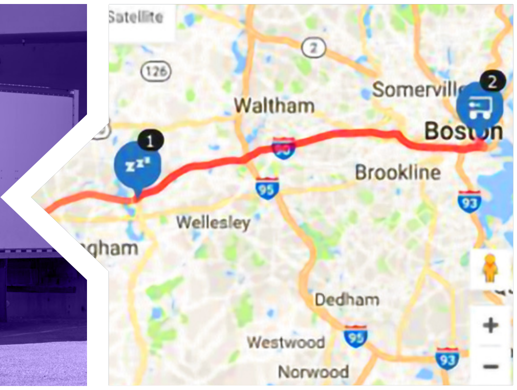
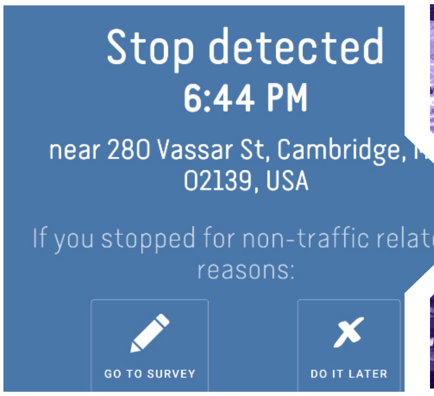
EXPLORATORY ADVANCED RESEARCH

Exploratory Advanced Research Program

Integrated Data Collection Method for Tracking Freight Movement

RESEARCH SUMMARY REPORT

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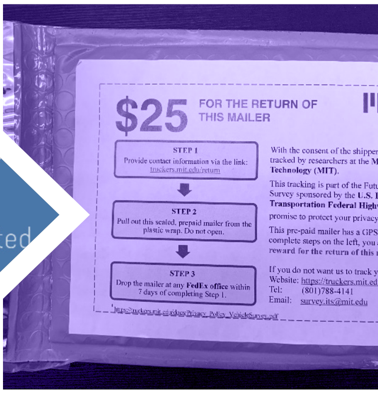
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16. Abstract

This research summary report describes research carried out to develop an integrated survey methodology and instrument to support the collection of freight movement data. The researchers leveraged the Future Mobility Sensing (FMS) framework, which combines tracking and sensing data with machine-learning algorithms on the back end and user participation to convert raw passive tracking data into processed and verified data. The researchers conducted case studies in each of three phases of the project to test the FMS system with vehicle tracking, shipment tracking, and an integrated test to track both vehicles and shipments together. The project served as a proof of concept that new and emerging technologies can overcome some of the existing challenges to freight logistics data collection.

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Freight, logistics, Future Mobility Sensing, FMS, commodity flow survey, mobile sensing, machine learning

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SI* (Modern Metric) Conversion Factors

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	654.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	millimeters	mL
gal	gallons	3.785	meters	L
ft^3	cubic feet	0.028	meters	m^3
yd^3	cubic yards	0.765	kilometers	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9	Celsius	°C
		or (F-32)/1.8		
		ILLUMINATION		
fc	foot-candies	10.76	lux	lx
ft	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

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m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yard	yd^2
ha	hectares	2.47	acres	mi
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	mililiters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candies	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	ft
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

Table of Contents

List of Figures

List of Tables

Introduction

Understanding and predicting shipping logistics is an essential consideration for planning infrastructure investments for the safe, efficient, and economical movement of freight. Freight flow data that can describe the routing of freight-carrying vehicles and the commodities being carried are lacking. The shortfall of freight flow data is not surprising, given the inclusion of proprietary business-sensitive information and the cumbersome, labor-intensive, and costly nature of the data collection process. This research summary report provides an overview of a project researchers conducted to investigate data collection techniques that can overcome the limitations of current freight survey methods. Gaining access to these data would expand understanding of how freight moves now and may help predict how it might move in the future.

Many challenges exist when it comes to freight flow data collection. One is the number of people—including consumers, shippers, commercial freight operators, and truck drivers—whose behavior impacts the demand on and efficiency of the freight transport system. Second is the proprietary nature of some data related to vehicle movements and economic data regarding the freight being shipped. Existing Government data for freight vehicle movements are separate from commodity flow, making it challenging to combine the two. The Government data also contain limited temporal and spatial details. Although researchers have undertaken many projects using Global Positioning System (GPS) data, these data alone are passive and do not include the knowledge and behavior of the different agents along the supply chain.

