Canadian long-haul trucking dataset meta-analysis

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Technical Report

Canadian Long-Haul Trucking Dataset Meta-Analysis

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Executive summary

The goals of this project are to determine the vehicle technology requirements to electrify heavy-duty (i.e., Class 7 and 8) freight-hauling trucks considering, specifically, the Canadian operational context and to identify potential locations for zero emission truck fast chargers and hydrogen refueling stations under several adoption scenarios. The analysis takes into account vehicle numbers and energy and power needs for long-haul trucking.

The analysis of available trucking datasets has revealed the ability to track aggregate truck traffic across the country, particularly along major Canadian shipping routes (e.g., Windsor-Quebec City Corridor); however, these datasets do not provide information on truck usage / identification, specifically: payload weight, volumetric capacity, and fuel consumption – all key variables to modeling Medium- and Heavy-Duty Zero-Emission Vehicles (MHZEV) requirements.

A methodology is proposed to address the objectives of identifying highly used trucking routes, as well as identifying potential locations for zero emission truck high power chargers and hydrogen refueling stations under several adoption scenarios.

Due to the limited truck usage/identification data (data currently available includes low resolution vehicle class, vocation, age, speed and payload weight), it is difficult to specify vehicle technology needs to electrify Class 8 freight-hauling trucks. To fill data gaps and address this objective, NRC proposes to perform statistical analysis of publicly available data (described in Section 3.6) and collection of additional data using telematics systems and field measurements utilizing data sources such as weigh-in-motion, virtual weigh station, cameras, Automatic number-plate recognition (ALPR), etc. (described in Section 5).

Proposed Data Analysis Methodology

The National Research Council (NRC) suggests the creation of data analysis techniques to tackle the issues of data shortages and inadequacies in the existing datasets.

Data analysis would focus on one year of American Transportation Research Institute (ATRI) collected data, covering all four seasons, for the three following key Canadian freight corridors:

- Windsor - Quebec City including Hamilton - Fort Erie;
- Vancouver – Calgary; and
- Calgary – Edmonton.

The NRC proposes, based on available datasets and their level of available details, a combined quantitative and qualitative methodology. Major analysis steps will include:

- Building of a base map of the selected road network;
- Identification of truck trip data from ATRI dataset; and
- Identification of major trucking routes statistics.

High-Resolution Digital Elevation Modeling (HRDEM) data could be used to characterize truck route altitude changes and historical weather conditions, while data obtained from Environment and Climate Change Canada (ECCC) and Natural Resources Canada (NRCan) could be used to link recorded weather and ambient temperature conditions to specific dates and times when analyzing truck routes datasets.

The following table provides a summary of how existing available datasets, proposed new datasets, or a hybrid approach, could be used to conduct the analysis of highly used Canadian trucking routes, quantify specifications of vehicle technology requirements to electrify heavy duty freight-hauling trucks and propose methods of identification of potential locations for Zero Emission Vehicle (ZEV) truck fast chargers and hydrogen refueling infrastructure.

Option to Address Objectives	Analysis of highly used Canadian trucking routes	Specification of vehicle technology requirements to electrify heavy duty freight-hauling trucks	Identification of potential locations for ZEV truck fast chargers and hydrogen refueling infrastructure
Use of existing data sources	Main data sources: ATRI, Geotab, CFAF Supplemental data sources: CVUS, MTO CVS, vehicle registration	Existing data sources are not sufficient. Difficult to extract the trip information from raw data. ATRI - Extraction of truck road trip information from the raw ATRI dataset will be challenging to accomplish to a very high percentage of accuracy. Geotab - Telematics data, available for all over Canada. Using Web UI and REST API for Python and JavaScript the NRC can perform data analytics on Geotab data.	Apply the NRC in-house developed data processing and analysis methodologies ATRI - Extraction and identification of truck stops and trips will be required Geotab - Geographical representation is skewed across Canada (Ontario and Quebec has more data, while northern territories have less data).
Collection of new data sources	Weigh-in-Motion (WIM) system deployment at fixed locations Automatic vehicle classifier (AVC) Automated License Plate Recognition (ALPR) Fleet telematic data	WIM- axle distances, individual axle weights, gross vehicle weight, vehicle speed, distance between vehicles AVC - characterizing truck identification data, specifically cab, axle and trailer configuration. Installation of temporary AVC systems at specific truck weigh stations along key Canadian long-haul transport routes. ALPR - vehicle crossing, tolls and border checkpoints Telematics - Location, speed and date/time parameters	Characterization of location and quantity of parking facilities, commercial truck stops, travel plazas and public rest areas. Extraction of truck stoppage location data from available GPS datasets and clustered stoppage points of multiple trips. Engagement of industry stakeholders (hydrogen/battery charging) forecast number of truck refilling opportunities per region of the country.
Hybrid use of existing and new data sources	Merging of ATRI data with new data sources.	Combination of available ATRI dataset(s) with access to additional fleet data. Potential creation and training of machine learning models	Engagement with charging infrastructure and hydrogen industry stakeholders. Forecasted AI implementation - dispatching and routing, real-time traffic monitoring and route reanalysis, SOC tracking and automatic scheduling of charge/refill opportunities and infrastructure availability/status.

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1 Introduction

1.1 Purpose

The purpose of this Canadian long-haul trucking dataset meta-analysis is to conduct a review of available trucking datasets against the following objectives:

1. Analyze highly used Canadian trucking routes;
2. Address remaining data gaps;
3. Specify the vehicle technology requirements (i.e., range, payload capacity, charging/refueling times, etc.) to electrify heavy duty Class 7 and 8 freight-hauling trucks (including regional and short haul operations and battery electric and hydrogen powered drivetrains) considering, specifically, the Canadian operational context;
4. Identify potential locations for zero emission truck fast chargers and hydrogen refueling stations under several adoption scenarios. The analysis takes into account vehicle numbers and energy and power needs for long-haul trucking.

For the purpose of this project, *long-haul trucking* is defined as the movement of goods or freight by truck at distances greater than 400 km, including urban, inter-urban, provincial, interprovincial and international routes.

1.2 Background

The Government of Canada has indicated an aspirational target of 35% of total new medium- and heavy-duty vehicle sales being zero-emission vehicles by 2030 [1], working towards 100% zero-emission new medium- and heavy-duty sales by 2040 [1], for a subset of vehicle types, where feasible. As part of Canada's stated vision to become a net-zero carbon society by 2050, major initiatives are being proposed across the industry sectors, which include the decarbonization of the transportation sector.

In 2017, within Canada, 90% of all freight shipments (~65.61 million) were hauled by truck [2]. Road transportation by truck is an important means of trade between Canada and the United States with Canadian total export and import by road mode of transport in 2020 being 54.2% and 71.5% by value, respectively [3]. Long-haul is generally categorized as distances greater than 400 km/day, regional as 160 to 400 km/day and local as upward of 160 km/day.

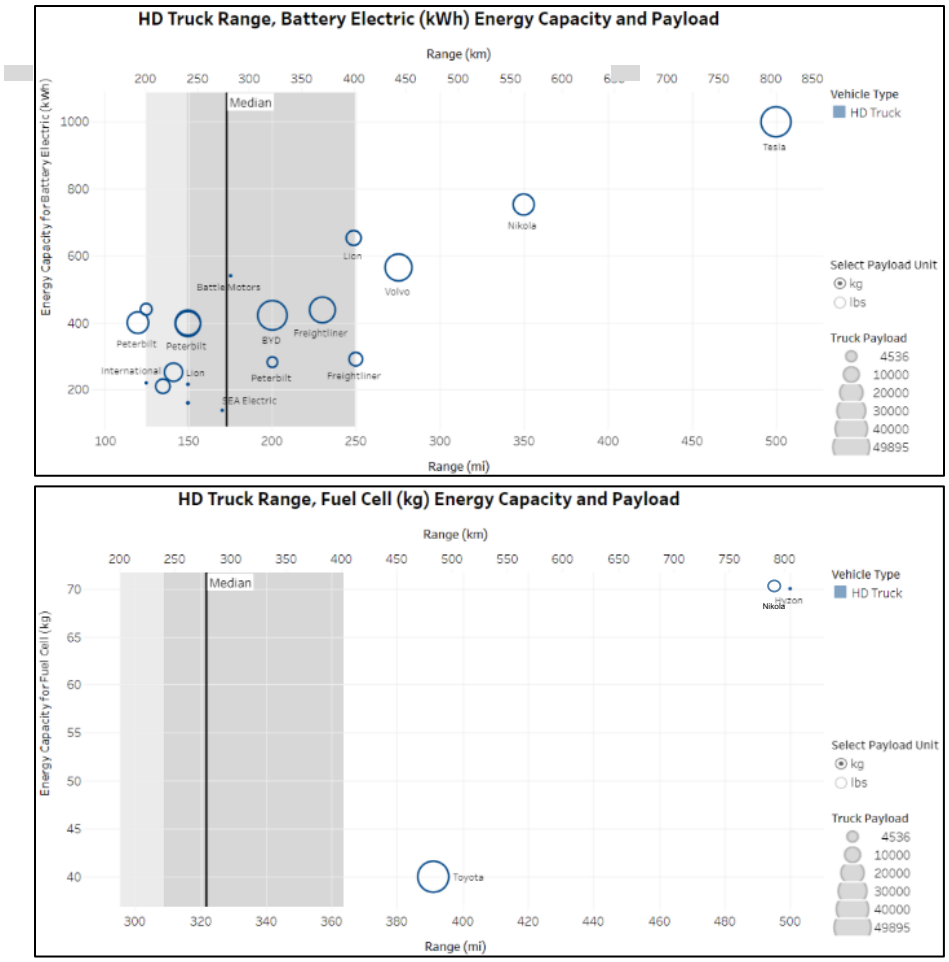
In recent years the long-haul trucking industry has experienced numerous notable impacts such as a significant increase in the price of diesel [4], severe equipment and parts shortages, rising inflation, and workforce shortages. Research conducted during this project aims to minimize the impact to the long-haul truck industry during the transition to battery electric and fuel cell trucks.

Long-haul transport trucks do not typically return each night to a truck depot at which they can recharge or refuel. The feasibility of broadscale deployment of zero-emission Class 8 trucks would require a nationwide network of alternative fuel or recharging stations. For intercity Class 8 trucks in long-haul service, a refueling range of around 800 to 1,000 kilometers is typical, as this is the distance a driver can cover in a typical day within federal hours of service limits.

New and emerging zero-emission vehicle technologies are increasingly capable of meeting the duty cycle requirements of typical Canadian long-haul routes; however, there is a need for improved data on Canadian trucking routes and vehicle characteristics to inform their penetration into the Canadian marketplace and minimal real-world data exists for battery electric long-haul truck operation in cold climates.

Currently available zero-emission Class 8 long-haul trucks have maximum operating ranges of between 240 and 440 kilometers [5, 6, 7], dependent on application. These trucks generally require charging times from 1.5 to 3 hours [5, 6, 7]. By way of comparison, Tesla, an original equipment manufacturer (OEM) new to the Class 8 long-haul market, is claiming a maximum operating range of 800 km and charge time of less than 1 hour [8]. Availability of zero-emission trucks, OEM status, and global availability by region (US, Europe, China, other regions) was captured in a 2022 CALSTART report [9].

Due to the lack of a currently developed standardised measurement procedure, electric medium- and heavy-duty vehicle makers disclosure of usable battery energy as a metric for comparison of actual vehicle range is difficult. A summary of the reported Canada and U.S. market availability of battery electric and fuel cell heavy-duty truck range, energy capacity and payload, at the time of this report, are provided in Figure 1.



Note: Figure may not be fully comprehensive due to new model announcements and small manufacturers not yet captured in the inventory

Figure 1: HD truck range, battery electric and fuel cell energy capacity and payload [10]

As of the time of this report, EV technology is becoming a commercially viable option within the long-haul market. Incremental technological advances are providing additional range capabilities, minimization of battery pack weight, and faster charging/refilling times [11]. Complementary technologies such as Trailer Dynamics eTrailer [12], which replaces a free-wheeling trailer axle with an electrified axle and an optional modular traction lithium-ion phosphate battery unit mounted beneath a trailer, have shown through real-world testing in collaboration with BMW Group Logistik that when combined with a battery-electric tractor unit a long-haul truck range of more than 600 km without recharging is possible [13]. Companies such as ZF [14], ConMet [15] and SAF-Holland [16] also currently have similar technology offerings.

For Canada to succeed in reaching its 2050 net-zero goal several potential roadblocks must be overcome including a significant scaling up of global mining operation production of the virgin raw materials needed for battery production [17, 18, 19], overcoming environmental and governmental imposed restrictions related to the extraction of raw materials necessary for electric vehicle batteries and the requirement of a nontrivial upgrade, doubling or tripling, of the Canadian electrical grid capacity [20, 21, 22].

Planning for a successful transition from traditional internal combustion engine (ICE) to Zero Emission Vehicle (ZEV) propulsion technologies should be based on a common understanding of long-haul trucking operations to ensure that the deployment of ZEVs and their charging/refilling infrastructure requirements will meet the operational reality of the industry. Transport Canada (TC) is looking to characterize Canadian long-haul trucking routes and their operational reality to guide decision making on the introduction of ZEV technologies in the long-haul truck sub-sector.

Significant research related to appropriate charging/refilling locations, quantity of charging/refilling stations and infrastructure costs associated with implementation within Canada will be required for creation of a solid techno-economic case. Engagement of numerous stakeholders including highway departments, vehicle manufacturers, the electrical distribution grid operators, and Canadian municipalities will be necessary.

Phase 1 of this project will serve to find and qualify relevant data sources and propose a data analysis methodology to gain a deeper understanding of long-haul heavy-duty (HD) trucking activities in Canada and quantify energy and power requirements in support of the transition of this sub-sector.

Phase 2, which is not scoped in this document, will use the proposed methodology to process the data and produce results to identify the crucial aspects of highly used trucking routes, as well as the energy and power requirements for long-haul trucks operating along these routes.

1.3 Objectives

The objective of the project is to review available trucking datasets to determine what can confidently be deduced from them, what crucial data are missing, and develop a plan to:

- Address remaining data gaps;
- Identify highly used Canadian trucking routes;
- Specify the vehicle technology needs to electrify Class 7/8 freight-hauling trucks (including regional and short haul) considering a Canadian operational context (including battery and hydrogen electric technologies); and
- Identify potential locations for zero emission truck fast power chargers and hydrogen refueling stations under several adoption scenarios. Analysis would take into account vehicle numbers, energy and power needs for long-haul trucking.

1.4 Project Scope

The project has been separated into two phases.

