

An integrated sensing-based urban freight data collection framework: methodology and pilot projects in Singapore

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Abstract

The paper illustrates the design and preliminary results of an integrated framework for urban freight data collection, under development in the pilot test-site of Singapore. It is based on next-generation sensing/surveying capabilities to enable future disaggregated logistics modelling to support policy-making in urban freight systems. The proposed freight data collection effort leverages pervasive GPS loggers, advanced sensing and communication technologies and machine learning architecture to deliver previously unobtainable data that reflect observed rather than stated information on the decisions of shippers, carriers and truck drivers. The general structure of the proposed data collection framework embeds: (a) sensing devices for tracking shipments, vehicles and driver behaviour; (b) a backend server database which collects and processes collected data (c) web-based and tablet-based reporting and surveying tools. The project is in its implementation stage, and some of the proposed approaches are under testing. Promising results have been already achieved, with specific reference to the capability of unobtrusively collect a wealth of valuable information, leading to better quality and quantity of data.

Keywords: commodity flow surveys; GPS and OBD based surveys; freight survey; commodity chain sensing.

1. Introduction and motivation

The paper illustrates the design and preliminary results of an integrated framework for urban freight data collection, under development in the pilot test-site of Singapore. It is based on next-generation sensing/surveying capabilities to enable future modelling and policy-making in urban freight systems. Specifically, the primary objective of the research is to develop proof-of-concept of a coherent, scalable and holistic collection of all freight data (production, logistics, transport), with the aim of tracking vehicles and shipments and for surveying relevant freight agents, leveraging state-of-the-art sensing technologies and approaches, obtaining unprecedented urban freight data. The research is motivated by the fact that the explanatory power of existing freight models is very often limited by lack of data, which implies simplifying assumptions and limited behavioural foundations of current modelling approaches for urban freight modelling and policy-making. In turn, this leads usually to feasibility studies and subsequent policies and investments based on biased forecasts.

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Various research groups are active worldwide in urban freight research (data collection, modelling, policy-making), as recalled in Section 2. In general, while some technologies are deployed in the effort of collecting urban freight related data, such as GPS for tracking a sample of vehicles, this data collection effort is still largely traditional. As a final general consequence, next generation ICT and solutions (real time traffic-based operations, flexible freight responsive services, dynamic and innovative pricing schemes, intelligent loading bays, next-generation collaborative logistics options, magnitude and impacts of e-commerce related movements) are enabled by technologies but not adequately supported by models – very detailed in their theoretical formulations but typically not integrated with overall urban dynamics nor supported by data.

Thus, in spite of ambitious and ground-breaking objectives in next-generation urban freight modelling and governance, data collection is still acknowledged as a major limitation in understanding and modelling urban freight (DLR workshop, 2014), along with the lack of proper behavioural models to support micro-simulation agent-based models. Despite the proprietary nature of freight related data of freight transportation systems, there is still a great need to have a rigorous comprehension of the behaviour of actors in the freight transportation markets (Mesa-Arango and Ukkusuri, 2014). While the need of integrated freight modelling and simulation capabilities for solution and policy analysis is unquestionable, current microscopic transportation simulation platforms have been restricted to the simulation of very specific logistic models, such as individual shipper's and carrier's operational decisions regarding vehicle assignment and routing (Barcelo et al, 2005). Only a few advanced modelling and simulation frameworks focused on multi-modal passenger travelling decisions, such as MATSim (Schroeder et al., 2012) and SimMobility (Lu et al., 2015), have recently taken the first steps to consider truck movements and their interactions with other modes of passenger travel, but have been struggling with the lack of data to build the necessary models to represent the complex interactions.

On one side, traditional, manual surveys to a sample of all relevant agents are very costly and time consuming, with questionable quality and validity of the answers, for many reasons: low response rates, non-representative samples based on convenience and intercept sampling, short respondent attention span and limited ability to accurately recall information, inability to capture a variety of important information (e.g. routing of vehicles, shipment paths). On the other side, the "big data" paradigm enables collection of huge amount of passive observations (e.g. truck movements through GPS traces), but underlying logistics and transport choices remain unrevealed, as does key information on explanatory variables (e.g. attributes of the decision-maker, perception of alternatives, decision patterns) needed for behavioural modelling. In addition, traditional freight data collection methods require a large amount of time from the design of the survey to the final release of survey results, often leading to the paradox of obtaining already dated information.

The proposed freight data collection effort leverages pervasive GPS loggers, advanced sensing and communication technologies and machine learning architecture to deliver previously unobtainable data that reflect observed and stated information on the decisions of shippers and carriers. The general structure of the proposed data collection framework embeds: (a) sensing devices for tracking shipments, vehicles and driver behaviour; (b) a backend server database which collects and processes collected data (c) web-based and tablet-based reporting and surveying tools.

Importantly, acknowledged that an urban commodity flow survey is needed to understand commodity generation (as a function of establishment characteristics), as well as the distribution and efficiency of the urban logistics systems when coupled with freight mode choices and

capacity utilisation, the key value of the proposed research is also to provide a holistic synthesis of all data collection activities, e.g. the commodity flow survey will be coupled with passive observations of shipments, and truck drivers' surveys will be coupled with GPS/OBD-based vehicle observations, forming an innovative framework that we call "Commodity Chain Sensing" (CCS). Along with the CCS, i.e. the core of the proposed integrated data collection framework, additional efforts are considered, either for data scalability or for getting insight on specific features of the logistic system with localised high resolution data. Also, the proposed technological approach allows fastening the survey execution times, thus leading to more up-to-date information.

The paper is organised as follows. Section 2 reviews key literatures related to freight data collection and survey techniques around the world. Section 3 introduces our proposed freight data collection approach and Section 4 shows the preliminary experimentation of technologies and evaluation. Section 5 concludes this study and discusses future improvements.