To address the need for better freight flow data collection, the Federal Highway Administration's (FHWA's) Exploratory Advanced Research (EAR) Program supported a project that used innovative technologies to collect data on freight movement to enhance understanding of the supply chain. A research team at the Massachusetts Institute of Technology (MIT) undertook the project, "Future Freight and Logistics Survey: Integrated Data Collection Using Mobile Sensing, Wireless Communication, and Machine Learning Algorithms," to identify and resolve inherent challenges in developing a complex freight demand modeling framework.

The researchers investigated the feasibility of commercially available technologies for tracking vehicle and shipment movements using smartphones, tablets, GPS loggers, mobile sensing, radio frequency identification (RFID), and wireless communication technologies. Based on this investigation's findings, the researchers developed innovative survey and visualization tools, integrated the Future Mobility Sensing (FMS) framework with freight flow data and modeling tools, and conducted case studies to test the feasibility of using the new technologies for data collection. Throughout the project, the researchers took steps to protect sensitive business information and minimize the data reporting burden on participants. The research served as a proof of concept that new and emerging technologies can be used to overcome some of the existing challenges of freight logistics data collection.

Based on their experience with this project, the researchers recommend conducting future studies as new technologies emerge. These studies could address the challenges faced in this project, including the burden on participants to verify information, participant recruitment, and partial visibility and knowledge among shipping agents along the supply chain. The researchers suggest that FMS could be used to track shipments that travel by rail, air, or water or those shipped across multiple modes. The researchers also identified potential FMS applications for public agencies, such as supplementing commodity flow surveys by collecting verified shipment GPS traces, mapping commodity flows to vehicle flows, furnishing detailed freight flow data for behavioral modeling, and providing an analytical tool for logistics performance.

Project Overview

Existing freight flow data models do not provide an adequate understanding of how transportation policy, planning, and operations impact business, from warehouse location to routing to delivery times. The researchers leveraged FMS to develop an integrated freight survey methodology and instrument to collect vehicle and shipment movement data to create a more thorough picture of freight logistics.

The project focused on overland freight transport, specifically freight carried by trucks in different environments (e.g., rural, urban, intercity, and interstate), and included three phases. In phase 1, the researchers developed and implemented a survey methodology and instrument for truck drivers to examine vehicle movement using GPS tracking and web-based surveys for data verification. Phase 2 tracked outbound, taggable shipments from business enterprises that operated their own in-house truck fleets. The researchers used the phase 2 survey to test the feasibility and scalability of the proposed survey methodology tool. In phase 3, the researchers applied lessons learned from phases 1 and 2 to pilot an integrated freight survey that collected data jointly on vehicles and shipments. Throughout the project, the team employed smartphones/tablets and GPS loggers for tracking vehicles and shipments, algorithms and machine learning for the backend server data processing, and a modular structure for the user interface that allowed surveys to be conducted independently or jointly.

Detailed and specific information on routes, travel times, and arrival/departure times is difficult to obtain through traditional means due to the intricate and lengthy collection process. GPS overcomes these issues by collecting these detailed data in a passive, minimally burdensome, and nonintrusive way. By combining the passive GPS location data with machine-learning algorithms to obtain processed data and participant verification to fill in gaps, the researchers built a more complete picture of freight logistics.

