Chapter 3

Measuring Cross-border Connectivity with Vehicles' Probe Data

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Abstract: Flow data is essential to quantification of connectivity among regions. The problem is trade flow, that is commonly available at the national level, much less compiled and rarely published. This Chapter demonstrates how to compile cross-border regional flow statistics from vehicles' probe data, i.e., high-frequency geographical coordinates of their location. Although problems such as handling of error stemming from unstable GPS receiving environment and difficulty of big data processing persists, this chapter shows that it can produce various measures related to inter-regional flow by cities from 4 slots of 48 hours periods of commercial Thailand's commercial vehicles' probe data that crossed the land border to neighboring countries.

Keywords: Urban, Connectivity, Probe data
JEL Classification: O18, C55, C80

1. Introduction

Connectivity within a country is often measured with transport infrastructure such as roads (See for example Axhausen et al., 2008; Patarasuk and Binford, 2012; Weiss et al., 2018). I contend that measuring connectivity without flow data risk confusing of a necessity with the sufficient conditions. On the one hand, cross-border connectivity has been quantified using trade policy, international trade flow or different variants and combinations of both (for example Leamer, 1988; Edwards, 1997). Trade policy is a form of soft infrastructure for international trade. International trade data enables construction of connectivity measures that take into account flow. Nonetheless, obtaining similar data required by this methodology to connectivity on city-scale is extremely difficult, because domestic trade is generally undocumented. The purpose of this chapter is to demonstrate how to quantify cross-border connectivity among cities using vehicles' probe data. The rest of this chapter is structured as follows. Section two describes summaries vehicles' probe data obtained for analysis in this chapter. Section three demonstrates how to derive various inter-regional flow indicators from probe data.

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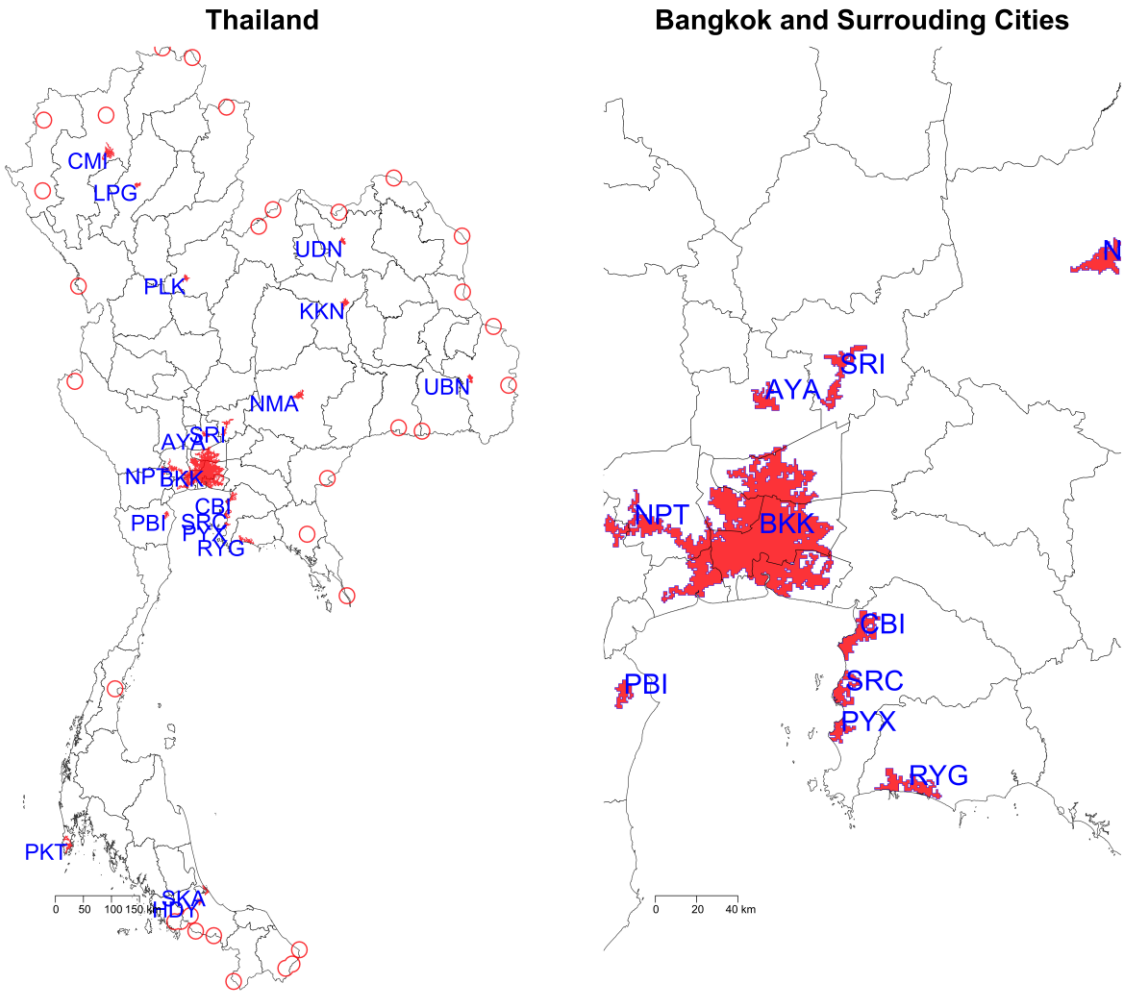
Section four concludes with policy implications

2. Vehicles' Probe Data

For demonstration purpose, 4 sets of consecutive 48 hours starting at 17:00 pm local time in Thailand of March the 4th and September the 12th 2017, and March the 3rd and September the 11th of 2018 of commercial vehicles' probe data has been obtained from a location data vending arm of a major transnational car manufacturer in Thailand. The commercial vehicles include mostly trucks and taxis. It is safe to assume that most vehicles crossing the border are trucks. Therefore vehicle and truck are used interchangeably in this chapter.

Figure 1. Top 19 Remotely-Sensed Cities and Border Areas in Thailand



Source: City boundaries (red) is based on Keola (2018). Border area boundaries (blue) is a 10 kilometers buffer from the location of nearest custom houses. The administrative boundary is based on GADM.
Note: AYA: Ayutthaya, BKK: Bangkok, CBI: Chonburi, CMI: Chiang Mai, HDY: Hat Yai, KKN: Khon Kaen, LPG: Lampang, NMA: Nakhon Ratchasima, NPT: Nakhon Pathom, PBI: Phetchaburi, PKT: Phuket, PLK: Phitsanulok, PYX: Pattaya, RYG: Rayong, SKA: Songkhla, SRC: Sriracha, SRI: Saraburi,

UBN: Ubon Ratchathani, UDN: Udon Thani.

The probe data obtained for this study contains the following data.