2. Literature review

The collection of national and local level freight data has been done in the past to understand the process of goods movements and its performance with the existing road infrastructure and freight solutions. The post-processing and analysis of the data usually will direct decision makers to enhance the economic, social and environmental sustainability of the freight industry. The freight transport data collection is conducted by the national government in most countries and usually takes place as part of the regional and inter-regional freight studies (Allen et al., 2014). Urban freight data has also been collected since 1960s mainly (i) to quantify urban freight operations and for research purposes, (ii) for policy-making decisions and (iii) for urban freight modelling as reviewed by Allen et al. (2012). The common types of data required from various road-based urban freight surveys and their survey methods can be summarised as shown in Figure 1, although it should be noted that there is a great variation in scale, scope (coverage) and intent of known surveys conducted. It can also be seen that a single survey is usually not sufficient to understand the urban goods movement. A combination of the surveys is usually conducted to capture a wider range of data in a particular study and the most "efficient" way is often expensive and requires significant manpower and material resources (Allen et al., 2014). For example, the establishment survey is usually conducted to focus on goods vehicle trips to/ from surveyed establishments while the commodity flow survey is mainly focused on detailed movement of goods flowing to/from establishments. Another example is the carrier survey, which can be used to understand the loading/ unloading activity and transfer of goods from the vehicle to establishment, but such observation is better dealt with using the driver survey (Allen et al., 2012).

Most of the self-completion surveys are done using post, fax, e-mails, online and in person by surveyors who will visit the respondents to collect the completed surveys. The vehicle trip diaries are usually conducted using the traditional self-completion questionnaires, with a reported response rate of about 30%, or the more costly method of having a surveyor to travel in the vehicles with the drivers (Allen et al., 2012). It is generally agreed that face-to-face surveys have a higher response rate compared to the various self-completion surveys but the cost and time consuming process per respondent may not be feasible for studies with limited budget. Notwithstanding the fact that some parts of our survey approaches will require self-completion, our reliance on various unobtrusive sensing technologies to collect data usually done face-to-

face, such as an on-board surveyor, will have added advantages in terms of accuracy, cost and time efficiency.

There are several papers and reports that covered the review of freight surveys conducted in different parts of the world, such as the UK (Browne et al., 2010), France (Guilbault and Gouvello, 2010, Ambrosini et al., 2010), Tokyo and Canada (Ambrosini et al., 2010). As an exhaustive review of all recent urban freight data collection efforts goes beyond the scope of this paper, we have limited our detailed reviews to the papers that are closely related to our research motivation and are grouped according to the geographical areas as follows.

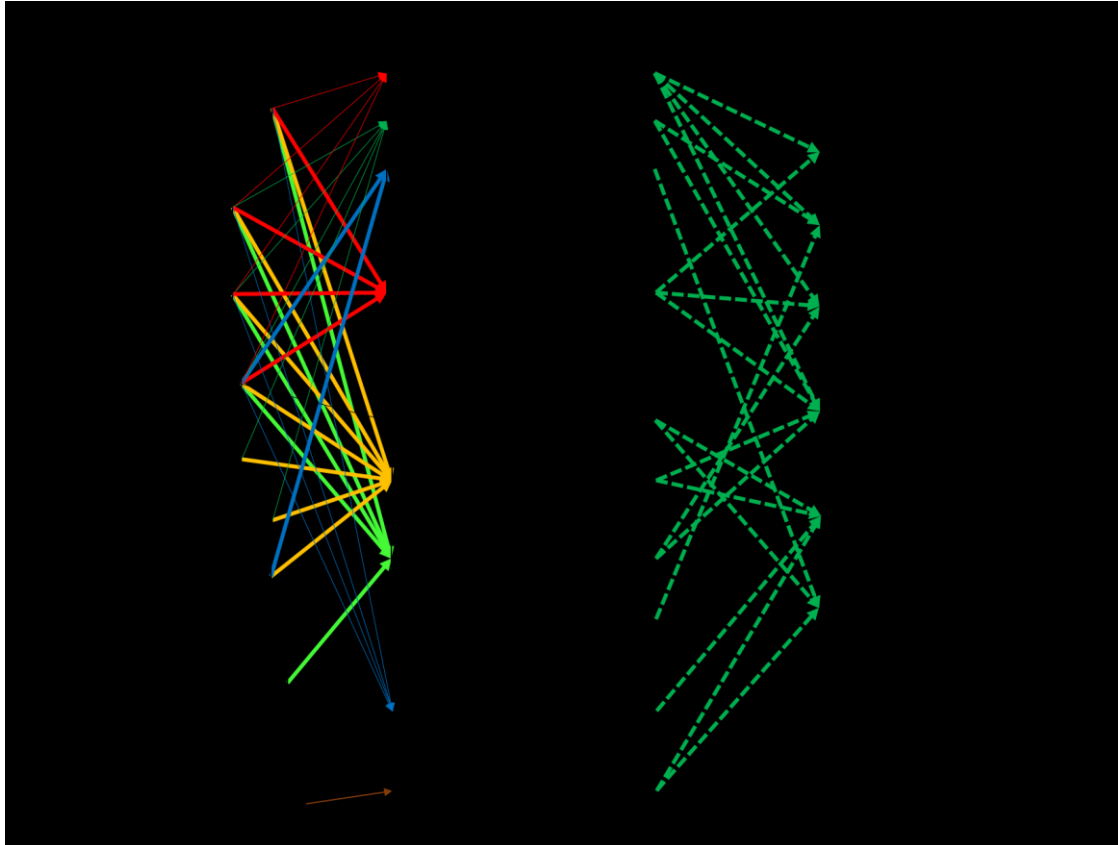


Figure 1: Data required from road-based urban freight surveys and methods of data collection

2.1 Europe

A recent relevant research group involved in data collection is the researchers from French Institute of Science and Technology for Transport, Development and Networks (IFFSTAR) at University of Paris-Est, in Paris, who are members of the MetroFreight consortium, a Volvo Research and Educational Foundations Centre of Excellence established in 2013 (<http://www.metrotrans.org/metrofreight>). Although its primary objective is urban freight research, education and outreach, a solid effort in data collection has been launched. Following an earlier design implemented during the 1990s in Marseille, Bordeaux and Dijon, a new urban freight survey, developed by the French Laboratory of Transport Economics (LTE), was recently implemented in Paris from 2010 to 2013. The aim of these surveys is to understand the relationship between the spatial and economic activities of the establishments and the operations

