T. and Van der Vaart, N. (2010), "Manual Flowmap 7.4", available at: http://flowmap.geo.uu.nl/downloads/FM740_Manual.pdf (accessed 18 April 2018).

De Oliveira, L.K, and Pereira, L.D.S.F. (2014). "An estimation of freight flow using secondary data: A case study in Belo Horizonte (Brazil)", International Journal of Urban Sciences, Vol. 18 No. 2, pp.291-307.

Delfmann, W., Dangelmaier, W., Günthner, W., Klaus, P., Overmeyer, L., Rothengatter, W., Weber, J. and Zentes, J. (2010), "Towards a science of logistics: cornerstones of a framework of understanding of logistics as an academic discipline", Logistics Research, Vol. 2010 No. 2, pp. 57-63, doi:10.1007/s12159-010-0034-5.

Duffy, D.N. (2017), Evaluation and Governing in the 21st Century – Disciplinary measures, Transformative possibilities, Palgrave Macmillan, London.

Ekici, Ş.Ö., Kabak, Ö. and Ülengin, F. (2016), "Linking to compete: Logistics and global competitiveness interaction", Transport Policy, Vol. 48 (2016), pp. 117-128.

Fedderke, J., Perkins, P. and Luiz, J. (2006), "Infrastructural Investment in Long-run Economic Growth: South Africa 1875-2001", World Development, Vol. 34 No. 6, pp. 1037-1059.

Fosgerau, M. and Kveiborg, O. (2004), "A review of some critical assumptions in the relationship between economic activity and freight transport", International Journal of Transport Economics, Vol. 31 No. 2, pp. 247-261, http://www.jstor.org/stable/42747700.

Fullenbaum, R. and Grillo, C. (2016), "Freight Analysis Framework Inter-Regional Commodity Flow Forecast Study Final Forecast Results Report", US Department of Transportation, available at: https://ops.fhwa.dot.gov/publications/fhwahop16043/fhwahop16043.pdf (accessed 29 November 2017).

Giuliano, P., Spilimbergo, A. and Tonon, G. (2013), "Genetic distance, transportation costs, and trade", Journal of Economic Geography, Vol. 14 No. 1, pp. 179-198.

Hausman, W.H., Lee, H.L. and Subramanian, U. (2005), "Global logistics indicators, supply chain metrics, and bilateral trade patterns", World Bank Policy Research Working Paper 3773, available at: https://www.biblioteca.fundacionicbc.edu.ar/images/0/04/Conexion_y_logistica_5-00.pdf (accessed 26 November 2017).

Hausman, W.H., Lee, H.L. and Subramanian, U. (2013), "The impact of logistics performance on trade", Production and Operations Management", Vol. 22 No. 2, pp. 236-252, doi:10.1111/j.1937-5956.2011.01312.x.

Havenga, J.H. (2012), "Rail renaissance based on strategic market segmentation principles", Southern African Business Review, Vol. 16 No. 1, pp. 1-21.

Havenga, J.H. (2013), "The importance of disaggregated freight flow forecasts to inform transport infrastructure investments", Journal of Transport and Supply Chain Management, Vol. 7 No. 1, pp. 1-7, https://doi.org/10.4102/jtscm.v7i1.106.

Havenga, J.H. and Pienaar, W.J. (2012), "The creation and application of a national freight-flow model for South Africa", Journal of the South African Institution of Civil Engineering, Vol. 54 No. 1, pp. 2–13.

Havenga, J.H. and Simpson, Z.P. (2018), "National freight demand modelling: a tool for macrologistics management", International Journal of Logistics Management, https://doi.org/10.1108/IJLM-11-2017-0290

Havenga, J.H.; Simpson, Z.P., King, D. de Bod, A. and Braun, M. (2016), "Logistics Barometer South Africa 2016", Stellenbosch University, available at: https://www.sun.ac.za/english/faculty/economy/logistics/Documents/Logistics%20Barometer/Logistics%20Barometer%202016%20Report.pdf (accessed 10 August 2018).

Horridge, M., Madden, J. and Wittwer, G. (2005), "The impact of the 2002–2003 drought on Australia", Journal of Policy Modeling, Vol. 27, pp. 285–308.

Hovi, I., Grønland, S., & Madslien, A. (2013). "Development of an improved decision support tool for freight transport planning in Norway", European Transport Conference, Frankfurt, Germany, 13 September, available at: abstracts.aetransport.org/paper/download/id/167 (accessed 30 June 2017).

Huber, S. (2017), "Transport chain choice modelling in freight transport demand models", Open Science Journal, Vol. 2 No. 4, available at: https://osjournal.org/ojs/index.php/OSJ/article/download/1066/96 (accessed 29 May 2018).

