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Enhancing farmer linkages to markets in developing countries through mapping of supply chains and optimising transport

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ABSTRACT

Getting products to market where transport infrastructure is underdeveloped or unreliable is a major barrier to agricultural development, particularly in less-developed countries. Transport represents a high proportion of farm gate costs of moving livestock and crops to processors and local markets throughout the region. This is confounded by poor transport network infrastructure throughout the supply chain, wet weather accessibility constraints, food losses in transit, and congestion. Evidence-based approaches can inform transport and logistics infrastructure investments at different locations to maximise cost reductions.

The Transport Network Strategic Investment Tool (TraNSIT) was developed by Australia's national science agency, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), to map freight movement and associated costs. The tool was applied to create the largest supply chain analysis ever conducted in Australia, mapping more than 170 commodities and 25 million vehicle trips per year. It is used extensively by the Federal and state governments to inform over $5 billion per year in major infrastructure and freight strategies.

Drawing on experience through an investment by the Australian Government in partnership with agencies in Vietnam and Indonesia, we show how the TraNSIT methods can be extended and implemented in these developing countries. Several challenges are addressed around securing commitment from key in-country ministries and state-owned enterprises, accessing quality data, and modelling freight and supply chains that differ considerably to those in developed countries. Applications to key cropping and livestock commodities are used to demonstrate how TraNSIT can be used to analyse existing supply chains and test scenarios for various infrastructure investments.

1. Introduction

Getting products to market where transport networks are unreliable is a major barrier to agricultural development. Increased demand for food and other freight products throughout South-east Asia may not necessarily translate to increased supply from the production end of the supply chain if produce is unable to be delivered to markets in a timely manner. High transport and logistics costs are exacerbated by issues such as climate and weather disruptions, up-country road networks that limit the use of higher productivity vehicles, expensive inter-island and cross-border trade often with poor vessel utilisation, inadequate up-country storage and handling for perishable products, and congestion at and surrounding ports and major processing facilities.

The World Bank has recognised the need to invest in transport infrastructure throughout Indonesia and Vietnam to improve connectivity and market access. In Vietnam, the World Bank's flagship Vietnam Development Report - Connecting Vietnam for Growth and Shared Prosperity (The World Bank Group, 2019) provides a comprehensive overview of connectivity issues in Vietnam and some strategic recommendations. In Indonesia, the National Medium-Term Development Plan 2020–2024 (RPJMN) focuses on infrastructure development, particularly connecting production areas with distribution mechanisms

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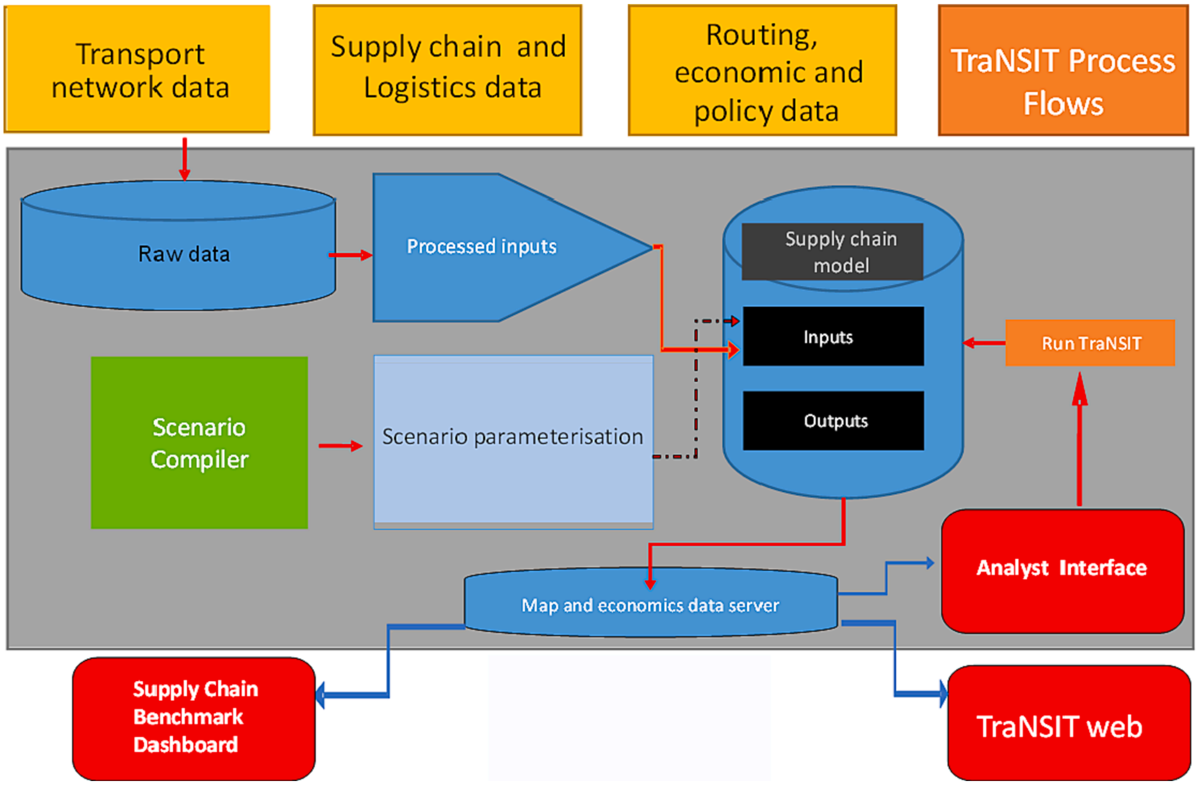

Fig. 1. Components of the Transport Network Strategic Investment Tool (TraNSIT).

and demand centres. The RPJMN infrastructure development strategies focus on building new tollways and roads - particularly those in outermost regions - new ferry ports, high-speed rail and freight trains. The plans recognise the need to develop and improve hinterland connections through multi-modal connectivity via road and rail links to industrial centres, cities and transport hubs.

The increased and changing demand for food profoundly affects regional food supply chains. Whereas previous research and development efforts and investments by governments and donors focused on improving productivity by producers to ensure adequate food supply, there has been far less effort in understanding the implications of changing market dynamics on post-farm gate supply chains. The issue of access to good quality supply chain infrastructure is now a regular feature of the political discourse, national government policy and investment from large donors such as:

- The World Bank, which recognised the need to invest in road and port infrastructure to improve connectivity to supply domestic markets and increase access to fresh produce throughout Indonesia (The World Bank Group, 2015); as well as supporting the transformation of agricultural value chains to improve market access through improved competitiveness in Vietnam (The World Bank Group, 2017).
- The Asian Development Bank, which allocated nearly-two-thirds of its budget for 2016–2018 to infrastructure development to create and expand economic activity and access to markets in 'lagging' areas (defined as those behind in socio-economic status and with specific reference to rural areas and supporting agricultural development). The Asian Development Bank's long-term strategy is to support agriculture and rural development mainly through infrastructure for rural transport, irrigation and water systems, and microfinance (ADB, 2008, ADB, 2014).
- The Japan International Cooperation Agency, which has supported the development of economic and social infrastructure through loan facilities to upgrade bridges throughout the Vietnamese road network (JICA, 2015).
- The Master Plan on ASEAN Connectivity 2025 (ASEAN, 2016), which recognised the need to increase investments in sustainable infrastructure that connect people to markets to deliver economic growth and improve the quality of life across the ASEAN states. This includes improving logistics and coordination across member states by identifying bottlenecks in supply chains and tackling critical policy issues.

Transport represents a high proportion of farm gate costs of moving livestock and crops to processors and local markets throughout the region. These costs are exacerbated by issues such as poor transport network infrastructure (e.g. roads, ports, bridges) throughout the supply chain (from production to storage, processors and markets), wet weather accessibility constraints, poor utilisation of livestock ships, food losses in transit, congestion and an inconsistent regulatory and policy regime which limits cross-border movements. In Indonesia, logistics costs are 14.08 % of total production costs (Sinaga, 2011). Data from the Industry Ministry showed Indonesia's logistics costs to be 23.6 % of the country's GDP in 2014, compared to 9.9 % in the United States (Jakarta Post, 2014). The Indonesian Logistics and Forwarders Association (ALFI) estimated logistics costs as greater than 25 % of GDP until 2015 and then forecast a reduction to 21 % by 2019 (pers comm).

To address these challenges, the Australian Government through the Department of Foreign Affairs and Trade (DFAT) and the Australian Centre for International Agricultural Research (ACIAR) funded project work in Indonesia and Vietnam from 2017 to 2021 to examine transport routes and costs for a set of priority agricultural commodities and examine changes due to 'what if' scenarios. This paper summarises the projects' innovations, methods and a subset of case studies, and discusses the potential long-term impacts.

Section 2 provides an overview of past applications of transport models used in developing countries for operational and strategic planning. Section 3 provides an outline of the methodology, originally

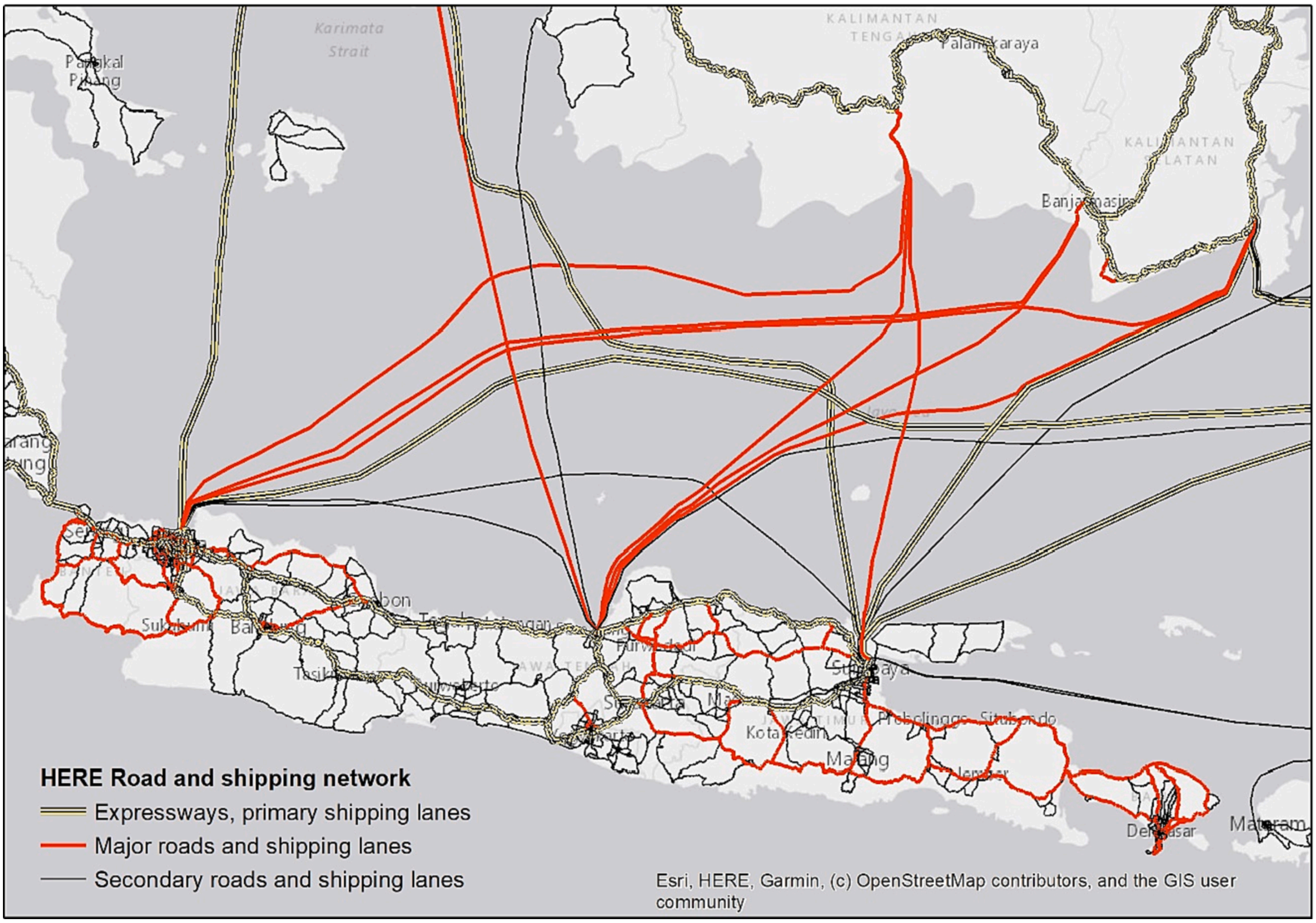

Fig. 2. Major roads and shipping routes in and to/from Java, Indonesia, based on the HERE (2019) road and shipping network.

implemented in Australia and adapted for Indonesia and Vietnam. Section 4 outlines the pathway to implementation adopted in Indonesia and Vietnam, including the establishment of key stakeholder relationships, data gathering and case studies. It highlights significant differences in method requirements between the two countries. Sections 5 and 6 summarise a subset of baselines and case studies undertaken for priority commodities in Indonesia and Vietnam, respectively. Section 7 summarises the projects' work.

2. Literature review

Computer-based mapping of the movement of agricultural and other commodities between enterprises provides a means to understand the transport and logistics elements of the supply chain from production to markets/ports. The literature is rich with analysis and modelling to better understand existing supply chains and logistics, with such a baseline being used to inform interventions to improve the system's performance. This literature review focuses on state-of-the-art analysis as well as major studies relevant to the regions which are a focus of this paper. The reviewed literature tends to fall into one of three categories:

- Top-down analysis, largely using national-level data, which provides a high-level overview of the current freight sector across the major travel modes.
- Bottom-up analysis that provides spatially granular supply chain and freight map data for a limited set of commodities or locations.
- Innovative application of mathematical methods to model freight movements across a network of enterprises or regions.