Phase 1 of this project will serve to find and qualify relevant data sources and propose a data analysis methodology to gain a deeper understanding of long-haul HD trucking activities in Canada and quantify energy and power requirements in support of the transition of this sub-sector.

Phase 1 has been divided in three tasks:

- Task 1: Survey of available data sources and evaluation for relevancy in meeting project objectives;
- Task 2: Data analysis methodology development to meet project objectives for Phase 2; and
- Task 3: Identification of significant data gaps and proposal for a methodology to collect new data, if required.

Phase 2 will utilize the methodology developed in Phase 1 to identify highly used trucking routes, specify zero emission technology needs in Canada, and identify potential locations for charging and hydrogen fueling infrastructure.

Data within this report covers only Phase 1 of the project.

2 Survey of Available Data and Establishment of Relevancy

NRC searched and evaluated the following data sources for their applicability in meeting the project's objectives.

- American Transportation Research Institute (ATRI)
- Canadian Freight Analysis Framework (Statistics Canada)
- Canadian Vehicle Use Survey
- Geotab / Altitude (NRCAN, NRC Group)
- MTO Ontario iCorridor Commercial Vehicle Survey (CVS) Traffic Counts
- Truck registrations and permits, international fuel tax agreements (Provinces and Territories)
- TransWest dataset (NRC)
- Large OEM data sets (e.g., Daimler and Volvo, contact NREL)
- U.S. datasets that may include relevant data (e.g., Smartway Transport Partnership, DOE Fleet DNA)
- Trucking Associations (CTA, PMTC)
- Annual for-hire trucking surveys (AHTS)
- Trucking Commodity Origin and Destination Surveys (TCOD)
- Freight Trucking Statistics (FTS)
- Transport Canada Travel Time Index (Urban Mobility Indicator)

A brief description of the reviewed candidate data sources is provided in the following sections.

2.1.1 American Transportation Research Institute (ATRI)

The American Transportation Research Institute (ATRI), headquartered in Washington, D.C., has been engaged in transportation and operational testing, with emphasis on the trucking industry, since 1954 [23]. Their research focuses on congestion and mobility, economic analysis, safety and security, technology and operations and transportation infrastructure. ATRI also has extensive commercial vehicle operation experience in a leadership/or participation role in national freight analysis, technology research initiatives and field operational tests.

The Ministry of Transportation of Ontario (MTO) has been partnering with Transport Canada as a licensed user to ATRI commercial vehicle GPS movement data since 2013, to support Canada-wide multimodal system performance monitoring. Commercial vehicle GPS movement data files are shared with MTO monthly. Transport Canada provided NRC with 3 days of ATRI data for the purpose of performing preliminary analysis and to confirm applicability of the dataset to meet the project objective.

ATRI statistics represent both US and Canada data. ATRI's 2023 report represents 2022 data encompassing 169,770 truck-tractors, 498,068 trailers, and over 13.6 billion vehicle miles traveled [24]. The sample thus represents approximately 7 percent of all miles traveled by combination trucks during

2022[1]. ATRI reporting indicates a majority of its data is based on smaller fleets (fewer than 100 truck-tractors) which reflects national fleet size trends. ATRI has stated that 8.2 percent of respondent fleets included at least one Class 8 truck-tractor powered by an alternative fuel source (CNG, battery electric, LNG, LPG) in 2022. No fleet respondents indicated to be using hydrogen fuel cells as a power source.

The ATRI dataset was selected for meta-analysis purposes for its ability to provide raw live truck movement data for analysis, its ability to satisfy several of the project objectives and its availability of up-to-date data across Canada.

2.1.2 Canadian Freight Analysis Framework (CFAF)

The Canadian Freight Analysis Framework (CFAF) integrates data from several sources by Statistics Canada including a trucking commodity origin and destination survey, a transactional-level record of goods exported into the US for estimation of values shipped by commodity, origin and mode per year, and surveys related to transport by air and rail, to create a comprehensive picture of freight flows across the country by geography, commodity and mode of transport [25]. The main data sources for transportation by road was from the Trucking Commodity Origin and Destination Survey on commodity, origin, destination, weight and revenues from the Canadian for-hire trucking industry. The framework database estimates tonnage, value, and tonne-kilometers by origin and destination, by commodity type, and by mode. The database can be used for assessment of domestic and international trade flows, patterns of freight movements, observing traffic volumes, and for analyzing impacts of transport policies.

The CFAF dataset was selected for meta-analysis purposes for its ability to characterize aggregate weight of shipments, type of commodity shipped (based off Standard Classification of Transported Goods) and aggregate origin-to-destination distance that the shipment was transported.

2.1.3 Canadian Vehicle Use Survey (CVUS)

Prior to conducting the Canadian Vehicle Use Survey (CVUS), Transport Canada and Natural Resources Canada co-sponsored the Canadian Vehicle Survey (CVS) which was published annually from 2000 until its discontinuation in 2009. Due to low participant response rates (~20%) Transport Canada, in collaboration with Natural Resources Canada (NRCan), Environment and Climate Change Canada (ECCC) and the provincial registrars, decided to halt the CVS and implement a pilot replacement survey, the CVUS, to validate the CVS methodology and results [26]. A CVUS pilot study was carried out in 2010 and after the analysis of initial results Transport Canada proceeded with a full-fledge survey, conducted from 2012 to 2014.

As a means of increasing the accuracy and volume of collected data, the CVUS study utilized electronic data loggers. The CVUS provided quarterly and annual estimates of the amount of road travel, broken down by types of vehicles and characteristics, such as age and gender of driver, time of day and season.

The in-scope vehicles for the CVUS include all motor vehicles, except buses, motorcycles, off road vehicles and special equipment (for example, cranes, street cleaners, snowplows and backhoes), registered in Canada anytime during the survey reference period, that have not been scrapped or

[1] Percentage based on the most recent figures for miles traveled, from 2021. Office of Highway Policy Information, "Table VM-1: Annual Vehicle Distance Traveled in Miles and Related Data – 2021" (March 2023), 2021 Highway Statistics Series, Federal Highway Administration, U.S. Department of Transportation.

salvaged. The population of interest consists of vehicle-days, composed from the in-scope vehicles and the days within the survey reference period.

A sister study, the Heavy-Duty Vehicle Use Study (CVUS-H), which included straight trucks, tractor trailer and cargo vans, was also run in 2014.

The CVUS dataset was selected for meta-analysis purposes for its ability to provide the following data, within the provinces of Quebec, Ontario, Manitoba and Saskatchewan: daily trip distances, truck configuration (straight, truck and trailer, tractor and multiple trailers, etc.), truck body style (dry van, reefer, tanker, hopper, dump, container carrier), cargo weight (tonnes) and vehicle age. The CVUS dataset does not breakout long haul trip vs regional trip vs local trips.

2.1.4 Geotab

Geotab, founded in 2000, is a privately held company and a global leader in connected transportation solutions providing telematics – vehicle and asset tracking – solutions to over 47,000 customers in 150 countries [27]. They specialize in connecting commercial vehicles to the internet and providing web-based analytics for fleet management.

Geotab offers an ITS platform, Altitude, which enables government entities at the local, state and provincial levels to identify areas for traffic improvements, model and predict the impact of specific interventions and monitor their effectiveness [28]. Altitude is the foundation for three core Geotab TS products including origin and destination, intersections and roads.

Geotab's *Origin and Destination* is a dataset for purchase to characterize the nature of commercial vehicle and freight activity, such as vehicle purpose and aggregate road analysis, across the US and Canada. Origin and destination aggregates insight into people and goods movement patterns, broken down by vehicle class and trip purpose. Geotab's *Road* is a dataset for purchase to characterize commercial vehicle and freight data combined with open-sourced street data to understand road traffic flow.

The Geotab dataset was selected for meta-analysis purposes due to Geotab O/D analysis and route analysis including the following variables: vehicle trip, journey, vocation, industry, vehicle class, intersections and roads traffic counts, etc. Data analytics can be done easily through Web UI.

2.1.5 MTO Ontario iCorridor Commercial Vehicle Survey (CVS)

The Ministry of Transportation (MTO) is the provincial ministry of the Government of Ontario that is responsible for transport infrastructure and related law in Ontario. MTO iCorridor is a web-based data visualization and information sharing platform to support analysis and provincial transportation planning [29]. iCorridor provides a wide range of information products that support MTO's transportation and land use planning decisions including but not limited to: highway traffic, and commercial vehicle characteristics; information on roadway and highway travel times and performance characteristics.

The MTO Commercial Vehicle Survey (MTO CVS) traffic count is collected at commercial vehicle survey locations (latitude/longitude) on provincial highways and international border crossings. Currently the MTO CVS is the most comprehensive source of intercity commercial vehicle characteristics and commodity flow information available.

The MTO CVS dataset was selected for meta-analysis purposes for its ability to provide commercial vehicle survey traffic count data from about 300 publicly available sites in Ontario.

2.1.6 Vehicle Registrations through Statistics Canada

Statistics Canada provides access to an interactive dashboard of current and historical data on new motor vehicle registrations that enables the comparison and analysis of new motor vehicle registrations data by fuel type, geography and vehicle type (including vehicles weighing 15,000 kg and more). Vehicles in Circulation in Quebec [30] is a publicly available vehicle registration administration database for the number of vehicles authorized to circulate in Québec, both for on-road vehicles and for vehicles designed for off-road traffic.

The Canadian vehicle registration dataset was selected as a key variable for meta-analysis purposes due to its ability to provide registration data for Class 7 and 8 vehicles and fuel type (gasoline, diesel, battery electric, hybrid, other fuel type) from 2017 to 2022.

2.1.7 Trans-West Fleet

The NRC, in collaboration with FP Innovations PIT Group (FPI), conducted a tire pressure monitoring system (TPMS) sensor evaluation test campaign in 2021 which monitored Quebec based trucking fleet Trans-West Group's long-haul trucks [31] over the period of 10 months. Ten 2019 Kenworth T680 Class 8 trucks were utilized in the test campaign. The selected trucks specialized in the transport of peat moss from Quebec to Alberta and British Columbia, and fruits and vegetables from California to Quebec. The trucks traveled from Quebec to the Canadian west coast and California on a weekly basis and in some instances returned via the east coast through Florida.

Recorded telemetry data was uploaded to a Trans-West server on a regular basis, and subsequently downloaded by FPI and supplied to the NRC for analysis. The trucks were outfitted with Isaac Instruments telematics systems which were used to record specific vehicle network data. This data included 87 unique SAE J1939 data channels recorded when the truck was driving, and a truncated list of 69 data channels when the truck was idling.

The Trans-West fleet dataset was not selected as a key variable for meta-analysis purposes due to the available data pertaining to only six trucks which traveled along limited routes in Quebec/Ontario. Available Trans-West telematics data may be implemented as supplemental data.

2.1.8 National Road Network (NRN)

The National Road Network (NRN) is a seamless geospatial vector dataset (current, accurate, consistent and maintained) of Canadian roadways that provides access to over 1 million kilometres of up-to-date centerline road network data [32]. The data is separated by provincial and territorial jurisdictions. The NRN contains trusted geospatial data on Canadian road characteristics, and forms a foundational layer of the GeoBase initiative - a federal, provincial and territorial government initiative that is overseen by the Canadian Council on Geomatics.

The road segmentations data from NRN dataset shall be utilized as supplemental data for truck routes (particularly for building of a base map) of the Canadian roadway network.

2.1.9 DOE Fleet DNA

The Fleet DNA project was designed by the United States Department of Energy's National Renewable Energy Laboratory (NREL) in partnership with Oak Ridge National Laboratory [33]. The project focuses on numerous vehicle platforms including Class 8 trucks. The truck data includes vehicle type and

configuration categized by regional and long-haul among others. The data contains information such as aggregated route distance, average speed, maximum acceleration, stops per mile and load and grade statistics from 1,150 days of driving collected from 70 tractors operating in the United States.

The DOE Fleet DNA dataset was not selected as a major component for meta-analysis purposes due to its limited quantity of truck statistics.

2.1.10 Trucking Associations

The Canadian Trucking Alliance is a federation of provincial trucking associations representing a broad cross-section of 4,500 carriers, owner-operators and industry suppliers. Provincial trucking associations include the Alberta Motor Transport Association (AMTA), Atlantic Provinces Trucking Association (APTA), British Columbia Trucking Association (BCTA), Manitoba Trucking Association (MTA), Ontario Trucking Association (OTA), Association du Camionnage de Québec (L'ACQ) and the Saskatchewan Trucking Association (STA). The Private Motor Truck Council of Canada (PMTC) is a Canadian association dedicated to the interests of private fleet operators that provides forums for fleet operators and industry stakeholders to exchange views and resolve issues.

Engagement with Canadian Trucking Alliance partners will occur during future phases of this project.

2.1.11 Annual For-Hire Trucking Survey (AFHTS)

The annual for-hire trucking survey's purpose is to measure the size, structure and economic performance of the trucking industry and to analyze its impact on the Canadian economy [34]. The survey data, last published in 2019, was administered as part of the Integrated Business Statistics Program. The survey includes detailed information on business types, operating statistics (tonnage, distance travelled, number of shipments, etc.), financial statistics, operating breakdowns (e.g., distribution of trucking revenue by type of trucking activity), fleet and employments. Survey data includes a sample size of approximately 2,500 enterprises records relating to all road transport in Canada.

The AFHTS dataset's focus on structure and economic performance within the trucking industry falls outside of the meta-analysis task goals but details pertaining to reported tonnage and distance travelled may be use in future phases of this project.

2.1.12 Trucking Commodity Origin and Destination Survey (TCOD)

The purpose of the annually conducted Trucking Commodity Origin and Destination (TCOD) survey is to measure the commodity movements and the outputs of the Canadian trucking industry [35]. Data is collected directly from survey respondents through on-site visits (most common method), electronic data reporting (sent from companies), and profiles via computer-assisted telephone interviews. The data contains information such as shipment distance travelled, establishment geographic location, trucking shipment (count, distance, weight) and can be utilized to measure the volume of traffic on highways and provincial and inter-provincial trade transported by trucking companies. TCOD data, available from 2004 to 2018, was replaced with a redesigned version in 2019, the Freight Trucking Statistics Survey.

The TCOD dataset was determined to not be appropriately positioned to inform the initial meta-analysis but may provide beneficial data at later stage of this project.

2.1.13 Freight Trucking Statistics (FTS)

The Freight Trucking Statistics activity-based survey's target population represents all road motor carriers that transport any type of goods including various commodities [36]. Survey respondents upload their electronic files of shipments data for every reporting period using questionnaires and reporting guides provided by Statistics Canada. The reference period of currently available data is January 2019 to January 2021. The data contains information such as distance travelled of shipment (point of origin to the destination of particular trip), geographic location of establishment, trucking shipment (count, distance, weight).