of transport such as vehicle choice, routing and scheduling. The final indicators on the logistics behaviour of the shippers, drivers and carriers obtained were used to support the ongoing development of the FRETURB software to estimate the demand of goods transport, road occupancy and environmental effects due to freight policies (Routhier and Toilier, 2007). This large effort was composed of three distinct surveys: an establishments survey, a delivery truck drivers survey and major transport companies survey. The final one is a survey of 100 main transport companies in the Paris region and it describes the business activities, the supply-chain of the organisation and the frequency of deliveries. The establishment survey follows a first characterisation of the establishment, in terms of storage, parking, urban environment and number of visiting vehicle. The survey itself is based on a logbook handed to the establishment, so that they can describe all the operations of delivery and pickups. Every time a driver delivers and/or picks up items from the surveyed establishment, the surveyed person of the establishment will pass a detachable sheet of paper from the logbook to the driver. The drivers would fill in their itineraries, cargo, deliveries and pickups, and mail back the form to the LTE. GPS tracking of the driver were also carried out along with the drivers survey, with an on-board investigator. The collected data represents the most comprehensive data collection so far, and is currently under analysis by the MetroFreight researchers to estimate origins and destinations of freight flows with a probabilistic model. Following this effort, other similar data collection methods are being designed for Los Angeles, New York, and Seoul, along with freight specific policy design case-studies (such as the use of bicycles for goods movement in Paris or the elimination of trucks for the collection of municipal solid waste).

Also in Europe, the BESTUFS project (BEST Urban Freight Solutions, <http://www.bestufs.net/>) is one of the well known European projects on urban freight. It included urban freight data harmonisation and published a Good Practice Guide on Urban Freight available in 17 European languages (Bestufs, 2008). This project has helped organise and compare existing urban freight data and methodologies have started to converge. The U.K. government for example has promoted "Freight Quality Partnerships" in all large British cities.

In Lisbon, Portugal, an establishment survey was carried out in 2013 to estimate the number and pattern of deliveries for urban retail establishments, with insights into the practical challenges of survey implementation (Alho and Silva, 2015). As with many establishment surveys, a stratified sampling methodology was applied. While the researchers attempted to explore the category, size and location of establishments, size was eventually not considered in the stratification process due to lack of data. A web-based self-completion survey method suffered poor response rate and was replaced with face-to-face interview, which saw better success.

In Rome Italy, traffic counts, an establishment survey and a truck driver survey were done in 1999 and 2008, the latter being used to monitor the effects of freight traffic regulations implemented in 2001. The study area focused on the retail and food service establishments located in the inner city of Rome while the study area for truck driver surveys was done in the trading area that is mainly affected by the attraction freight flows. The surveys were subsequently used to build a freight model aggregated at the zone level (Nuzzolo and Comi, 2014).

Although the freight data collection activities are spreading across Europe, these efforts lack for a consistent design and implementation towards a periodic data collection framework and its integration in modelling and simulation platforms.

2.2 North America

Researchers at the University of Illinois at Chicago conducted an online establishment survey at a national scale in 2011 (Mohammadian et al, 2013). The intent was to acquire information on individual shipments and firm logistics decisions, to facilitate behavioural microsimulation of freight flow in Illinois. More than 249,000 firms were contacted via mass e-mail, yielding 1,003 completed surveys and 1,844 individual shipment forms. This experience alludes again to survey recruitment difficulties.

Canadian establishment surveys have been conducted in Calgary in 2000 with around 3,000 business establishments, and Edmonton in 2001 and 2002 with around 4,500 other establishments. This effort is aimed at improving the knowledge of goods movement generation, distribution patterns, relations between vehicle movement and commodity movements, influence of employment size and type on commodity shipments. Information on the full range of commodities being transported by the surveyed business establishments was collected, together with description of vehicle movements arising with a transportation activity. An establishment-based process was implemented, similar to the household-based approach for personal travel surveys, along with shipper behaviour data (Ambrosini et al, 2010).

In Ontario, the province has significant experience in freight data collection in the form of roadside intercept surveys, establishment surveys, truck traffic counting, and vehicle surveys. Ontario's Ministry of Transportation carries out the Commercial Vehicle Survey (CVS), a province-wide roadside vehicle survey for heavy trucks only, approximately every five years since 1995 (Roorda et al, 2013). It was also part of the National Roadside Survey (NRS) conducted across Canada during 1999-2001, which uses a common method (HDR iTrans, 2010). The most recent CVS was conducted at about 150 roadside sites in the Province of Ontario in 2012. Truck drivers report on themselves, their vehicle, carrier and commodity, as well as their origin, destination and route. The survey was conducted by the surveyors using tablet applications with mapping capabilities to help the drivers with precise identification of their route, trip origin and destination. The CVS is estimated to capture about 75% of the vehicle-kilometers of truck travel on highways. Interview data from the CVS are expanded to reflect the seven-day continuous traffic vehicle classification counts that are collected at survey sites. Unfortunately, only trucks with a gross vehicle weight of 4,500 kg or more are sampled (Roorda et al, 2013).

More recently, the University of Toronto published a detailed recommendation for a coordinated urban freight data collection and data management plan for the Greater Toronto and Hamilton Area (Roorda et al, 2013). The intention of the proposed data framework was to facilitate performance measurement and modelling. At point of publishing details of the proposed data collection framework, a pilot survey of more than 1,000 establishments was conducted, collecting information about shipments, vehicle trips and tours. A response rate of 22% was achieved using a combination of online, mail-back and telephone survey methods.

The Canadian Vehicle Use Survey (CVUS) is another relevant data collection effort that is aimed to monitor how Canadians make use of their vehicles. The survey was done on the light trucks and vans that are less than 4.5 tonnes since 2011 and heavy-duty vehicles since 2013. It was reported that 80% of the Canadian fleet from 6 out of 10 provinces is covered as of April 2015. The participants are sampled quarterly and are monitored for 3 weeks using a data logger (CAD\$800/unit) with a touchscreen on which allows the driver to input information about each trip, reason for each stop, weight or volume of the cargo, commodity class, monitors the on-road fuel consumption and idling time (Ludmer and Allie, 2015).

2.3 Asia

The Korea Transport Institute (2011) surveyed the locations of freight terminals and main depots and their corresponding service areas for the four major parcel companies providing services for Seoul. The survey tells that the geographical characteristics of local terminals and depots as well as the size of their service areas determine what kind of transportation networking strategy the company employs (KOTI, 2011).