Survey Instruments

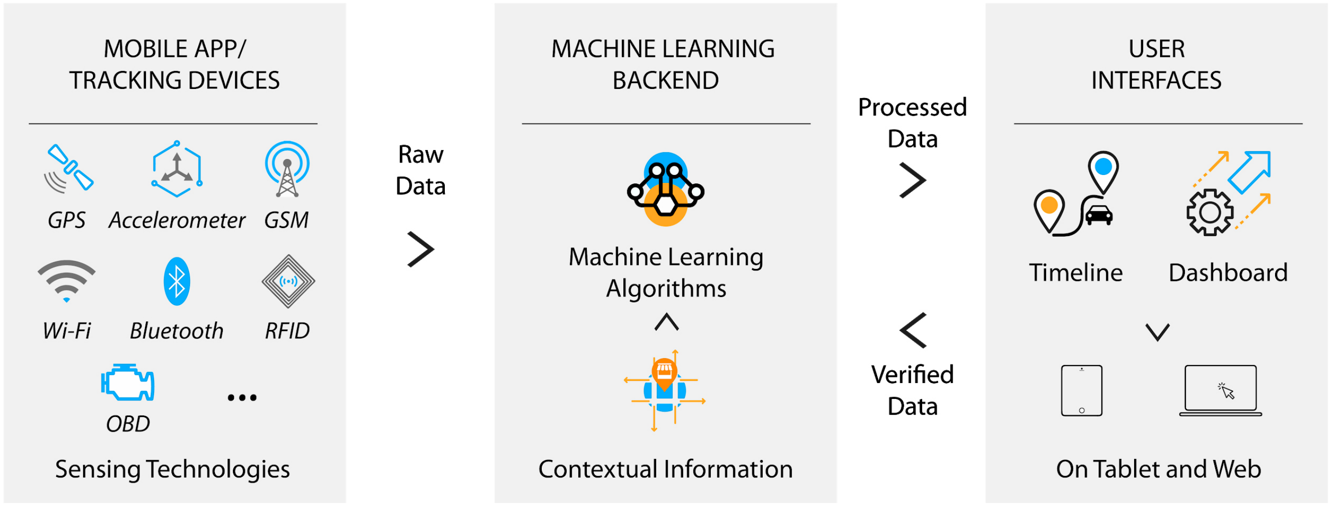
The project team employed FMS as the underlying technology for the survey instrument. FMS is a data collection and visualization platform. The FMS framework consists of the following components, which work together to build a comprehensive picture of freight movement data (figure 1):

- Mobile application or tracking devices (e.g., GPS logger or smartphone/tablet application) that use sensing technologies to track and store data.
- Backend server system where collected data are sent for postprocessing based on different machine-learning algorithms that fill in gaps in the raw GPS data, such as map matching—a process of determining the movement of a vehicle on a digital map with road networks based on a sequence of GPS coordinates—and stop detection.
- User interfaces, both mobile and web-based, that present processed data to the user for verification.

In addition, user-verified data are fed to the machine-learning backend to ensure the data are as complete as possible.

FMS provides better quality data (including geographic and temporal dimensions), a larger volume of data, and greater supply chain visibility than other previously tested methods. For example, the Canadian Vehicle Use Survey employed GPS devices to collect trip and stop information in combination with operational information collected from the drivers through a

Figure 1. Chart. FMS platform architecture.



© 2018 MIT Intelligent Transportation Systems Lab. Reused per data rights under FHWA-funded DTFH6115C00033, *Future Freight and Logistics Survey: Integrated Data Collection Using Mobile Sensing, Wireless Communication and Machine Learning Algorithms: Final Deliverables*, on page 108. Adapted from You et al. 2018.
GSM = Global System for Mobiles; OBD = onboard diagnostics.

user interface (Allie 2014). The researchers took the investigation further by gathering data from multiple sources and presenting them in intuitive and interactive dashboards that summarized the statistics and data analytics from the processed data.

As the project progressed, the researchers built on the knowledge gained from each previous phase. For phase 2 of the project, FMS was extended to track shipments in a platform called FMS-Freight. FMS-Freight included the investigation of sensing technologies for tracking shipments, geographic information systems data, and carrier data. FMS-Freight collected and processed survey data about trip information from businesses based on their role(s) in freight movement (i.e., shipping, receiving, and/or transporting), associated shipments, and vehicle operations.

FMS-Freight followed the same data progression as the FMS platform. Raw sensor data were collected primarily through GPS, positioning from cellular phone service, and accelerometers. The collected data were then processed by machine-learning algorithms that detect shipment stops and infer stop activities and travel modes. The researchers provided shippers with a web-based, user-friendly interface to review shipment timelines and provide additional information in response to survey questions.

Timeline
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11:45 PM (10 days before)
Cambridgeport,Albany Street,Cambridge,USA
11:03 AM
(missing information - tap to edit)

Data Collection and Pilot Studies

The project team undertook three pilot studies to test the survey instruments. The phase 1 study surveyed freight vehicle drivers to understand their routes, stop sequences, and parking choices as well as any incidents they encountered. In phase 2, the research team designed a shipment survey methodology targeted at businesses with outbound, taggable shipments to collect data at the path-based and origin-destination levels. In phase 3, the researchers conducted an integrated survey that collected freight vehicle and shipment data jointly using the same FMS framework used in the earlier phases.