The FTS dataset was determined to not be appropriately positioned to inform the initial meta-analysis but may provide beneficial data at later stage of this project.

2.1.14 Transport Canada Travel Time Index (Urban Mobility Indicator)

The Travel Time Index (TTI) is a quarterly updated dataset reflecting 21 key trade corridors in Vancouver, Calgary, Toronto, Montréal and Halifax [37]. TTI is the ratio of actual travel time to the ideal or "free-flow" travel time or, equivalently, the ratio of free-flow speed to actual speed. The data used for calculations is supplied by HERE Technologies, a company that collects detailed speed data from Canada's entire road network. The TTI dataset will supplement ATRI data.

3 Selected Datasets for Meta-Analysis

Of the reviewed candidate data sources, the following six were determined to be useful for meta-analysis purposes:

- American Transportation Research Institute (ATRI);
- Canadian Freight Analysis Framework (CFAF);
- Canadian Vehicle Use Survey (CVUS);
- Geotab's Origin and Destination and Geotab's Road Traffic;
- Ministry of Transportation (MTO) commercial vehicle survey traffic count in Ontario; and
- Vehicle registration.

The six datasets indicated above were selected for their ability to provide up to date publicly available data coverage distribution for a majority of Canadian provinces and territories, quality and flexibility of the raw data for analysis algorithms, ability to assess highway truck capacity and forecast shipment origin/destination data, ability to access preprocessed raw truck movement data (latitude, longitude, speed), provision of rich API/functions availability for truck route and traffic analysis and detailed truck related information (truck class, vocation, industry, trip).

NRC used the following criteria to characterize useful candidate datasets:

- All variables recorded;
- Main data sources and methodology used in data collection;
- How representative the data is of the Canadian fleet (also taking into account cross-border traffic);
- Extent that Class 7 and Class 8 trucks are included in dataset;
- Total size of dataset and applicability to other Medium- and Heavy-Duty Vehicle (MHDV) classes and vocations;
- Advantages and disadvantages of each dataset in meeting the project objectives, and options for analysis; and
- Data gaps.

Suitability of the selected datasets to meet the project objectives (analysis of truck routes and traffic, identification and locational position of trucks, characterization of road network coverage) as well as estimate costs associated with access to datasets is outlined in Table 1.

In addition to the six above-mentioned datasets, road segmentations data from National Road Network (NRN) GeoBase Series from NRCan and Statistics Canada will be used in the analysis. High-Resolution Digital Elevation Modeling (HRDEM) data [38], available for download from the Canadian Open Government web site, shall be used to characterize truck route altitude changes. Historical weather conditions data obtained from ECCC and NRCan shall be used to link recorded weather and ambient temperature conditions to specific dates and times when analyzing truck routes datasets.

Table 1: Summary of datasets selected for analysis

Database Name	Route Analysis	Traffic Analysis	Truck Location Data	Truck Identity Data	Truck Use Data	Estimated Cost
ATRI	Yes	Yes	Yes	No	Limited (speed only)	TC Paid
Geotab Road Traffic Dataset	No	Yes	Yes	Limited (only vehicle class, vocation)	Limited (speed only)	$75k (one month data), $425k (one year data)
Geotab OD Dataset	Yes	Yes	Yes	Limited (only vehicle class, vocation)	Limited (speed only)	$50k (one month data)
CFAF Commodities	Yes	No	Yes	No	No	Publicly available
MTO Vehicle Survey Traffic Count	No	Yes	Yes	No	No	Publicly available
Vehicle Registry Data	No	No	No	Yes	Yes (except for speed)	Available from Transport Canada
National Road Network (NRN)	Yes	Yes	Yes	No	For altitude changes	Publicly available
Weather Data	No	No	No	No	For ambient temperature and weather conditions	$1000 (for one year)

3.1 Data Source Analysis Methodology Development

NRC completed a data source survey to establish the relevancy of available data in meeting the project objectives. NRC developed a methodology for analysis of the data source survey by extracting truck location and identification data, as well as use data when available, from the candidate datasets. Truck location, identity and use data parameters are outlined below.

Truck location data parameters included**:**

- Locations of routes;
- Average and maximum trip lengths, frequency of trips binned by trip length;
- Total Vehicle Kilometers Travelled (VKT) on particular corridors;
- Frequency, duration, and location of stops (possibilities for charging/fueling); and
- VKT by season.

Truck identity data parameters included**:**

- powertrain type;
- vehicle Class, vocation, sleeper vs day cab, etc.;
- vehicle age; and
- axle configuration (allowing comparison to maximum allowable weight).

Truck use data parameters included**:**

- fuel consumption;
- power and energy requirements;
- vehicle weight and payload;
- volumetric capacity;

- speed;
- accelerations and decelerations;
- ambient temperature / weather; and
- altitude changes.

An appropriate truck count sample size that statistically represents the Canadian population of medium and heavy trucks, of the full Canadian fleet, is representative within available ATRI data. In 2022 the ATRI sample represented approximately 7 percent of all miles traveled by combination trucks within Canada and the United States [24]. Regarding data confidence, a review of several credible studies [39, 40, 41] showed that supporting data often struggle with limited fleet size, narrow time windows, inconsistencies, outdated (10+ years) or incomplete data, and so on. However, by cross-referencing several data sources, the confidence (≥ 80%) in the reported conclusions should be relatively strong for truck route analysis and truck stop locations.

Gaps and deficiencies in the analyzed datasets were determined to include missing truck usage data (fuel consumption, payload weight, volumetric capacity, vehicle weight) and truck identification data (powertrain type, vehicle vocation, sleeper or day cab, vehicle age, axle configuration).

Non-sampling and sampling error data accuracy issues were experienced during previously conducted Canadian vehicle use surveys, referenced in report section 2. Non-sampling errors include such issues as population coverage, differing respondent interpretation of questions, the provision of incorrect information from respondents and mistakes in recoding and/or processing data. Careful questionnaire design is key to reducing non-sampling error issues. Sampling errors occur because population estimates are derived from a sample of the population rather the entire population. Sampling error is dependant on factors such as sample size, sampling design, and the method of estimation.

The following tables provide a summary of the analysis of the selected commercial freight vehicle datasets and their suitability to meet project objectives.

Table 2: ATRI data source, data collection methodology and advantages and disadvantages

Main Data Source	Within the ATRI dataset in 2022: for-hire carriers held 52.7percent of the total trucking market, while private fleets at 37.4 percent of the total trucking market [24].
Methodology Used for Data Collection	Truck GPS data
Inclusion of Class 7/8 Trucks in Dataset	Yes, all truck classes
Total Truck Counts in Canada	1.25 million trucks with Class ≥ 3 in 2021
Truck Counts in Dataset	177K Truck Counts in July 2021 140K monthly average in 2021
Advantages	• Better up to date coverage across Canada • Good quality raw data is very flexible for analysis to meet the project requirements • Apply the in-house developed data processing and analysis methodologies • Cost-effective in the long run
Disadvantages	• Difficult to extract the trip information from raw ATRI dataset (i.e., long haul trip vs regional trip vs local trip) • No truck usage data and identity data • Effort for research and development of the methodologies to process and analyze the huge volume geolocation data.

Table 3: Geotab – Origin and Destination data source, data collection methodology and advantages and disadvantages

Main Data Source	Fleet management data
Methodology Used for Data Collection	Telematics devices from fleet management
Inclusion of Class 7/8 Trucks in Dataset	Yes. Truck classes: light, medium, and heavy-duty truck
Total Truck Counts in Canada	1.25 million trucks in 2021 (Class ≥ 3)
Truck Counts in Dataset	Truck Counts for trucks with Class 3 and more (Class ≥ 3) in 2022: ~110K number of active Geotab commercial vehicles in Canada in 2022: 328,000, 13.3% of medium trucks 15.9% of heavy trucks
Advantages	• Up to date data available for all over Canada • Raw truck movement data has been preprocessed and is ready to use • Applications have very rich API/functions available for the truck route and traffic analysis • Dataset has the detailed information (truck class, vocation, industry, trip)
Disadvantages	• Uncertainty in analysis of results due to Geotab proprietary data preprocess and query procedures • Geographical representation across Canada (Ontario and Quebec has more data, while northern territories have less data) • Location name on-route and during stop is not available, ability to identify potential charger locations which is important for possibilities for charging. • Dataset has high annual cost (2021 quote): 1-month historical roads data across Canada: $75,000 CAD and 12 months historical roads data across Canada: $425,000 CAD.

Table 4: CVUS data source, data collection methodology and advantages and disadvantages

Main Data Source	For-hire trucking industry, public and private sectors or partners cargo-tonnage, tonnage-km, vehicle configuration, type of cargo
Methodology Used for Data Collection	Electronic data logger connected to truck vehicle network (CAN) (incl. GPS data). Online/paper/phone survey collection of basic information about vehicle (trip purpose, fuel Information input)
Inclusion of Class 7/8 Trucks in Dataset	Yes
Total Truck Counts in Canada	~280k fleet size (Class 8), 42k unique reported trips
Truck Counts in Dataset	~280k fleet size (Class 8), 42k unique reported trips
Advantages	• Data coverage distribution across Canada limited to a few provinces (Quebec, Ontario, Manitoba, and Saskatchewan)
Disadvantages	• Unable to extract the trip information from dataset (i.e., long haul trip vs regional trip vs local trip) • ~40% dataset (196k fleet size) is under 15t GVWR • Available data may not represent current data due to capture date of ~10 years ago

Table 5: CFAF data source, data collection methodology and advantages and disadvantages

Main Data Source	The Canadian for-hire trucking industry
Methodology Used for Data Collection	Data was collected from Statistics Canada surveys and/or other sources such as the trucking commodity origin and destination survey which collected commodity, origin, destination, weight and revenues from the Canadian for-hire trucking industry.
Inclusion of Class 7/8 Trucks in Dataset	Yes, all truck classes
Total Truck Counts in Canada	23.8 million truck counts in 2017 in Canada
Truck Counts in Dataset	65.6 million of freight shipments in 2017 in Canada (a shipment represents the movement of a single commodity from an origin to a destination for-hire truck industries)
Advantages	• Publicly available dataset through Statistics Canada open dataset at open Canada website • The truck shipment data for origin/destination can be used in a variety of analyses including assessing highway capacity and forecasting traffic, evaluating investments in infrastructure.
Disadvantages	• Need to study the relationship for the freight shipments and full truckload shipping for census agglomeration (CA), census metropolitan area (CMA), rest of province (ROP) or province/territory • The size of the sample requires a methodology that includes a four-stage sampling design to adequately capture the population. As a result, data users should use caution when comparing year-over-year changes between commodity groups and /or detailed geography

Table 6: MTO data source, data collection methodology and advantages and disadvantages

Main Data Source	Database
Methodology Used for Data Collection	Data based on hourly truck traffic, directional traffic indicated, commercial vehicle survey station data (latitude and longitude coordinate of site) is useful for determination of potential charging locations: border plaza, truck inspection station, lay-by, roadside, super lay-by.
Inclusion of Class 7/8 Trucks in Dataset	Yes. Utilize FHWA classifications.
Total Truck Counts in Canada	Truck AADTT percentages are derived from a short-term vehicle length classification and are an approximation of the percent of truck traffic for an average day.
Truck Counts in Dataset	Estimates are based on observed hourly distribution at more than 100 directional Commercial Vehicle Survey sites across the province, AADTT and other information.
Advantages	Truck frequency indicated
Disadvantages	• Unable to determine stop locations appropriate for charging purposes • Identification of truck/trailer configuration, weight data not reported • Determination if truck just starting trip, mid-trip or near trip completion not able to be determined • Truck origin and destination not indicated

Table 7: Vehicle Registration data source, data collection methodology and advantages and disadvantages

Main Data Source	Canadian new motor vehicle registration survey was conducted by Statistics Canada since January 2018. Fuel consumption survey was conducted by Statistics Canada since 2004 and discontinued in 2014.
Methodology Used for Data Collection	Vehicle survey and new motor vehicle registration survey
Inclusion of Class 7/8 Trucks in Dataset	Vehicle registration has data for truck class 7/8 New motor vehicle registration survey does not have data for truck types
Total Truck Counts in Canada	Total truck counts in Canada from 1999 to 2021
Truck Counts in Dataset	Total truck counts in Canada from 1999 to 2021
Advantages	• Vehicle registration has total truck counts in Canada and all provinces for all vehicle classes and fuel types from 2011 to 2021 • Publicly available through the Government of Quebec
Disadvantages	• Not all truck identity data and truck usage data are available in the vehicle registration dataset. • New motor vehicle registrations data does not have specific truck categories: limited to categories - trucks 4.5 tonnes to 14.9 tonnes, trucks 15 tonnes and over

3.2 Data Gaps Analysis and Recommendations

Following the completion of the data source survey, it was determined that an additional task would be required to identify the data gaps that would prevent a comprehensive analysis and achievement of the project objectives.

It has been determined that the ATRI and Geotab datasets, with support of CFAF data, are well suited to quantify truck location and some truck usage (speed) data. Although some data related to truck identification and truck usage does exist within the selected datasets, the ability to link a specific truck at a specific time at a specific location is not possible.

A data gap summary of the analysis of the six selected commercial freight vehicle dataset's ability to meet project objectives is provided in Table 8**.**

'Available' indicates that the quality of the specific data variable within the dataset is sufficient to meet the project objectives, 'partial' indicates that the quality of the specific data variable within the dataset meets some the project objectives but additional data is required to enhance the qualify the data variable, and 'N/A' (not available) indicates that the specific data variable(s) within the dataset is missing or insufficient to meet the project objectives.