The Tokyo Metropolitan Freight Survey (TMFS), conducted in 2003 by the Tokyo Metropolitan Region, consisted of three surveys: a questionnaire survey to logistics establishments (30,000 respondents from about 120,000 questionnaires mailed out) about their facilities' daily commodity flows and logistics activities; a questionnaire survey about the routes of large size truck drivers; and a local delivery survey of loading and unloading activities in five Central Business District (CBD). The survey was used to support policies on the relocation of logistic facilities, on the location of local delivery facilities, on the redesign of the road network for large trucks and to promote effective loading and unloading tasks in the CBD (Hyodo et al., 2007, Shimizu et al, 2007).

Freight data collection in Singapore is limited and the last known establishment survey is conducted by Nanyang Technological University between 2001-2002 with the help from Land Transport Authority, International Enterprise Singapore and Infocomm Development Authority (<http://www3.ntu.edu.sg>). The establishment survey is conducted using traditional manual surveys to collect company information, goods vehicle movements and the companies' views on the impacts of traffic management schemes on their businesses. It was reported that out of the 500 companies targeted, only 80 companies (16%) responded.

As reported in a few studies available in the literature – see for instance the recent review by Gonzales-Feliu et al. (2013) – main challenges to be faced in tracking urban freight related vehicles are: lower GPS data quality, mainly due to the interferences of the urban environment (e.g. tall buildings and narrower streets); shorter stop durations, also likely to be confounded for instance with stops related to queuing at traffic lights stops and/or to congestion; a denser road network, with additional challenges for the map matching of GPS traces; larger number of origins and destinations, resulting in complex and heterogeneous tour patterns. Recent insights on these issues are reported in the papers by Camargo and Tok (2014), dealing with the validation of trucks route choice enumeration algorithms using GPS data; Sturm et al. (2014), providing a GPS and driver log-based survey of grocery trucks in Chicago; Yang et al. (2014), dealing with enhancement of stop identification.

3. Proposed freight data collection approach

3.1 General framework

The main goal of conducting the integrated freight surveys is to develop a proof-of-concept of a coherent, scalable and holistic collection of all freight data (production, logistics, transport) with the aim of tracking vehicles and shipments and for surveying relevant freight agents, leveraging state-of-the-art sensing technologies and approaches. The general framework for the proposed freight data collection with their group of survey methods and associated technologies is shown in Figure 2.

The fusion of the commodity chain sensing (CCS) data collection efforts has been targeted to:

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- i. collect all needed data/information for the generation of the entire population of freight agents (establishments, retailers, end-consumer, transport providers, etc.) for statistical and modelling purposes;
 - ii. collect network-wide commercial vehicle flow measurements, where our team has carried out a feasibility study to derive traffic counts and vehicle classification from traffic camera images or videos. Such data will allow us to determine partial o-d observation through automatic identification of vehicles at different locations and the calibration of estimated vehicle flows;
 - iii. collect detailed operational high-resolution data, with a feasibility study for camera and sensor-based observations and driver interviews at loading/unloading bays;
 - iv. implement innovative truck drivers' surveys using tablets on-board the vehicles, coupled with GPS and On-Board Diagnostics (OBD) technologies plus vehicle telematics for real-time analysis;
 - v. collect detailed driving cycle and vehicle performance data including instantaneous fuel consumption, engine rpm, air intake temperature, etc, collected within the logger-based truck drivers survey by introducing OBD devices. This additional information enables one to gain insight on fuel use, emissions, and truck idling.

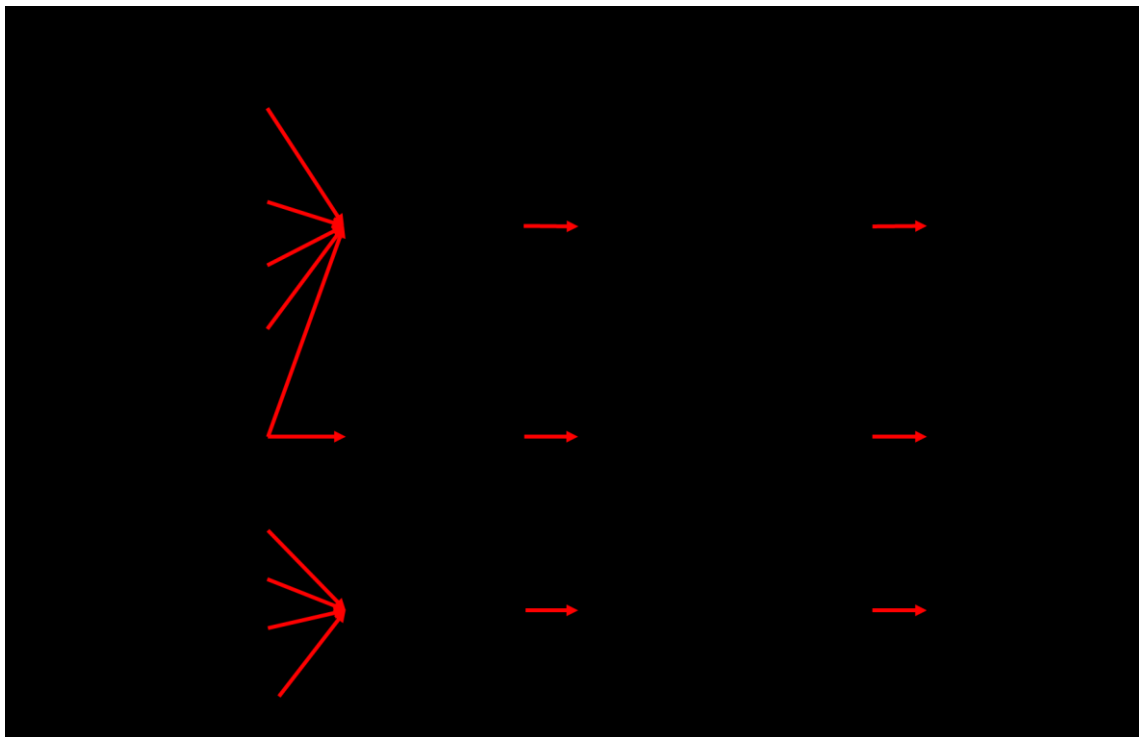


Figure 2: General framework of proposed freight data collection framework

Integration between the freight movement surveys and truck/ driver surveys and sensing technologies will be pursued through the general structure of the proposed tools depicted in Figure 3.