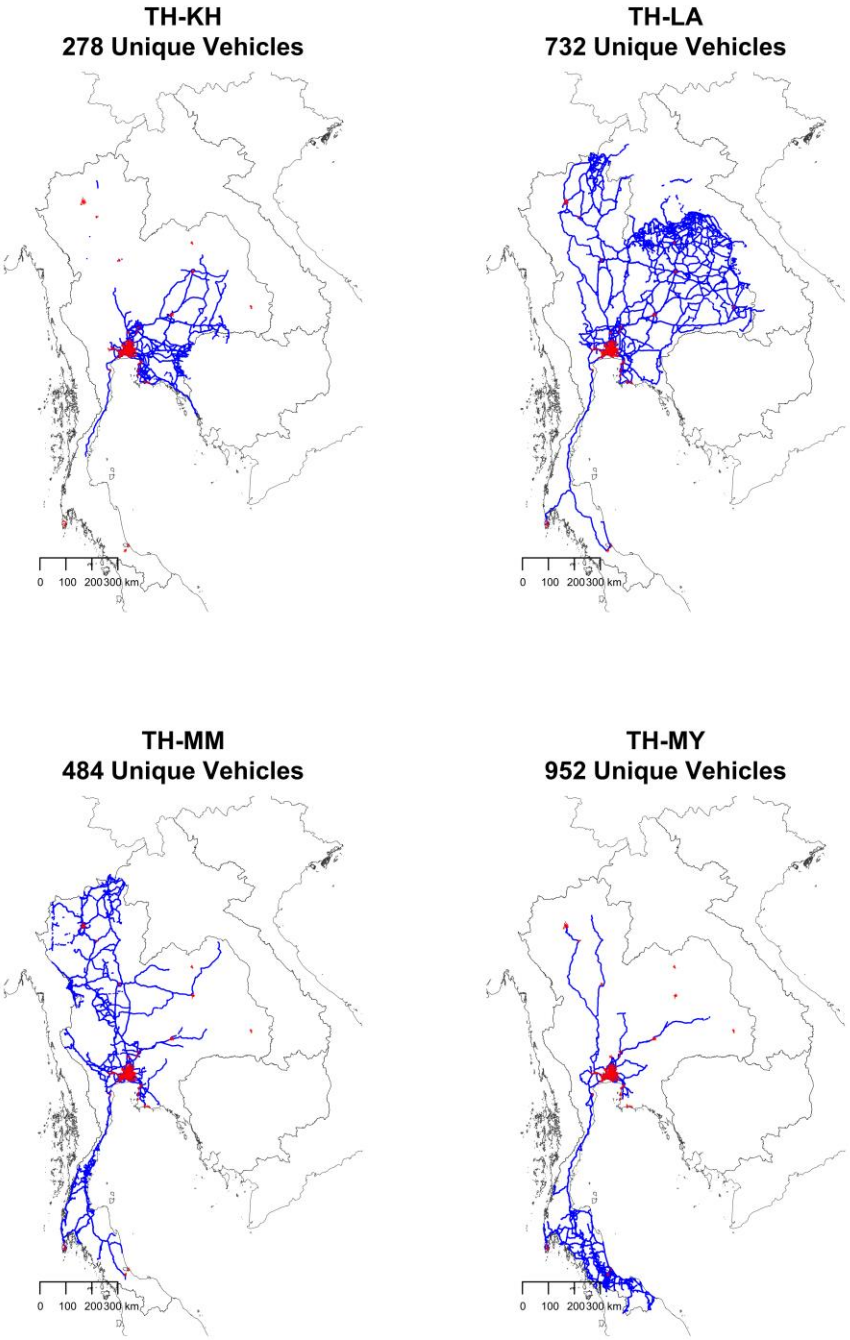
imei: international mobile equipment identity
lat: latitude
lng: longitude
speed: kilometers per hour
direction: from 0 to 360 degree
error: from 0 to 1000
acc: engine status
meter: meter status for taxi
ts: timestamp in second from January 1st, 1970
datasource: code of data provider

Only probe data of vehicles appearing in two or more pre-defined city boundaries, or at least once in border areas as illustrated in Figure 1, were included in the data set. In order to avoid Modifiable Areal Unit Problem (MAUP), arising from the pre-defined subjective and ambiguous spatial unit of analysis, boundaries of cities in Thailand are generated following Keola (2018). The boundaries of top 19 cities in Thailand are defined by continuing area with consistent density thresholds of population and infrastructure density represented by two remote sensing data sets, i.e., LandScan and DMSP-OLS (Defence Meteorological Satellite Program Operational Linescan System) nighttime light. The thresholds of population and infrastructure density for urbanness is 200 or more people, and 40 or more nighttime light intensity per square kilometers. The differences between these remotely-sensed cities and administrative boundaries in Thailand are as follows. Even though Bangkok remains the largest cities by area in Thailand, the remotely-defined boundary is larger than the administratively defined area. The remotely-sensed Bangkok extends beyond adjacent provinces in the North, East, and South but left out some Northeastern area of its own. On the contrary, the boundary of Chiang Mai, the second largest city is much smaller than the boundary of its first-level (province) administrative boundary. This statement holds for the boundaries of all other cities derived according to the thresholds mentioned above. In other words, for most cities or urban areas administratively defined in Thailand, the physical aspects remotely-sensed by satellite is quite different from Bangkok. Furthermore, the area of Bangkok is vast when compared to the rest of the cities in Thailand. The area of Bangkok is about 3,411 km^2, while it is 310 km^2 for Chiang Mai, or 243 km^2 Nakhon Pathom. However, I argue that this reflects rightly the polycentric urbanization in Thailand. Unless otherwise stated, the area names in this chapter refer to the boundaries generated by the density of remotely-sensed population and Nighttime light.

The following cleaning is first applied. Speed is computed for each data points based on positions and time stamp of previous data points. This is especially important for GPS-based probe data because the accuracy of reported location vary due to many factors affecting the strength of receding satellite signal. In fact, many locations in other continents are observed, which resulted in unrealistic enormous speed. Data points with speed higher than 120 km/h are then excluded. This threshold is selected based on the

fact that it is quite difficult for most trucks to travel beyond this speed in Thailand. It may be easier for taxis travel faster, but that would violate a traffic law, and thus sensible to exclude them when evaluating intra- or inter-urban connectivity. Many of data points with unrealistic location information are removed through the above cleaning process.

Figure 2. Traces of Thailand's Trucks Crossing into Neighboring Countries



Source: Author based on probe data. The administrative boundary is based on GADM.

Note: KH: Cambodia, LA: Laos, MM: Myanmar, MY: Malaysia.

Next only vehicles that appeared in neighboring Cambodia, Laos, Myanmar and/or Malaysia are extracted. The traces of these vehicles combined from all four periods are shown in Figure 2. In total, 278, 732, 484, and 952 vehicles were observed in Cambodia, Laos, Myanmar, and Malaysia. Since the total number is computed by unique imei, or the ID of GPS device mounted on the vehicles for all four sampled periods of 48 hours, it would underestimate the real total figure if the same vehicle cross border more than once.

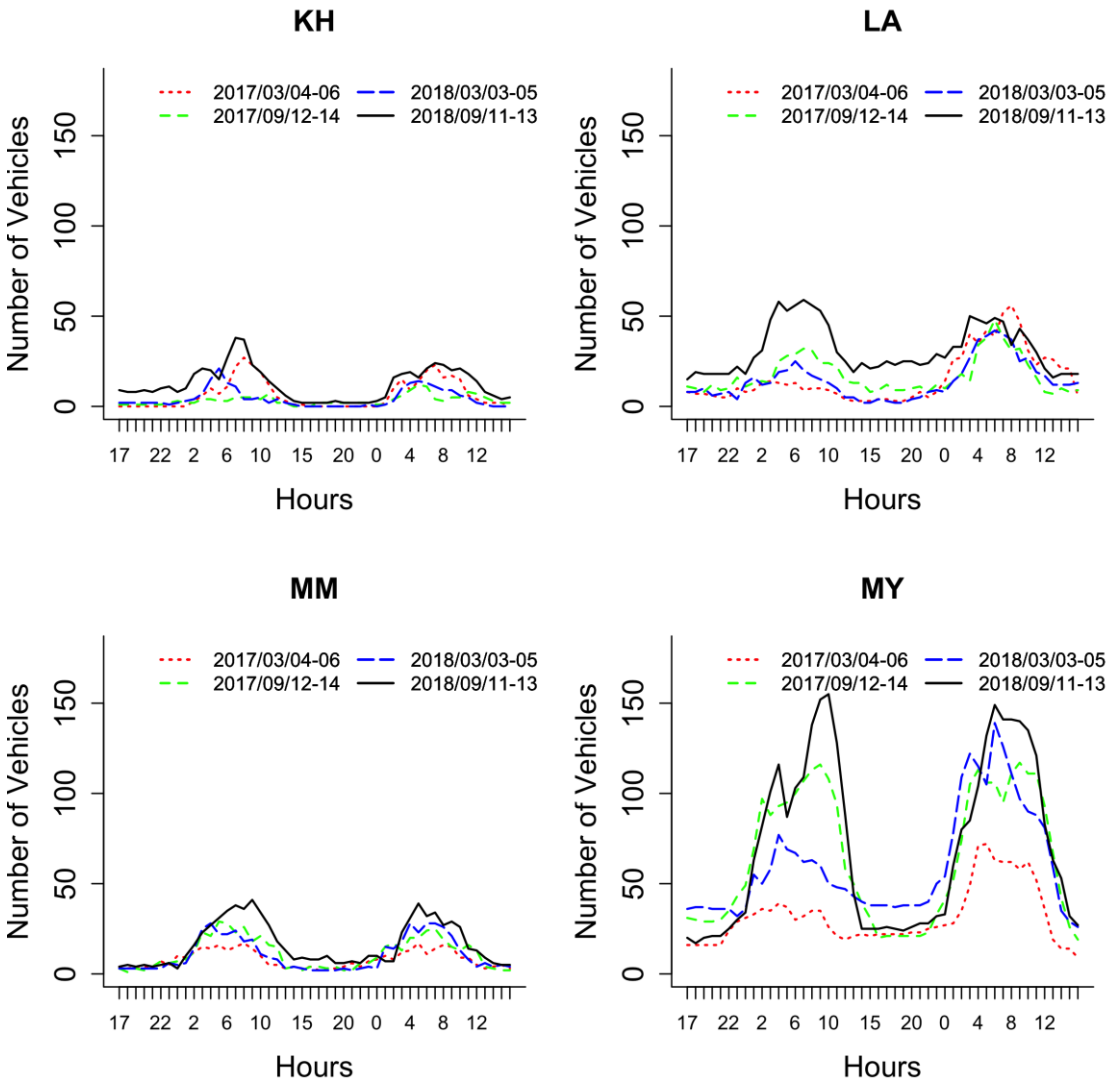
The vehicles that appeared in neighboring countries illustrate distinct different spatial characteristics. The vehicles that were observed in Cambodia come mainly from/through Bangkok and lower North-eastern region of Thailand. The vehicles observed in Laos come from/through almost all region, except Western Thailand. The vehicles that crossed to Myanmar come mainly from/through Western and Southernmost of Thailand. However, traces stretching to some Northern and central Laos were also observed. The traces of the vehicles that appeared in Malaysia are different from those observed in Cambodia, Laos, and Myanmar in a way that they were only seen along major national roads connecting major cities in Thailand. Besides, the extent of the traces of Thailand's vehicles in Myanmar and Malaysia are minimal. This shows that most of these vehicles probably crossed to deliver or pick up goods in designated areas near the border crossings. The traces went a little bit deeper into Cambodia's territory, but not much further border areas. On the contrary, traces of Thailand's trucks were observed deep into Laos' territory, especially in the North and central regions. Some traces revealed that these vehicles crossed into Laos in Southern Laos before traveling up to central Laos for hundreds of kilometers.