Table 8: Summary of availability, deficiencies and missing data within selected datasets

Dataset	ATRI	Geotab	CFAF	CVUS	MTO	Vehicle Registration
Truck Location Data						
Locations of routes	Available	Available	Partial [5]	N/A	Partial [5]	N/A
Average and maximum trip lengths, frequency of trips binned by trip length	Available	Available	Partial [5]	N/A	N/A	N/A
VKT on particular corridors	Available [1]	Available	Partial [5]	N/A	N/A	N/A
Frequency, duration, and location of stops (possibilities for charging/fueling)	Available	Available	Partial [5]	N/A	N/A	N/A
VKT by season	Available	Available	N/A	Available	N/A	N/A
Truck Identification Data						
Powertrain type and engine displacement	N/A	N/A [6]	N/A [6]	N/A	N/A	N/A
Vehicle class, vocation, cab configuration	N/A	Partial [4]	N/A [6]	Partial [4]	Partial [8]	Partial [8]
Vehicle age	N/A	N/A [6]	N/A [6]	Available	N/A	Available
Axle configuration (allowing comparison to maximum allowable weight)	N/A	N/A [6]	N/A [6]	N/A	N/A	N/A
Truck Usage Data						
Fuel consumption	N/A	N/A	N/A	Partial	N/A	N/A
Power and energy requirements	N/A	N/A	N/A	N/A	N/A	N/A
Vehicle weight and payload	N/A	N/A	Available [7]	N/A	N/A	N/A
Volumetric capacity	N/A	N/A	N/A	N/A	N/A	N/A
Speed	Available	Available	N/A	N/A	N/A	N/A
Accelerations and decelerations	N/A	N/A	N/A	N/A	N/A	N/A
Ambient temperature / weather	Available [2]	Available [2]	N/A	N/A	N/A	N/A
Altitude changes	Available [3]	Available [3]	N/A	N/A	N/A	N/A

[1] Dependent on GeoBase data from National Road Network and Census Cartographic boundary files

[2] Cross referenced to third party weather data

[3] Dependent on open data from Canadian Digital Elevation Model

[4] Class and vocation only

[5] Origin and destination only

[6] Suppressed the confidentiality requirements of the Statistics Act

[7] Payload weight only

[8] Class only

3.3 Summary of Preliminary Findings

Given the available datasets, it is reasonable to continue to develop a data analysis methodology to meet the project objectives. A summary of data gaps and deficiencies of the six analyzed datasets is provided in Appendix A.

Analysis of the main selected data sources revealed high representative geographical coverage of truck transportation travel within some provinces such as Ontario, Quebec, British Columbia and Alberta and very low coverage in some provinces in Northern Canada.

Details pertaining to industry sectors and truck information (make, model, powertrain, cab configuration) are not easily correlated across available datasets – lack of correlation to a specific truck at a specific time and location. Detailed analysis pertaining to vehicle technology benchmark requirements, such as traction battery capacity and fuel cell power, are not able to be determined to a high level of confidence due to insufficient weight and duty cycle metric correlation within available datasets.

Of the six datasets analyzed, ATRI, Geotab, and CFAF were determined to be well suited to inform the bulk of data analysis requirements with CVUS, MTO CVS and vehicle registration datasets being used as supplemental sources, where possible, to fill data gaps.

With a 1-year ATRI Canada-wide dataset, a data analysis methodology can be developed to analyse highly used Canadian trucking routes to further inform Government of Canada heavy duty decarbonization policy objectives, such as: the identification of the quantity and potential locations for zero emission truck high power chargers and hydrogen refueling stations; sales mandate and emissions targets, and suitable zero emission truck technologies for Canadian conditions and geography. ATRI data has been determined as the most cost-effective way to achieve similar data coverage as Geotab data.

ATRI truck traffic data contains only truck GPS movement data (truck ID, timestamps, latitude and longitude, and speed). Extraction and identification of truck stops and trips (including long haul, regional and local trips) from the ATRI raw data source will be required, and will also be challenging to accomplish to a very high accuracy percentage.

NRC performed preliminary exploratory data analysis on a 3-day ATRI Canada-wide sample dataset which provided guidance in determining a research and development of data processing and analysis methodologies that will be required.

Geotab fleet management telematics data can be used as an alternative data source to the ATRI truck GPS data. Geotab datasets contain detailed information such as vocation, industry, truck fuel type, and trip data. Using Web UI (a user-friendly platform) and REST API for Python and JavaScript (with advanced analysis required) the NRC can perform data analytics on Geotab data.

There is an expense associated with acquiring Geotab data, for example, 1-month of historical road traffic data across Canada costs $75,000 CAD and 12 months of historical road traffic data across Canada costs $425,000 CAD (quoted 2021 values). Due to significant costs associated with obtaining Geotab O/D and traffic datasets, the NRC recommends delaying the purchase of these datasets but permit allowance for reassessment at a later date, if the data is deemed necessary.

CFAF shipments dataset can be used as a baseline to validate the other dataset sources.

The NRC is proposing the creation of data analysis methodologies to tackle data gaps and shortcomings present in the currently available datasets. The details of this proposed approach are elaborated in the subsequent sections.

4 Proposed Data Analysis Methodology

A proposed methodology for addressing the objectives of identifying highly used trucking routes, as well as identifying potential locations for zero emission truck high power chargers and hydrogen refueling under several adoptions' scenarios is outlined in the following sections.

4.1 Dataset analysis

The NRC recommends that the Canadian trucking route data analysis be conducted in two phases.

Phase 1 would focus on data analysis of one year of ATRI collected data, covering all four seasons, for the three following key Canadian freight corridors:

- Windsor - Quebec City including Hamilton - Fort Erie;
- Vancouver – Calgary; and
- Calgary – Edmonton.

The total observations of one year of ATRI data, across Canada, is estimated to include 2.5 billion data points.

Phase 2 would involve conducting trucking route data analysis along the entire Trans-Canada Highway network as well as Ontario 400-series highways 400, 401, 402 and 416, Quebec autoroute 40, Alberta provincial highway 2 and British Columbia Highway 5.

Major highway routes selected for trucking route data analysis are shown in Figure 2. A full listing of highway routes selected for data analysis are provided in Table 9. No Canadian territorial highway routes are to be included in the analysis.

Figure 2: Major Canadian highway routes selected by the NRC for trucking route data analysis
Adapted from [42, 43, 44]

Table 9: Canadian highway routes selected for Phase 2 data analysis

Province / Territories	Highway (included)
British Columbia	1, 16, 3
Alberta	1, 16, 201, 2
Saskatchewan	1, 16
Manitoba	1, 16
Ontario	17, 417, 7, 11, 69, 71, 400, 401, 402, 416
Quebec	20, 185, 117, 40
New Brunswick	2
Nova Scotia	104, 105
Prince Edward Island	1
Newfoundland and Labrador	1
Northwest Territories, Nunavut and Yukon	None

Based on available datasets and their level of details, a combined quantitative and qualitative methodology is proposed, using three major steps:

Step 1: Building of a base map of the selected road network

The base map for a determined road network or corridor will be constructed using publicly available resources. Identified resources shall include NRCan's national road network data [45], Statistics Canada's road network files [42] and other public domain datasets, such as OpenStreetMap [46].

Road segments pre-defined by NRCan or Statistics Canada will be simplified and merged to best suit the analysis goals. This simplification process is critical for analysis in the following steps. If necessary, new segmentations shall be generated.

Step 2: Identification of truck trip data from ATRI dataset

Within this proposed analysis stage (on corridor or national network levels), the methodology of identifying heavy truck freight trip starts and ends shall mainly consist of two key steps: the first step will identify truck stops through the analysis of raw ATRI GPS data and the second will select valid trip starts and ends from identified truck stops [47]. Truck trips for the period of one-year shall be extracted from the results of identified stops.

Truck stops will be characterized as short stops, medium stops and long stops and valid trip starts/ends shall be on the medium and long stops. Distinguishing heavy truck valid trip starts and ends and temporary stops (non-origin and destination stops) will be done using time thresholds which are to be determined by the distribution of long-haul truck dwell times at stop locations [48].

Long-haul trucking freight will be characterized into three activities: loading or unloading at the start and end of a trip, transporting goods during a trip, and no activities after the trip. Long-haul trucking activities have different temporal associated time characteristics. Temporary stops for refueling during the trip are usually short periods of time, loading and unloading at the trip starts and ends are relatively longer periods of time and truck parking after a trip is characterized as a very long period of time.

Step 3: Identification of major trucking routes analysis

Extracted long-haul truck trips data will be matched with the road network's base map, built in Step 1, to determine trip routes through the use of road segments in the base map.

After the construction of the base map, alignment of important traffic statistics and distributions shall be obtained for major routes between large logistics hubs (cities) or more granular routes between population centers or industry areas. These statistics and distributions shall include:

- Travel distance distribution of all trips;
- Count - travel distance matrix between selected cities;
- Vehicle Kilometers Travelled (VKT);
- Traffic count distributions; and
- Additional parameters (yet to be determined)

Based on the results of the statistics analysis the following data metrics shall be determined: major long-haul trucking routes together with their associated traffic features such as VKT, travel distance distribution, average speed, speed changes, stops and additional parameters (yet to be determined).

4.2 Weather condition analysis

Daily ambient temperature and other weather conditions (precipitation, wind speed and direction) on each road segment in the corridor or network shall be determined through the use of ECCC weather station data complemented with data from a weather information supplier.

Seasonal comparison and statistical analysis shall be conducted for the routes identified in Step 3 of the data analysis methodology. Weather data and associated analysis results shall be used as an input for the determination of energy consumption along long-haul trucking routes.

4.3 Elevation analysis

The incorporation of elevation data is a critical input for the determination of energy requirements along long-haul trucking routes. Significant data exists within Canada's road networks database, but data specific to grade along highway segments does not appear to be readily available or explicitly included in the reviewed datasets.

Therefore, the HRDEM data shall be used for analysis of long-haul truck route altitude changes. The HRDEM product is derived from airborne LiDAR data, offered at 1 m or 2m resolution, and satellite images. A distribution of LiDAR and satellite data coverage of Canada is shown in Figure 3. HRDEM includes Digital Terrain Models (DTM) (derived data available are slope, aspect, shaded relief, color relief and color shaded relief maps), Digital Surface Models (DSM) (dataset derived data available are shaded relief, color relief and color shaded relief maps) and other derived data.

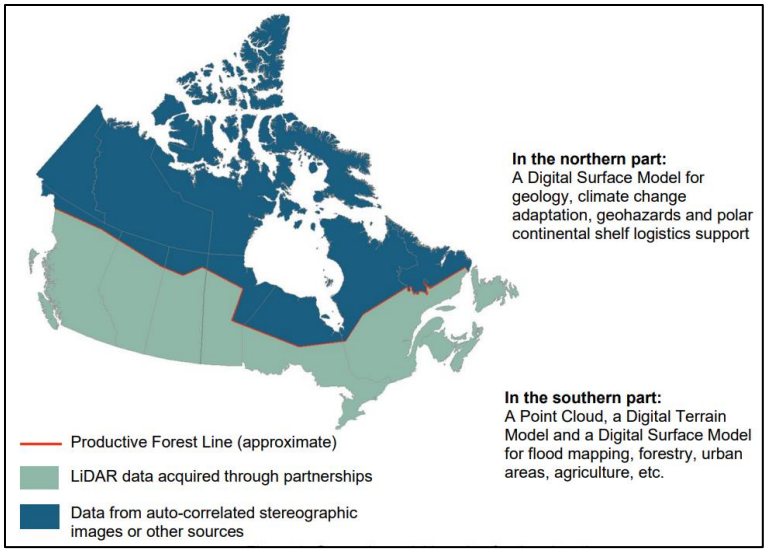


Figure 3: HRDEM general acquisition plan for elevation strategy [49]

Although highway road grade (an incline or decline in a highway as a ratio of rise over run expressed as a percentage) is connected to elevation, the two parameters factor differently when calculating energy consumption requirements. A road grade incline will demand more tractive power while a decline provides opportunities for recouping of power through the use of regenerative braking. Elevation is a key variable to consider when calculating internal combustion engine performance, air density decreases as elevation increases, causing a decreased oxygen supply and therefore output power, while electric powertrain performance is not affected by elevation changes.

The analysis based on HRDEM data shall provide a qualitative input parameter as well as potential analysis and determination of truck energy requirements on inclines and energy recovery on declines.

4.4 Truck usage and features analysis

Based on available data and its limitations, truck usage statistics analysis will cover the following items:

- Vehicle Class: provincial level statistics, based vehicle registration data (Class 7/8)
- Vocation: statistics based CVUS data
- Sleeper vs day cab, etc.: statistics based CVUS data
- Vehicle age: national level statistics-based vehicle registration data
- Axle configuration: national level statistics based CVUS data
- Vehicle Weight: national level statistics based CVUS data, Route-level statistics based on provincial WIM sensors (S.5.9) is an option for investigation
- Fuel consumption: based CVUS data.
- Power and energy requirements: no data sources currently known
- Volumetric capacity: no data sources currently known

The following data is also a key statistic which can not be extracted from current available data:

Powertrain type (engine displacement, engine horsepower and torque rating, transmission gearing): national level statistics based American and Canadian truck manufacturer sales data

The relevancy of available CVUS data, last updated circa 2014, with regard to the characterization of present-day truck usage and features data parameters will need to be explored. Optimizations implemented by truck manufacturers in the area of aerodynamic and powertrain efficiencies over the past decade may minimize the usefulness of the CVUS dataset.

Reinstatement of an updated CVUS methodology to obtain data relevant to determined data gaps (truck identification and usage) should be explored for relevancy and a reinstatement costing estimate should be undertaken.

4.5 Collection of additional data from major trucking routes

Due to limitations of available data, the NRC proposes collecting the following data for the 3 major trucking routes identified in section 4.1, for 12 months:

- Vehicle weight
- Axle configuration
- Vehicle age

In addition to the parameters above, the vehicle speed should also be captured at the same locations for validation purposes.

Options for collecting this data are presented in Section 5 of this report. This first phase of data collection should be designed to evaluated variance of the collected parameters at different collection sites within and between routes. The results of this phase could then be used to determine the necessity and extent of any further data collection required for the next phase.

Results of data obtained during the truck usage and features analysis (Section 4.4) shall be compared with the data collected.

4.6 Estimation of energy requirement for major trucking routes

Analysis of ATRI data can provide a reasonably reliable estimation for VKT, speed and many other traffic variables of the identified major long-haul trucking routes. However, due to vehicle feature and truck usage data gaps within the existing datasets, it will be difficult to perform a fully qualitative estimation of the energy requirement for each segment of the identified major long-haul trucking routes.

As a means to address vehicle feature and truck usage data gaps, the NRC is proposing the implementation of a qualitative analysis methodology to estimate energy requirements. An Energy Need Index (NEI, 1 – 5 with 1 as the least energy demand requirement, 5 as the greatest demand requirement) is proposed to address the challenge. Within the Energy Need Index method, the statistics values from other available datasets (i.e., CVUS) will be used for variables related to truck identity (i.e., powertrain type, vehicle class, vocation, sleeper vs day cab, vehicle age and axle configuration) and truck usage (i.e., fuel consumption, vehicle weight and payload, volumetric capacity).