Top-down approaches usually apply national and publicly available statistics on regional agricultural (or other commodity) production and supply chains, to provide a summary of transport and logistics for the country. In Australia, a state-of-logistics study by Higgins et al. (2011) developed and tested a methodology that estimates the costs of logistics for a number of Australian food commodities (mango, sugar, wine, livestock) and identifies supply chain path challenges. In South Africa, the Council for Scientific and Industrial Research (CSIR) conducted a state-of-logistics study to identify infrastructure investment priorities across the major industry sectors including agriculture (CSIR, 2005). This study led to sector-level projects between CSIR and South African agriculture industries being established. In Indonesia, a major survey of trucking companies and logistics enterprises (The Asia Foundation, 2008) was undertaken to identify vehicle costs and on-road payments for nine overland routes. It identified several inefficiencies in the freight sector, including discrepancies between national and local policies, and inconsistent permitting. The survey was able to disaggregate the vehicle operating costs for the different routes, which provided useful parameters for the current paper. A state- of-logistics Indonesia 2015 study (Bann et al. 2015), a collaboration by several organisations, provided several baseline analyses for the logistics and transport networks. It included case studies of dwell times for port containers, coastal shipping network efficiency and maritime hub and spokes. Key data was compiled from in-country terminals and state-owned enterprises providing transport or logistics services. For Vietnam, a recent report (The World Bank Group, 2019) provided a broad top-down analysis of the transport and supply chain networks. It identified critical transport corridors and their connectivity, transport costs on the trade routes, mapping of aquaculture value chains, and analysis of food losses through the chain.

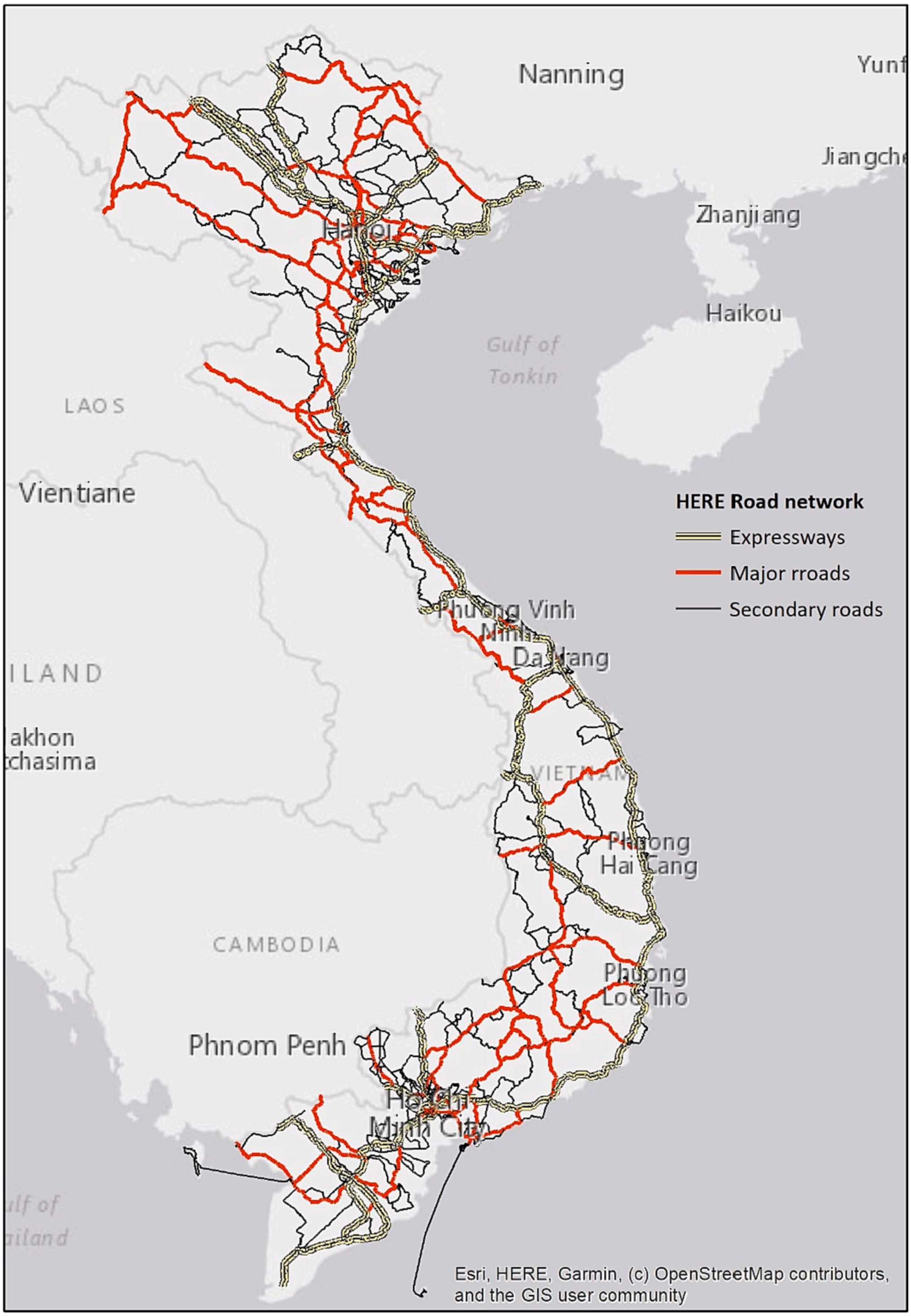

Fig. 3. Major roads in Vietnam, based on the HERE (2019) road network.

Table 1
Summary of transport costs for some typical vehicles in Indonesia at various average speeds.

Type	MODELLED COST (RP/KM) PER TRAVEL SPEED - Sealed Roads			MODELLED COST PER TRAVEL SPEED (RP/KM) - Unsealed Roads	
	100 km/h	60 km/h	20 km/h	60 km/h	20 km/h
Suzuki Carry	2,988	3,363	5,915	3,525	6,301
Colt Diesel	4,960	5,389	8,647	5,686	9,302
8 Tonne Fuso	6,806	7,308	11,298	7,768	13,162
Tronton (4 axel)	8,323	8,990	14,094	9,771	14,874
Semi-Trailer	9,839	10,428	16,390	11,380	18,984

Table 2
Summary of transport costs for some typical vehicles in Vietnam at various average speeds.

Type	MODELLED COST (VND/KM) PER TRAVEL SPEED - Sealed Roads			MODELLED COST PER TRAVEL SPEED (VND/KM) - Unsealed Roads	
	100 km/h	60 km/h	20 km/h	60 km/h	20 km/h
Small truck (1 tonne)	4,930	5,550	9,760	5,810	10,390
Small truck (2 tonne)	8,180	8,900	14,260	9,380	15,340
Medium truck (8 Tonne)	11,320	12,060	18,640	12,810	21,710
Large truck (20 Tonne)	15,480	17,200	27,040	18,780	31,310

Table 3
Draft Shipping operating costs ($/tonne or TEU- Twenty Foot Equivalent)) for a 250 m ship with a payload of 40,000 tonnes.

				Distance	
VESSEL TYPE	500KM	1000KM	2000KM	4000KM	8000KM
Bulk dry	$4.73	$5.97	$8.43	$13.36	$23.22
Bulk fuel	$4.71	$5.92	$8.34	$13.17	$22.84
Cargo	$4.34	$5.19	$6.87	$10.24	$16.98
Container (TEU)	$170.93	$201.80	$263.53	$386.99	$633.91

While the various analyses within the report are quite broad, they provide information (e.g. on travel costs, time) that can be validated with the case studies in this paper.

Bottom-up methods focus more on specific commodity or freight movements along the transport network or between regions. In Indonesia, a freight network simulation model was developed by Mahmudah et al. (2010) using a logit model for modal choice. The model was applied to the palm oil industry in Kalimantan Province, using spatial data about the transport network and palm oil plantations from several local and national sources. Primary outputs were freight volumes and costs from the plantations to the factories and ports. This was the first transport mapping of a commodity between production and the downstream enterprises of the supply chain in Indonesia. Kusumah and Wibawa (2017) mapped the inter-regional trade of major commodities (e.g. rice, sugar) through a large-scale survey. It identified a range of bottlenecks across the transport infrastructure and network that would not be identifiable through national statistics. Though expensive, these types of primary data collection identify important baseline features of the current logistics that need to be incorporated into a supply chain or transport model. Binh (2022) applied a freight simulation model to supply – demand statistics for the provinces around Hanoi, to forecast freight volumes along the major freight corridors. The use of data aggregated to provinces significantly limits the ability to map freight to smaller feeder roads.

An alternative approach to mapping freight movements across the road network is the use of Commercial Vehicle Tracking System (CVTS) data. CVTS data are derived from GPS tracking devices on commercial vehicles that can be used to monitor travel routes, times and timing of stops, with the ability to collect additional information such as commodity type, payload and truck type. A large study conducted in Vietnam by Lam et al. (2019) used CVTS data for case studies in Ho Chi Minh City and Hanoi, to understand key freight routes and congestion points by the time of day. A disadvantage of the CVTS data is its limited application to scenario analysis. For example, infrastructure investments (such as roads, ports, storage facilities) would not capture the elasticity of changes in the supply chain and freight paths that would occur.

There is a vast body of literature that focuses on new mathematical models or new implementation of existing ones. A major weakness of most of these papers is the over-simplified representation of the real-world problem so as to fit the mathematical model, and application of synthetic datasets. There are a few good examples of mathematical programming applications to freight and supply chains in developing countries. Here, we highlight key examples relevant to the scope of our paper. Heng et al. (2007) produced a capacitated facility location problem that minimises transport costs across the network for the various agricultural and other users, subject to expenditure and other constraints. It was tested on a dataset in the Puok District in Cambodia, with an investment budget for public infrastructure. The model formulation is mathematically complex and would be difficult to scale up and solve for a larger part of the country, particularly with a denser road network and an increased number of enterprises. For Indonesia, Russ et al. (2005) implemented an assignment model for intermodal freight, which was solved by a genetic local search algorithm. Application to Indonesia used an origin – destination survey and involved setting up 51 aggregated zones for the transport network. Outputs provided indicative information on the high-volume freight routes. Porteous (2015) produced a mathematical programming model for consumer demand for different classes of grains, combined with a grain storage and trade module. The model was applied to a synthetic dataset for 230 markets across 42 African countries.

Some notable papers focusing on transport in developed countries include Liedtke (2009) who implemented a bottom-up transport commodity simulation model using a statistical model for allocating origin to destination locations (companies) and freight volumes. The method was tested on two datasets of 100 and 1000 companies in Germany, mapping out truck volumes along the network. This model is able to represent more complex supply networks for complex commodities than traditional commodity flow optimisation models. However, it still relies on a largely synthetic dataset, and it is difficult to achieve a thorough validation with industry and freight providers. Ottemoller and Friedrich (2019) developed a commodity flow optimisation model minimising weighted distances between zones, where flows between businesses can be turned on or off. This model was tested on the poultry supply chain in Germany, assigning movements between enterprise zones. Such a model can be used to select new processing or storage enterprises that minimise total transport costs or other measures. A challenge with this type of mathematical programming method is that the synthetic outputs are divorced from actual movements between enterprises. There are also additional real-world criteria such as complex vertical supply chains, biosecurity considerations and geographical limitations that impact likely flows between zones/enterprises and can be difficult to integrate into mathematical programming models.

This paper makes significant contributions to transport modelling literature by overcoming many of the limitations of previous studies. It provides:

- A rigorous "ground-up" mapping of supply chains for several commodities on a large scale not achieved previously, with the capacity to provide both local and national scale analysis capability. It