The different spatial distribution of traces that crossed into different neighboring countries may arise from various reasons. For instance, they may capture the logistic efforts to minimize traveled distance by arranging trucks for regions in Thailand that are closer to destinations across the border. Alternatively, they may capture a logistic arrangement to minimize extra costs arising from insufficient cargo. The traces of trucks seen in non-major roads all over the North and Northeastern Thailand before crossing into Laos may reflect the relatively small demand on the other side. In addition, they may also capture the complementarity among regions in Thailand and neighboring countries. The fact that many trucks come from Bangkok confirms the polycentric urbanization/industrialization in Thailand, but also at the same time reflect the similarity of industrial structure of Thailand's provincial economies and neighboring regions across the border. For example, logistics with Malaysia may be more direct travel between major urban areas in both countries.

Figure 3 illustrates the number of Thailand's trucks detected in neighboring countries by the time of the day, and for each period from obtained probe data. The largest number of Thailand's trucks cross into Malaysia when compared to the rest of the neighboring countries. This is to be expected given the state of economic development of Malaysia in ASEAN. Malaysia is the only country having higher per capita GDP than Thailand among countries adjacent to it. It is somehow unexpected to see Laos in the second spot as the size of Laos' economy is not only smaller than Myanmar but also Cambodia. Nonetheless, the bilateral agreements on cross-border transport that allow more foreign trucks into Laos undoubtedly contribute to this.

Whereas variation among different periods exists, a clear pattern can be observed. The number of trucks increases from late afternoon daily. Variation of the number of vehicles detected can be affected by many factors. Some GPS loggers may require the engine to be turn on to acquire and transmit location data. However, some do function regardless of the status of the engine. Mobile phone signal may also affect these devices to transmit their location data to the server. So the increase of the number of trucks detected in neighboring countries may reflect the time most trucks cross the border, but can also be influenced by the timing more trucks resume transiting location data, etc. More field surveys would be necessary to identify the real reasons behind this periodic fluctuation of the number of trucks in neighboring countries.

Figure 3. Hourly Number of Thailand's Trucks in Neighboring Countries

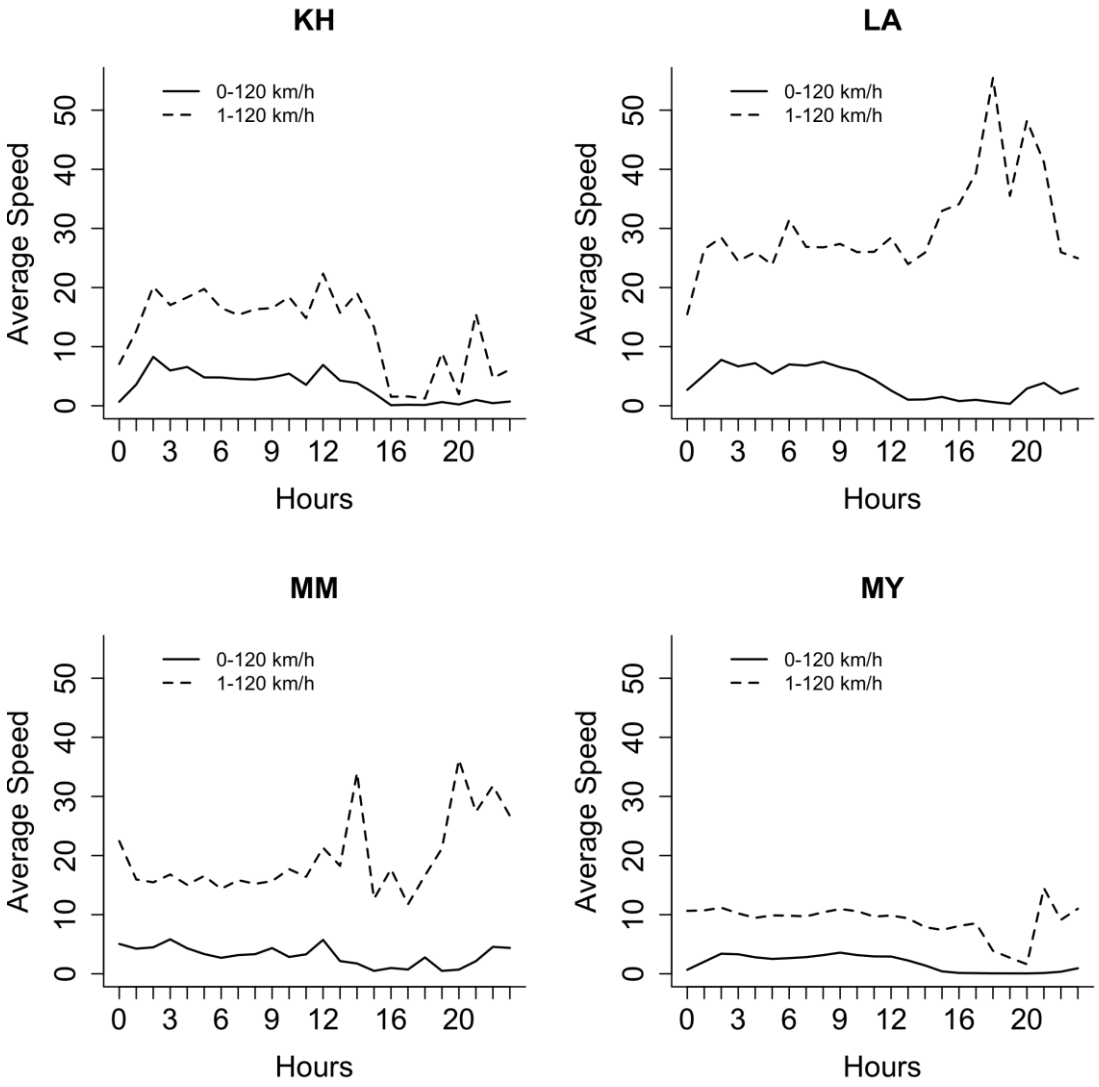


Source: Author based on probe data.
Note: KH: Cambodia, LA: Laos, MM: Myanmar, MY: Malaysia.

Figure 4 shows the hourly average speed of Thailand trucks by countries that they

report location data. This is the hourly average across all four periods of 48 hours of each. Since the speed shown in Figure 4 is derived from location data, and not the speed reported by GPS devices, both average including positive speed less than 1km/h and from1km/h and above are drawn. This is to make sure the later include only trucks that are actually moving. Not much can be said from said from this figure. The only robust observation from Figure 4 is the average speed of moving trucks with speed from 1 km/h in Laos is significantly higher than the rest.