Through the use of aggregated national and provincial statistics data (such as the CVUS dataset) for long-haul trucking vehicles, estimated percentages shall be assigned to truck identity variables available in the statistics data. These percentage values can possibly be effectively calibrated if combined with collected wayside data.

By using truck vehicle class as an example, assume there are 3 types of truck vehicle classes (light duty, medium duty and heavy duty). If national statistics data are comprised of 80% of heavy-duty trucks and 10% for light-duty and medium-duty trucks, these statistics can be assigned to all route segments, unless more granular data is available.

This analysis will provide a more accurate percentage distribution for different provinces and could be assigned to all route segments within each province. This qualitative analysis methodology can also be used for data gaps in truck usage variables.

Through integration of all available variables, such as trip counts, VKT, vehicle class, vehicle weight and payload, vehicle age, an Energy Need Index can be estimated for each segment of the selected trucking routes.

5 Options For Further Data Collection

The NRC's proposed methodologies for both utilization of existing datasets and collection of new data shall consider the following criteria: data gaps, privacy issues, data availability / interest from OEMs or fleets, timelines to gather data, how to best represent the full Canadian fleet, availability of technology to collect data (e.g. on-board telematics systems), which parameters to collect and possibilities of using data collection methodologies in other jurisdictions (e.g. U.S. vehicle inventory and use survey).

The following outlines recommendations for proposed additional work and development of a methodology for collecting new data which satisfies the following criteria:

- addresses potential data privacy issues;
- determination of key missing parameters to collect; and
- leverages available technology to collect data.

The NRC, through a combination of results obtained through statistical analysis of publicly available data (described in Section 3.6) and data obtained from field measurements (utilizing data sources such as weigh-in-motion, virtual weigh station, cameras, ALPR, etc.) intends to address data limitations related to vehicle features and truck usages.

A summary of recommended sources for addressing of existing data variable gaps within existing available datasets are outlined in Table 10.

Table 10: Proposed methods of addressing data gaps

Data Variable Determined to be Gap withing Existing Datasets	Provincial Traffic Datasets	Infrastructure Sensor Metadata	Automatic Vehicle Classifier (AVC)	Telematics	Automated License Plate Recognition (ALPR)	Electronic Logging Device (ELD)	Existing Refueling and Layover Locations
Vehicle Class	Partial [1]	Yes	Potentially	Yes [2]	Yes	Potentially	No
Make, Model	No	Potentially	No	Yes [2]	Yes	Potentially	No
Powertrain Type	No	No	No	Yes [2]	Potentially	No	No
Axle Configuration	Yes	Potentially	Potentially	Potentially	Potentially	No	No
Vehicle Weight	Yes	No	No	Potentially	No	No	No
Vehicle Age	No	Potentially	No	Potentially	Yes	No	No
Vocation	No	Potentially	Potentially	Yes	Potentially	No	No
Trailer Information	Yes	Potentially	Potentially	Potentially	No	No	No
Vehicle Payload	Yes	No	No	Potentially	No	No	No
Refueling Infrastructure Location	No	No	No	Potentially	No	Potentially	Yes
Relevancy to meet project objectives	Medium	High	Medium	High	Medium	Low	Medium

[1] Classifies based on axle configuration rather than weight

[2] Dependent on provision of data from participating trucking fleet

A brief overview of the NRC proposed methods for obtaining additional data sources to address existing data gaps is outlined in the following sections.

5.1 Collection of Meta Data Acquired from Infrastructure Sensors (AI and Machine Vision)

Forecasted artificial intelligence implementation within the long-haul trucking industry, specifically related to dispatching and routing, real-time traffic monitoring and route reanalysis, real-time state of charge (SOC) tracking and automatic scheduling of charge/refill opportunities and infrastructure availability/status, platooning opportunities and partial or full autonomous commercial adoption indicate opportunities for efficiencies in the areas of optimized charging and refueling opportunities.

Leveraging of past and current research involving traffic camera imagery using a computer vision-based system, similar to that conducted by Statistics Canada and published in 2022 [50], should be explored. Accessibility to collected data through use of Application Programming Interfaces (APIs), orientation of infrastructure-based sensors (viewing angle, ability to pan-tilt-zoom camera) and weather and lighting variations may provide data collection challenges and insufficient access to necessary data to meet the project objectives.

Some weigh stations are currently equipped with machine vision to provide images of commercial vehicles matched with the weigh-in- motion (WIM) information, for pre-screening purposes or for providing images for vehicle identification using ALPR or optical character recognition of DOT numbers. Machine learning could be used as a means to improve WIM systems' accuracy. Representative examples of road infrastructure sensors implementation are shown in Figure 4.

Figure 4: Example of roadside sensor install for data collection and analysis using AI, machine vision and Weigh-in-Motion systems [51, 52]

Commercial video-based traffic count and classification product solutions, such as International Road Dynamics (IRD) iTheia [53], allow for image capture, from existing video cameras installed at inspection stations, and image annotation which overviews images to weigh station operator software. IRD also offers patented and open-source methods of commercial vehicles tire type specificity classification through use of machine learning as shown in Figure 5. Camera sensor installation distance and orientation determine available image resolution and vehicle make and model recognition (MMR) software ability to recognize truck make and model.

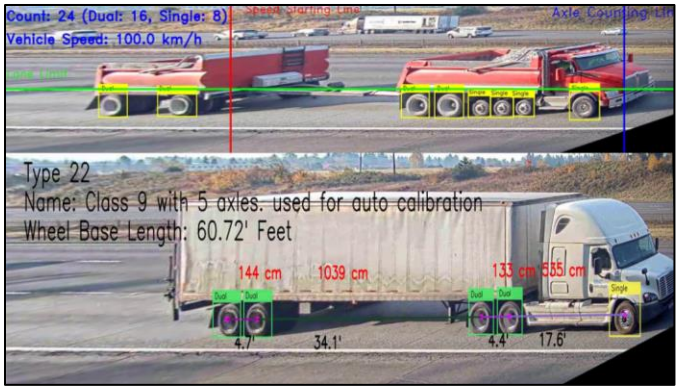


Figure 5: International Road Dynamics commercial vehicle classification example [51]

When possible, leverage of existing infrastructure is advised to minimize installation requirements and costs. Estimation of traffic volume or obtaining of truck usage and identification data using existing camera infrastructure may not be possible due to limitations such as traffic camera setup (optimum camera angles are shown in Figure 6) and the provision of only static images, retrieved at second or minute intervals, as opposed to streaming videos.

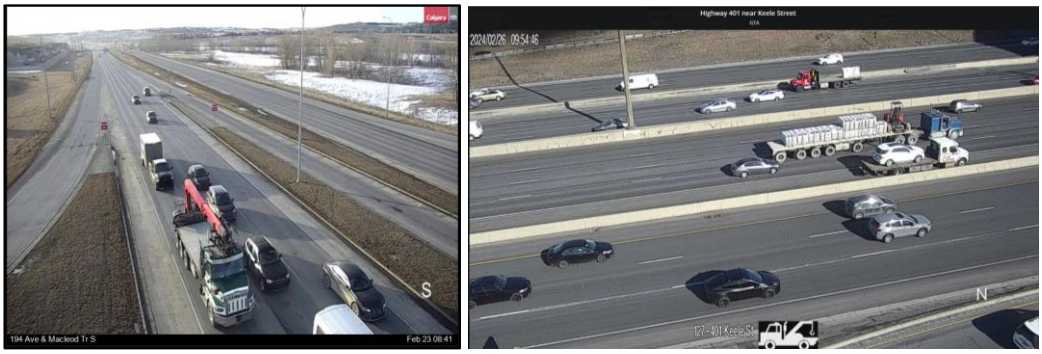


Figure 6: Representative existing infrastructure traffic camera views of Canadian highways [54, 55])

Leveraging of existing available traffic camera data in locations adjacent to truck stop fueling locations is advised, when possible. Representative potentially accessible traffic camera views of heavy-duty truck traffic flow entering and exiting an Ontario commercial cardlock fueling station are shown in Figure 7.

Figure 7: Ontario traffic camera capture of HWY 401 (exit 538) on-ramp and off-ramp access to fuel refueling cardlock location

Significant work is expected to be required to determine the accessibility of traffic camera data (provincial/municipal operated) along key long-haul trucking roadway corridors, characterization of the quality of available data (frame rate, view perspective of roadway, etc.), implementation of data privacy and data sharing/cost considerations/agreements and the logistics relating to installation of new infrastructure sensors (WIM, AVC, etc.) along key long-haul trucking roadway corridors for high quality characterization of truck usage and features correlation to route and traffic data.

5.2 Automatic Vehicle Classifier (AVC)

Applicability of Automatic vehicle classifier (AVC) systems is recommended to be researched. AVC systems, through use of a profile scanner, produce a matrix depiction of the vehicle as seen from the overhead position of a laser, as shown in Figure 8. Such data could be useful to characterize truck identification data, specifically cab, axle and trailer configuration, similar to long truck classification in the Canadian Prairie Region research conducted by University of Manitoba [56]. Utilization of existing or the installation of temporary AVC systems at specific truck weigh stations along key Canadian long-haul transport routes should be researched for potential of useful truck identifying data collection.

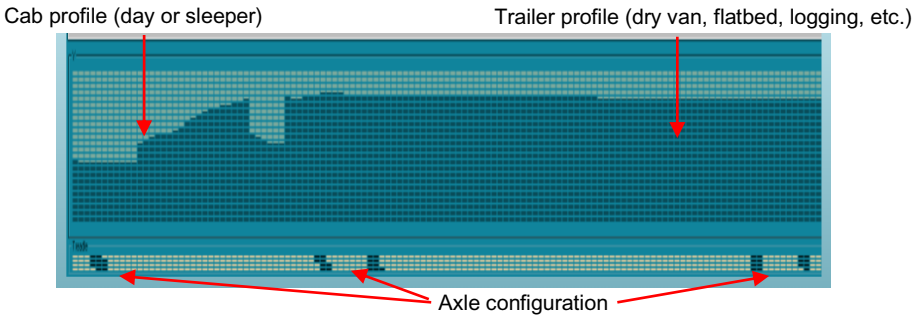


Figure 8: Profile image produced by single lane laser automatic vehicle classifier system [57]

Appropriate AVC systems installation locations would be determined though stakeholder engagement (border crossing, highway toll station, etc.), preliminary implementation cost estimates (supporting infrastructure requirements, API and data access) and the ability to combine AVC collected data with additional data (vehicle weight, age, make and model) to meet the project objectives.

5.3 Access to Trucking Fleet Telematics Data

Telematic systems incorporate global positioning systems (GPS) and on-board diagnostics (OBD) technologies which permit the capability of capture and recording of geo-spatial position and truck powertrain/chassis data of an individual truck. Telematic system functionality ranges from basic, minimum electronic logging to meet regulatory requirements, to comprehensive with the possibility of inclusion of features such as asset management, preventative maintenance, route optimization, recommendations for fuel efficient and operational improvements and driver behavior and management.

A 2019 study [58] reported telematics system utilization by Canadian trucking fleets to be 50% (some large Canadian fleets have achieved 100% implementation) and that with implementation of Canadian ELD requirements (in effect as of June 2021) a significant increase in telematic deployment systems in Canada was expected [59]. Major Canadian telematic providers and estimates number of deployed units include:

- Geotab (~230,000 devices in Canada) GeoTab purchased BSM Technologies in 2019;

- Isaac Instruments (~20,000 devices in Canada);
- Fleet Complete (~80,000 devices in Canada);
- Blackberry Radar (~1,000 devices in Canada) targets tracking of trailers, intermodal containers and chassis;
- FleetMind (~1,500 devices in Canada) targets the waste management industry; and
- Verizon Connect Canada (~1,800,000 devices in Canada and United States).

The above stated companies universally feature GPS fleet tracking and asset management, routing and navigation, ELDs, and dispatch and scheduling features.

NRC selection of fleets to meet project objectives shall focus on the following parameters:

- Inclusion of all Canadian provinces to ensure best possible geographic representation of travel on Canadian highways;
- focus on long-haul operations (tractors) versus medium-short haul (straight trucks). Selected fleets may consist of a mix of both;
- Include various types of freight hauling, including for-hire truckload, less-than-truckload, intermodal, drayage, and private;
- trailer configurations may include dry van, flatbed, refrigerated, tanker, intermodal bulk, live/hopper bottom, curtain sides, dump, drop deck. Additional configuration possibilities may exist; and
- Inclusion of all Canadian fleets who cross the border into the United States (preferably at various border crossing locations)

With the intention of targeting a cross-section of Canadian HDV fleets, the NRC has determined a list of ninety-three Canadian long-haul trucking fleets deemed suitable for meeting the project objectives, if agreement to access fleet telematics data is possible. No trucking fleets were selected from the Canadian territories.

Selected fleet breakdown by province is as follows: British Columbia (10), Alberta (8), Saskatchewan (3), Manitoba (7), Ontario (45), Québec (11), New Brunswick (4), Nova Scotia (2), Prince Edward Island (2) and Newfoundland and Labrador (1). A complete listing fleet company names, city and province of their headquarters and, where possible, number of trucks in the fleet is provided in Appendix C.

The largest long-haul trucking fleet inventories (estimated trucks) in Canada are as follows:

- **New Brunswick:** Day & Ross (~4,000), RST Sunbury (~600)
- **Québec :** TFI International (~11,400), C.A.T. (~1,600), Groupe Robert (~800)
- **Ontario:** Challenger Motor Freight (~2,400), Canada Cartage Systems (~1,500), Manitoulin Transport (~1,200), Kriska Transportation Group (~850), Charger Logistics (~800), Titanium Transportation Group (~800), Pride Group Logistics (~700), Highlight Motor Group (~700)
- **Manitoba:** Bison Transport (~2,000)
- **Alberta:** Mullen Group (~4,000), Trimac (~2,000)

In recent years NRC-AST has conducted research projects which involved collaboration with trucking fleets Trans-West, Bison Transport and Groupe Robert. Potential opportunities of accessing telematics data from future scheduled industry-government project collaborations, such as FPInnovations Zero

Emissions Trucking Testbeds involving on-road analysis of BEV trucks in the Montreal area[2], should be explored.

Variations in telematic data collection, parameter selection, recording and reporting methodologies are expected between fleets with some key parameters such as location, speed and date/time parameters assumed to be typical recorded parameters. Truck telemetry data is extremely useful especially if able to be combined with truck identification and usage data (required to be provided by fleet manager).

Available telematics data shall be used in concurrence with other available collected data parameters. Telematics data variables which may be applicable to meeting the project objectives are provided in Appendix D. Availability of data parameters for recording and analysis purposes will vary by truck manufacturer and in some cases by model.