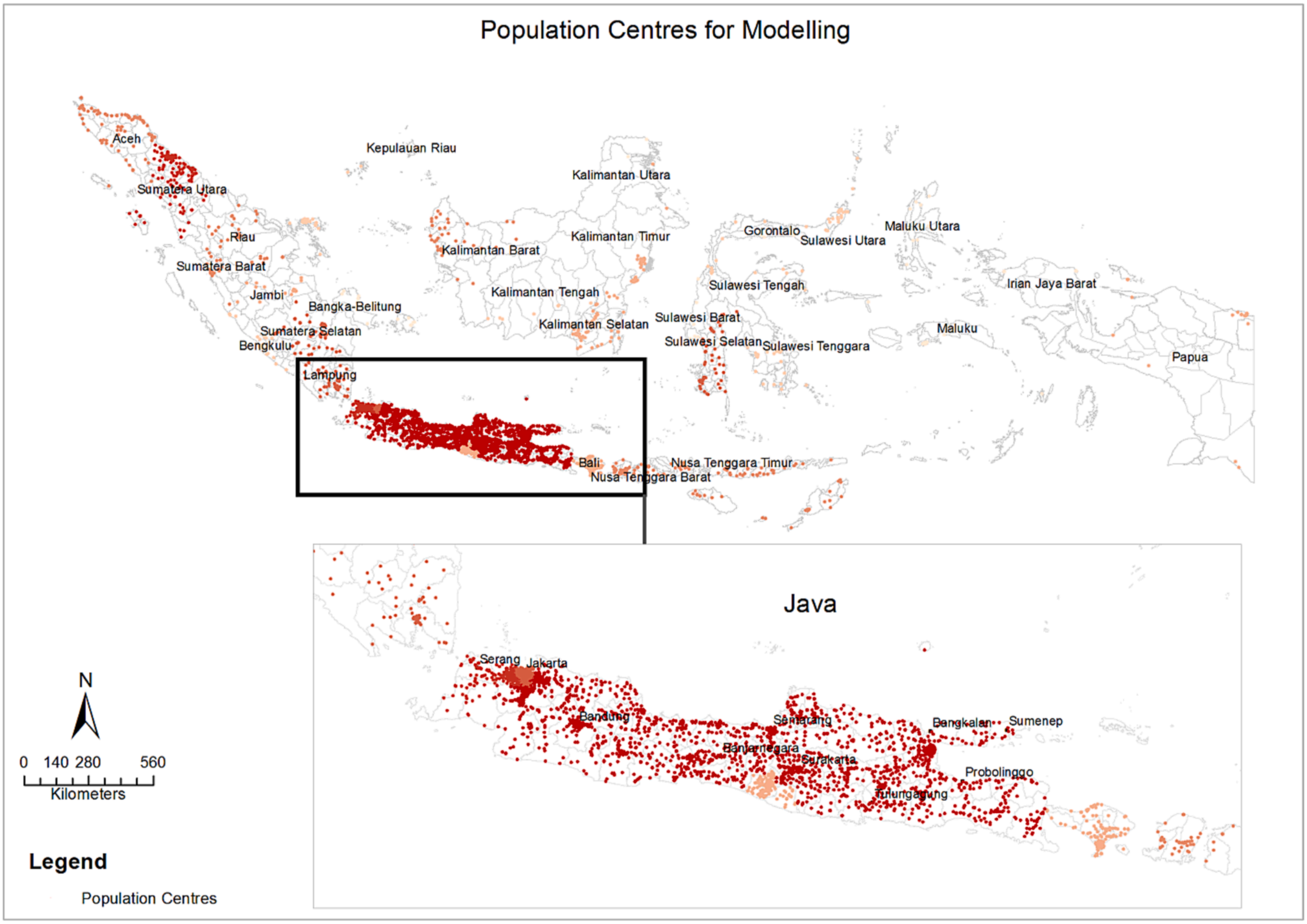

Fig. 4. Location of the representative markets for Java, based on Kecamatan population statistics (2015).

represents a major exercise involving a large number of ministries, enterprises and agencies from Indonesia and Vietnam, pulling together a logistics knowledge base not previously achievable.

- Application of a proven transport planning tool developed in Australia, TraNSIT, to Indonesia and Vietnam for priority commodities, showing how it accommodates real- world considerations of supply chains.
- Demonstration of application to major infrastructure investments, showing the benefits to each enterprise or supply chain path, with on-ground validation and acceptance of the technology.

3. Methods

Supply chain mapping of key commodities in Indonesia and Vietnam was a complex exercise over the life of the four year project, and required several methodological steps:

1) Stakeholder engagement: Identifying the most important Ministry's, agencies, state owned companies, associations and research organisations. These were important to ensure identification of important commodities, access to data, in-country validation, and a longer term adoption of the tools;
2) Data gathering: building relationships with key stakeholders allowed access to key data sets on the production and supply chains of each priority commodity. There were often data gaps (e.g. location of rice mills in Indonesia), which were obtained through primary data gathering and published reports. This is the most time-consuming step of the methodology due to uncertainty of access to data and the long lead times;
3) Technical transport analysis using TraNSIT. Involved adapting the version of TraNSIT in Australia to Indonesia and Vietnam through the following steps:
   a. Set up of a road and coastal shipping transport network;
   b. Parameterising operating cost models for trucks and vessels, through data and knowledge provided by stakeholders;
   c. Developing a set of origin to destination movements for each commodity and supply chain path using the data gathered;
   d. Testing and calibrating the model in collaboration with in country staff;
4) Producing a wide range of baseline analysis outputs, as shown in this report;
5) Application to identify benefits from a range of transport interventions, such as road upgrades;
6) Incorporation of the methods into TraNSIT Web for future in-country use.

TraNSIT was initially developed in Australia to provide an evidence-based approach for identifying infrastructure investment and policy changes that reduce transport costs across agricultural supply chains (Higgins et al. 2017; Higgins et al. 2018). It is a strategic transport model that maps the transport movements (road, rail and domestic shipping) and costs between enterprises, aggregated to monthly and annual freight volumes. It has been implemented in Australia for over 170 commodities including agriculture, general freight, fuels, forestry, construction and minerals. It models more than 730,000 supply chains between 520,000

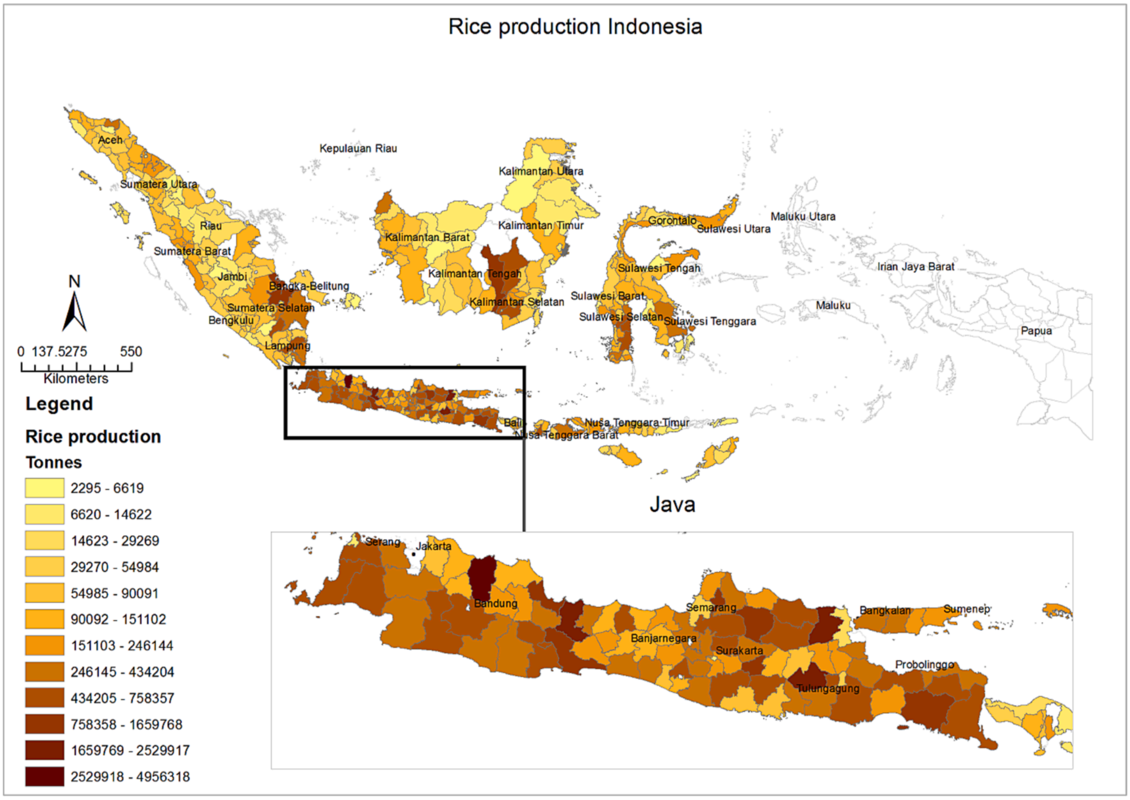

Fig. 5. Indonesia rice production.

enterprises, representing over 25 million freight trips per year.

TraNSIT has directly informed some of Australia's largest infrastructure projects, including the AU$14 billion Inland Rail project (Department of Infrastructure 2022), AU$3.5 billion Roads of Strategic Importance and the Northern Australia Beef Roads Programme.

It is a modularised tool (Fig. 1) where data for a commodity supply chain is an input to the core engine, along with the infrastructure or regulatory scenarios to test. Two user-friendly tools have been developed – the Supply Chain Benchmark Dashboard (CSIRO 2022) and TraNSIT Web (red boxes in Fig. 1). TraNSIT Web is a Web-based version of TraNSIT produced for the Australian context, allowing non-technical users to navigate across the tool's baseline outputs. The tool is currently being used by multiple Australian Government agencies and by all state and territory governments. The Supply Chain Benchmark Dashboard allows the user to analyse the baseline outputs across different supply chains for different commodities and regions (CSIRO 2022).

TraNSIT is programmed in Python uses the ESRI ArcGIS network analyst capability while accommodating multiple features about the road (and/or rail or ship) network. Transport network data are critical and roads of different ranking (e.g. primary, secondary and minor (including unsealed)) are included. In these projects, a road layer license for Indonesia and Vietnam was sourced from HERE. Additional information defining ranking, access restrictions and other road information was incorporated. The HERE network contains additional features including speed, road conditions (sealed, narrow sealed, unsealed) and other features (heavy vehicle access restrictions, bridge limits) that impact travel costs and vehicle routes. The major routes represented by the HERE network data for Java and Vietnam are shown in Fig. 2 and Fig. 3, respectively.

TraNSIT uses a ground-up costing model for road, rail and shipping. For road, it is based on published equations for vehicle operating costs (Tan et al. 2012; QDTMR, 2011). Additional vehicle types for Indonesia and Vietnam were incorporated after being identified through meetings with in-country stakeholders such as the Indonesian Trucking Association. A snapshot of the transport costs for different speeds and vehicles are provided in Table 1 and Table 2 for Indonesia and Vietnam, respectively. The vehicle operating cost model developed for Australia was parameterised for Indonesia and Vietnam using data and published information provided by in-country stakeholders. The costing model was enhanced for different types of unsealed roads, accommodating additional vehicle maintenance costs. The costing models were validated and refined in 2019 through feedback from stakeholders (e.g. Indonesian Logistics Association, Vietnamese Logistics Business Association) and published reports (e.g. The World Bank Group, 2014). Loading and unloading time and costs within the vehicle operating cost model are enterprise-specific and are included in the freight travel time and cost, as are vehicle decoupling times and costs.

Unlike Australia, Indonesia relies heavily on shipping between the islands, particularly transporting agriculture from western Indonesia to Java. For Indonesia, the shipping lanes are already included in the transport network (Fig. 2). Some shipping and port costs were obtained from state-owned enterprises such as PT. Pelni in Jakarta. A draft shipping module was produced in late 2019 (Table 3) and will be added to TraNSIT for future applications in Indonesia and Vietnam.

TraNSIT simulates the number of vehicle trips moved between origin and destination enterprises per month. The goal is to optimise the transport route and vehicle selection along the road/rail/shipping network for each of these trips from origin to destination, and then calculate the cumulative impacts at the enterprise or regional scale while evaluating against constraints on the number of vehicle trips on each route. To determine the optimal route, the analysis takes into account parameters such as costs, vehicle access, vehicle types and hierarchical value of the road segments. The least-cost vehicle combination selected depends on vehicle access restrictions throughout the journey from origin to destination.

This process is repeated for all routes, always searching for the minimum-cost route (including penalty costs such as road tolls) and selecting it as the optimal route. TraNSIT maps supply chains and tests

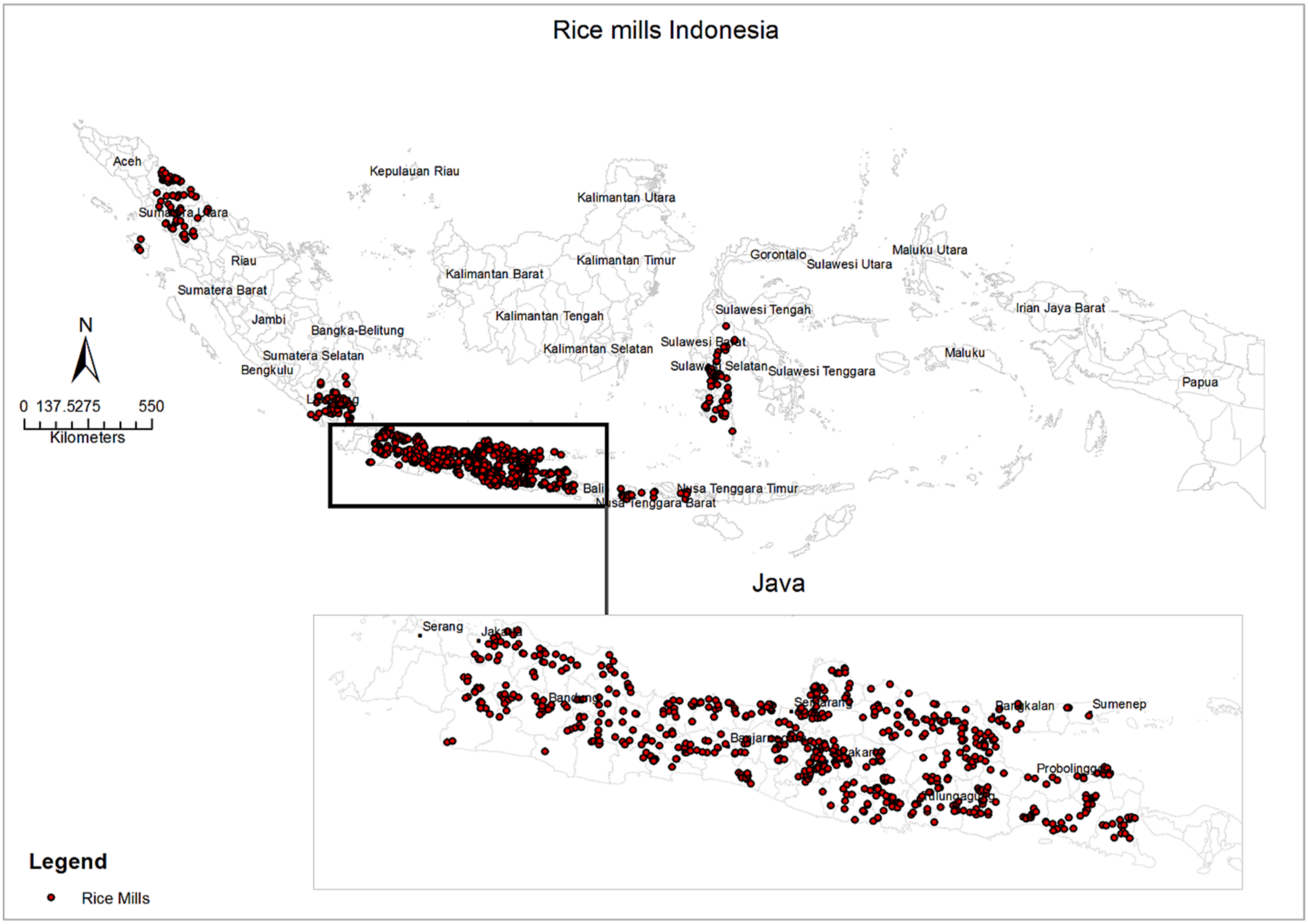

Fig. 6. Indonesia rice mill locations.