Figure 4. Hourly Average Speed of Thailand's Trucks in Neighboring Countries



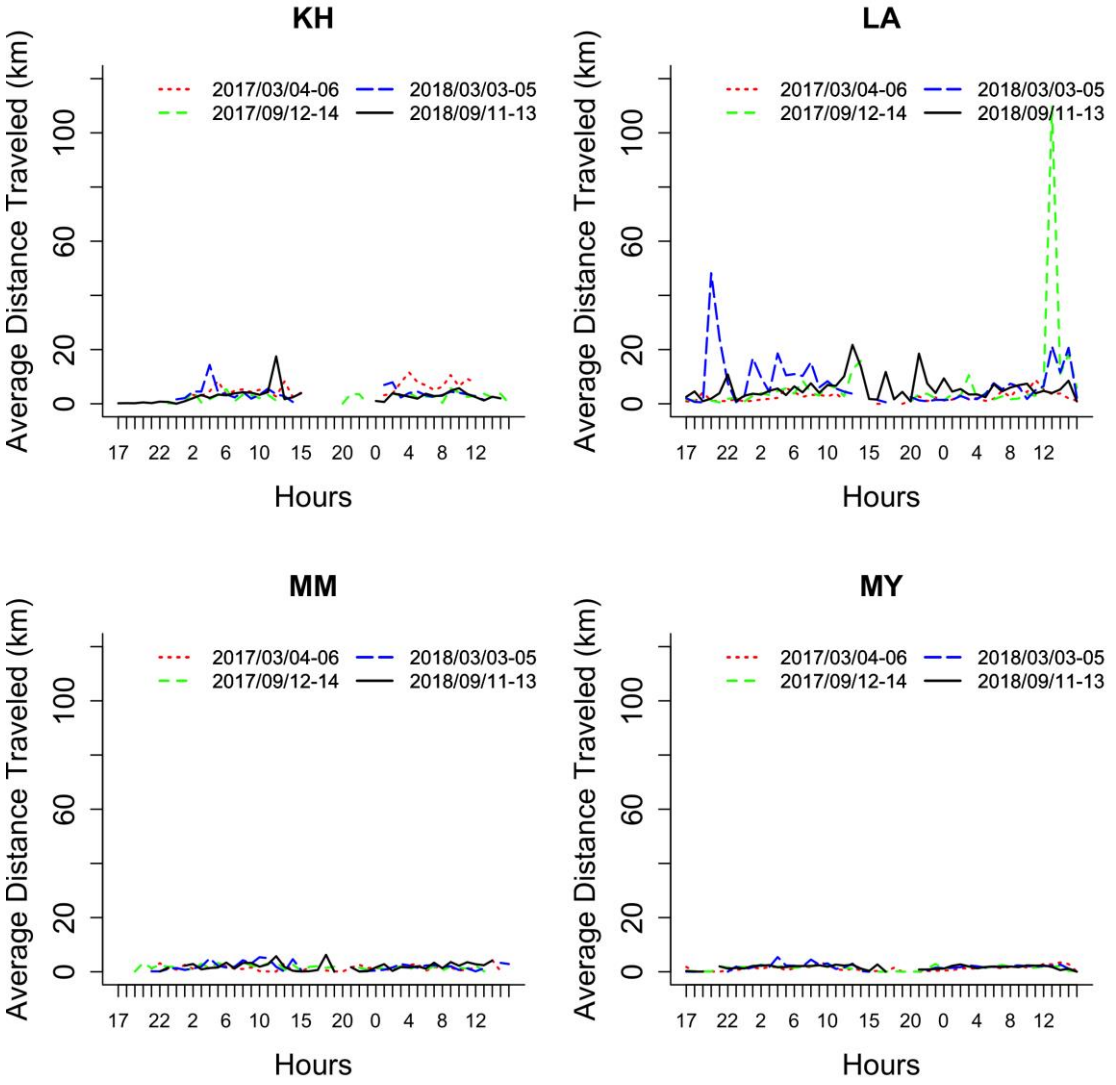
Source: Author based on probe data.

Next Figure 5 illustrates total distance traveled by Thailand's trucks in neighboring countries by the time of the day. The distance traveled by Thailand's trucks in Myanmar is comparatively small when compared to the rest. This may be a result of the fact that Thailand's trucks are only allowed into designated free zones near the border crossing in Myanmar. Total distance traveled is longer in Cambodia than in Myanmar, but the

difference is not that large. On the contrary, total distance traveled are comparative long in Malaysia and Laos. Judging from the number of Thailand's trucks detected in these countries, this is likely reflecting more trucks traveling shorter distances in Malaysia, and fewer trucks traveling a longer distance in Laos.

This section summarizes, from various aspects, aggregated pictures of Thailand's trucks crossing to Cambodia, Laos, Myanmar, and Malaysia. In the next section, I will demonstrate how probe data can be used to generate cross-border connectivity, especially on the city level.

Figure 5. Hourly Total Traveled Distances of Thailand's Trucks in Neighboring Countries



Source: Author based on probe data.
Note: AYA: Ayutthaya, BKK: Bangkok, CBI: Chonburi, CMI: Chiang Mai, HDY: Hat Yai, KKN: Khon Kaen, LPG: Lampang, NMA: Nakhon Ratchasima, NPT: Nakhon Pathom, PBI: Phetchaburi, PKT: Phuket, PLK: Phitsanulok, PYX: Pattaya, RYG: Rayong, SKA: Songkhla, SRC: Sriracha, SRI: Saraburi, UBN: Ubon Ratchathani, UDN: Udon Thani.

3. Connectivity between Thailand's Cities and Neighbouring Countries

This demonstrates how to generate cross-border urban connectivity from vehicles' probe data. One of the significant research questions using probe data is the identification of origin and destination (OD) of each trip. For taxi trips within urban areas, OD can be relatively identified if data on the status of a meter is available. It is however much more difficult for trucks that usually travel longer distance requiring several stops for rest, fuel refiling along the way. It is indeed possible to somehow identify the purpose of each stop to some degree of certainty by combining location data with high-resolution online maps such as OSM (OpenStreetMap) and Google map. The question of whether it is appropriate to ignore transit region for long distance traveled by trucks. The connectivity can be more precisely measured by taking into account the role of transit regions. I argue that this is especially necessary for developing countries where alternative routes are limited.

Table 1. The frequency of Origin of Cross-border Trucks

Start	KH	LA	MM	MY
AYA	0	15	27	9
BKK	63	84	141	81
CBI	12	18	6	12
CMI	3	3	21	0
HDY	0	0	9	789
KKN	3	42	0	0
LPG	0	12	3	0
NMA	3	111	0	6
NPT	0	9	9	0
PBI	0	12	42	27
PKT	0	0	6	30
PLK	0	15	0	3
PYX	3	0	0	0
RYG	12	9	6	0
SKA	0	0	3	18
SRC	30	48	39	0
SRI	171	81	39	3
UBN	0	84	3	0
UDN	0	102	0	0

Total	300	645	354	978

Source: Author based on probe data.
Note: AYA: Ayutthaya, BKK: Bangkok, CBI: Chonburi, CMI: Chiang Mai, HDY: Hat Yai, KKN: Khon Kaen, LPG: Lampang, NMA: Nakhon Ratchasima, NPT: Nakhon Pathom, PBI: Phetchaburi, PKT: Phuket, PLK: Phitsanulok, PYX: Pattaya, RYG: Rayong, SKA: Songkhla, SRC: Sriracha, SRI: Saraburi, UBN: Ubon Ratchathani, UDN: Udon Thani.

OD is identified by detection of vehicles within predefined city boundaries in this study. Probe data obtained from this study starts at 5 pm and last for 48 hours for each period. So for each truck that crossed into neighboring countries, the start city can be identified as the first city that it was detected. It should be noted that the result may change if the start time changes. Table 1 shows the frequency assuming start time is 7 pm. Number of trucks starting trips from Bangkok is relatively large for all four neighboring countries, but it is the largest only for Myanmar. About 40% of trucks that crossed to Myanmar during the studies periods were first detected in Bangkok. It should be noted that some trucks may start from areas outside city boundaries defined by this study. Therefore, starting from Bangkok means the first city that it was detected was Bangkok in that situation. Other primary origins for trucks heading to Myanmar include Phetchaburi, Siracha, and Saraburi, but the scales are about one third or less than that of Bangkok. For Cambodia, the most significant origin is Saraburi, account accounted for a little more than half of the trucks crossed into Cambodia. Bangkok and Siracha are the second and third primary origin of trucks later detected later in Cambodia. However, there is no absolute primary origin of trucks heading to Laos. Nakhon Ratchasima, Udon Thani, Ubon Ratchathani, Bangkok, and Saraburi are all closely major origins for Trucks that later appreciate in Laos. As far as Laos is concerned, urban areas other than Bangkok are likely to function as a hub of Laos bounded cargo. Hat Yai is the absolute most significant origin of origin for trucks crossing into Malaysia, accounting for more than ten times than that of Bangkok, the second largest origin.