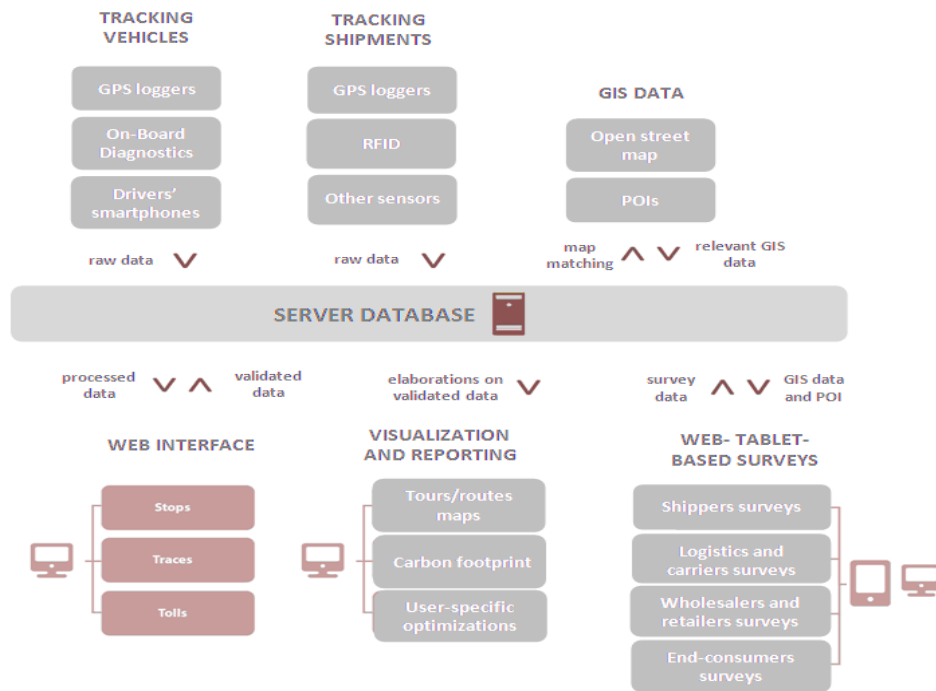


Figure 3: Integration of technologies for the freight movement surveys and truck/driver surveys

3.2 Sampling frame and design

Acknowledging that a good sampling design is important to ensure that the surveys for different freight activities are adequately represented and to ensure that the commodity flows can be traced to the final destination, the purpose of the proposed sampling frame and design is to integrate the surveys and link the agents involved in handling the shipment in a “snowballing” process as shown in Figure 4. The survey area of Singapore is first divided into the planning zones as shown in (1). The planning zones have been used by the Singapore Urban Redevelopment Authority (URA) to facilitate urban planning and each of this zone has a population of about 150,000 (www.ura.gov.sg). In process (2), the sampling frame for the establishments (supplier, wholesaler, manufacturer and retailer) is taken from the list of Singapore-based firms registered with the Accounting and Corporate Regulatory Authority (ACRA) that are related to the list of freight activities (e.g. manufacturing, retailing, wholesaler, etc.). The sampling frame for the construction sites will be based on the existing actual sites during the survey period.

The next step is to have a stratified sampling for each planning region as shown in (3). Firstly, the stratified sampling for establishments will be done based on industry type and company size (number of employees) (3a). This will be followed by the establishment survey, commodity flow survey and loading/unloading observations especially for retail malls. Among the questions asked during the establishment survey is the establishments’ associated customers and/or suppliers. The questions that are related to the inbound and outbound delivery/ pick-up and their associated logistics operators and carriers will also be surveyed. From the list provided by each establishment, a stratified sampling will be conducted for each of the establishment’s end-consumers based on industry type, employee/company size and household characteristics (3b) followed by conducting the end-consumer survey. The construction sites will be stratified

based on the size of the project and will also be handed the end-consumer survey to be completed. The establishments' associated logistics operators and carriers will be sampled based on the employee/company size followed by the establishment/commodity flow survey (3c) and carrier survey (3d) respectively.

The stratified sampling for shipment tracking will be conducted on each establishment's, logistics operator's and carrier's shipment based on the shipment size (3e). As mentioned by Mohammadian et al. (2013), several respondents failed to complete their surveys after the first shipment due to the survey length (that includes questions related to delivery/pick-up time, waiting time, shipment path, time of travel, etc.), which is usually unavoidable because of the shipment quantities. As much as we would like to track all inbound and outbound shipments, such shipment tracking process will be constrained by the availability of survey budget. Our proposed shipment tracking sampling will be used as a proof-of-concept for the technology that we hope will eventually replace the shortcomings of shipment surveys conducted in the past. Lastly, the driver/truck survey will be conducted using the stratified sampling of the truck fleet based on vehicle type for the establishments (for own trucks) and the truck fleet of their associated logistics operator or carrier (3f).