Table 4
Annual tonnages of Rice between each supply chain leg.

RICE ORIGIN TO DESTINATION	TOTAL TONNES
Property to Mill	62,893,600
Port to Storage	500,000
Rice Mill to Storage	38,994,032
Rice Storage to Market	39,486,736
Total	**141,874,369**

impacts of changed transport-related logistics, including:

- Determining the current logistics of key commodities, identifying pinch points from paddock to plate;
- Evaluating and optimising logistics arrangements from production, from processing and storage (including centralised warehousing options) to retail in order to ensure efficient operation from paddock to plate;
- Prioritising investment and identifying inefficiencies;
- Identifying critical infrastructure and testing upgrades to transportation route infrastructure including road improvements, bridge construction, ports and shipping routes;
- Providing transport freight flows and costs and testing impacts for upgraded fleets including truck, train and ship fleets; and
- Providing costs and freight flows for policy settings and testing policy changes.

4. Stakeholder engagement

For both Indonesia and Vietnam, engaging with in-country stakeholders was the largest component of the research. It ensured:

- The relevant ministries, associations, state and private owned companies and institutes were fully supportive of the research and willing to commit resources;
- Access to high quality production and processing data to the necessary granularity for TraNSIT;
- Effective validation of model outputs from key stakeholders representing each commodity and sector; and
- A path to long-term in-country adoption of TraNSIT, and continued growth to additional commodities.

4.1. Indonesia

Supply chain efficiency is an essential but challenging goal for Indonesia. Consequently, the introduction of the projects in Indonesia attracted significant attention from various organisations including the national government, industry, associations, research agencies and farmers' groups. These organisations expressed their strong support and willingness to participate and share information for the development of TraNSIT.

During the development of TraNSIT within Indonesia from 2017 to 2021, stakeholder engagement occurred through multiple discussions, meetings, roundtables and visits; both to critical distribution points (e.g.

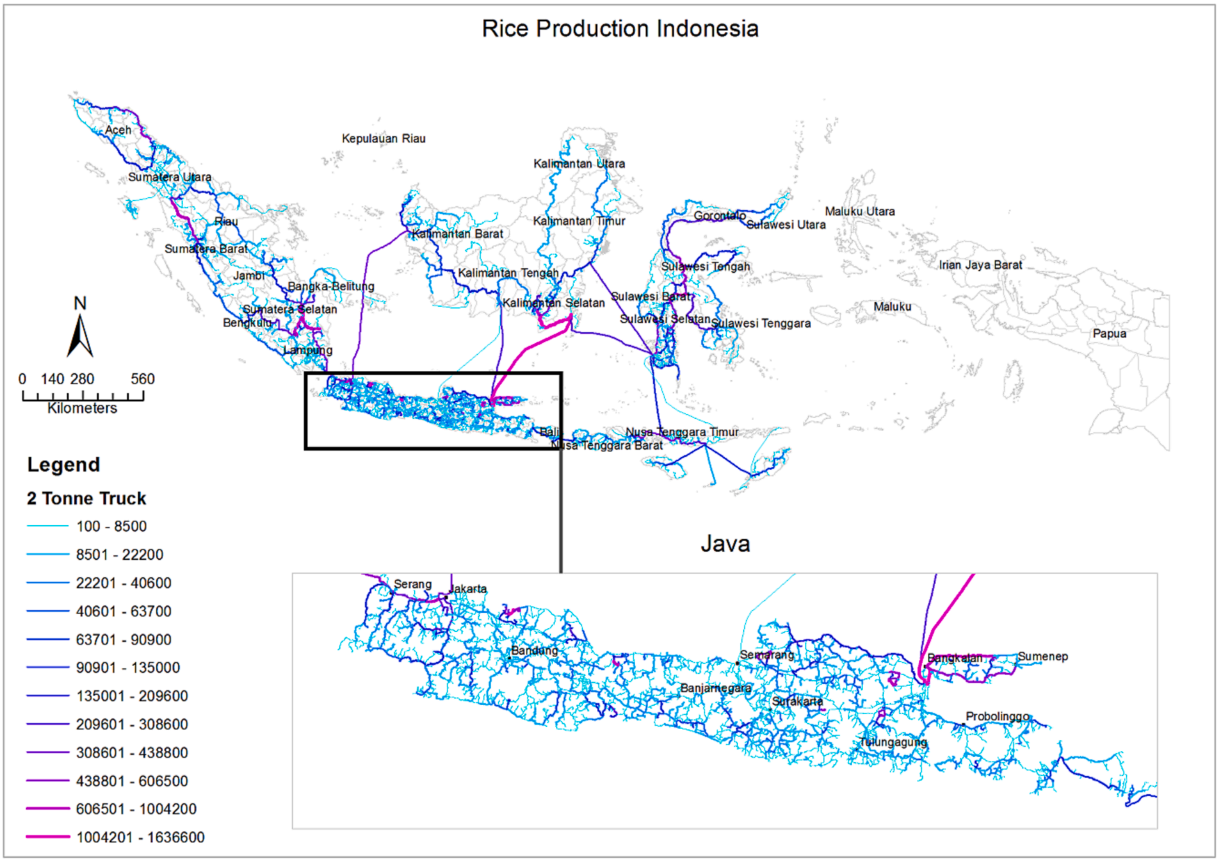

Fig. 7. Vehicle density (annual trailers) for transport of rice across Indonesia from farms to rice mills (inset Java).

ports, mills) and to field production sites and transportation routes. General interest in the tool was high and stakeholders showed much interest, providing consistently positive feedback. These stakeholders were identified as key to supporting case studies, data collection and longer-term use of TraNSIT.

Participants at the meetings and roundtable discussions recognised that TraNSIT would support critical aspects of the National Development Plan (2019–2025) to reduce logistics costs and increase GDP. Prominent agencies included: the Indonesian Ministry of National Development Planning (Bappenas), Coordinating Ministry for Maritime Affairs and Investment, Coordinating Ministry for Economic Affairs, Ministry of Agriculture, Ministry of Transportation, and the Central Statistics Agency (BPS).

Of these agencies, Bappenas, as the planning agency which oversees most of the national development policy for logistics and transportation in Indonesia, engaged throughout the projects' life, supplying data and information and reviewing and assessing initial outputs. Other ministries and state-owned enterprises relevant to the commodities examined supported the projects with additional and necessary data and information, providing time and effort to be involved.

Multiple discussions with food production, processing and transportation industry representatives revealed that current logistics are inefficient and expensive. Without a baseline, it was difficult to identify opportunities for increased productivity. Industry representatives highlighted internal logistical problems as a particular concern, particularly the expense and unreliability of freight transportation between islands. One of the critical relationships developed was with the Indonesian Chamber of Commerce and Industry (KADIN), which involves and includes all industry and industry bodies in Indonesia. According to KADIN, enterprises representing various industry sectors were inspired by the possibilities and outcomes TraNSIT offered, particularly those showing where and how to improve Indonesia's logistics and supply chain conditions.

Engagement also established a sustained communication channel with specific sectorial associations. In the process, these associations supported TraNSIT's development in Indonesia by providing data and valuable information to build the model and review and assess the outputs. For example, the Indonesian Logistics Association supplied information on specific case studies regarding logistics and supply chains in Indonesia, and the Indonesian Trucking Association provided data for and assessed the trucking and costing models.

4.2. Vietnam

A key part of these projects in Vietnam was to identify, engage and collaborate with relevant stakeholders, particularly national government institutions, but also provincial government, multilateral and bilateral donors (e.g. World Bank), industry organisations and the private sector. Initial engagement with core stakeholders identified analytical priorities and scenarios for analysis. Stakeholders were also integrally involved in compiling datasets and relevant information, planning and implementing analyses, reviewing and interpreting results, and providing policy insights.

The Ministry of Agriculture and Rural Development (MARD) and the Ministry of Transport (MoT) were identified as the two most relevant and important national ministries for transport and logistics policy, planning and investment decision-making. There was broad support and engagement by institutions within these ministries to build on existing Australian Government-funded initiatives in the Northwest Highlands.

As with Indonesia, initial meetings in Vietnam focused on higher level engagement - with DFAT; the Australian Embassy; Vietnamese ministries (MoT and MARD) responsible for national policy development for logistics, transport and agriculture; their research arms and logistics companies (e.g. Linfox). These consultations improved

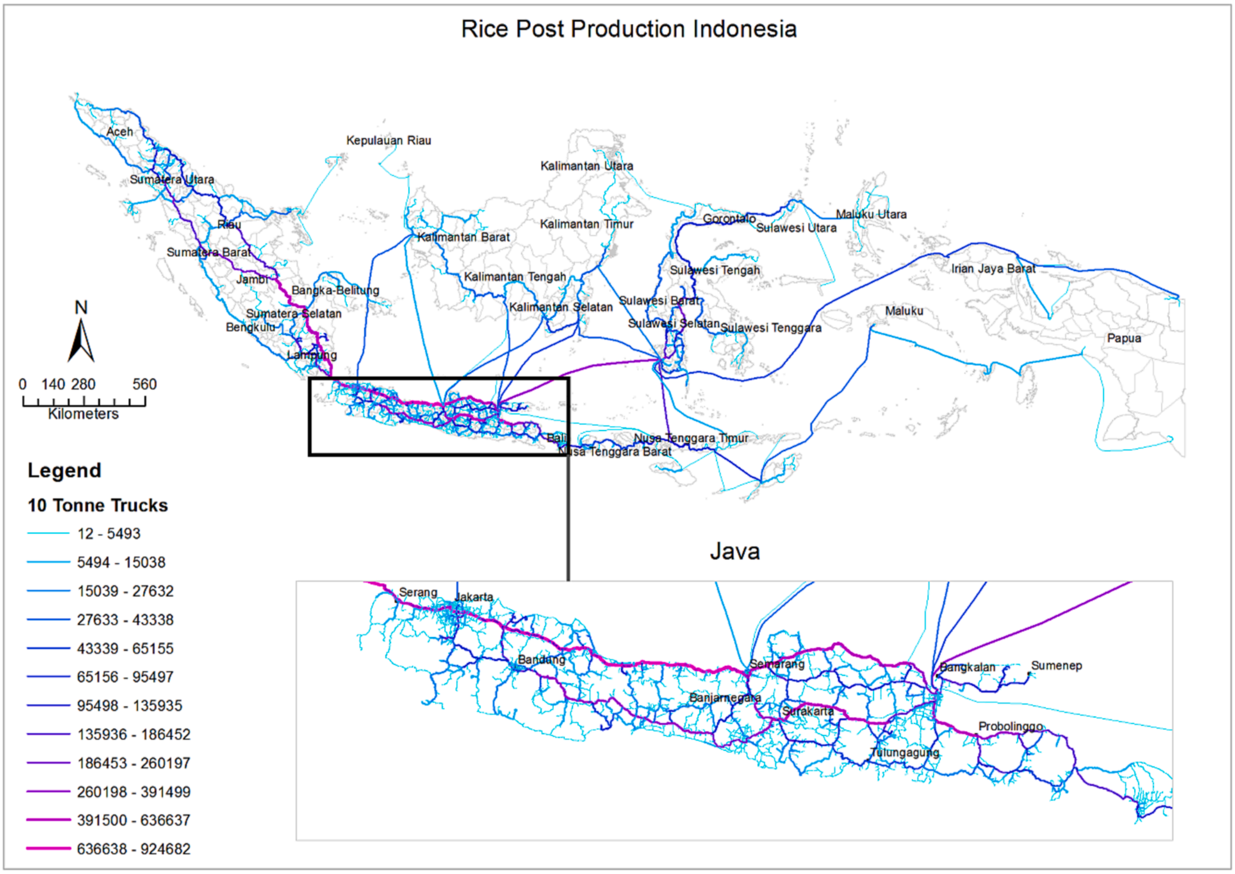

Fig. 8. Vehicle density (annual trailers) for transport of rice across Indonesia from rice mills to storage and markets (inset Java).

understanding of the country's transport and logistics challenges, policy and institutional context and introduced partners to the TraNSIT model and the projects' goals.

Working through a series of applied case studies and capability building activities, the projects directly partnered with the Transport Development and Strategy Institute (TDSI) within the MoT and multiple institutions within MARD including: Institute for Policy and Strategy for Agriculture and Rural Development (IPSARD); Northern Mountainous Agriculture and Forestry Science Institute (NOMAFSI); Vietnam National Institute of Agricultural Planning and Projection (NIAPP); and the Centre for Informatics and Statistics (CIS).

The projects also strengthened engagement and working linkages with the Centre for Agrarian Systems Research and Development (CASRAD), the People's Committee (PPC) and relevant Departments of Son La Province and Moc Chau District, the International Centre for Tropical Agriculture (CIAT), the Vietnam Logistics Association, the Aus4Transport initiative and individual transport logistics and agri-business companies. Most agencies were involved in the specific case study activities in Vietnam, and a collaboration agreement with NOMAFSI was established to support field work and collect data.