Table 2 to 5 look into details of paths taken by these cross-border trucks. These paths are generated from trips taken by each truck. KH.OM.OC is by far the best connected to cities in Thailand. This does not exclude the possibility of it being just a significant gateway of Thailand's truck entering Cambodia. In fact, it is highly likely to be so. However, since it is the place where Thailand's trucks visit the most, it can be regarded as better connected judging from the flow data. Any other districts trading with Thailand's through it are just enjoying indirect connectivity. The interesting point of Thailand's trucks crossing to Cambodia is some trucks did Saraburi-KH.OM.OC trips twice in 48 hours period. In fact, there were 30 such trips in the obtained probe data (Table 1). Driving from Saraburi to Cambodia's border takes only a little more than 3 hours. So if the demand exists, making several consecutive trips is not actually unrealistic. Although the frequency is high, trips from Cambodia to Thailand and then return to Cambodia can be observed among several locations in Thailand and Cambodia. For trucks bounding to Laos, the most common path is Ubon Ratchathani to LA.CH.PH (Table 2). There were 64 such trips in the sample. To why the return trips of the same path were not observed cannot be easily explained. These trucks may need to stay longer in Laos or cannot leave soon enough. The distinction of Thailand's trucks in Laos is some of them traveling spend all 48 hours traveling through several districts in

Laos. It is a well-known fact that many urban areas in Laos along the Western border are better connected to cities in Thailand than among themselves. Traces of cross-border trucks reflects this fact well. Given the distances from cities in Thailand return trips from Myanmar were observed on the most common top 30 paths taken by trucks detected in Myanmar. On the contrary, multiple trips within 48 hours periods are somewhat typical for Malaysia bounded trucks.

Table 2. The frequency of Paths of Cross-border Trucks (Cambodia)

Path	Count
SRI-KH.OM.OC	105
BKK-KH.OM.OC	30
SRI-KH.OM.OC-SRI-KH.OM.OC	30
SRC-KH.OM.OC	24
KH.OM.OC-SRI-KH.OM.OC	18
BKK-CBI-KH.KK.MS	12
KH.BA.PP-KH.PL.SK	6
RYG-SRC-KH.BA.PP	6
SRI-AYA-SRI-KH.OC.SR	6
SRI-BKK-CBI-KH.KK.MS	6
SRI-KH.OM.OC-SRI-KH.PL.SK	6
BKK-AYA-BKK-KH.OM.OC	3
BKK-CBI-KH.BA.PP	3
BKK-CBI-KH.KK.MS-NMA-KH.KK.MS	3
BKK-CBI-SRC-KH.BA.PP	3
BKK-KH.BA.PP	3
BKK-KH.KK.MS	3
BKK-SRC-CBI-BKK-CBI-BKK-CBI-BKK-CBI-BKK-KH.KK.MS-BKK-KH.KK.MS-BKK	3
CBI-BKK-AYA-BKK-KH.OM.OC	3
CBI-BKK-CBI-KH.KK.MS	3
CBI-BKK-KH.BA.PP	3
CBI-SRC-CBI-SRI-KH.OM.OC	3
CMI-KH.BA.PP	3
KH.BA.PP-KH.OM.ML-KH.BA.PP	3
KH.BA.PP-RYG-SRC-RYG-KH.KK.MS	3
KH.OM.ML-KH.OM.OC	3
KH.OM.OC-NMA-KH.OM.OC	3
KH.OM.OC-SRC-KH.OM.OC	3
KH.PL.SK-KH.PL.PL-SRI-KH.OM.OC	3

Source: Author. The administrative boundary is based on GADM.
Note: KH.BA.PP: Batdâmbâng-Phnum Proek, KH.BA.RM: Batdâmbâng-Rotanak Mondol, KH.KG.RB: Kâmpóng Chhnang-Rolea B'ier, KH.KK.MS: Kaôh Kong-Mondol Seima, KH.KK.SM: Kaôh Kong-Smach Mean Chey, KH.KK.TB: Kaôh Kong-Thma Bang, KH.KS.AR: Kâmpóng Spœ-Aoral, KH.KT.KS: Kâmpóng Thum-Kampong Svay, KH.OC.AV: Otdar Mean Chey-Anlong Veaeng, KH.OC.BA: Otdar Mean Chey-Banteay Ampil, KH.OC.SR: Otdar Mean Chey-Samraong, KH.OM.ML: Bântéay Méanchey-Malai, KH.OM.OC: Bântéay Méanchey-Ou Chrov, KH.OM.PN: Bântéay Méanchey-Preah Netr Preah, KH.OM.TP: Bântéay Méanchey-Thma Puok, KH.PH.CK: Preah Vihéar-Choam Khsant, KH.PH.KL: Preah Vihéar-Kuleaen, KH.PL.PL: Krong Pailin-Pailin, KH.PL.SK: Krong Pailin-Sala Krau, KH.PO.PK: Pouthisat-Phnum Kravanh, KH.PP.RK: Phnom Penh-Ruessei Kaev, KH.PY.MS: Prey Vêng-Me Sang, KH.RO.AM: Rôtânôkiri-Andoung Meas, KH.SI.AC: Siemréab-Angkor Chum, KH.SI.PK: Siemréab-Puok, KH.SI.VR: Siemréab-Varin, KH.SR.RH: Svay Rieng-Romeas Haek.

Table 3. The frequency of Paths of Cross-border Trucks (Laos)

Path	count
UBN-LA.CH.PH	69
NMA-KKN-UDN-LA.VT.HA	48
SRI-UBN-LA.CH.PH	24
UDN-LA.KH.TH	21
KKN-UDN-LA.VT.HA	18
SRI-NMA-KKN-UDN-LA.VT.HA	15
BKK-SRI-NMA-LA.KH.TH	12
BKK-SRI-NMA-LA.SV.KH	12
NMA-KKN-UDN-LA.VT.HA-LA.VT.XT	12
SRI-LA.XA.KE	12
UDN-LA.BL.PS	12
UDN-LA.VT.HA-LA.VT.XS	12
UDN-LA.VT.MA	12
LA.SV.KH-LA.SV.XP-LA.SV.KH	9
LPG-UDN-LA.KH.TH	9
NMA-LA.SV.KH	9
SRC-CBI-BKK-AYA-LA.XA.NG	9
SRC-NMA-KKN-UDN-LA.VT.HA	9
UBN-UDN-LA.VT.HA	9
UDN-LA.VI.XA	9
UDN-LA.VT.HA-LA.VT.XS-LA.VT.HA-LA.VT.XS	9
AYA-LA.XA.BO-LA.XA.KE-LA.XA.BO	6
BKK-LA.VT.HA	6
BKK-NMA-LA.SV.KH	6
CBI-BKK-AYA-PLK-LA.BK.HO	6
KKN-UDN-LA.VT.MA	6
LA.VT.HA-LA.VT.XS	6
LA.VT.MA-UDN-LA.VT.MA	6
LA.VT.XS-LA.VT.SS-LA.VT.XS-LA.VT.XT-LA.VT.MA-LA.VT.XT-LA.VT.XS	6