5.4 Automated License Plate Recognition (ALPR)

Automated Licence Plate Recognition (ALPR) is a technology that uses optical character recognition on images to read vehicle registration plates to create vehicle location data. ALRP can use closed-circuit television, road-rule enforcement cameras such as red-light cameras, speed enforcement cameras, photo radar, or cameras specifically designed for the task. Such technology is currently in use at vehicle crossing tolls and border checkpoints.

The installation of ALPR systems, affixed to infrastructure near roadways, would permit tracking of long-haul trucks at specific locations along highways throughout Canada.

Analysis of ATRI data would guide selection of measurement locations that best align with high flow traffic locations (in numerous provinces) to accomplish the task of addressing data gaps. NRC intends to utilize in-house machine vision expertise for analysis of collected ALPR data. If it is determined that analysis requirements are beyond the abilities of NRC the option of subcontracting to a qualified third-party vendor will be explored. Commercial cloud-based ALPR solutions, such as Plate Recognizer [60], offer services (license plate recognition, vehicle make and model, color and orientation) for $75 (50k lookups/month) to $375 (500k lookups/month).

ALPR systems can include databases of licence plates which are of interest, such as long-haul trucks. Potential sources of ALPR data may include provincial insurance companies, affiliated provincial agencies such as the Ministry of Transportation and the Canadian Police Information Centre.

Implications of privacy, when handling recorded ALPR data, must be fully understood due to the potential ability of determining where specific vehicles are at specific times. Historically, the use of ALPR systems has raised significant privacy concerns. No federal or provincial level specific regulations or statutes expressly regulate data generated in the automotive sector, such as geolocation data, safety event data, or driver availability data. Where data generated by a vehicle and collected by a manufacturer (or other entity) is not strictly about the vehicle itself and can be associated with an identifiable individual, the data will likely constitute ‘personal information’ and be subject to a patchwork of Canadian privacy laws [61].

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[2] FPInnovations to conduct testbed to support clean energy adoption in the trucking sector - FPInnovations [76] FPInnovations will conduct 12-month, operational testing and monitoring of class 8 battery electric trucks in and around the Montreal area. Operating on similar transportation routes, five battery electric trucks, and five diesel trucks will be instrumented, and data collected during this period.

Recommendations of a recent Office of the Privacy Commissioner of Canada investigation [62] involving a 2019 Canadian Border Security Agency (CBSA) ALPR data privacy breach included the implementation of a dedicated VPN tunnel for transmission of ALPR image files and associated metadata, utilization of SSH File Transfer Protocol and the implementation of robust security procedures by any third-party contractors who has access to collected ALPR data.

Due to above stated privacy concerns additional research will be required to determine the feasibility of obtaining ALPR data.

5.5 Electronic Logging Device (ELD) Data

An Electronic logging device (ELD) is a piece of hardware attached to a commercial motor vehicle engine which records hours of driving, data on whether the engine is running and if the vehicle is in motion, total distance driven, and duration of engine operation.

ELD data (location, fuel economy, time spent off the road) could possibly be utilized to confirm truck fuel stops and analysis of route choices. Capture of ELD telemetry data would benefit the end goal of this project but issues relating to data privacy may limit access to ELD data. Certified ELD vendors within Canada recommended to be contacted include Assured Techmatics, Certified Tracking Solutions, Fleet Complete, Geotab (for possible additional data beyond what NRC currently has access to), ISAAC Instruments (past involvement with Trans-West and NRC TPMS research project), J. J. Keller & Associates, Motive Technologies, Omnitracs, ORBCOMM, Pedigree Technologies, and Penske Truck Leasing.

The availability and applicability of ELD data should be explored as a supplemental source for the identification of potential charger locations.

5.6 Characterization of existing long-haul truck refueling and layover locations

Determination of location and quantity of parking facilities, commercial truck stops, travel plazas and public rest areas is a useful dataset for characterization of potential electric charging and hydrogen refilling locations.

Studies [63, 64, 65] have reported that truck drivers prefer commercial truck stops (facilities especially for truckers, usually by a highway, that includes a diner, fuel pumps, and a garage) and travel plazas (convenience store, gas station, other such amenities) for most activities and long-term rest and prefer public rest areas when stopping for a short parking duration.

Extraction of truck stoppage location data from available GPS datasets and clustered stoppage points of multiple trips (arrival time distribution, duration distribution identifying where possible the functional nature of the stops) could be utilized as a means of cross referencing known existing truck refilling infrastructure locations across Canada to truck stoppage location data.

The following metrics shall be used to characterize potential charging and refilling locations sites and their functionality:

- Contains an area with sufficient space to permit a long-haul truck and trailer to safely maneuver (i.e., park in a position for extended period of time which does not hinder flow of other traffic, drive-thru fuel island, turn around in a large arc);

- Sites which currently contain accessibility to a diesel fuel pump or cardlock access to efficient high-speed diesel fuel dispensers; and
- Parking spaces availability for short to medium duration stops.

An initial review of available Canadian truck stops location data [66] by the NRC determined 476 potential charge/refill opportunity locations across Canada (ON:115, AB:106, BC:72, QC:53, SK:48, MB:28, NB:21, NL:9, NS:9, PEI:7, YT:6 and NWT:2).

To validate a truck being stopped for a time deemed necessary to facilitate a refueling (>20 minutes) locations identified from available datasets shall be compared with known points of interests involving major refueling stations, parking on the wayside, loading/unloading, distribution centres, shopping malls, manufacturing companies, and industrial areas.

A representative example of a 50 km radius distance surrounding known diesel fueling infrastructure utilized by long-haul trucking fleets in New Brunswick is shown in Figure 9. These sites represent potential charging and refueling opportunity locations.

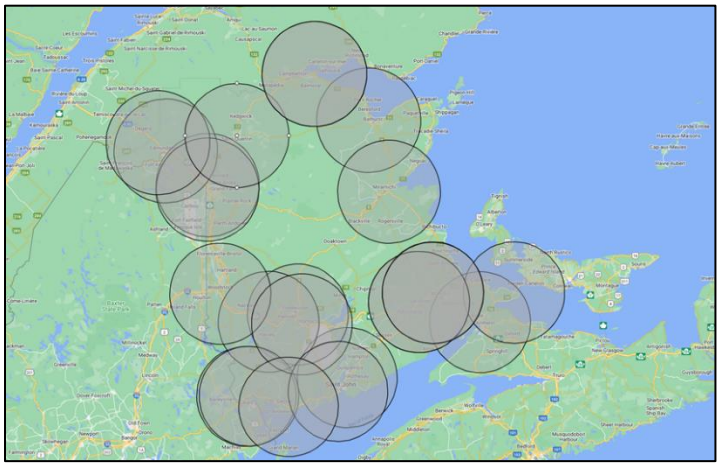

Figure 9: Representative 50 km radius surrounding potential charging and refueling infrastructure locations in New Brunswick (source: Google)

Data obtained through this analysis would be used for determination of locations appropriately configured for charger/hydrogen refilling infrastructure with the potential of also being able to address vehicle technology requirements.

5.7 Industry and Stakeholder Engagement

Engagement of hydrogen industry stakeholders, hydrogen production (CHARBONE Hydrogen Corporation [67] and Air Liquide), refueling stations projects (Calsun Energy [68], Air Products [69], and HTEC [70]), work involving hydrogen powered class 8 engines (Cummins Accelera (previously Hydrogenics) [71]), is highly recommended to ensure relevant proposed and ongoing infrastructure projects are properly captured into long-haul recommended hydrogen refueling site analysis.

Opportunities to engage additional hydrogen industry stakeholders, proposed industry and government collaboration/funding projects and industry partnerships should be explored. Outcomes of such outreach could be valuable in guiding analysis related to the number of trucks refilling opportunities per region of the country and to provide a better quantified estimated of travel distances between refilling hubs.

5.8 United States Registered Vehicles traveling on Canadian Roadways

To fully capture commercial long-haul truck traffic within Canada, the NRC must also include trucks registered outside of Canada since these trucks also utilize existing Canadian roadways and refueling infrastructure.

Lacking specificity relating to truck identification within existing datasets, license plate or Commercial Vehicle Safety Alliance (CVSA) decal data for example, complicates the ability to determine a trucks country of origin when analyzing data. The NRC shall research methods of obtaining registration data for U.S based trucks (license plate, CVSA decal) that adhere with privacy laws as well as technologies capable of capture and interpretation of data obtained from roadside sensors. Research pertaining to the collection, analysis and storage of data of long-haul trucks who are registered outside of Canada but are traveling within Canada on Canadian roadways will also be required. ARTI data, along with Canada-wide truck GPS data, also includes data 15 miles (24 km) inside the U.S. Border [29].

Decal reader systems, utilizing artificial intelligence and machine vision technology, have been proposed as additional features to be added to existing pre-screening locations in North America [51].

5.9 Provincial Traffic Datasets

All provinces maintain traffic data collections programs, which collect data for a variety of infrastructure planning activities. In general, these programs employ a combination of permanent and temporary sensors to gather data on traffic volumes, composition, and sometimes speed. A variety of reporting formats are used; it would need to be determined to what degree of granularity would be optimal for this analysis, but it's likely that all systems would be capable of reporting common statistics such as Average Annual Daily Traffic (AADT).

Automated systems which separate traffic volumes into specific classifications, such as the US Federal Highway Administration (FHWA) vehicle classification system shown in Figure 10, are commonly used. These systems do not directly measure weight, but axle weight limitations would constrain heavy commercial highway vehicles to Classes 5-13. It's recommended that these datasets be used for independent cross-validation of equivalent values derived from the telematics-derived datasets under study.

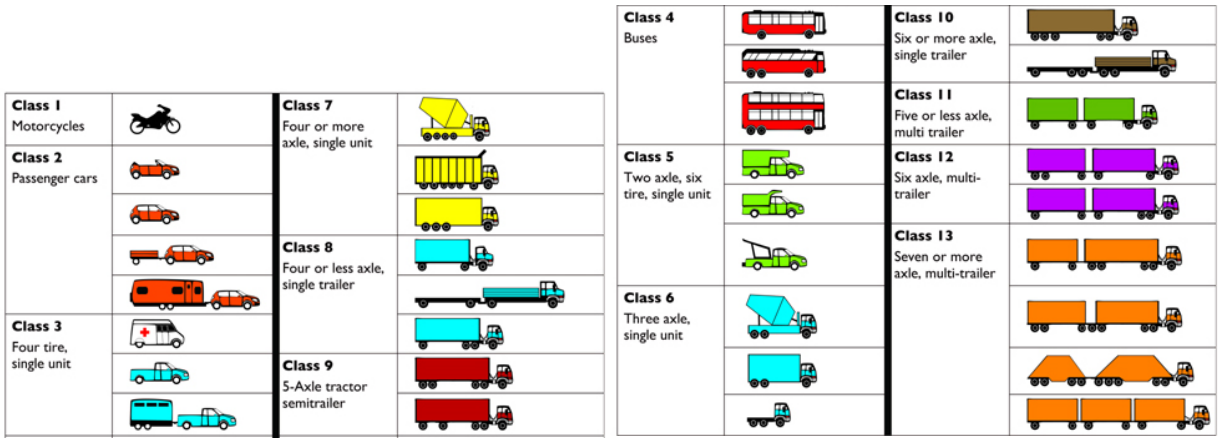

Figure 10: FHWA Vehicle Categories [72]

In addition, all ten Canadian provinces and Northwest Territories deploy Weigh-in-Motion (WIM) systems at fixed locations [73]. These systems use a variety of methods to measure the axle loads of vehicles passing over them at highway speeds. These systems can collect the same data and perform the same analysis as the standard traffic sensors, but also allow for the collection of vehicle and axle weights. When combined with other systems, additional information can be associated which each vehicle; at least some WIM stations currently deployed in Canada do incorporate additional sensor technology, but it is not known how many.

All ten provinces were contacted as part of this work; however only four were able to respond in full prior to publication of this report. Based on information received to date, it appears likely that the provincial WIM systems could serve to fill the vehicle weight and axle configuration gaps for the work envisioned. They appear to typically be sited on the most travelled highways; however, it would still need to be confirmed that they exist on all the corridors identified in Table 9. As this data would be independent of the datasets examined in this report, it would not be possible to directly augment them, however it would give route-level statistics.

5.10 Addressing Privacy Issues Related to Accessing Data

The Privacy Act in Canada protects the privacy of individuals with respect to their personal information. This Act governs the federal government's collection, retention, use and disclosure of that information. In regards to the ATRI dataset, data has been aggregated which results in unique truck data points being removed or obfuscated (i.e., truck identification and usage data except speed).

Information sharing agreements may be necessary for access to necessary additional datasets.

Anonymization of all applicable data will be necessary to protect driver personal information and potential trucking fleet competitive advantage [74]. A data sharing agreement with participants would also be a requirement.

6 Conclusion

Available trucking datasets allow for tracking aggregate truck traffic across the country, particularly major Canadian shipping routes (e.g., Windsor-Quebec City Corridor), but do not provide information on truck usage / identification, specifically: payload weight, volumetric capacity, and fuel consumption – all key variables to modeling MHZEV requirements.

A methodology is proposed to address the objectives of identifying highly used trucking routes, as well as identifying potential locations for zero emission truck fast chargers and hydrogen refueling under several adoption scenarios.

Due to the lack of truck usage/identification data, specification of vehicle technology needs to electrify Class 8 freight-hauling trucks is difficult. To fill data gaps and address this objective, NRC proposes to collect additional data using telematics systems, leveraging existing infrastructure sensors and surveying of industry and trucking fleets.

Similar long-haul trucking public charging infrastructure modeling, energy and power requirement research conducted in Europe [75] and the US [76] concluded that with timely investment, policy support and prioritized infrastructure deployment the feasibly of gradual MHZEV technology adoption into the long-haul trucking industry is capable of falling within government stated implementation timelines.