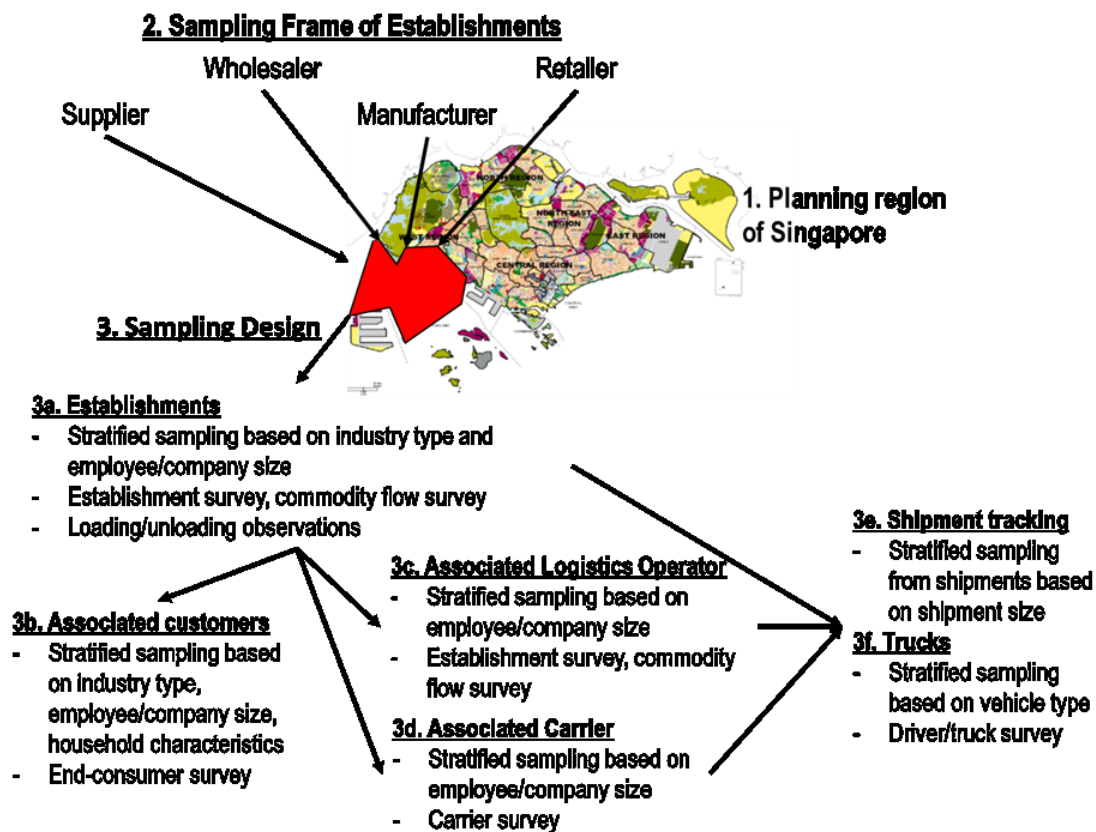


Figure 4. Proposed sampling frame and design

3.3 Commodity chain sensing technologies

In the passenger sector, a recent development in data collection has been proposed by the Intelligent Transportation System at the Massachusetts Institute of Technology (MIT) of

Boston (USA) in the form of the Future Mobility Sensing (FMS) framework (<http://its.mit.edu/fms>), developed and tested in the Singapore-MIT Alliance for Research and Technology (SMART) in Singapore (<https://happymobility.org>). The FMS concept combines various sensing devices (smartphones, GPS loggers) with machine learning techniques and validation surveys, revealing a lot of mobility behaviour unobtrusively and without effort from the respondents, and it has been proven to provide an innovative data collection framework for passenger surveys (Zhao et. al., 2015). Specifically, raw data from vehicles and shipments can be cleaned and map matched, and coupled with GIS-related information, e.g. point of interests (POI). This enables using machine learning algorithms that infer the user's stops and activities based on the collected data as well as contextual information such as POIs, user history, weather, incidents etc. The output of these algorithms is displayed in an easy-to-understand web-interface for the user to validate. The user validation is then fed back to the backend to refine the machine learning algorithms. Validated data allow for further personalised visualisations and elaborations (maps, fuel use and carbon footprint analyses) to be shared with survey respondents. The same system can also process all web-based and tablet-based surveys of all relevant freight agents (shippers, logistics operators, carriers, end-consumers), transmitting information from GIS sources to the surveys and collecting back GIS-located survey data.

4. Preliminary experimentation of technologies and evaluation

The project is in its implementation stage, and some of the proposed approaches are under testing. Promising results have been already achieved, and some of them with specific reference to the capability of unobtrusively collect a wealth of valuable information, leading to better quality and quantity of data for understanding the behavioural logistics and transport decisions to develop freight demand microsimulation models. The completed activities include:

- i. observations at loading/unloading bays in Bugis and Orchard, two central shopping and business districts in Singapore;
- ii. a pilot of a combination of tablet-based and traditional surveys, investigating both within-mall and outside-mall retailers, with 210 tablet-based pilot surveys in Spring 2014 in commercial districts and 555 surveys in Summer 2014 island-wide;
- iii. an urban truck route choices study, aiming to track a variety of commercial vehicles with more frequent stops and more diverse activities.
- iv. on-board diagnostics devices (OBD), which aims to monitor vehicle drive cycle and engine parameters

The results from the completed activities contributed to the preparation of the sampling frame and design in the context of Singapore, for example the knowledge of various sizes of the food businesses that may have implications to the frequencies of deliveries. The results from a truck route choices study provided inputs for improving the technical aspects and user-interface of the system to conduct the driver survey in Singapore. In addition to the driver survey is the use of on-board diagnostics devices, which are ready to be integrated within the CCS framework. The following sub-sections describe the details of the completed activities.

4.1 Un/loading bay observations

This study is conducted to collect information related to the delivery data such as product type, number of workers, purpose of trip, size and quantity of commodity delivered/picked-up, arrival and departure time, vehicle type and surveys with drivers using tablet-based questionnaires. The peak arrivals for this particular un/loading bay at a retail mall, Bugis Junction, are observed to be during the late morning and mid-afternoon at 11am and 3pm respectively as shown in Figure 5. It was noted that deliveries of fresh food and other food products start early in the day such as 6am and other products such as pharmaceuticals and fashion apparels are delivered only from 10am onwards. It appears that food has to be delivered for preparation early in the day even before the mall starts operation, whereas other products are delivered only when the shops are open.

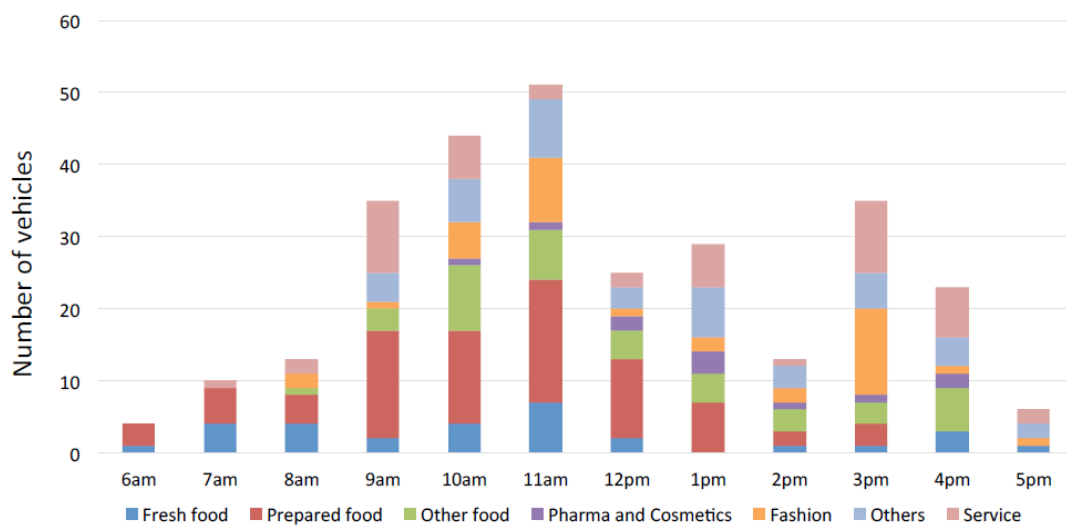


Figure 5: Hourly arrivals by type of commodity at Bugis Junction (data collected on April 2014)