In each phase, a holistic approach was used to gather as much relevant data as possible, with GPS loggers tracking vehicle movements and other technologies gathering shipping data, smartphone/tablet and web applications used to input user data, and backend algorithms processing the data. The holistic approach is adaptable to different situations, locations, questionnaires, and more. Data are integrated across all entities, and assisted machine learning is applied to raw GPS data. Table 1 shows the holistic approach applied to the surveys.

Table 1. Overview of the holistic approach for next-generation freight surveys.

Type	Holistic Framework	Unified Technologies
Entity	**Methodology**	**Survey Instrument**
Carriers/drivers/vehicles	• Sampling frame and design. • Self-administered or face-to-face questionnaire. • Data integration. • Validation.	• Tracking device: GPS, OBD, smartphones, tablets, passive observations, big data. • Backend server. • User interface: web based, smartphones, tablet.
Shipments	• Sampling frame and design. • Self-administered or face-to-face questionnaire. • Data integration.	• Tracking device: GPS, GPS + GSM, RFID, Bluetooth. • Backend server. • User interface: web based.

GSM = Global System for Mobiles; OBD = onboard diagnostics.

Phase 1: Survey of Truck Drivers

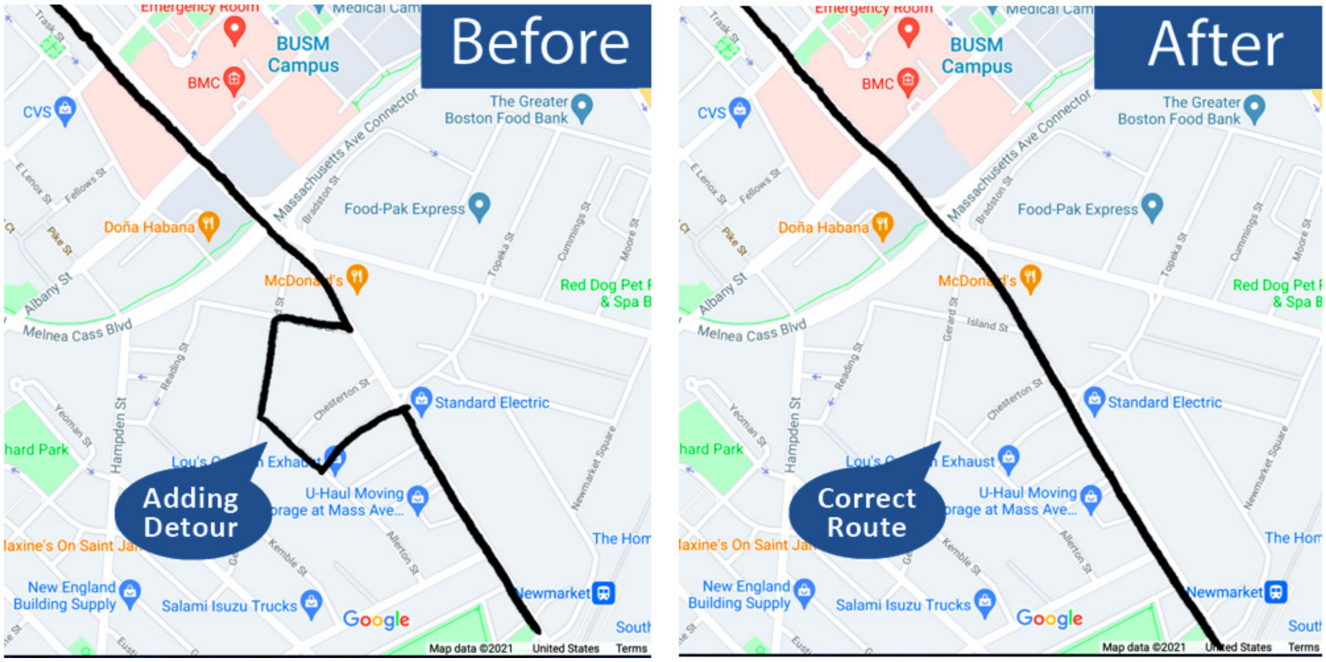
To demonstrate the applicability and value of FMS, the team conducted a small-scale pilot study in intercity and urban areas near Boston, MA. The researchers recruited 28 drivers, and 18 of them completed the necessary tasks. The FMS framework processed the GPS data from each vehicle with the map-matching algorithm. Map matching makes improvements such as removing false stops (e.g., waiting at traffic signals) and adding missing stops through user validation. FMS also generated the dynamic shortest paths where data were missing. Figure 2 shows a case where map matching generated an incorrect detour when applying the shortest path algorithm. These incorrect detours may occur due to low GPS accuracy or shorter estimated travel times. FMS pulled additional data from the vicinity to include in the map-matched route and revise the shortest path algorithm.