Acronyms and Abbreviations

AADT	Average Annual Daily Traffic
AFHTS	Annual for-hire trucking surveys
AHTS	Annual for-hire trucking surveys
AI	Artificial intelligence
ALPR	Automated License Plate Recognition
AMTA	Alberta Motor Transport Association
API	Application programming interface
APTA	Atlantic Provinces Trucking Association
AST	NRC Automotive and Surface Transportation Group
ATRI	American Transportation Research Institute
AVC	Automatic Vehicle Classifier
BCTA	British Columbia Trucking Association
BEV	Battery electric vehicle
CA	Census agglomeration
CAD	Canadian currency dollar
CAN	Controller area network
CFAF	Canadian Freight Analysis Framework
CMA	Census metropolitan area
CTA	Canadian transportation agency
CVS	Commercial Vehicle Survey
CVSA	Commercial Vehicle Safety Alliance
CVUS	Canadian Vehicle Use Survey
CVUS-H	Canadian Vehicle Use Study - Heavy-Duty
DOE	Department of Energy
ELD	Electronic Logging Device
FHWA	US Federal Highway Administration
GPS	Global positioning systems
GVWR	Gross Vehicle Weight Rating
HD	Heavy duty
HDV	Heavy duty vehicle
HRDEM	High-Resolution Digital Elevation Modeling
ICE	Internal combustion engine
ID	Identification
kg	Kilogram
km	Kilometer
kWh	Kilowatt-hour
L'ACQ	Association du Camionnage de Québec
lbs	Pound
MHDV	Medium- and Heavy-Duty Vehicle
MTA	Manitoba Trucking Association
MTO	Ministry of Transportation of Ontario
MHZEV	Medium- and Heavy-Duty Zero-Emission Vehicles

NRC	National Research Council of Canada
NRCan	Natural Resources Canada
NREL	National Renewable Energy Laboratory
NRN	National Road Network
OBD	On-board diagnostics
OEM	Original equipment manufacturer
OTA	Ontario Trucking Association
PMTC	Private Motor Truck Council of Canada
ROP	Rest of Province
SOC	State of charge
STA	Saskatchewan Trucking Association
TC	Transport Canada
TCOD	Trucking Commodity Origin and Destination Surveys
TFS	Freight Trucking Statistics
TPMS	Tire pressure monitoring system
TTI	Travel Time Index
US	United States of America
VKT	Vehicle Kilometers Travelled
WIM	Weigh-in-Motion
ZEV	Zero-emission vehicles

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Appendix A - Data Gaps of Analyzed Datasets

Table 11: ATRI dataset data gaps

Data Gaps	Privacy Issues	Data From Original Equipment Manufacturers (OEMs) or Third-party Providers	Timelines To Gather Project Data	Sample Size Requirement for Dataset to best represent Canadian trucking operations	Available Technology to Collect Data	Data Collection Methodologies in Other Jurisdictions
Missing Truck Identity Data	Filtered by the confidentiality requirements	Original Equipment Manufacturers (OEMs)	1 year (seasonal)	10% of truck counts for medium and heavy trucks across Canada	Original Equipment Manufacturers (OEMs), Electronic logging device (ELD)	Data from vehicle fleet management, Data collected with survey vehicle, Registration data
Missing Truck Usage Data except for truck speed	Filtered by the confidentiality requirements	Third-party Providers	each truck trip for one year	10% of truck counts for medium and heavy trucks across Canada	On-board diagnostics (OBD), Electronic logging device (ELD)	Data from vehicle fleet management, Data collected with survey

Table 12: Geotab dataset data gaps

Data Gaps	Privacy Issues	Data From Original Equipment Manufacturers (OEMs) or Third-party Providers	Timelines To Gather Project Data	Sample Size Requirement for Dataset to best represent Canadian trucking operations	Available Technology to Collect Data	Data Collection Methodologies in Other Jurisdictions
Missing Truck identity data (except for truck class and vocation)	Truck private information was filtered on purpose	Original Equipment Manufacturers (OEMs)	monthly data for one year	10% of Truck counts for medium and heavy truck cross Canada	On-board diagnostics (OBD), Electronic logging device (ELD)	Data from vehicle fleet management, Data collected with survey, Vehicle registration data
Missing Truck usage data (only speed and vehicle class/weight)	Truck private information was filtered on purpose	Third-party Providers	each truck trip for one year	10% of Truck counts including for medium and heavy truck cross Canada	On-board diagnostics (OBD), Electronic logging device (ELD)	Data from vehicle fleet management, Data collected with Survey

Data Gaps	Privacy Issues	Data From Original Equipment Manufacturers (OEMs) or Third-party Providers	Timelines To Gather Project Data	Sample Size Requirement for Dataset to best represent Canadian trucking operations	Available Technology to Collect Data	Data Collection Methodologies in Other Jurisdictions
Missing location name on-route and during stop	Truck private information was filtered on purpose	Third-party Providers	each truck trip for one year	10% of Truck counts including for medium and heavy truck cross Canada	GPS data and census data	Geospatial data

Table 13: CFAF dataset data gaps

Data Gaps	Privacy Issues	Data From Original Equipment Manufacturers (OEMs) or Third-party Providers	Timelines To Gather Project Data	Sample Size Requirement for Dataset to best represent Canadian trucking operations	Available Technology to Collect Data	Data Collection Methodologies in Other Jurisdictions
Missing truck identity data	Filtered by the confidentiality requirements of the Statistics Act	Data From Original Equipment Manufacturers (OEMs)	1 year (seasonal)	10% of truck counts for medium and heavy truck across Canada	Original Equipment Manufacturers (OEMs) Electronic logging device (ELD)	Data from vehicle fleet management, Data collected with survey, Vehicle registration data
Missing truck usage data	Filtered by the confidentiality requirements of the Statistics Act	Third-party Providers	each truck trip for one year	10% of truck counts for medium and heavy truck across Canada	On-board diagnostics (OBD) Electronic logging device (ELD)	Data from vehicle fleet management, Data collected with survey
Missing truck stop Data	Filtered by the confidentiality requirements of the Statistics Act	Third-party Providers	each truck trip for one year	10% of truck counts for medium and heavy truck across Canada	GPS data and census data	Geospatial data

Table 14: CVUS dataset data gaps

Data Gaps	Privacy Issues	Data From Original Equipment Manufacturers (OEMs) or Third-party Providers	Timelines To Gather Project Data	Sample Size Requirement for Dataset to best represent Canadian trucking operations	Available Technology to Collect Data	Data Collection Methodologies in Other Jurisdictions
Location missing (GPS)	Privacy act	3rd party	1 year (seasonal)		Telematics provider and/or large fleet operators	Fleet telemetry recommended
Highway/roadway designation usage	Privacy act	3rd party	1 year (seasonal)		Telematics provider and/or large fleet operators	Fleet telemetry recommended
Time of day of travel		3rd party	6 months		Telematics provider and/or large fleet operators	Fleet telemetry recommended
Vehicle powertrain (gas/diesel)		3rd party	1-3 month		Telematics provider and/or large fleet operators	
Border crossing (Charge opportunity across US border feasible)	Privacy act	3rd party	1-3 month		Telematics provider and/or large fleet operators	Fleet telemetry recommended
Min data above 100km trips (~75% 1-100km)		3rd party	1-3 month		Telematics provider and/or large fleet operators	
Significant idle time reported but not able to determine location and if positioned in location appropriate for charge opportunity	Privacy act	3rd party	1 year (seasonal)		Telematics provider and/or large fleet operators	Fleet telemetry recommended

Data Gaps	Privacy Issues	Data From Original Equipment Manufacturers (OEMs) or Third-party Providers	Timelines To Gather Project Data	Sample Size Requirement for Dataset to best represent Canadian trucking operations	Available Technology to Collect Data	Data Collection Methodologies in Other Jurisdictions
Day cab/sleeper truck		3rd party	1-3 month		Telematics provider and/or large fleet operators	
Ambient temp not reported		3rd party	1 year (seasonal)			Fleet telemetry recommended
Stop location information indicated as unknown	Privacy act	3rd party	1 year (seasonal)		Telematics provider and/or large fleet operators	Fleet telemetry recommended
Minimal data 4.5T to 15t GVWA		3rd party				CFAF probable source for data
Manitoba stop location data mostly indicated classified as unknown	Privacy act	3rd party	1 year (seasonal)		Telematics provider and/or large fleet operators	Fleet telemetry recommended
Manitoba - no data for trips greater than 100km		3rd party	1 year (seasonal)		Telematics provider and/or large fleet operators	
Manitoba - cargo weight indicated as known	Privacy act	3rd party				CFAF probable source for data
Manitoba - cargo description indicated as known	Privacy act	3rd party				CFAF probable source for data
Manitoba - truck config indicated as unknown		3rd party	1 year (seasonal)		Telematics provider and/or large fleet operators	

Data Gaps	Privacy Issues	Data From Original Equipment Manufacturers (OEMs) or Third-party Providers	Timelines To Gather Project Data	Sample Size Requirement for Dataset to best represent Canadian trucking operations	Available Technology to Collect Data	Data Collection Methodologies in Other Jurisdictions
Saskatchewan - no drop off location or reason indicated	Privacy act	3rd party	1 year (seasonal)		Telematics provider and/or large fleet operators	Fleet telemetry recommended
Saskatchewan - truck config and body style indicated as unknown		3rd party	1 year (seasonal)		Telematics provider and/or large fleet operators	
Saskatchewan - cargo desc and weight indicated as unknown	Privacy act	3rd party				CFAF probable source for data

Table 15: MTO dataset data gaps

Data Gaps	Privacy Issues	Data From Original Equipment Manufacturers (OEMs) or Third-party Providers	Timelines To Gather Project Data	Sample Size Requirement for Dataset to best represent Canadian trucking operations	Available Technology to Collect Data	Data Collection Methodologies in Other Jurisdictions
Truck identity not reported			3 months		telematics	
Truck usage not reported			3 months		telematics	
Seasonal weather not reported			3 months		telematics	
Vehicle class not reported			3 months		telematics	
Vehicle configuration not reported			3 months			
Province of Ontario information only						

Table 16: Vehicle Registry dataset data gaps

Data Gaps	Privacy Issues	Data From Original Equipment Manufacturers (OEMs) or Third-party Providers	Timelines To Gather Project Data	Sample Size Requirement for Dataset to best represent Canadian trucking operations	Available Technology to Collect Data	Data Collection Methodologies in Other Jurisdictions
No truck identity data except for vehicle class and fuel type	Filtered by the confidentiality requirements	Vehicle registrations, Statistics Canada	1 year (seasonal)	10% of truck counts for medium and heavy truck cross Canada	OEMs Electronic logging device (ELD)	Data from Vehicle fleet management Data collected with Survey Vehicle Registration Data
No truck usage data	Filtered by the confidentiality requirements	Third-party Providers	each truck trip for one year	10% of truck counts including for medium and heavy truck cross Canada	On-board diagnostics (OBD) Electronic logging device (ELD)	Data from Vehicle fleet management Data collected with Survey

Appendix B - Summary of applicability of selected dataset data variables

1. ATRI

2. Geotab origin and destination

3. Geotab road traffic

4. CFAF

5. CVUS

6. AATDD

			Truck Location Data										Comments
			Locations of Routes	Average Trip Lengths	Maximum Trip Lengths	Frequency of Trips Binned by Trip Length	Total Vehicle Kilometers Travelled (VKT) on Particular Corridors	Frequency of Stops	Duration of Stops	Location of Stops	Possibilities for Charging/Fueling	VKT by Season	
ATRI	Variables in raw data	Latitude/Longitude	yes										
		Speed											
		Readdate	yes										
		Heading	yes										
		Truckid											
	Variables from spatial analysis	**Truck Use Summary** (time in motion/stop, blocks of time moving/stopped, distance driven on road network, average speed in motion, frequency in time blocks)	yes				yes	yes	yes	yes	yes	yes	--Depends on GeoBase data from National Road Network - NRN --Depends on Census Cartographic boundary files
		Stop Files (stop start/end timestamps, length of stop, locations of the stop, frequency of stops)	yes					yes	yes	yes	yes		--Depends on Census Cartographic boundary files
		Road Link Statistics (truck count road segment, truck travel direction and average the speed on the road segment in the time of period)	yes										--Depends on GeoBase data from National Road Network - NRN
		Point of Interest (identify truck location, trip origin/destination location, trip pair times)	yes							yes	yes	yes	--Depends on Census Cartographic boundary files
		Origin / Destination Trip Matrix O/D matrixes of all the trip (Excluding stops along the way")	yes	yes	yes	yes	yes						--Depends on Census Cartographic boundary files

			Truck Identification Data										Comments
			Powertrain type	Vehicle Class	Vehicle Vocation	Sleeper vs. Day Cab	Vehicle Age	Axle Configuration (allowing comparison to maximum allowable weight)					
ATRI	Raw Data	Latitude/Longitude											
		Speed											
		Readdate											
		Truckid											
	Variables from spatial analysis	Truck Use Summary											
		Stop Files											
		Road Link Statistics											
		Point of Interest											
		Origin / Destination Trip Matrix											

			Truck Usage Data										Comments
			Power and energy requirements										
			Fuel Consumption	Vehicle Weight	Vehicle Payload	Volumetric Capacity	Speed	Accelerations	Decelerations	Ambient Temperature	Weather (rain or snow)	Slope (altitude changes)	
ATRI	Raw Data	Latitude/Longitude											
		Speed					yes						
		Readdate											
		Truckid											
	Variables from spatial analysis	Truck Use Summary											
		Stop Files											
		Road Link Statistics											
		Point of Interest											
		Origin / Destination Trip Matrix											
		Other								yes	yes	yes	--Slope depends on open data from Canadian Digital Elevation Model --Weather depends on weather data supplier

			Truck location data										Comments
			Locations of Routes	Average Trip Lengths	Maximum Trip Lengths	Frequency of Trips Binned by Trip Length	Total Vehicle Kilometers Travelled (VKT) on Particular Corridors	Frequency of Stops	Duration of Stops	Location of Stops	Possibilities for Charging/Fueling	VKT by Season	
GeoTab (O/D)	Time	Start Time										yes	Frequency of stops and location of stops are available in Geotab Road traffic dataset which is different from Geotab Origin & Destination dataset
		End Time										yes	
	Stats	Vehicle Classes											
		Trip Chain Duration											
	Origins	Origin ZoneId	yes (only for O/D)				yes						
		Origin_Description	yes (only for O/D)				yes						
	Destination	Destination ZoneId	yes (only for O/D)				yes						
		Destination_Description	yes (only for O/D)				yes						
	Statistics Based on Journey	Number of Journeys											
		Journey Duration											
		Travel Speed											
		Distance		yes	yes	yes	yes					yes	
		Time At Destination											
	Vehicle Class Breakdown	Num_of_Journeys - Light Duty Trucks											
		Num_of_Journeys - Medium Duty Trucks											
		Num_of_Journeys - Heavy Duty Trucks											
	Vocation Breakdown	Num_of_Journeys - Long Distance											
		Num_of_Journey - Hub and Spoke											
		Num_of_Journeys - Local											
	Industry Breakdown	Industry Data											
	Statistical for Road Metrics	NumberOfJourneys											
		JourneysPerDay											
		AvgJourneyDuration (minutes)											
		AvgNumberOfTripsPerJourney											
		AvgTravelSpeed (km/h)											
		AvgRunningSpeed (km/h)											
		AvgDistance (km)		yes	yes	yes							
		AvgIdleDuration (minutes)							yes				
		AvgInterTripDuration (minutes)							yes				
		AvgTimeAtDestination (minutes)											