4.2 Tablet-based and traditional retailer surveys

The retailer survey asked questions on two levels, the first level was establishment specific characteristics, such as the establishment area, number of employee, total number of supplying sources and the total delivery frequency; on the second level, the questions were the supplying source type, the product mix, the quantity, delivery frequency and time of delivery of the most recent delivery. By asking questions on two levels, it is possible to analyse delivery patterns at different units of analysis, namely, establishment, receiver-shipper, and delivery (for details on the surveyed establishments and method the reader is referred to Lee, et al., 2015).

Preliminary analysis (Table 1) showed that on average cosmetics and fashion apparel establishments receive much fewer deliveries than other stores such as food retail and service, and pharmacies. Pharmacies are usually franchise, and they receive many small deliveries from wholesalers and distributors and a few large deliveries from their own warehouses. Food services require many deliveries in general, and small businesses (Food court) would receive more small deliveries from a more fragmented channel consisting of wholesaler and other stores, while large businesses (Formal food service) receive bigger deliveries from their own warehouses. There is an indication that the larger the company, the more likely they would consolidate deliveries within the company.

Table 1: Delivery frequency and size by industry and supply source

	<i>Cosmetics</i>	<i>Accessory Store</i>	<i>Apparel Store</i>	<i>Food Court</i>	<i>Formal Food Service</i>	<i>Food Retail</i>	<i>Pharmacy</i>
<u>Another store</u> Count	0	0	3	8	3	0	0
Avg. frequency			Once a week	Multiple times a week	Multiple times a week		
Avg. size			1x1x1m ³	.5x.5x.5m ³	1x1x1m ³		
<u>Wholesaler</u> Count	6	1	11	35	87	18	11
Avg. frequency	Once a week	Once a week	Once every two weeks	Multiple times a week	Multiple times a week	Multiple times a week	Multiple times a week
Avg. size	.5x.5x.5m ³	1x1x1m ³	1x1x1m ³	.5x.5x.5m ³	1x1x1m ³	1x1x1m ³	.5x.5x.5m ³
<u>Manufacturer</u> Count	3	1	27	14	32	8	5
Avg. frequency	Once every two weeks	Once a week	Once a week	Multiple times a week	Multiple times a week	Once a week	Once every two weeks
Avg. size	.5x.5x.5m ³	.5x.5x.5m ³	1x1x1m ³	.5x.5x.5m ³	1x1x1m ³	1x1x1m ³	.5x.5x.5m ³
<u>Corporate warehouse</u> Count	22	8	118	5	68	15	15
Avg. frequency	Once a week	Multiple times a week	Multiple times a week	Multiple times a day	Multiple times a week	Multiple times a week	Multiple times a week
Avg. size	1x1x1m ³	.5x.5x.5m ³	1x1x1m ³	1x1x1m ³	1x1x1m ³	1x1x2m ³	1x1x2m ³

4.3 Urban truck route choice study

This survey is based on the truck route choice study conducted in the US in an intercity context (<https://truckers.mit.edu>). The data collection system developed is a combination of a GPS logger fitted in a driver's truck with a web-based survey. The GPS logger is able to collect data continuously on the location and movement of the truck and transmit the information using wireless communication networks to the research centre's server. At the server, algorithms are applied to match the observations to road segments on a GIS database map. Further algorithms are then run to identify stops made by the truck drivers, as well as points of interest passed during the trip. The processed information is shown to the participants using dedicated personal webpages. The truck drivers are asked to log in to these webpages in order to validate and correct the information on their movement and to provide additional information that could not be inferred from the location information (e.g. pick-up and delivery schedules for loads, tolls and their

methods of payment). The web interface may also be used to administer various questionnaires soliciting additional information not directly related to the location data.

This study revealed significant variability in driver tour patterns and route choice behaviour. The system has been adapted to urban freight environment aiming to track a variety of commercial vehicles with more frequent stops and more diverse activities. The main challenges that need to be addressed are lower GPS data quality, shorter stop durations, denser road networks, and large numbers of origins and destinations. New questionnaires have been designed to cater for the modelling needs for urban freight, and technical feasibility of the system has been studied through a small pilot test in Singapore. An example of the truck driver survey is shown in Figure 6.

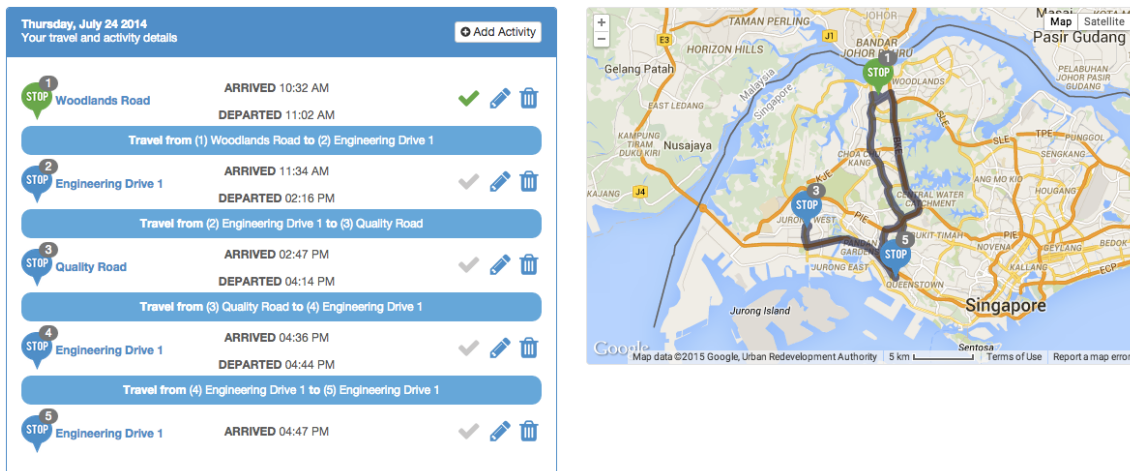


Figure 6: An example of the truck driver survey in Singapore

4.4 On-board diagnostics devices

In addition, we are extending the logger-based truck drivers survey with the use of OBD devices, which can capture more detailed information of the vehicle drive cycle and engine parameters, including fuel consumption, engine rpm, air intake temperature etc. This additional information enables us to gain insight about fuel use, emissions, and idling behaviour, and supplements the collection of GPS data. Some of the sample results, i.e. parameters logged and idling observed, are shown in Figures 7 and 8.