During the pilot, the drivers responded to daily surveys about each stop visualized on the website. The drivers were asked about the purpose of the stop and the amount, type, and value of shipments delivered or picked up at each stop. The survey also asked drivers about the location of parking, reasons for choosing a parking place, and other parking-related questions.

If any incidents (e.g., planned special events, vehicle crashes, work zones, detours) altered drivers' routes or stops, the drivers were asked to pinpoint the location on the map and input the start time and end time of incidents. The end-of-day driver surveys revealed incidents that would not have previously been known with the use of traditional data collection methods.

The researchers analyzed both the raw data and the survey responses in terms of driver characteristics, vehicle characteristics, vehicle operations, typical cargo characteristics, frequent places, stop survey results, and end-of-day survey results. The survey provided comprehensive insights into freight activity and driver behavior. Data of this nature add more behavioral realism to transportation models and other types of analyses.

Figure 2. Maps. Map matching improvement example, including incorrect detours.



Original map © 2016 Google® Maps™. Map annotations by MIT to show an incorrect detour created by the map-matching algorithm and the results after applying the shortest path algorithm.

Phase 2: Survey of Freight Shipments and Shippers

In phase 2 of the project, the research team investigated methods to include shipment transport legs and transshipment locations. By using FMS-Freight, the research team set out to gather high-resolution shipment data from business establishments where the shipments originated to the end receiver destinations. The survey included GPS data on shipments, web-based surveys for data verification, and machine learning. The researchers refined the stop-detection algorithm to compensate for sparse GPS data locations collected. The researchers added mode detection algorithms to track shipments that traveled by truck and then by airplane and activity inference algorithms to reduce participant burden. These algorithms accounted for differences in stop activities and multimodal transport with respect to vehicle tracking. The researchers also revamped the user interfaces to include data analysis and a visualization tool or dashboard. The online dashboards were meant to appeal to businesses and encourage them to participate in the pilot study because the dashboards provide valuable, easy-to-access information about the shipper's performance.

The researchers recruited business establishments with outbound taggable shipments (e.g., electronic equipment, flowers, and printed materials). The survey collected information related to the establishment, historical shipments, tracked shipments, and user-verified shipment traces. Six businesses in Massachusetts and 57 shipments were successfully tracked and verified. Each business designated a shipping/logistics manager (SLM) to provide shipment information. A GPS device was then attached to each shipment in a tracking mailer. The web interface displayed the shipment's journey as tracked by the GPS devices, and the SLM completed shipment verification (e.g., stop activity) after the shipment was delivered.

The survey demonstrated the feasibility of collecting shipment data, an important component of freight planning and modeling.