IMF. (2018), "World Economic Outlook", April 2018, available at: https://www.imf.org/en/Publications/WEO/Issues/2018/03/20/~/media/Files/Publications/WEO/2018/April/text.ashx?la=en (accessed 18 April 2018).

Ivanova, O. (2014), "Modelling Inter-Regional Freight Demand with Input-Output, Gravity and SCGE Methodologies", in Tavasszy, L. and De Jong, G. (Eds), Modelling Freight Transport, Elsevier, London, pp. 13-42.

Jankauskaite, Z., Gounder, S. & Bean, W.L. (2013), "Investigation of road freight challenges and costs in South Africa", 9th Annual State Of Logistics Survey for South Africa, available at https://www.csir.co.za/sites/default/files/Documents/final_9th%20SoL%20for%20web.pdf (accessed 18 September 2018).

Kockelman, K., Browne, M. and Leonardi, J. (2009), "The acquisition of long-distance freight data: Synthesis of a workshop", in Bonnel, P., Lee-Gosselin, M., Zmud, J. and Madre, J-L. (eds), Transport Survey Methods, Bingley: Emerald Group Publishing Limited, pp.311-320.

Kojima, K. (1982), "Macroeconomic versus international business approach to direct foreign investment", Hitotsubashi Journal of Economics, Vol. 23 No. 1, pp.1-19.

Korzhenevych, A. (2012), "TRANS-TOOLS – An integrated support tool for European transport pokorzlicy", Information zur Raumentwicklung, Vol. 7 No. 8, pp. 349-366.

Kresge, D.T. and Roberts, P.O. (1971), Techniques of Transport Planning: Systems Analysis and Simulation Models, Volume 2, Brookings institution.

Lahr, M.L. (2016), "Regional Input-Output Analysis: An Appraisal of an Imperfect World", available at: http://dx.doi.org/doi:10.7282/T3H1340W (accessed 7 March 2018).

Leontief, W. (1986), Input-output economics, Oxford University Press: Oxford.

Lin, J., Tai, K., Tiong, R.L.K. and Sim, M.S. (2016), "A general framework for critical infrastructure interdependencies modeling using economic input-output model and network analysis", in Complex Systems Design and Management Asia: Proceedings of the Second Asia-Pacific Conference on Complex Systems Design and Management in Singapore, 2016, Springer, Cham, pp. 59-74.

Liu, W., Li, W. and Huang, W. (2006), "Analysis of the dynamic relation between logistics development and GDP growth in China", in *International Conference on Service Operations, Logistics, and Informatics*, Shanghai, China, 21-23 June, IEEE, pp. 153-157.

Mačiulis, A., Vasiliauskas, A.V. and Jakubauskas, G. (2009), "The impact of transport on the competitiveness of national economy", *Transport*, Vol. 24 No. 2, pp.93-99.

Marcos, C.B. and Martos, L.P. (2012), "Estimating the Demand for Freight Transport: The Private versus Public Trade-Off in Andalusian Food Industry", available at: encuentros.alde.es/anteriores/vieea/autores/B/36.doc (accessed 5 March 2018).

Martinez-Zarzoso, I. and Nowak-Lehmann, F.D. (2007), "Is distance a good proxy for transport costs? The case of