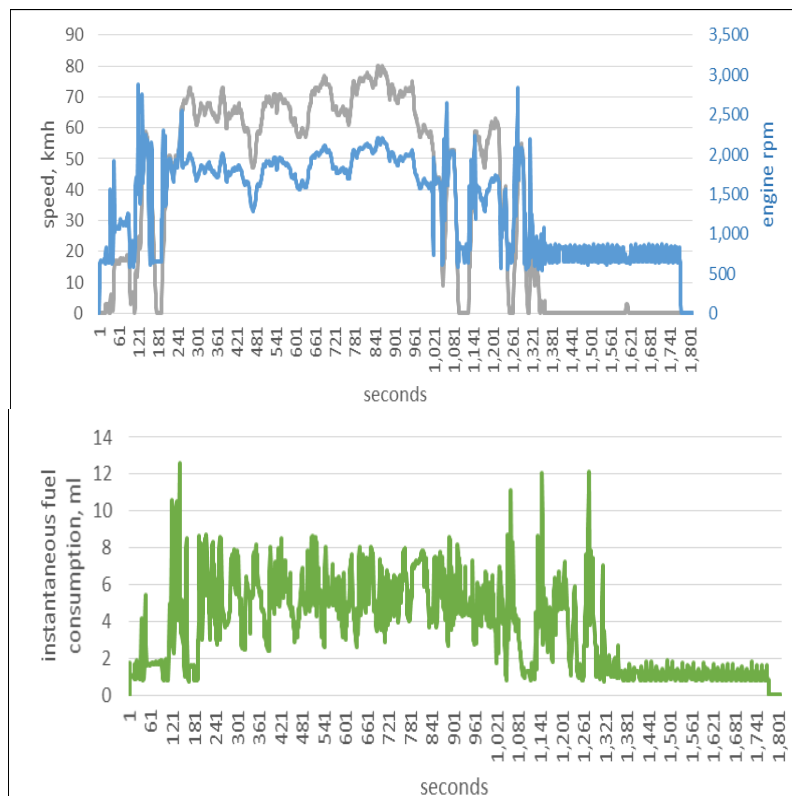


Figure 7: Select parameters logged using an OBD device for a single truck trip sample. Engine idling (engine rpm > 0) is captured at the end of this trip.

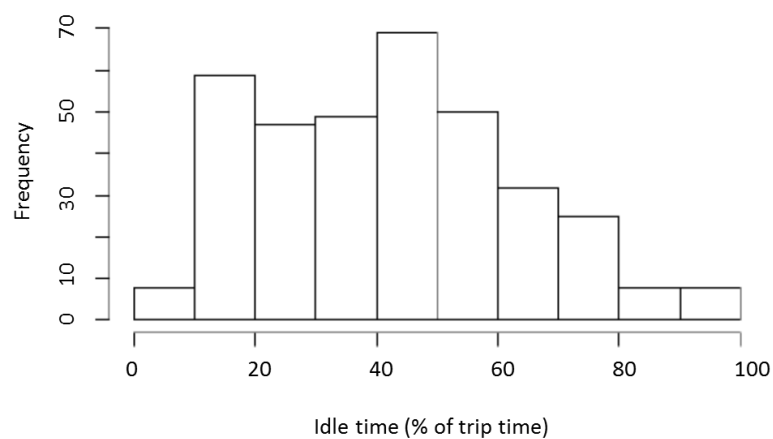


Figure 8: Distribution of idling time as a percentage of trip time for a sample truck tracked in an urban environment over 30 days. A significant amount of idling was observed – an average of 42% of trip time and 15% of fuel use was consumed while the truck was idling.

Focusing on the Singapore context, the ongoing research designs and demonstrates scalable collection of high-resolution data on freight agents' behaviours/choices and freight movements, not captured through traditional surveys, leading to integrated knowledge of logistics and transport characteristics of shipments. It sets the foundation for continued freight data

collection to better understand long-term trends in city-scale commodity flows and urban goods movements.

5. Conclusions

This paper has reviewed the past efforts in conducting freight surveys and agree with several of the researchers that there are existing data gaps to address such as supply chain as a whole, geographical data about goods vehicle trips in urban areas, speed and route data for goods vehicles (Allen et al., 2014). Several of the experiments and IT applications (limited to web-based surveys and GPS), are available to collect more attractive data set for specific surveys (Patier and Routhier, 2008). Building on the survey methods and technologies developed in the past, this research proposed an integration of the establishment survey, commodity flow survey and carrier survey termed as “Commodity Chain Sensing” (CCS), along with truck/driver survey, using innovative and state-of-the-art future mobility sensing (FMS) based sensing devices coupled with GPS loggers and OBD devices, and tag-based tracking for shipment tracking. The main aim is to collect quality freight movement data in a cost-effective and unobtrusively manner to help public and private sector decision-makers to address issues related to road space allocation, congestion, energy consumption, environment, safety, security issues that are closely linked to freight matters and land use planning. The data collected will also help in modelling logistical behavioural models that is planned to advance the capabilities of existing simulation frameworks for multi-modal passenger travelling decisions such as SimMobility (Lu et al., 2015).

The description in this paper is the initial step to explore new ways of collecting freight data either at a national level or urban level. We foresee that our approach for conducting the freight surveys will lead to the advantages of less labour intensive needs to verify and process data and such surveys can be repeated easily and cost effectively. However, we also acknowledge that the likely negative impact is the time required for responders to be familiar with the technology, which may delay the implementation of a large-scale survey.

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