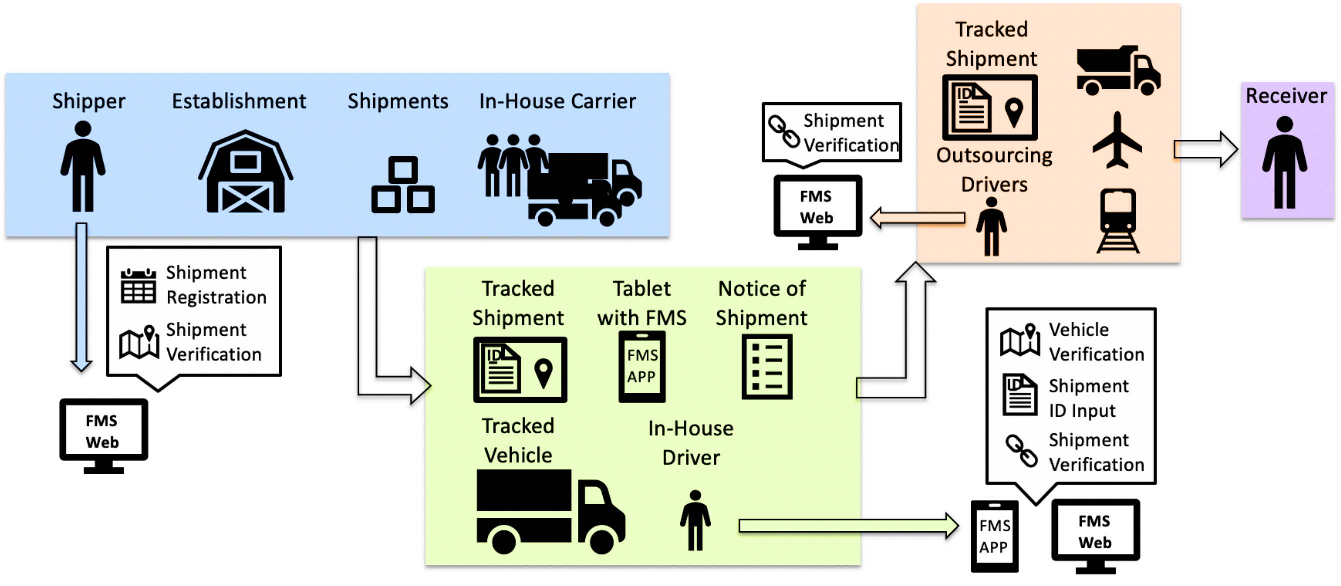
Phase 3: Integrated Survey of Truck Drivers and Freight Shippers

Conventional freight surveys lack details and data accuracy and are often expensive and burdensome to conduct. In phase 3 of the project, the researchers modified the survey methodology to carry out an integrated freight survey. Modifications made to FMS-Freight allowed the researchers to collect data from multiple respondents (i.e., shipper, carrier, and driver) under a unified framework. In addition, phase 3 allowed for tracking untaggable shipments (i.e., a shipment to which a GPS tracker cannot be easily attached, such as live animals and fish, bulk gravel, or liquid in a tank truck) using vehicle tracking. The researchers also adjusted the survey to streamline information sharing among respondents and reduce respondent burden. Additionally, phase 3 allowed for uploading and manually inputting big data (i.e., historical shipment and vehicle activity logs), an expansion over phase 2, which only allowed uploading of files. Lastly, the project team developed a trace matching algorithm and a matching mechanism to identify the vehicle carrying a shipment based on raw GPS data supplemented by the vehicle license number.

To demonstrate the feasibility of the integrated methodology, the team conducted a pilot survey. A total of six business establishments participated in the survey, all of which had outgoing shipments and operated their own truck fleets. The business establishments were located in different States and represented various industries, commodity types, vehicle types, and shipment distances. Ten drivers participated in the vehicle survey. The research team used GPS trackers placed in packages to trace 50 shipments and vehicle routes.

The case study showed that participants could easily follow the survey procedure, and it required minimal involvement from the surveyors. Having multiple mechanisms in the FMS framework for data sharing facilitated information sharing among survey respondents and improved information accuracy. The results of the case study also showed that it was feasible to track shipments considered untaggable by using vehicle tracking. Figure 3 depicts how the researchers mapped commodity flows to vehicle flows.

Figure 3. Chart. Integrated shipment tracking and vehicle tracking.



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Results

The three pilot surveys each resulted in a small sample and therefore may not serve as a good representation of the overall freight movement. In addition, recruiting eligible participants proved challenging because many were either ineligible or unwilling to participate. GPS data collection is passive and requires minimum participant effort and therefore may increase participation in freight logistics surveys; however, it does not provide all the data necessary to fully understand freight movements. Using FMS helped enhance the data, but it increased the burden on participants who had to complete surveys and may have had an adverse impact on recruitment. To mitigate this impact, the researchers designed the FMS-Freight application to be simple for the user, and the machine learning was enhanced to minimize the burden.

Despite the challenges posed by recruitment and the small sample size, the researchers demonstrated the potential of the methodology and technology for better freight movement data collection. The FMS system offered an approach to freight surveys that leveraged the latest developments in innovative technologies to address weaknesses that are inherent in more traditional survey methods. Specifically, the innovations developed in this project allowed for a greater quantity and better quality of data to be collected due to the combination of passive collection methods and data processing using algorithms enhanced by user verification.