The engagement with stakeholders provided useful insights into some of the institutional opportunities and challenges affecting the adoption and integration of new analytical technologies, tools, and approaches such as TraNSIT in Vietnam. Barriers and challenges to technical and institutional collaboration and adoption include:

- Fragmented and limited integration of spatial and statistical data and analysis to support decision-making within and across institutions;
- Limited locally available expertise in advanced computer programming, spatial analytics, GIS analysis, remote sensing and optimisation modelling within institutions;
- Limited use of spatial data processing platforms and innovative analytical tools for big data analysis, optimisation simulation and modelling;
- Limited use of, or access to advanced computing and data processing hardware or software, including open-source platforms;
- Resource, labour and funding constraints which make it difficult for institutions to commit to or easily adopt complex new analytical systems and platforms; and
- Limited collaboration and sharing of data and analytical outputs within and between institutions.

5. Implementation - Indonesia

Within the agriculture and food sector, the Indonesian Government is focused on: i) increasing exports, ii) developing human resources, iii) maintaining price stability for consumers, iv) improving food security, v) increasing farmer welfare, vi) reducing imports and vii) optimising domestic production (Ackerman et al., 2020). The government currently prioritises 11 staple foods, of which rice and beef receive the most attention. The government is interested in increasing industry investment in agribusiness development, either through direct investment or industry support to cooperative-type systems. Rice, cattle/beef and sugarcane/sugar were the focus commodities for our case studies in Indonesia.

Due to difficulties in capturing specific domestic market locations and demand across the country, indicative locations were ascertained based on the locations of post offices. These locations were sufficiently detailed (Fig. 4) to determine an accurate representation of freight movement along the road and domestic shipping network. Using population statistics from BPS (2015) for each Kecamatan (administrative district), an estimate of the population serviced from each post office

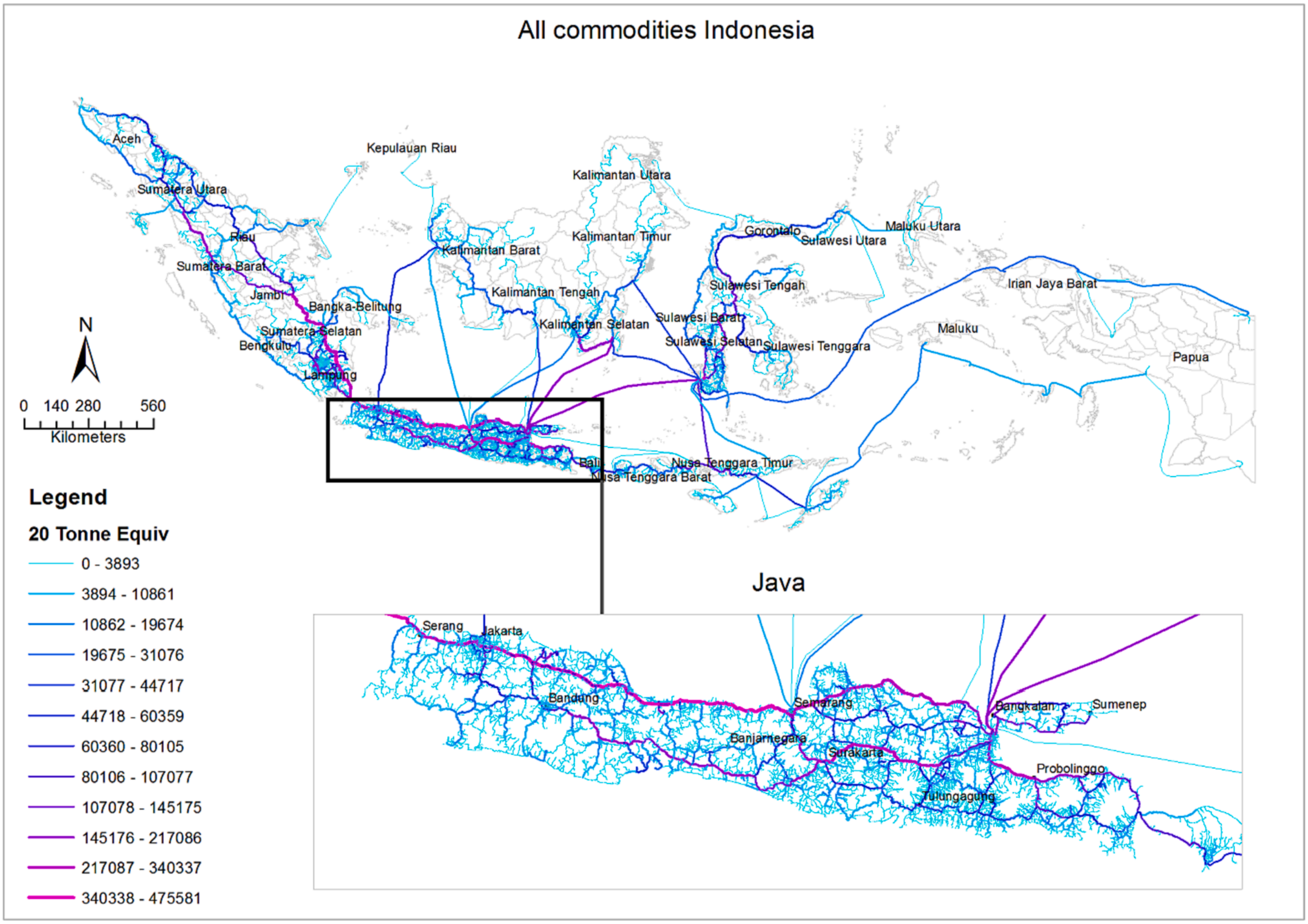

Fig. 9. Aggregated movements across all assessed commodities (rice, cattle, sugar) across the supply chains in Indonesia.

Table 5
Costs and transport metrics for the national supply chains assessed, Indonesia.

Commodity	Origin	Destination	Tonnes	Average Distance	Average Duration	Total Cost per Annum (000′ Rp)	Cost per Tonne (000′ Rp)
Rice	Property	Rice Mill	62,710,000	178.9	5.7	25,242,342,750	403
	Rice Mill	Storage	38,608,392	47.7	1.2	2,762,430,448	72
	Port	Storage	500,000	129.8	2.4	59,286,150	119
	Storage	Market	39,342,212	804.5	22.7	17,407,945,255	442
Cattle	Import	Abattoir	713,900	181.2	4.1	258,717,360	362
	Property	Abattoir	716,400	194.6	5.7	348,528,600	487
	Abattoir	Market	251,196	174.3	4.0	48,161,809	192
Sugarcane	Property	Mill	24,960,926	80.6	2.4	12,071,103,814	484
	Mill	Market	2,913,468	663.9	20.5	2,707,951,967	929

location was derived. Per capita demand for commodities was calculated as an estimate of the consumption for each market.

5.1. Baseline - rice

Detailed rice production and processor location data were gathered from the Ministry of Agriculture. Production data captured by Landsat 8 data were extracted from PDF files (http://sig.pertanian.go.id). Farm number and locations were determined from average yield per farm of approximately 5 tonnes/hectare, allowing for the higher yields achieved in Java.

The location data was linked with production data at Kecamatan scale for all Indonesia, to infer production tonnes for each cropping cycle. The data collected on the rice supply chain throughout Indonesia was run through the TraNSIT model.

Model outputs determined there were 64.4 million tonnes of annual rice production across 4130 production locations totalling 12.7 million hectares representing the approximately 15 million small holder farmers. Monthly rice production was estimated based on harvest cycles and timing for each region. Fig. 5 shows the distribution of rice production across the country. Rice production tonnage depends on the timing of the crop rotations and the wet seasons. The wet-season crop rotation has by far the largest area planted and crop yield. Some regions plant dry-season crops (May to August and/or September to December), though the yields are considerably less.

Once harvested, rice is transported to one of the many rice mills located in the country as shown in Fig. 6. These mills range from small to large, with varied mill capacities. For the purpose of the rice case study, these mills were represented by 992 processing points located near the production regions. Since the capacities of the mills were unknown, we

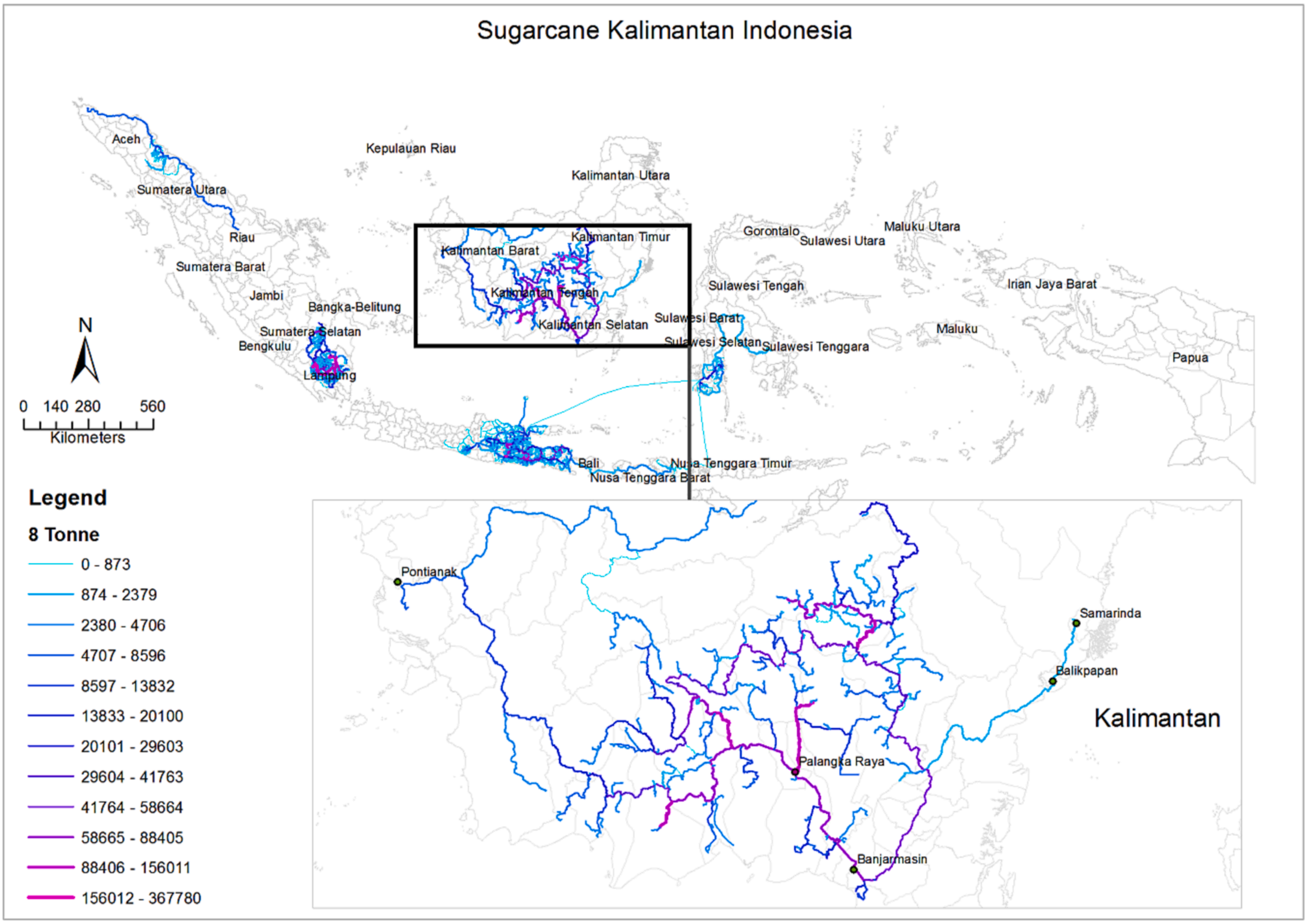

Fig. 10. Freight movements of sugarcane with 80,000 ha of cane production shifted from West Java to Kalimantan.

assumed them to have unlimited milling capacity for the purposes of the analysis.

From the mills, about 40 million tonnes of milled rice was moved to rice wholesalers and markets (Table 4). Consumption was estimated as 150 kg per person per year with market demand determined as a function of population (at 2016) for the 4592 points representing the 7,024 Kecamatan across the country. Domestic rice production is supplemented by 500,000 tonnes of imported rice which is mostly distributed through Perum BULOG (an Indonesian state-owned company).

A total of 141 million tonnes was moved across the supply chain (Table 4), including 63 million tonnes of hulled rice moved from production to mills, and 39 million tonnes of milled rice moved on to storage and market. Imported rice was included in the modelling (port to storage).

There is considerable variation in rice logistics across the country, including type and capacity of vehicle used for transport. For the modelling, the average vehicle payload from property (farm) to mill was set at 2 tonnes, at 10 tonnes between mill and storage and at 10 tonnes between storage and market. Up-country transport from farms is predominantly by smaller vehicles, partly due to road access limitations for larger vehicles.

The supply chain data and the assumed vehicles parameters were uploaded to the TraNSIT trip module and resulted in 74,000 supply chain movements leading to over 30 million vehicle trips per year. These trips were modelled through TraNSIT, providing insights into the paths used to move rice across the supply chain. Fig. 7 shows freight from farms to rice mills with 2-tonne capacity vehicles - these are predominantly short trips to the nearest mill.

Fig. 8 shows the freight task from the mills to storage and to markets across Indonesia. These comprise longer distance trips, particularly between the islands.