Source: Author. The administrative boundary is based on GADM.
Note: LA.AT.PH: Attapu-Phouvong, LA.BK.HO: Bokeo-Houixai, LA.BK.NA: Bokeo-Nam You, LA.BK.TO: Bokeo-Tonpheung, LA.BL.BO: Bolikhamxai-Bolikhanh, LA.BL.PD: Bolikhamxai-Pakkading, LA.BL.PS: Bolikhamxai-Paksane, LA.BL.TH: Bolikhamxai-Thaphabath, LA.CH.BA: Champasak-Bachiangchaleunsook, LA.CH.PE: Champasak-Pakxe, LA.CH.PH: Champasak-Phonthong, LA.KH.HI: Khammouan-Hinboon, LA.KH.MA: Khammouan-Mahaxay, LA.KH.TH: Khammouan-Thakhek, LA.KH.XE: Khammouan-Xebangfay, LA.LM.NT: Louang Namtha-Namtha, LA.LM.VI: Louang Namtha-Viengphoukha, LA.LP.PK: Louangphrabang-Phoukhoune, LA.SL.LK: Saravan-Lakhonepheng, LA.SV.AT: Savannakhét-Atsaphangthong, LA.SV.KH: Savannakhét-Khanthabouly, LA.SV.OU: Savannakhét-Outhoomphone, LA.SV.PH: Savannakhét-Phine, LA.SV.SE: Savannakhét-Sepone, LA.SV.SO: Savannakhét-Songkhone, LA.SV.TX: Savannakhét-Thaphalanxay, LA.SV.XB: Savannakhét-Xaybuly, LA.SV.XP: Savannakhét-Xayphoothong, LA.VI.HI: Vientiane-Hinhurp, LA.VI.KA: Vientiane-Kasy, LA.VI.PH: Vientiane-Phonhong, LA.VI.VA: Vientiane-Vangvieng, LA.VI.XA: Vientiane-Xanakharm, LA.VT.CH: Vientiane [prefecture]-Chanthabuly, LA.VT.HA: Vientiane [prefecture]-Hadxaifong, LA.VT.MA: Vientiane [prefecture]-Mayparkngum, LA.VT.NA: Vientiane [prefecture]-Naxaithong, LA.VT.SA: Vientiane [prefecture]-Sangthong, LA.VT.SK: Vientiane [prefecture]-Sikhottabong, LA.VT.SS: Vientiane [prefecture]-Sisattanak, LA.VT.XS: Vientiane [prefecture]-Xaysetha, LA.VT.XT: Vientiane [prefecture]-Xaythany, LA.XA.BO: Xaignabouri-Botene, LA.XA.HO: Xaignabouri-Hongsa, LA.XA.KE: Xaignabouri-Kenethao, LA.XA.NG: Xaignabouri-Ngeun, LA.XA.PA: Xaignabouri-Parklai, LA.XA.TH: Xaignabouri-Thongmyxay, LA.XA.XA: Xaignabouri-Xayabury, LA.XI.PE: Xiangkhoang-Pek, LA.XI.PK: Xiangkhoang-Phookood, LA.XS.HO: Xaisômboun-

Hom, LA.XS.LO: Xaisômboun-Longsane, LA.XS.PH: Xaisômboun-Phun, LA.XS.XA: Xaisômboun-Xaysomboun.

Table 4. The frequency of Paths of Cross-border Trucks (Myanmar)

Path	count
BKK-PBI-MM.TN.KG	57
BKK-AYA-MM.KN.MY	36
SRI-BKK-PBI-MM.TN.KG	33
SRC-CBI-BKK-AYA-MM.KN.MY	27
PBI-BKK-PBI-MM.TN.KG	15
MM.TN.KG-PBI-BKK-PBI-MM.TN.KG	12
AYA-BKK-AYA-MM.KN.MY	9
AYA-MM.KN.MY	9
CMI-MM.SH.MH	9
CMI-MM.SH.TC	9
AYA-BKK-CBI-SRC-CBI-BKK-AYA-MM.KN.MY	6
BKK-MM.TN.KG	6
BKK-NPT-MM.KN.MY	6
BKK-SRI-BKK-PBI-MM.TN.KG	6
NPT-PBI-MM.TN.KG	6
PBI-BKK-MM.TN.KG	6
PBI-NPT-MM.KN.MY	6
PKT-MM.TN.KG	6
SRC-CBI-BKK-AYA-PLK-MM.SH.TC	6
SRI-MM.KN.MY	6
AYA-SRI-BKK-PBI-MM.TN.KG	3
BKK-AYA-MM.SH.TC	3
BKK-CBI-SRC-CBI-BKK-AYA-MM.KN.MY	3
BKK-CBI-SRC-CBI-BKK-PBI-MM.TN.KG	3
BKK-MM.KN.HP	3
BKK-MM.KN.MY	3
BKK-NPT-MM.KN.HP	3
BKK-PBI-PKT-MM.TN.KG	3
BKK-SRC-BKK-BKK-SRC-BKK-SRC-CBI-BKK-MM.KN.MY	3

Source: Author. The administrative boundary is based on GADM.
Note: MM.AY.PT: Ayeyarwady-Bassein, MM.BA.TA: Bago-Taungoo, MM.KN.HP: Kayin-Hpa-an, MM.KN.KK: Kayin-Kawkareik, MM.KN.MY: Kayin-Myawady, MM.MO.ML: Mon-Mawlamyine, MM.SH.LL: Shan-Loilen, MM.SH.LS: Shan-Lasho, MM.SH.MH: Shan-Mongsat, MM.SH.MP: Shan-Mongphat, MM.SH.TC: Shan-Tarchilaik, MM.TN.DW: Tanintharyi-Dawei, MM.TN.KG: Tanintharyi-Kawthoung, MM.TN.MK: Tanintharyi-Mergui.

Table 5. The frequency of Paths of Cross-border Trucks (Malaysia)

Path	count
HDY-MY.PL.PE	270
HDY-MY.KH.KP	240
MY.PL.PE-HDY-MY.PL.PE	96
HDY-MY.PL.PE-HDY-MY.PL.PE	90
HDY-MY.KH.KP-HDY-MY.KH.KP	69
MY.KH.KP-HDY-MY.KH.KP	54
BKK-PBI-HDY-MY.KH.KP	51
HDY-SKA-HDY-MY.PL.PE	45
MY.PL.PE-MY.KH.KP	36
BKK-PBI-HDY-MY.PL.PE	18
PKT-HDY-MY.KH.KP	18
MY.PL.PE-HDY-MY.PL.PE-HDY-MY.PL.PE	15
CBI-BKK-PBI-HDY-MY.KH.KP	12
HDY-MY.KH.KP-MY.PL.PE	12
HDY-MY.KN.PM	12
HDY-MY.PL.PE-MY.KH.KP	9
MY.KH.KP-MY.PL.PE	9
PBI-BKK-PBI-HDY-MY.KH.KP	9
void-MY.KH.KP	9
AYA-SRI-BKK-PBI-HDY-MY.PL.PE	6
HDY-MY.KH.KP-MY.PL.PE-MY.KH.KP	6
HDY-MY.PK.HU	6
HDY-SKA-HDY-MY.KH.KP	6
PBI-HDY-MY.KH.KP	6
PBI-HDY-MY.PL.PE	6
PKT-HDY-MY.PL.PE	6
PKT-MY.KH.KP	6
SKA-HDY-MY.KH.KP	6
AYA-BKK-SRC-CBI-BKK-PBI-HDY-MY.KH.KP	3

Source: Author. The administrative boundary is based on GADM.
Note: MY.KH.KP: Kedah-Kubang Pasu, MY.KH.PT: Kedah-Padang Terap, MY.KN.KB: Kelantan-Kota Bharu, MY.KN.PM: Kelantan-Pasir Mas, MY.KN.TM: Kelantan-Tanah Merah, MY.KN.TU: Kelantan-

Tumpat, MY.PK.HU: Perak-Hulu Perak, MY.PL.PE: Perlis-Perlis, MY.SA.BL: Sabah-Beluran, MY.SK.MR: Sarawak-Marudi, MY.TE.KT: Trengganu-Kuala Terengganu.

Finally, I generated a traffic matrix for traffic frequency among cities in Thailand and sub-national administrative areas in each neighboring countries. The cities in Thailand are the top 19 remotely-sensed urban boundaries as stated at the outset. The sub-national administrative areas in each country are inevitably those visited by Thailand's trucks in the obtained probe data. The results are shown in Table 6 to 9. One advantage of probe data is traffic frequency can be generated for both directions. The traffic looks very unbalanced for all four neighbors. This study obtains only four periods of 48 hours of data. I anticipate this to improve significantly if more periods of probe data are collected. Nevertheless, data trucks from the other sides would be necessary to resolve this unbalance substantially. Even then, there would be still likely to be less of Cambodia's, or Laos' trucks crossing to Thailand given the unbalance stage of industrialization.

Thailand's cities that are most connected to Cambodia is Saraburi, flowed distantly by Bangkok, Siracha and Chonburi. On the opposite direction, KH.OM.OC is by far Cambodia's district is most connected to Thailand. Many major cities in Northeastern Thailand are similarly connected to districts in Laos. Udon Thani which is located about 50 km from Laos' capital city a little more connected than the rest. Laos' districts that are most connected to Thailand are in the capital city and province on that right bank of the Mekong river that are connected to Thailand on land. Thailand's cities that are most connected to Myanmar are Bangkok, Petchaburi and Ayutthaya. Myanmar's MM.TN.KG is best connected to Thailand. Hat Yai is by far Thailand's city that is best connected to Malaysia. Malaysia's MY.PL.PE and MY.KH.KP is better connected to Thailand, Hat Yai in particular.