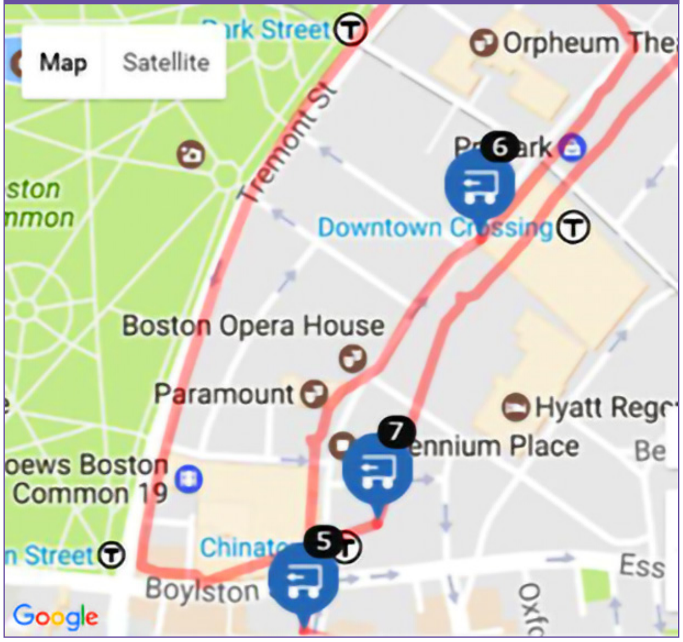
The project demonstrated the concept for the following key components:

- Integrated freight survey methodology, including shipper/carrier/driver information collection, shipment/vehicle tracking, and timeline verification.
- Freight survey platforms, including smartphones, websites, and tablet applications.
- Data processing algorithms and visualization capabilities.
- Data analysis and visualization tools (i.e., dashboards).

FMS proved to be a helpful tool for processing the GPS data through machine learning and map matching to make improvements such as removing false stops and adding missing stops through user validation. The processed stop data, when combined with the FMS-Freight survey, demonstrated the potential of new methods for collecting and analyzing data to provide new insights into freight travel patterns.

FMS also has the capability to analyze unusual travel patterns with unexpected stop sequencing. For example, figure 4 shows a stop pattern of a shipping carrier, where the driver appears to travel from stop 5 to stop 6 while bypassing the location of stop 7, which is closer to stop 5. Raw data may reveal that the driver took this route, but they would not provide insights into why. By using FMS and user validation, the researchers discovered that stop 6 was designated as an express delivery and took priority over other stops.

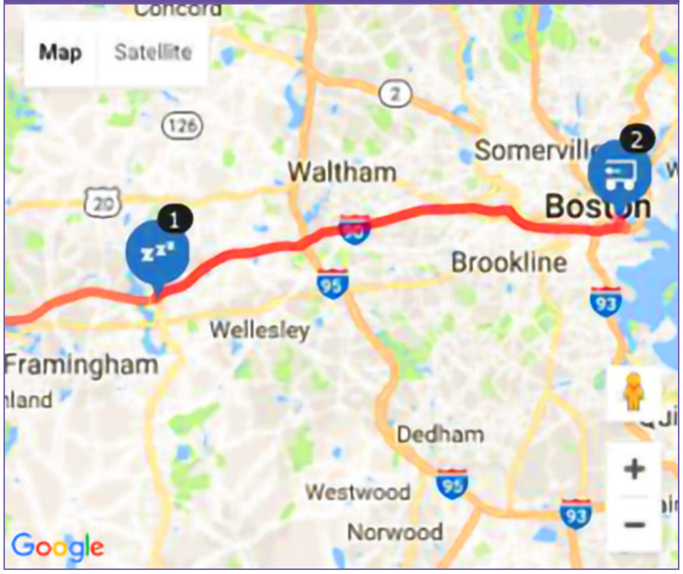
Figure 4. Map. Route and stop taken by the driver (left) and typical congestion in Boston, MA (right) (Ding-Mastera et al. 2018).



Original map © 2018 Google® Maps™. Map annotations by Ding-Mastera et al. 2018 to show the driver's route and rest stop.