5.2. *Baseline - rice, cattle and sugar combined*

Production and supply chain data were collected for the rice, sugar and cattle supply chains. Individually, each of the commodities represents only a small proportion of the freight task on each road, except for some roads that are dominated by specific commodities, e.g. a feeder road to a sugar mill. Combining the movements for the commodities provides a greater coverage of the freight task across the road and coastal shipping network. This can be used to test interventions (such as road or port investments) at different locations that may lead to cost reductions or improve the supply chain resilience of multiple commodities.

For the three major commodities examined, Fig. 9 shows the combined freight demand across the road and inter-island shipping network. Compared to the individual commodities, there is usage of a much larger part of the road network and larger volumes of freight along the key freight routes (e.g. Jakarta to Surabaya).

Table 5 provides an estimate of the costs for moving the commodities across the supply chains for each supply chain leg. Much of the production leg (property to processor) for all three commodities is moved on small trucks, resulting in poor efficiency and increases transport costs. TraNSIT provides the opportunity to analyse the costs across supply chains both spatially and across sectors to identify potential investment strategies that can benefit multiple stakeholders.

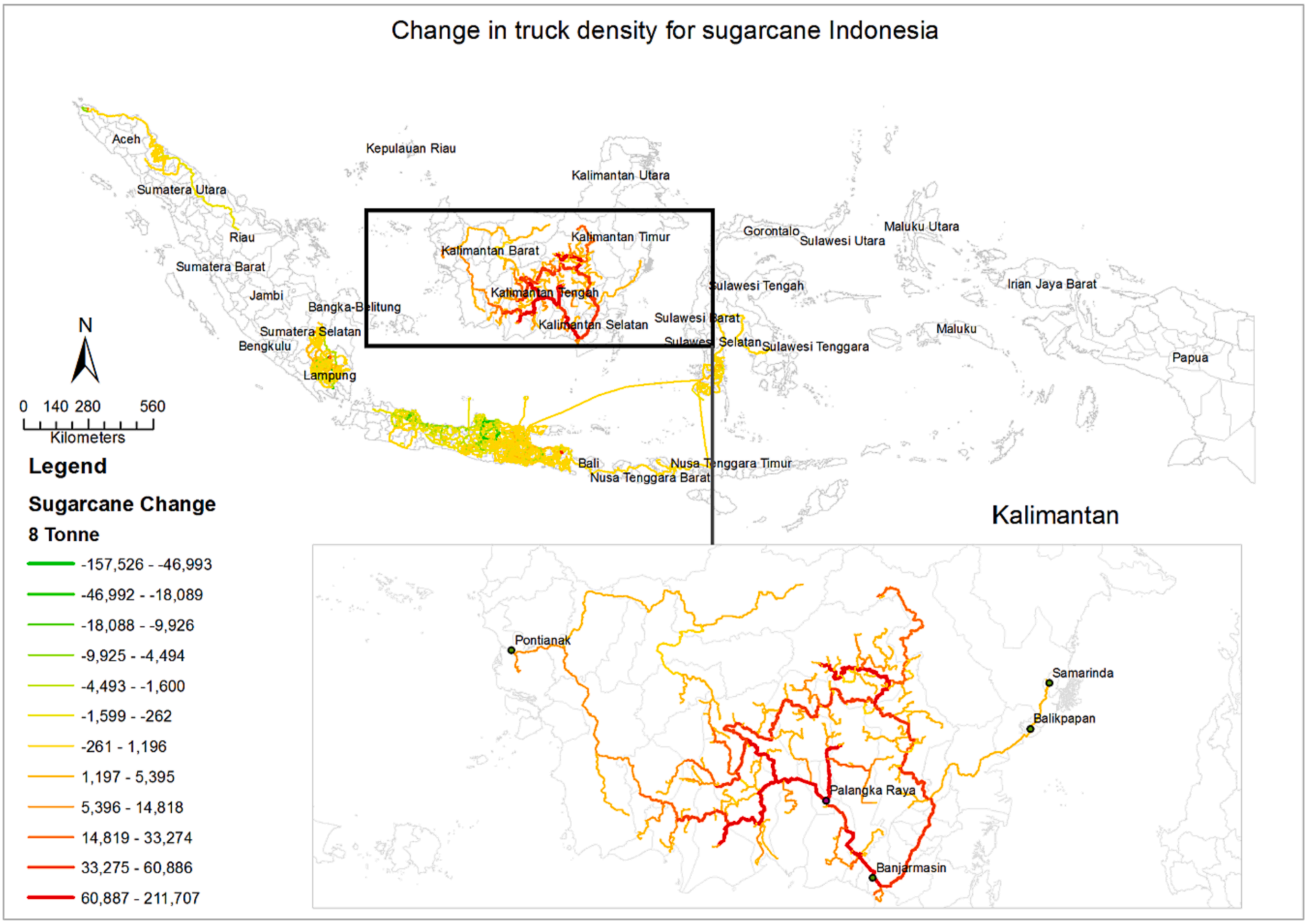

Fig. 11. Change in freight movements of sugarcane along the road and coastal shipping network from the scenario (80,000 ha of cane moved from Java to Kalimantan) versus the baseline.

5.3. Scenario – Relocating sugarcane production from West Java to Kalimantan

The supply chain mapping of cattle, rice and sugar in TraNSIT allowed testing of system-wide impacts from a range of interventions or production scenarios. We developed and tested a proof-of-concept scenario where a significant amount of sugarcane production (80,000 ha) and processing was relocated from West Java to Kalimantan. It is in response to Indonesian capital proposed move from Java to Kalimantan, and the need for local agriculture to support the anticipated population growth in the region. This scenario was suggested by Rajawali Nusantara Indonesia (RNI) and the Indonesian Sugar Association, and based on companies moving sugar out of Java to meet growing demand in other islands (Sulaiman et al. 2019), totalling about 80,000 ha or 20 % of Indonesia's sugar production. To support this scenario, five new large sugar companies were located near the hypothetical farms in Kalimantan. Raw sugar from these mills was modelled to supply populations in Kalimantan and islands to the east of Java.

Fig. 10 shows the volumes of sugarcane freight along the road and coastal shipping network across Indonesia, incorporating the hypothetical farms and new mills in Kalimantan. Fig. 11 shows the change in these movements from the baseline, highlighting where transport increases (red) or decreases (green). These freight movements are as expected. Compared to the baseline, there were significant reductions in raw sugar movements from Java to other islands on most routes, which reduced freight volumes along some of the most congested routes. There was also less freight on the congested road network between Jakarta and Surabaya.

6. Implementation - Vietnam

The potential case studies initially identified were:

- Maize and cassava supply chains in the north supplying feed mills and other uses, including cross-border trade;
- Possible road access improvements and market access for Northwest Highlands supply chains;
- Impact of major infrastructure investments (e.g. toll roads, intermodal hubs, Cau Lang bridge);
- Limitations to commodity export supply chains (e.g. rice, tea, coffee, fish and prawns) and potential exports (dragonfruit, mango) due to lack of warehousing and port facilities; and
- Opportunities relating to regional movements of live cattle from Australia.

Based on data availability and discussions with stakeholders, we focused on national maize and cassava supply chains and the key crops for Son La Province (Northwest Highlands). Cassava is an important crop in Vietnam – being an important source of local food, feed for livestock and source of cash income. Maize is an important food crop in Vietnam (most important staple after rice) and is also the primary feed source for the domestic poultry and livestock industry. Across Son La Province, maize, cassava, coffee and sugarcane were chosen as the target crops for analysis, as they produce the largest tonnages of total farm

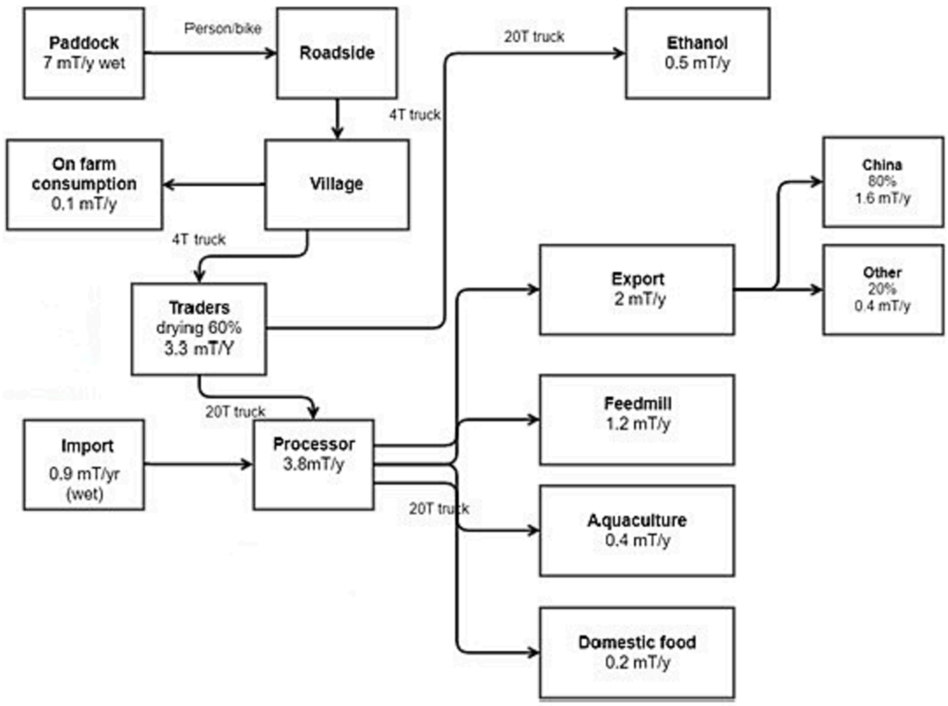

Fig. 12. Diagram of the cassava supply chain in Vietnam.

output and transported volumes in the province. Here, we present results from the national cassava baseline and a scenario analysing changed costs and freight movements due to development of the proposed Hoa Binh to Moc Chau Expressway in Northwest Vietnam.

6.1. Cassava

With exports (mainly to China) valued at over US$1 billon per annum, cassava production is dominated by poor smallholder farmers, often living in remote areas. Vietnam also imports large volumes of cassava from Cambodia for processing in the south. With volatile markets and prices, this makes cassava a dynamic and important crop. Sourcing cassava is also heavily dependent on price and the efficiency of collecting, transporting and aggregating fresh roots from remote smallholder farmers to supply starch factories.

The main purpose of our work in Vietnam was to demonstrate that TraNSIT could be used to describe and analyse commodity product flows and transport at national and province levels, also incorporating import and export trade flows. Production data for 2018 was sourced from the Vietnam General Statistics Office (GSO) for national scale province-level data, and from the provinces' agricultural production yearbooks for finer-resolution district-level data. Farm number and locations were determined from yield data also provided by the GSO/MARD, with production locations refined through application of the European Space Agency's landcover dataset ('cropping' class) to separate cropping from non-cropping land across the country. The location of all cassava processing factories was sourced from the International Center for Tropical Agriculture (CIAT).

The cassava national baseline modelled 7 million tonnes of annual production across 9901 production locations and 0.9 million tonnes of imported cassava chips (from Cambodia via the Xa Mat border gate north-west of Ho Chi Minh City). Once harvested, cassava is transported to district traders and then to one of the 45 major starch factories located in the country. The majority is then transported via coastal shipping from Ho Chi Minh and Da Nang ports to Hai Phong Port. From Hai Phong, the majority is exported to China via the Mong Cai or Tan Thanh border gates in northern Vietnam. About 1.2 million tonnes/year is also used for stockfeed production. An overview of the cassava supply chain is shown in Fig. 12, which includes the export and domestic processing stages.

Fig. 13 shows the average annual production volumes (tonnes) of cassava across the provinces in Vietnam, which was used to derive the production locations. Fig. 13 also shows the location and capacity of the 105 starch factories that are used to process cassava, and 391 feedmills which, along with three key export ports, are the major final destination enterprises. Average vehicle payload is 4 tonnes from farm to processor and 20 tonnes to port/feedmill.

A total of 11,888 supply chain paths were defined in setting up the cassava baseline for modelling in TraNSIT. Application of TraNSIT to the baseline determined that the total annual cost of transport for cassava across Vietnam was US$94 million (2.1 trillion Vietnam Dong), with total transport cost and cost per tonne being the highest for the 'property to trader' supply chain leg. Cost and transport metrics per supply chain leg are provided in Table 6.

Fig. 14 shows the resulting vehicle density from TraNSIT across the road network for the whole domestic cassava supply chain - between farms, processing and port enterprises for domestic port transfer, and from Hai Phong Port to the land border gates with China. It highlights the increased traffic volumes on major roads throughout the country, particularly to the north of country, from Hai Phong Port to border gates with China. Fig. 15 separates out the different supply chain legs, highlighting the different networks and densities of roads used for each.

Colours grade from light blue (light vehicle density) through dark blue to pink (heavy vehicle density).

Vehicle density is annual trailers, 4-tonne equivalent for farm to trader, 20-tonne equivalent from trader to processor and processor to domestic port. Line thickness equates to vehicle density.