competing transport modes", *The Journal of International Trade and Economic Development*, Vol. 16 No. 3, pp. 411-434.
Meadows D. H., Meadows D. L, Randers, J., & Behrens W.W. (1972), *The Limits to Growth*, Potomac Associates, Washington D.C.
Mommens, K., van Lier, T. and Macharis, C. (2017), "Freight demand generation on commodity and loading unit level", European Journal of Transport & Infrastructure Research, Vol. 17 No. 1, pp. 46-62.
Müller, S., Wolfermann, A., & Huber, S. (2012), "A nation-wide macroscopic freight traffic model", Procedia - Social and Behavioural Sciences, Vol, 54, pp. 221-230.
OECD (2017), "The value of data for development", in Development Co-operation Report 2017: Data for Development, OECD Publishing, Paris, doi: http://dx.doi.org/10.1787/dcr-2017-7-en.
Ottemöller O. and Friedrich H. (2017), "Implications for Freight Transport Demand Modelling from Interdisciplinary Research: Developing a Concept for Modelling Freight Transport Within Supply Networks of the Automotive Industry", in Abele E., Boltze M. and Pfohl HC. (eds), *Dynamic and Seamless Integration of Production, Logistics and Traffic*, Springer, Cham.
De Dios Ortúzar, J. and Willumsen, L.G. (2011), *Modelling Transport*, 4th edition, Chichester, Wiley.
Portugal-Perez, A. and Wilson, J.S. (2012), "Export performance and trade facilitation reform: Hard and soft infrastructure", World Development, Vol. 40 No. 7, pp. 1295-1307.
Pradhan, R.P. and Bagchi, T.P. (2013), "Effect of transportation infrastructure on economic growth in India: the VECM approach", *Research in Transportation Economics*, Vol. 38 No. 1, pp. 139-148, https://doi.org/10.1016/j.retrec.2012.05.008.
Rantasila, K. and Ojala. L. (2015). "National-level logistics costs: an overview of extant research", International Journal of Logistics Research and Applications, Vol. 18 No. 4, pp. 313-324, DOI: 10.1080/13675567.2015.1016413.
Raza, M. and Aggarwal, Y. (1986), Transport Geography of India: Commodity flows and the regional structure of the Indian economy, Concept Publishing Company: New Delhi.
Simpson, Z.P., Havenga, J.H. & Aritua, B. (2016), "Freight-flow modelling and macrologistics: Customising the Southern African model for application in India", paper presented at the 21st Annual Logistics Research Network, 7–9 September, University of Hull, Kingston upon Hull.
Smith, R.H.T. (1970), "Concepts and Methods in Commodity Flow Analysis", *Economic Geography*, Vol. 46, pp. 404-416.
Song, L. and Van Geenhuizen, M. (2014), "Port infrastructure investment and regional economic growth in China: Panel evidence in port regions and provinces", Transport Policy, Vol. 36, pp.173-183, https://doi.org/10.1016/j.tranpol.2014.08.003.
Stinson, M., Pourabdollahi, Z., Livshits, V., Jeon, K., Nippani, S. and Zhu, H. (2017), "A joint model of mode and shipment size choice using the first generation of Commodity Flow Survey Public Use Microdata", International Journal of Transportation Science and Technology, Vol 6, pp. 330-343, https://doi.org/10.1016/j.ijtst.2017.08.002.
Su, S.I.I. and Ke, J.Y.F. (2017), "National Logistics Performance Benchmarking: A Process-based Approach Using World Bank Logistics Performance Index Database", *Journal of Supply Chain and Operations Management*, Vol. 15 No. 1, pp. 55-78.
Tavasszy, L. and De Jong, G. (2014), "Introduction", in L. Tavasszy and G. de Jong (eds.), Modelling freight transport, Elsevier, Amsterdam, pp. 1–12.
UK Department for Transport. (2002), "Integrated Transport and Economic Appraisal: Review of Freight Modelling, Report B2: Review of models in continental Europe and elsewhere", Consultant report for UK Department for Transport Integrated Transport and Economic Appraisal.
United Nations. (1987), "Report of the World Commission on Environment and Development: Our Common Future", available at: http://www.un-documents.net/our-common-future.pdf (accessed 30 October 2017).
United States Census Bureau. (2018), "Commodity flow survey", available at: https://www.census.gov/econ/cfs/ (accessed 18 April 2018).
Utrecht University. (2013), "Flowmap webpage", available at: http://flowmap.geo.uu.nl/index.php (accessed 24 April 2018).
Van Es, J. (1977), "Freight transport models as a tool for management", in Transport decisions in an age of uncertainty, proceedings of the third World Conference on Transport Research in Rotterdam, Netherlands, 1977, Springer, Dordrecht, pp. 586-592.

Wendling, Z.A, Levy, M.A., Esty, D.C., de Sherbinin, A., and Emerson, J.W. (2014), "The 2018 Environmental Performance Index", joint research by the Yale Center for Environmental Law & Policy, the Center for International Earth Science Information Network Columbia University and the World Economic Forum, available at https://epi.envirocenter.yale.edu/2018-epi-report/introduction (accessed 22 May 2018).

World Bank. (2016), "Connecting to Compete 2016 – Trade logistics in the global economy. The Logistics Performance Index and its indicators", available at: https://openknowledge.worldbank.org/bitstream/handle/10986/24598/Connecting0to00n0the0global0economy.pdf (accessed 1 April 2018).

World Bank. (2018), "Connecting to Compete 2018 – Trade logistics in the global economy. The Logistics Performance Index and its indicators", available at: https://openknowledge.worldbank.org/bitstream/handle/10986/29971/LPI2018.pdf (accessed 16 August 2018).

Zaman, K. & Shamsuddin, S. (2017), "Green logistics and national scale economic indicators: Evidence from a panel of selected European countries", *Journal of Cleaner Production*, Vol. 143, pp. 51–63. doi:10.1016/j.jclepro.2016.12.150