Incidents occurring during a trip, such as detours and congestion, also cannot be determined from raw data. Basic machine learning may be able to determine where congestion occurred based on historical traffic data or a comparison of expected versus actual travel times, but the analysis would not provide reliable or verified data. FMS allowed the researchers to collect details about incidents that drivers encountered during a trip. The end-of-day surveys that the drivers completed in phase 1 revealed incidents that would not have been uncovered through traditional data collection methods. For example, figure 5 shows that a driver stopped at a highway rest area on the way to a delivery in Boston, MA. Traditional data collection methods and map matching would assume that this stop is routine, and its purpose was to refuel, rest, or get food. However, FMS revealed that the driver encountered congestion on the highway and took an unscheduled stop to wait for traffic flow to improve.

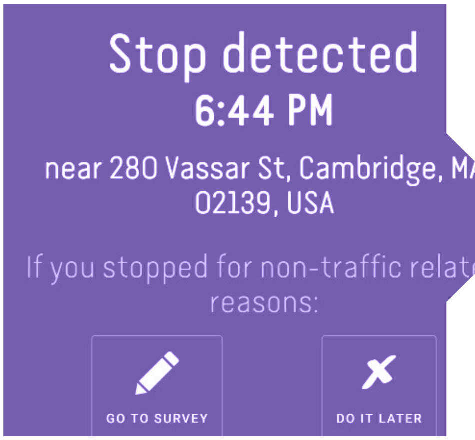
Figure 5. Map. Example stop travel pattern (Ding-Mastera et al. 2018).



Original map © 2018 Google® Maps™. Map annotations by Ding-Mastera et al. 2018 to show the driver's stop pattern.

The FMS system also captured valuable information about parking, including the type of parking location as well as information about the parking decisions made by drivers. The FMS data revealed that most drivers are familiar with the locations and routes they travel, and therefore they have more advanced knowledge of parking locations, which alleviates the need to search for street parking. This knowledge was evident in the data for urban drivers who generally did not have to drive around to find parking. Lastly, the FMS data showed that most drivers parked within a short distance of their intended stop. The parking data provided the researchers with important insights into freight movements and route choice.

The researchers learned that timeline verification is important for understanding the motives behind freight movements and for adjusting the data-processing algorithms. Although vehicle timeline verification was not difficult, shipment timeline verification was challenging because the transportation of cargo involves multiple agents as opposed to a single driver or shipper.



Stop detected
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near 280 Vassar St, Cambridge, MA
02139, USA

If you stopped for non-traffic related
reasons:

Conclusions and Recommendations

Understanding freight logistics today and predicting future freight logistics are important considerations for planners and policymakers. It is imperative for planners to have detailed data on freight vehicle movement, stops, and shipments to develop models and make decisions regarding the supply chain and land use. The researchers for this project gained valuable insights into utilizing newer technologies to collect important data about the supply chain.

The FMS framework researchers used for this project combined communications and tracking technologies to get a clearer picture of freight movement and the behaviors that impact it. FMS facilitated every aspect of the survey, including recruitment and management. The design of FMS reduced the burdens on respondents and surveyors, and the system allowed for data sharing among stakeholders along the logistics chain and with government agencies. The ability to deliver concise messages to receptive participants also proved critical to the study's pilot survey recruitment success.

The broader and deeper data collected through the FMS platform allow for more comprehensive insights into supply chain activity and driver behaviors. These insights, in turn, add more behavioral realism to transportation models and other types of analysis. The project has the following potential applications for public agencies:

- Supplement commodity flow surveys by collecting verified shipment GPS traces.
- Fill the knowledge gap about how to map commodity flows to vehicle flows.
- Furnish detailed freight flow data for behavioral modeling.
- Provide an analytical tool for logistics performance.

Despite the advantages inherent in the FMS system, challenges to freight flow data collection still exist. For example, partial visibility and knowledge among agents along the supply chain remain a problem, and there is a burden on participants to verify passively collected data, such as stop verifications. In addition, participant recruitment remains challenging due to privacy concerns and low incentives.

Future studies could address the identified challenges as new technologies evolve. Although this research project examined only freight transported by roads, FMS also has the potential to work for commodities that travel by rail, air, or water or those that are shipped across multiple modes.

Resources

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