6.2. Scenario – Implementing Hoa Binh to Moc Chau expressway

In May 2019, the Prime Minister approved the Hoa Binh to Moc Chau expressway. The proposed investment for the new 85 km route was expected to cost more than VND 22,000 billion, and to improve road connectivity between the economic and political centres of Hanoi with

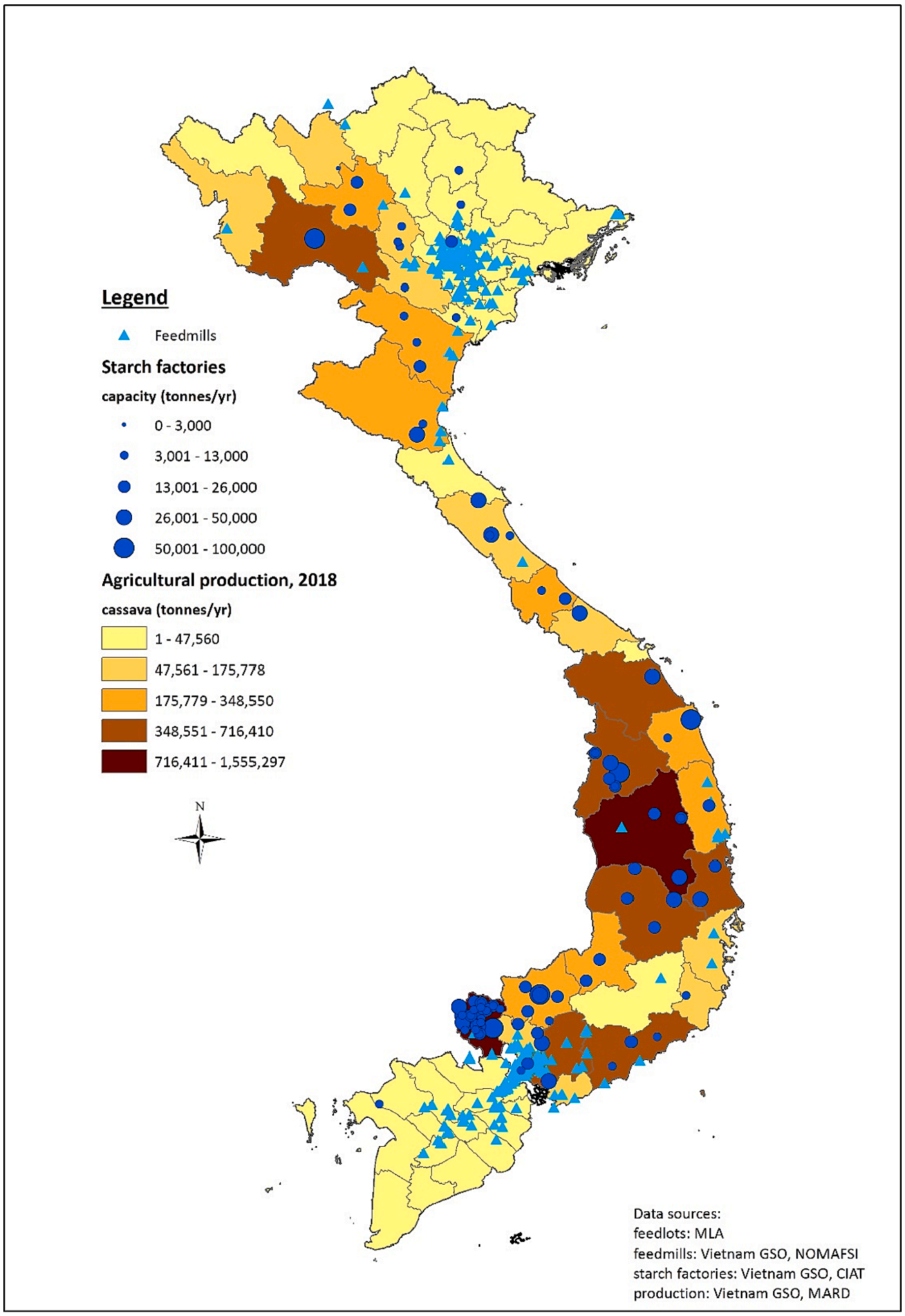

Fig. 13. Average production volumes of cassava (tonnes/yr) by province, feedmills and starch factories, Vietnam.

Table 6
Costs and transport metrics for the national cassava supply chain, Vietnam.

ORIGIN	DESTINATION	TOTAL TRANSPORT COST (MILLION VND, (MILLION US $))	COST/TONNE (VND, (US$))	TRAILERS	TONNES	TONNES/ TRUCK	AVERAGE TRIP DURATION (HRS)	AVERAGE DISTANCE (KM)
Property	Trader	1,358,051 (60.0)	196,881 (9)	1,724,800	6,899,200	4	0.54	23
Trader	Factory	482,649 (21.3)	149,358 (7)	323,000	3,230,000	10	1.85	114
Import border	Factory	14,995 (0.7)	32,587 (1)	23,075	461,500	20	0.77	31
Internal port	Export port	101,380 (4.5)	84,636 (4)	59,899	1,197,980	20	2.49	186
Factory	Export port	172,278 (7.6)	129,217 (6)	66,604	1,332,080	20	4.17	296

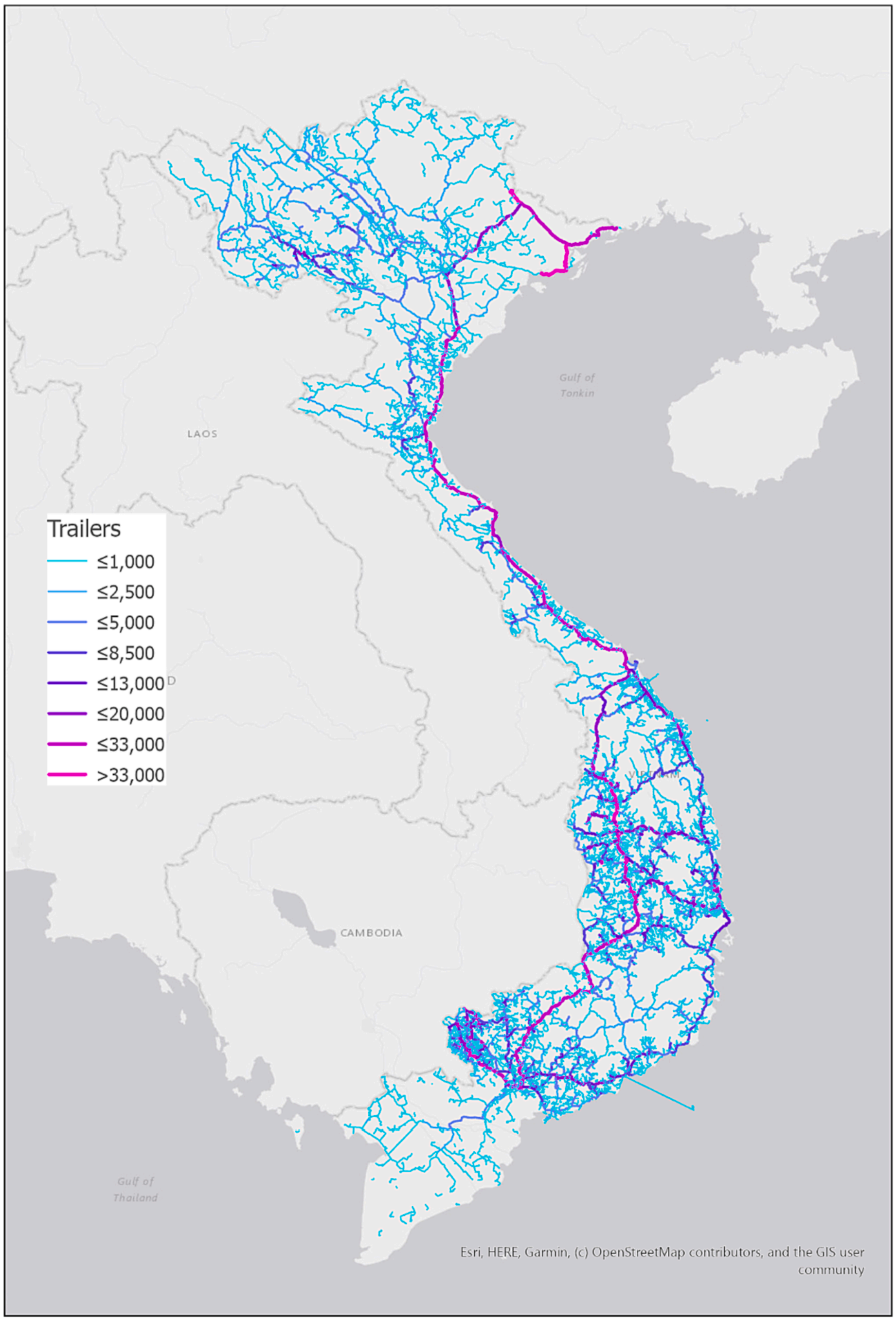

Fig. 14. Vehicle density (20 tonne equivalent, annual trailers) for transport of cassava across Vietnam, from farms to traders, processors, domestic and Hai Phong ports (road transport only).

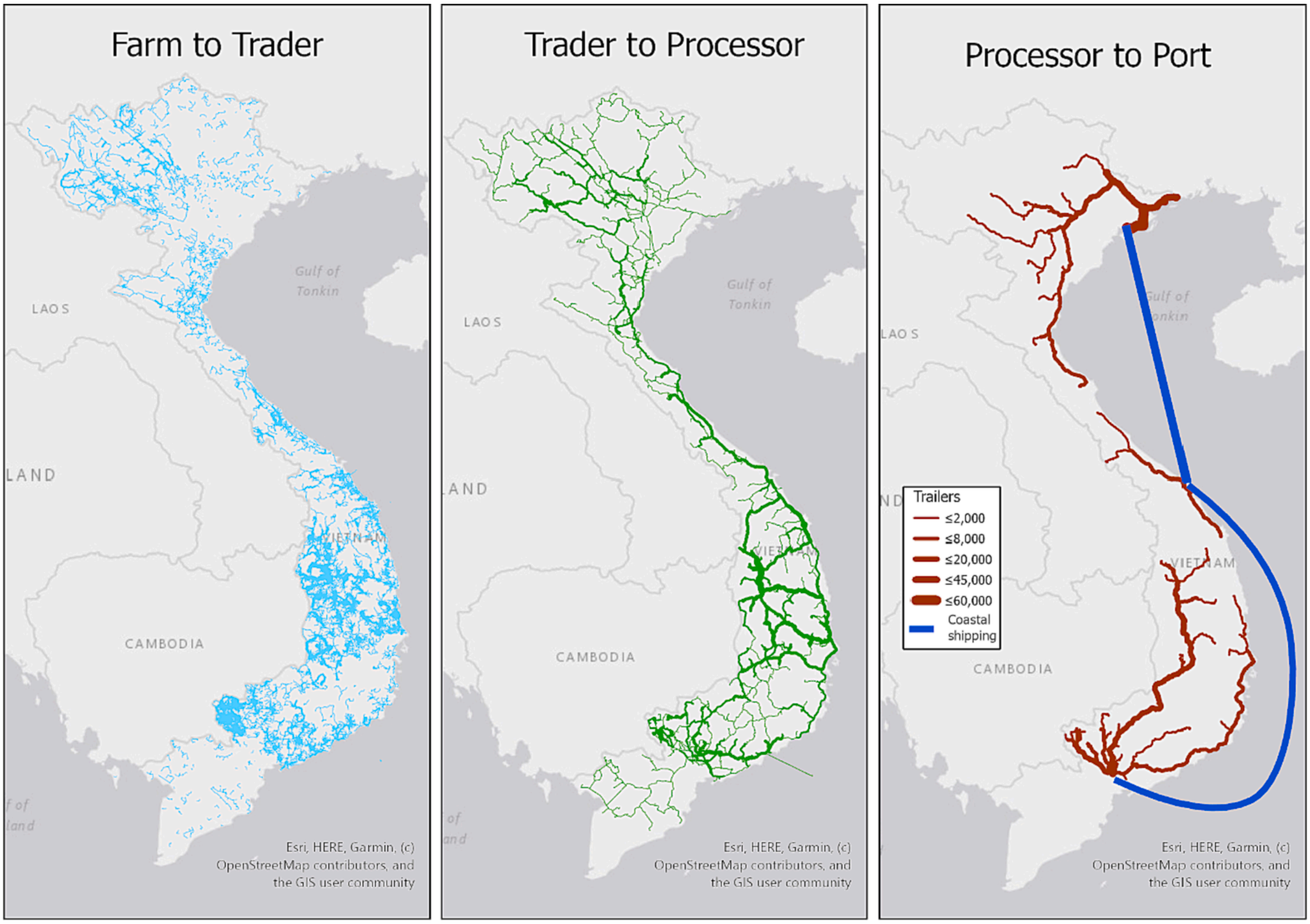

Fig. 15. Vehicle density (annual trailers) for transport of cassava across Vietnam, from a) famers to traders b) traders to processors (starch factories); and c) processors (starch factories) to land and coastal ports (brown lines) and coast ports to Hai Phong Port (blue lines) via coastal shipping.

Fig. 16. Proposed route for new 85 km Hoa Binh – Moc Chau expressway expected to be completed in 2024. Source: VN Express1.

Son La, and other north-western provinces.

The prospect of the new expressway raises important questions for local provincial and district investors and planners, transport and logistics companies and agricultural product traders in Son La.

- What is the likely impact of the new expressway on agricultural freight and transport costs and times between Son La and Hanoi? Which districts stand to gain the most/least?
- How will the new expressway impact transport costs and market connectivity for different agricultural sectors such as maize, cassava, sugarcane, coffee, vegetables?
- Who will benefit the most from the expressway i.e. Son La farmers, traders, or processors?
- How will the expressway affect the use of other routes in the local network?