Table 6. The frequency of Traffic of Cross-border Trucks (Cambodia)

Origin	Destination	Frequency	Origin	Destination	Frequency
SRI	KH.OM.OC	174	KH.OM.OC	SRI	57
BKK	KH.OM.OC	36	KH.KK.MS	BKK	3
SRC	KH.OM.OC	33	KH.KK.MS	NMA	3
BKK	KH.KK.MS	30	KH.OM.OC	NMA	3
CBI	KH.KK.MS	27	KH.BA.PP	RYG	3
BKK	KH.BA.PP	12	KH.BA.PP	SRC	3
CBI	KH.BA.PP	12	KH.OM.OC	SRC	3
RYG	KH.BA.PP	12	KH.PL.SK	SRI	3
SRC	KH.BA.PP	12	KH.BA.PP	AYA	0
SRI	KH.OC.SR	12	KH.KK.MS	AYA	0
NMA	KH.KK.MS	9	KH.OC.SR	AYA	0
SRC	KH.KK.MS	9	KH.OM.OC	AYA	0
AYA	KH.OC.SR	9	KH.OM.PN	AYA	0
CBI	KH.OM.OC	9	KH.OM.TP	AYA	0
SRI	KH.PL.SK	9	KH.PL.SK	AYA	0
SRI	KH.BA.PP	6	KH.BA.PP	BKK	0
SRI	KH.KK.MS	6	KH.OC.SR	BKK	0
AYA	KH.OM.OC	6	KH.OM.OC	BKK	0
CMI	KH.BA.PP	3	KH.OM.PN	BKK	0
KKN	KH.KK.MS	3	KH.OM.TP	BKK	0
RYG	KH.KK.MS	3	KH.PL.SK	BKK	0
NMA	KH.OM.OC	3	KH.BA.PP	CBI	0
PYX	KH.OM.OC	3	KH.KK.MS	CBI	0
SRI	KH.OM.TP	3	KH.OC.SR	CBI	0
AYA	KH.BA.PP	0	KH.OM.OC	CBI	0
HDY	KH.BA.PP	0	KH.OM.PN	CBI	0
KKN	KH.BA.PP	0	KH.OM.TP	CBI	0
LPG	KH.BA.PP	0	KH.PL.SK	CBI	0
NMA	KH.BA.PP	0	KH.BA.PP	CMI	0

Source: Author. The administrative boundary is based on GADM.
Note: KH.BA.PP: Batdâmbâng-Phnum Proek, KH.BA.RM: Batdâmbâng-Rotanak Mondol, KH.KG.RB: Kâmpóng Chhnang-Rolea B'ier, KH.KK.MS: Kaôh Kong-Mondol Seima, KH.KK.SM: Kaôh Kong-Smach Mean Chey, KH.KK.TB: Kaôh Kong-Thma Bang, KH.KS.AR: Kâmpóng Spœ-Aoral, KH.KT.KS: Kâmpóng Thum-Kampong Svay, KH.OC.AV: Otdar Mean Chey-Anlong Veaeng, KH.OC.BA: Otdar Mean Chey-Banteay Ampil, KH.OC.SR: Otdar Mean Chey-Samraong, KH.OM.ML: Bântéay Méanchey-Malai, KH.OM.OC: Bântéay Méanchey-Ou Chrov, KH.OM.PN: Bântéay Méanchey-Preah Netr Preah, KH.OM.TP: Bântéay Méanchey-Thma Puok, KH.PH.CK: Preah Vihéar-Choam Khsant, KH.PH.KL: Preah Vihéar-Kuleaen, KH.PL.PL: Krong Pailin-Pailin, KH.PL.SK: Krong Pailin-Sala Krau, KH.PO.PK: Pouthisat-Phnum Kravanh, KH.PP.RK: Phnom Penh-Ruessei Kaev, KH.PY.MS: Prey Vêng-Me Sang, KH.RO.AM: Rôtânôkiri-Andoung Meas, KH.SI.AC: Siemréab-Angkor Chum, KH.SI.PK: Siemréab-Puok, KH.SI.VR: Siemréab-Varin, KH.SR.RH: Svay Rieng-Romeas Haek.

Table 7. The frequency of Traffic of Cross-border Trucks (Laos)

Origin	Destination	Frequency	Origin	Destination	Frequency
UDN	LA.VT.HA	231	LA.VT.MA	UDN	9
KKN	LA.VT.HA	168	LA.XA.KE	SRI	6
NMA	LA.VT.HA	147	LA.XA.BO	AYA	3
UBN	LA.CH.PH	105	LA.XA.KE	AYA	3
UDN	LA.VT.XS	75	LA.VI.XA	BKK	3
SRI	LA.VT.HA	51	LA.XA.KE	BKK	3
UDN	LA.VT.MA	51	LA.VT.HA	PBI	3
NMA	LA.SV.KH	48	LA.VT.XS	PBI	3
KKN	LA.VT.XS	42	LA.BK.HO	RYG	3
NMA	LA.KH.TH	39	LA.BK.HO	SRC	3
BKK	LA.VT.HA	39	LA.VT.HA	SRI	3
SRI	LA.KH.TH	36	LA.VT.XS	SRI	3
NMA	LA.VT.XS	36	LA.XA.BO	SRI	3
UDN	LA.KH.TH	33	LA.VT.HA	UDN	3
UDN	LA.BL.PS	30	LA.XA.KE	UDN	3
SRI	LA.SV.KH	30	LA.BK.HO	AYA	0
KKN	LA.VT.XT	30	LA.BK.NA	AYA	0
UDN	LA.VT.XT	30	LA.BL.PD	AYA	0
BKK	LA.SV.KH	27	LA.BL.PS	AYA	0
SRC	LA.VT.HA	27	LA.BL.TH	AYA	0
NMA	LA.VT.XT	27	LA.CH.BA	AYA	0
BKK	LA.XA.NG	27	LA.CH.PH	AYA	0
SRI	LA.CH.PH	24	LA.KH.HI	AYA	0
BKK	LA.KH.TH	24	LA.KH.MA	AYA	0
UDN	LA.VI.XA	24	LA.KH.TH	AYA	0
AYA	LA.XA.NG	24	LA.SV.KH	AYA	0
CBI	LA.XA.NG	24	LA.SV.OU	AYA	0
SRC	LA.XA.NG	24	LA.SV.SE	AYA	0
BKK	LA.BK.HO	21	LA.SV.SO	AYA	0

Source: Author. The administrative boundary is based on GADM.

Note: LA.AT.PH: Attapu-Phouvong, LA.BK.HO: Bokeo-Houixai, LA.BK.NA: Bokeo-Nam You, LA.BK.TO: Bokeo-Tonpheung, LA.BL.BO: Bolikhamxai-Bolikhanh, LA.BL.PD: Bolikhamxai-Pakkading, LA.BL.PS: Bolikhamxai-Paksane, LA.BL.TH: Bolikhamxai-Thaphabath, LA.CH.BA: Champasak-Bachiangchaleunsook, LA.CH.PE: Champasak-Pakxe, LA.CH.PH: Champasak-Phonthong, LA.KH.HI: Khammouan-Hinboon, LA.KH.MA: Khammouan-Mahaxay, LA.KH.TH: Khammouan-Thakhek, LA.KH.XE: Khammouan-Xebangfay, LA.LM.NT: Louang Namtha-Namtha, LA.LM.VI: Louang Namtha-Viengphoukha, LA.LP.PK: Louangphrabang-Phoukhoune, LA.SL.LK: Saravan-Lakhonepheng, LA.SV.AT: Savannakhét-Atsaphangthong, LA.SV.KH: Savannakhét-Khanthabouly, LA.SV.OU: Savannakhét-Outhoomphone, LA.SV.PH: Savannakhét-Phine, LA.SV.SE: Savannakhét-Sepone, LA.SV.SO: Savannakhét-Songkhone, LA.SV.TX: Savannakhét-Thaphalanxay, LA.SV.XB: Savannakhét-Xaybuly, LA.SV.XP: Savannakhét-Xayphoothong, LA.VI.HI: Vientiane-Hinhurp, LA.VI.KA: Vientiane-Kasy, LA.VI.PH: Vientiane-Phonhong, LA.VI.VA: Vientiane-Vangvieng, LA.VI.XA: Vientiane-Xanakharm, LA.VT.CH: Vientiane [prefecture]-Chanthabuly, LA.VT.HA: Vientiane [prefecture]-Hadxaifong, LA.VT.MA: Vientiane [prefecture]-Mayparkngum, LA.VT.NA: Vientiane [prefecture]-Naxaithong, LA.VT.SA: Vientiane [prefecture]-Sangthong, LA.VT.SK: Vientiane [prefecture]-Sikhottabong, LA.VT.SS: Vientiane [prefecture]-Sisattanak, LA.VT.XS: Vientiane [prefecture]-Xaysetha, LA.VT.XT: Vientiane [prefecture]-Xaythany, LA.XA.BO: Xaignabouri-Botene, LA.XA.HO: Xaignabouri-Hongsa, LA.XA.KE: Xaignabouri-Kenethao, LA.XA.NG: Xaignabouri-Ngeun, LA.XA.PA: Xaignabouri-Parklai, LA.XA.TH: Xaignabouri-Thongmyxay, LA.XA.XA: Xaignabouri-Xayabury, LA.XI.PE: Xiangkhoang-Pek, LA.XI.PK: Xiangkhoang-Phookood, LA.XS.HO: Xaisômboun-Hom, LA.XS.LO: Xaisômboun-Longsane, LA.XS.PH: Xaisômboun-Phun, LA.XS.XA: Xaisômboun-Xaysomboun.