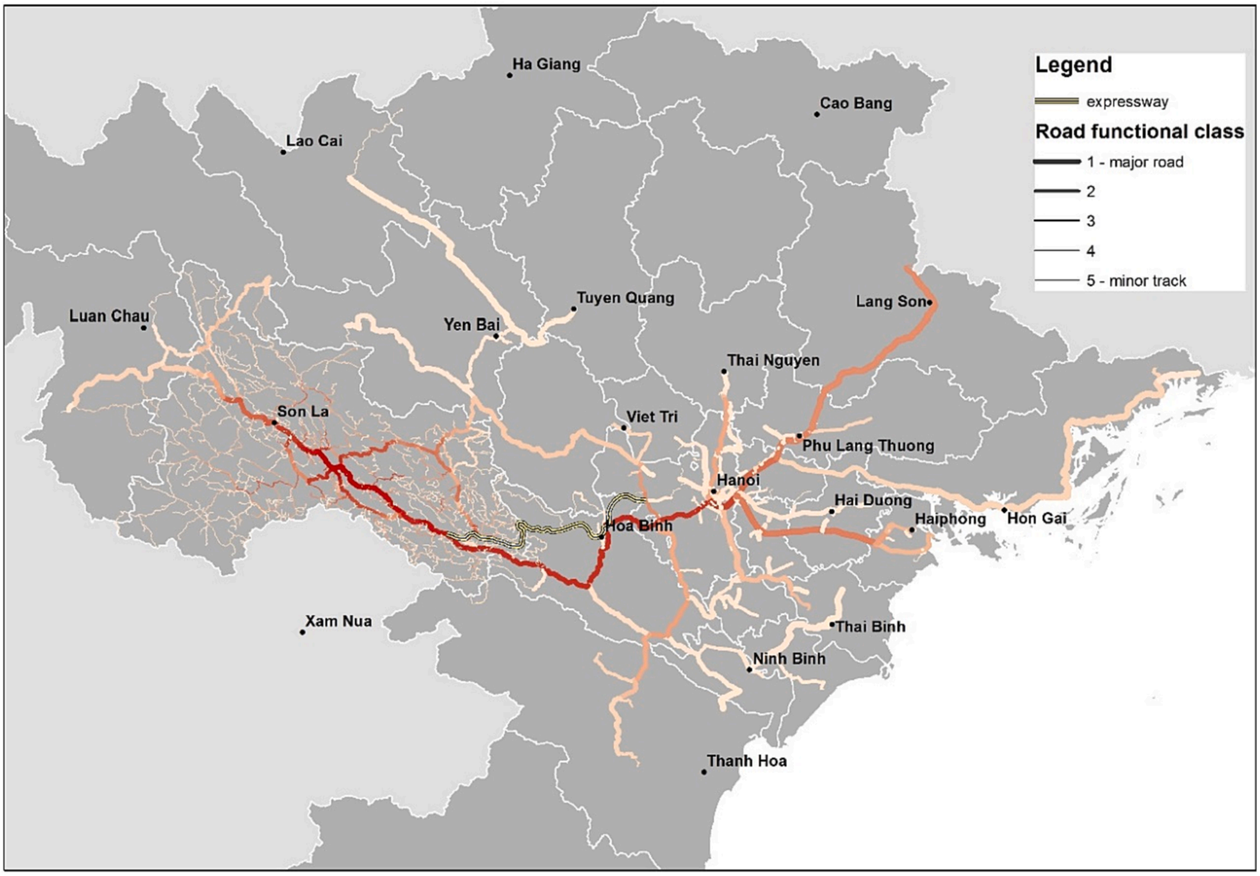

Fig. 17. Current road usage for all mapped commodities (cassava, maize, sugar, coffee) with production in Son La Province, and approximate location of proposed Hoa Binh to Moc Chau expressway. Note: line colour shows density of usage for different road classes: light usage (pale pink) -> heavier usage (dark red); line thickness shows road type: major roads (thick) -> minor roads (thin).

TraNSIT was used to explore these questions, particularly how the new proposed expressway would impact on agricultural transport flows and costs compared to the current main road - the National Highway 6 corridor. The expressway scenario was based on the original route proposed in 2018, which traverses Da Bac District in Hoa Binh Province (Fig. 16). The scenario assumed the new expressway would allow average truck speeds of 100 km/hr on the flats and 80 km/hr in the hills.

The current density of usage (baseline) modelled in TraNSIT for the different road classes is shown in Fig. 17. The map also shows the approximate location of the proposed expressway. Density of usage is the intensity of truck use for the combined tonnage of cassava, sugar, maize, and coffee produced in and transported from Son La to various market destinations.

The modelled change in road usage after development of the expressway is shown in Fig. 18, highlighting areas of increased (red) and decreased (green) freight. Under the modelled assumptions, up to 400,000 tonnes of road freight would be transferred from National Highway 6 to the new expressway between Moc Chau and Hoa Binh.[1] The expressway may result in only relatively small changes in freight and truck density along most feeder roads in the province. However, a small number of specific provincial and district feeder road segments may carry significantly higher or lower freight densities under the new configuration, even though they are many kilometres from the start/end of the new expressway.

Total annual transport costs were also calculated for the baseline and expressway scenario (Table 7). Reduction in total transport cost between farms, traders, factories, and destination market segments resulting from the expressway ranged between US$110,000–300,000. Traders may receive the greatest absolute transport cost reduction (US$300,000) from the expressway. However, processors would stand to benefit the most in relative terms, with a 10 % reduction in transport costs from factories.

Of the four agricultural commodities, total transport costs associated with cassava and maize supply chains were reduced most in absolute terms (US$220,000–270,000). The relative transport cost savings are quite modest, ranging between 3 and 4 % for all four crops.

The cost of transporting cassava starch and chips, processed sugar and coffee from the processing factories located around Son La city and Mai Son to destination markets would be reduced by around 13–18 % by the new expressway.

The predicted reductions in per trip transport time, cost and length resulting from the Hoa Binh – Moc Chau expressway for different route sections are shown in Table 8. The new expressway would save about 2½ hours of travel time for all sections, which translates to a total transport cost and distance saving of between 8 and 45 % and US$56 – US$87, depending on the road section. Not surprisingly, transport and freight movements between Moc Chau and the Hoa Lac interchange will benefit most in terms of overall time, cost and distance savings, as they are closest to the new and upgraded expressway sections.

[1] Expressway scenarios did not include the additional cost of tolls, which may impact overall cost savings and route selection. It would be possible to examine the overall impact of toll cost scenarios in TraNSIT.

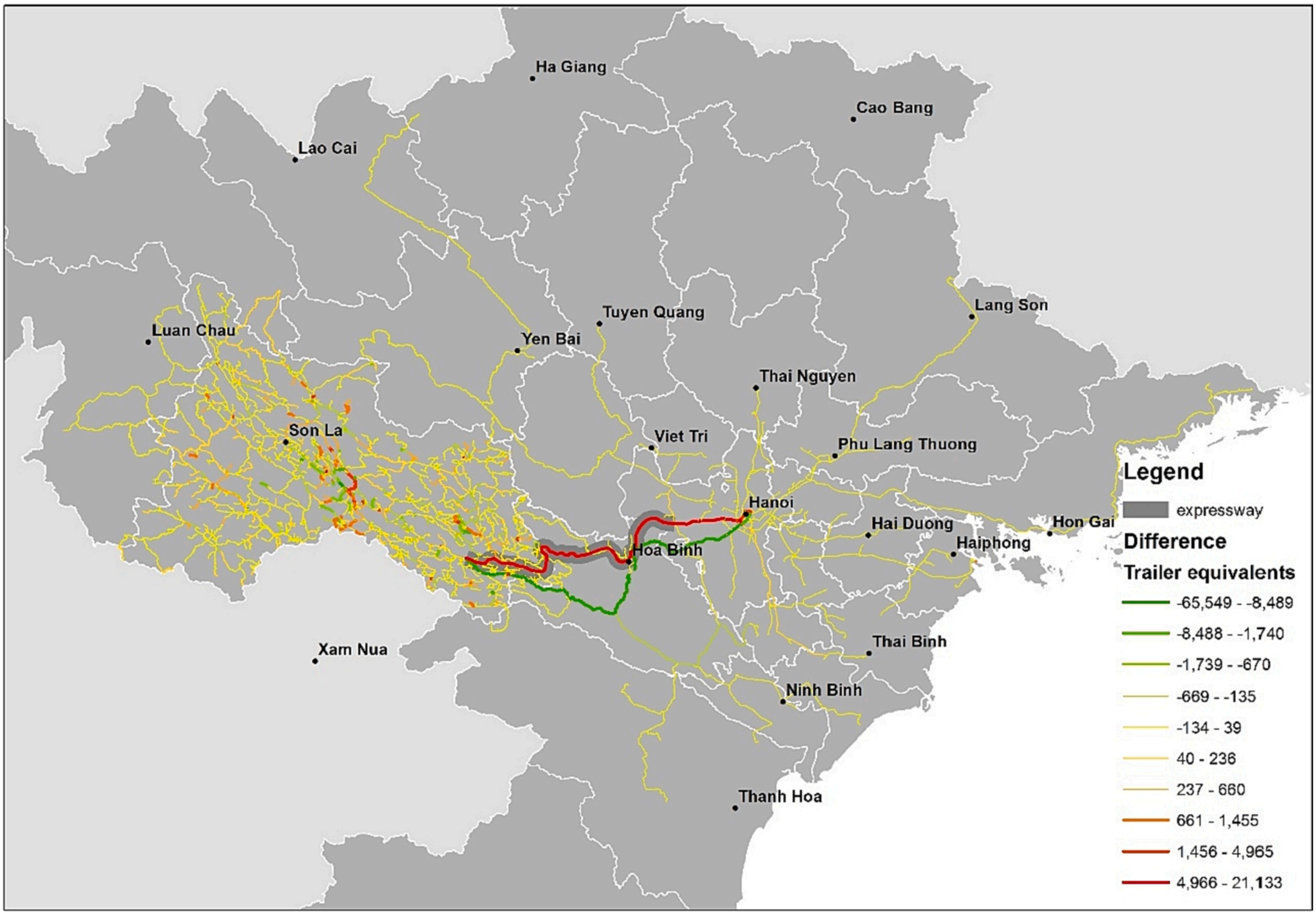

Fig. 18. Difference in road usage for all mapped commodities (cassava, maize, sugar, coffee) with production in Son La Province after completion of Hoa Binh to Moc Chau expressway, and approximate location of proposed expressway.

Table 7
Annual costs through use of the Hoa Binh to Moc Chau expressway compared to the baseline.

	BASELINE (MILLION VND, (MILLION US$))	EXPRESSWAY (MILLION VND, (MILLION US$))	DIFFERENCE
All	405,985 (17.65)	391,730 (17.03)	4 %
Sector			
Farm	251,298 (10.93)	248,902 (10.82)	1 %
Trader	106,444 (4.63)	99,573 (4.33)	6 %
Factory	48,242 (2.10)	43,255 (1.88)	10 %
Commodity			
Cassava	157,074 (6.83)	152,040 (6.61)	37 %
Coffee	7,168 (0.31)	6,937 (0.30)	3 %
Maize	151,590 (6.59)	145,263 (6.32)	4 %
Sugar	90,153 (3.92)	87,490 (3.80)	3 %
Costs by commodity from processing factory			
Cassava	24,732 (1.08)	21,521 (0.94)	13 %
Coffee	2,144 (0.09)	1,871 (0.08)	13 %
Maize	12,976 (0.56)	13,021 (0.57)	10 %
Sugar	8,391 (0.36)	6,842 (0.30)	18 %

7. Summary

This current study demonstrated how the TraNSIT tool can be applied to complex, real-life transport investment and planning scenarios in Indonesia and Vietnam. These applications can directly support public and private sector institutions and planners to better analyse problems, evaluate options and allocate resources in ways that reduce transport and logistics costs, and improve connectivity for agricultural value chains, smallholder farmers and rural communities.

While technically feasible, major institutional complexities, capability gaps and resourcing challenges complicate the adoption and integration of TraNSIT and broader spatial analytic approaches. These barriers must be addressed for these tools and approaches to be realistically integrated into an operational analytical and institutional systems capable of translating outputs to impacts. We proposed recommendations and solution options to address institutional capability gaps, hardware and software gaps and resourcing, and cross-institutional collaboration challenges that currently hinder the adoption of TraNSIT technology outputs in Vietnam and Indonesia. The implementation of innovation models and platforms that promote multi-stakeholder and multi-institutional collaboration in a digital data and spatial analytics hub or cooperative research centre, with a focus on transportation and connectivity, could be one important next step.

CRediT authorship contribution statement

Andrew Higgins: Methodology, Formal analysis, Investigation. **Caroline Bruce:** Methodology, Formal analysis. **Stephen McFallan:** Methodology, Formal analysis, Investigation. **Chris Chilcott:** Conceptualization, Investigation. **Adam McKeown:** Methodology, Formal analysis. **Liana Williams:** . **John Ackerman:** Supervision. **Dian Yuanita Wulandari:** Data curation. **Rodd Dyer:** Supervision, Investigation. **Nga Le:** Data curation.

Table 8
Change in per trip transport time, cost and length resulting from the Hoa Binh to Moc Chau expressway compared to the baseline, for different sections of the expressway.

	BASELINE			EXPRESSWAY			DIFFERENCE (%)		
EXPRESSWAY SECTION	TIME (HRS)	COST (VND (US$))	LENGTH (KM)	TIME (HRS)	COST (VND (US$))	LENGTH (KM)	TIME	COST	LENGTH
Son La – Hoa Binh	7.89	8,166,610 (355.36)	307.44	5.17	6,661,260 (289.62)	282.33	35 %	18 %	8 %
Moc Chau – Hoa Binh	3.20	3,307,170 (143.91)	124.42	1.32	2,003,300 (87.10)	100.39	59 %	39 %	19 %
Moc Chau – Hoa Lac Interchange	4.20	4,511,450 (196.31)	167.29	1.52	2,497,570 (108.59)	127.68	64 %	45 %	24 %
Moc Chau – Hanoi	5.13	5,283,330 (229.89)	194.36	2.39	3,739,340 (162.58)	168.81	53 %	29 %	13 %

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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