Table 8. The frequency of Traffic of Cross-border Trucks (Myanmar)

Origin	Destination	Frequency	Origin	Destination	Frequency
PBI	MM.TN.KG	159	MM.TN.KG	BKK	15
BKK	MM.TN.KG	156	MM.TN.KG	PBI	15
BKK	MM.KN.MY	114	MM.KN.HP	BKK	3
AYA	MM.KN.MY	111	MM.SH.TC	BKK	3
CBI	MM.KN.MY	48	MM.KN.MY	CMI	3
SRC	MM.KN.MY	48	MM.KN.MY	LPG	3
SRI	MM.TN.KG	42	MM.KN.HP	NMA	3
NPT	MM.KN.MY	15	MM.TN.KG	NPT	3
BKK	MM.SH.TC	15	MM.TN.KG	RYG	3
PBI	MM.KN.MY	12	MM.TN.KG	SRC	3
AYA	MM.SH.TC	12	MM.KN.HP	SRI	3
CMI	MM.SH.TC	12	MM.KN.HP	AYA	0
BKK	MM.KN.HP	9	MM.KN.MY	AYA	0
SRI	MM.KN.MY	9	MM.MO.ML	AYA	0
CMI	MM.SH.MH	9	MM.SH.MH	AYA	0
CBI	MM.SH.TC	9	MM.SH.TC	AYA	0
SRC	MM.SH.TC	9	MM.TN.DW	AYA	0
NPT	MM.TN.KG	9	MM.TN.KG	AYA	0
PKT	MM.TN.KG	9	MM.TN.MK	AYA	0
LPG	MM.SH.TC	6	MM.KN.MY	BKK	0
PLK	MM.SH.TC	6	MM.MO.ML	BKK	0
HDY	MM.TN.KG	6	MM.SH.MH	BKK	0
SRC	MM.TN.KG	6	MM.TN.DW	BKK	0
UBN	MM.TN.KG	6	MM.TN.MK	BKK	0
NPT	MM.KN.HP	3	MM.KN.HP	CBI	0
SRI	MM.KN.HP	3	MM.KN.MY	CBI	0
CMI	MM.KN.MY	3	MM.MO.ML	CBI	0
HDY	MM.KN.MY	3	MM.SH.MH	CBI	0
LPG	MM.KN.MY	3	MM.SH.TC	CBI	0

Source: Author. The administrative boundary is based on GADM.
Note: MM.AY.PT: Ayeyarwady-Bassein, MM.BA.TA: Bago-Taungoo, MM.KN.HP: Kayin-Hpa-an, MM.KN.KK: Kayin-Kawkareik, MM.KN.MY: Kayin-Myawady, MM.MO.ML: Mon-Mawlamyine, MM.SH.LL: Shan-Loilen, MM.SH.LS: Shan-Lasho, MM.SH.MH: Shan-Mongsat, MM.SH.MP: Shan-Mongphat, MM.SH.TC: Shan-Tarchilaik, MM.TN.DW: Tanintharyi-Dawei, MM.TN.KG: Tanintharyi-Kawthoung, MM.TN.MK: Tanintharyi-Mergui.

Table 9. The frequency of Traffic of Cross-border Trucks (Malaysia)

Origin	Destination	Frequency	Origin	Destination	Frequency
HDY	MY.PL.PE	627	MY.PL.PE	HDY	225
HDY	MY.KH.KP	537	MY.KH.KP	HDY	144
PBI	MY.KH.KP	93	MY.PL.PE	SKA	12
BKK	MY.KH.KP	87	MY.KH.KP	SKA	9
SKA	MY.PL.PE	69	MY.KH.KP	AYA	3
BKK	MY.PL.PE	39	MY.KN.PM	AYA	0
PBI	MY.PL.PE	39	MY.KN.TM	AYA	0
PKT	MY.KH.KP	24	MY.PK.HU	AYA	0
SKA	MY.KH.KP	21	MY.PL.PE	AYA	0
CBI	MY.KH.KP	18	MY.KH.KP	BKK	0
HDY	MY.KN.PM	12	MY.KN.PM	BKK	0
SRI	MY.PL.PE	12	MY.KN.TM	BKK	0
AYA	MY.KH.KP	6	MY.PK.HU	BKK	0
HDY	MY.PK.HU	6	MY.PL.PE	BKK	0
AYA	MY.PL.PE	6	MY.KH.KP	CBI	0
PKT	MY.PL.PE	6	MY.KN.PM	CBI	0
NMA	MY.KH.KP	3	MY.KN.TM	CBI	0
NPT	MY.KH.KP	3	MY.PK.HU	CBI	0
PLK	MY.KH.KP	3	MY.PL.PE	CBI	0
SRC	MY.KH.KP	3	MY.KH.KP	CMI	0
SRI	MY.KH.KP	3	MY.KN.PM	CMI	0
SKA	MY.KN.PM	3	MY.KN.TM	CMI	0
NMA	MY.PL.PE	3	MY.PK.HU	CMI	0
CMI	MY.KH.KP	0	MY.PL.PE	CMI	0
KKN	MY.KH.KP	0	MY.KN.PM	HDY	0
LPG	MY.KH.KP	0	MY.KN.TM	HDY	0
PYX	MY.KH.KP	0	MY.PK.HU	HDY	0
RYG	MY.KH.KP	0	MY.KH.KP	KKN	0
UBN	MY.KH.KP	0	MY.KN.PM	KKN	0

Source: Author. The administrative boundary is based on GADM.
Note: MY.KH.KP: Kedah-Kubang Pasu, MY.KH.PT: Kedah-Padang Terap, MY.KN.KB: Kelantan-Kota Bharu, MY.KN.PM: Kelantan-Pasir Mas, MY.KN.TM: Kelantan-Tanah Merah, MY.KN.TU: Kelantan-Tumpat, MY.PK.HU: Perak-Hulu Perak, MY.PL.PE: Perlis-Perlis, MY.SA.BL: Sabah-Beluran, MY.SK.MR: Sarawak-Marudi, MY.TE.KT: Trengganu-Kuala Terengganu.

Summary

This Chapter demonstrates how to compile cross-border regional flow statistics from vehicles' probe data, i.e., high-frequency geographical coordinates of their location. Although problems such as handling of error stemming from unstable GPS receiving environment and difficulty of big data processing persists, this chapter shows that it can produce various measures related to inter-regional flow by cities from 4 slots of 48 hours periods of commercial Thailand's commercial vehicles' probe data that crossed the land border to neighboring countries. Specifically, it can produce connectivity measure considering flow and also account for direction.

Many commercial trucks are equipped with GPS logger that can report location information. In theory, these location data is available in almost real time. Such data will not only enable urban connectivity measurement that considers flow but doing so with consideration of flow in real time a reality. Although probe data is privately generated, I argue that commercial vehicles' probe data processes public goods aspects similar to trade and other statistics being assembled by the statistical authorities. The effort by public sectors to collect and publish probe data of commercial vehicles would greatly benefit not only research communities but also society through better evaluation and understanding of within and between urban connectivity.

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