			Truck identity data										Comments
			Powertrain type	Vehicle Class	Vehicle Vocation	Sleeper vs. Day Cab	Vehicle Age	Axle Configuration					
GeoTab (O/D)	Time	Start Time											
		End Time											
	Stats	Vehicle Classes		yes									
		Trip Chain Duration											
	Origins	Origin ZoneId											
		Origin_Description											
	Destination	Destination ZoneId											
		Destination_Description											
	Statistics Based on Journey	Number of Journeys											
		Journey Duration											
		Travel Speed											
		Distance											
		Time At Destination											
	Vehicle Class Breakdown	Num_of_Journeys - Light Duty Trucks		yes									
		Num_of_Journeys - Medium Duty Trucks		yes									
		Num_of_Journeys - Heavy Duty Trucks		yes									
	Vocation Breakdown	Num_of_Journeys - Long Distance			yes								
		Num_of_Journey - Hub and Spoke			yes								
		Num_of_Journeys - Local			yes								
	Industry Breakdown	Industry Data											

			Truck Usage Data										Comments
					Power and energy requirements								
			Fuel Consumption	Vehicle Weight	Vehicle Payload	Volumetric Capacity	Speed	Accelerations	Decelerations	Ambient Temperature	Weather (rain or snow)	Slope (altitude changes)	
GeoTab (O/D)	Time	Start Time											
		End Time											
	Stats	Vehicle Classes											
		Trip Chain Duration											
	Origins	Origin ZoneId											
		Origin_Description											
	Destination	Destination ZoneId											
		Destination_Description											
	Statistics Based on Journey	Number of Journeys											
		Journey Duration											
		Travel Speed											
		Distance					yes						
		Time At Destination											
	Vehicle Class Breakdown	Num_of_Journeys - Light Duty Trucks		yes									
		Num_of_Journeys - Medium Duty Trucks		yes									
		Num_of_Journeys - Heavy Duty Trucks		yes									
	Vocation Breakdown	Num_of_Journeys - Long Distance											
		Num_of_Journey - Hub and Spoke											
		Num_of_Journeys - Local											
	Industry Breakdown	Industry Data											
										yes	yes	yes	Slope depends on open data from Canadian Digital Elevation Model Weather depends on weather data supplier

			Truck identity data										Comments
			Powertrain type	Vehicle Class	Vehicle Vocation	Sleeper vs. Day Cab	Vehicle Age	Axle Configuration (allowing					
GeoTab Road Traffic (signal progression)	Time	Analysis Start Time	yes	-	-	-							
		Analysis End Time		yes									
	Stats	Vehicle Class Scheme											
		Vehicle Class											
		Measurement System											
		Percentile											
		Plot Sequence											
		IntersectionId											
		Street Names											
		Entry Cardinals											
		Exit Cardinals											
	Statistics Based on Altitude Data Dictionary	Time Without Initial Dwell											
		Time With Initial Dwell											
		Y Axis Values Ordinal											
		Distance From Start											
		Travle Speed											
		Total Observed Count											
	Vehicle Class Breakdown	Num_of_Journeys - Light Duty Trucks											
		Num_of_Journeys - Medium Duty Trucks											
		Num_of_Journeys - Heavy Duty Trucks											

			Truck usage data										Comments
					Power and energy requirements								
			Fuel Consumption	Vehicle Weight	Vehicle Payload	Volumetric Capacity	Speed	Accelerations	Decelerations	Ambient Temperature	Weather (rain or snow)	Slope (altitude changes)	
GeoTab Road Traffic (signal progression)	Time	Analysis Start Time											
		Analysis End Time											
	Stats	Vehicle Class Scheme											
		Vehicle Class											
		Measurement System											
		Percentile											
		Plot Sequence											
		IntersectionId											
		Street Names											
		Entry Cardinals											
		Exit Cardinals											
	Statistics Based on Altitude Data Dictionary	Time Without Initial Dwell											
		Time With Initial Dwell											
		Y Axis Values Ordinal											
		Distance From Start											
		Travle Speed											
		Total Observed Count											
	Vehicle Class Breakdown	Num_of_Journeys - Light Duty Trucks											
		Num_of_Journeys - Medium Duty Trucks											
		Num_of_Journeys - Heavy Duty Trucks											

			Truck usage data										Comments
					Power and energy requirements								
			Fuel Consumption	Vehicle Weight	Vehicle Payload	Volumetric Capacity	Speed	Accelerations	Decelerations	Ambient Temperature	Weather (rain or snow)	Slope (altitude changes)	
GeoTab Road Traffic (signal progression)	Time	Analysis Start Time											
		Analysis End Time											
	Stats	Vehicle Class Scheme											
		Vehicle Class											
		Measurement System											
		Percentile											
		Plot Sequence											
		IntersectionId											
		Street Names											
		Entry Cardinals											
		Exit Cardinals											
	Statistics Based on Altitude Data Dictionary	Time Without Initial Dwell											
		Time With Initial Dwell											
		Y Axis Values Ordinal											
		Distance From Start											
		Travle Speed											
		Total Observed Count											
	Vehicle Class Breakdown	Num_of_Journeys - Light Duty Trucks											
		Num_of_Journeys - Medium Duty Trucks											
		Num_of_Journeys - Heavy Duty Trucks											

		Truck location data										Comments
		Locations of Routes	Average Trip Lengths	Maximum Trip Lengths	Frequency of Trips Binned by Trip Length	Total Vehicle Kilometers Travelled (VKT) on Particular Corridors	Frequency of Stops	Duration of Stops	Location of Stops	Possibilities for Charging / Fueling	VKT by Season	
CFAF	Year											A shipment represents the movement of a single commodity from an origin to a destination for-hire truck industries. Two kinds of truck-based transportation—the Less than Truckload (LTL) and the Full Truckload (FTL) shipping methods
	Mode											
	SCTGGroup											
	OrigCMA	yes (only for O/D)							yes (only for O/D)			
	OrigProv											
	OrigCtry											
	DestCMA	yes (only for O/D)							yes (only for O/D)			
	DestProv											
	DestCtry											
	Shipments											
	Weight											
	Revenue											
	Distance		yes	yes	yes	yes						
	TonneKm											
	Value											

		Truck identity data										Comments
		Powertrain type	Vehicle Class	Vehicle Vocation	Sleeper vs. Day Cab	Vehicle Age	Axle Configuration					
CFAF	Year											
	Mode											
	SCTGGroup											
	OrigCMA											
	OrigProv											
	OrigCtry											
	DestCMA											
	DestProv											
	DestCtry											
	Shipments											
	Weight											
	Revenue											
	Distance											
	TonneKm											
	Value											

		Truck Usage Data										Comments
				Power and energy requirements								
		Fuel Consumption	Vehicle Weight	Vehicle Payload	Volumetric Capacity	Speed	Accelerations	Decelerations	Ambient Temperature	Weather (rain or snow)	Slope (altitude changes)	
CFAF	Year											
	Mode											
	SCTGGroup											
	OrigCMA											
	OrigProv											
	OrigCtry											
	DestCMA											
	DestProv											
	DestCtry											
	Shipments											
	Weight			yes								
	Revenue											
	Distance											
	TonneKm											
	Value											

			Truck location data										Comments
			Locations of Routes	Average Trip Lengths	Maximum Trip Lengths	Frequency of Trips Binned by Trip Length	Total Vehicle Kilometers Travelled (VKT) on Particular Corridors	Frequency of Stops	Duration of Stops	Location of Stops	Possibilities for Charging / Fueling	VKT by Season	
CVUS	Stop Reason (Pick up Cargo, Drop off Cargo, Vocational-Service Call, Vocational-P/D Cargo, Unknown)	Geographical Area										yes	
		Fleet Size											
		Final Sample Size										yes	
		Reported Trips											
		Reported Days											
		Active Days										yes	
	Stop Location (Truck Termial, Rail/Port/Airport, Farm/Mine/Resource, Manufacturer,Warehouse/Depot, Other)	Geographical Area											
		Fleet Size											
		Final Sample Size											
		Reported Trips											
		Reported Days											
		Active Days											
	Weight Class	Geographical Area		yes									
		Fleet Size		yes									
		Final Sample Size											
		Reported Trips											
		Reported Days											
		Active Days		yes									
	Cargo (Metric Tonnes)	Geographical Area											
		Fleet Size		yes									
		Final Sample Size											
		Reported Trips		yes									
		Reported Days		yes									
		Active Days		yes									
	Trip Length	Geographical Area											
		Fleet Size		yes									
		Final Sample Size								yes			
		Reported Trips		yes						yes			
		Reported Days		yes						yes			
		Active Days		yes						yes			

			Truck identity data										Comments
			Powertrain type	Vehicle Class	Vehicle Vocation	Sleeper vs. Day Cab	Vehicle Age	Axle Configuration (allowing comparison to maximum allowable weight)					
CVUS	Vehicle Gross Weight and Age	Geographical Area		yes			yes						
		Fleet Size		yes									
		Final Sample Size		yes									
		Reported Trips		yes			yes						
		Reported Days		yes			yes						
		Active Days		yes			yes						
	Body Style (Dry Van, Refrigerated Van, Flat Bed/Stake, Tanker, Dump, Container Carrier, Hopper, Other)	Geographical Area											
		Fleet Size											
		Final Sample Size											
		Reported Trips											
		Reported Days											
		Active Days											
	Configuration (Straight Truck, Straight Truck and Trailer, Tractor Only, Tractor and Trailer, Piggy Back, Other)	Geographical Area											
		Fleet Size											
		Final Sample Size		yes									
		Reported Trips		yes									
		Reported Days		yes									
		Active Days		yes									
	Weight Class	Geographical Area											
		Fleet Size					yes						
		Final Sample Size											
		Reported Trips											
		Reported Days											
		Active Days											
	Trip Length	Geographical Area											
		Fleet Size		yes									
		Final Sample Size		yes									
		Reported Trips		yes									
		Reported Days		yes									
		Active Days		yes									

			Truck usage data										Comments
					Power and energy requirements								
			Fuel Consumption	Vehicle Weight	Vehicle Payload	Volumetric Capacity	Speed	Accelerations	Decelerations	Ambient Temperature	Weather (rain or snow)	Slope (altitude changes)	
CVUS	Vehicle Gross Weight and Age	Geographical Area											
		Fleet Size											
		Final Sample Size	yes	yes	yes								
		Reported Trips	yes	yes	yes								
		Reported Days	yes	yes	yes								
		Active Days	yes	yes	yes								
	Body Style (Dry Van, Refrigerated Van, Flat Bed/Stake, Tanker, Dump, Container Carrier, Hopper, Other)	Geographical Area											
		Fleet Size											
		Final Sample Size											
		Reported Trips											
		Reported Days											
		Active Days											
	Configuration (Straight Truck, Straight Truck and Trailer, Tractor Only, Tractor and Trailer, Piggy Back, Other)	Geographical Area	yes		yes								
		Fleet Size											
		Final Sample Size	yes		yes								
		Reported Trips	yes		yes								
		Reported Days	yes		yes								
		Active Days	yes		yes								
	Weight Class	Geographical Area	yes		yes								
		Fleet Size											
		Final Sample Size											
		Reported Trips		yes									
		Reported Days		yes									
		Active Days											

		Truck location data										Comments
		Locations of Routes	Average Trip Lengths	Maximum Trip Lengths	Frequency of Trips Binned by Trip Length	Total Vehicle Kilometers Travelled (VKT) on Particular Corridors	Frequency of Stops	Duration of Stops	Location of Stops	Possibilities for Charging/Fueling	VKT by Season	
AATDD 2008	ID	yes										
	Road Name									yes		
	Region									yes		
	NumLink											
	Offset											
	2008 AADTT											2008 Annual Average Daily Truck Traffic
	2006 AADTT											2006 Annual Average Daily Truck Traffic
	WD 00-23	yes										2008 Weekday (WD) hourly truck volume; 00 - 23 represents starting hour of the day (e.g. 12 represents 12 P.M. - 1 P.M.).
	WN 00-23	yes										2008 Weekend (WN) hourly truck volume; 00 - 23 represents starting hour of the day (e.g. 12 represents 12 P.M. - 1 P.M.).
	WD Total	yes										
	WN Total	yes										
	Shape Length											

		Truck identity data										Comments
		Powertrain type	Vehicle Class	Vehicle Vocation	Sleeper vs. Day Cab	Vehicle Age	Axle Configuration (allowing comparison to maximum allowable weight)					
AATDD 2008	ID											
	Road Name											
	Region											
	NumLink											
	Offset											
	2008 AADTT											2008 Annual Average Daily Truck Traffic
	2006 AADTT											2006 Annual Average Daily Truck Traffic
	WD 00-23											2008 Weekday (WD) hourly truck volume; 00 - 23 represents starting hour of the day (e.g. 12 represents 12 P.M. - 1 P.M.).
	WN 00-23											2008 Weekend (WN) hourly truck volume; 00 - 23 represents starting hour of the day (e.g. 12 represents 12 P.M. - 1 P.M.).
	WD Total											
	WN Total											
	Shape Length											

		Truck usage data										Comments
				Power and energy requirements								
		Fuel Consumption	Vehicle Weight	Vehicle Payload	Volumetric Capacity	Speed	Accelerations	Decelerations	Ambient Temperature	Weather (rain or snow)	Slope (altitude changes)	
AATDD 2008	ID											
	Road Name											
	Region											
	NumLink											
	Offset											
	2008 AADTT											2008 Annual Average Daily Truck Traffic
	2006 AADTT											2006 Annual Average Daily Truck Traffic
	WD 00-23											2008 Weekday (WD) hourly truck volume; 00 - 23 represents starting hour of the day (e.g. 12 represents 12 P.M. - 1 P.M.).
	WN 00-23											2008 Weekend (WN) hourly truck volume; 00 - 23 represents starting hour of the day (e.g. 12 represents 12 P.M. - 1 P.M.).
	WD Total											
	WN Total											
	Shape Length											

Appendix C - Telematic data parameters of interest

	Data parameter	PGN	PGN Description	SPN	SPN Description
1	Fuel Level (tank 2 if installed)	65276	Dash Display	38	Ratio of volume of fuel to the total volume of fuel in the second or right-side storage container.
2	Parking Brake Switch	65265	Cruise Control/Vehicle	70	Switch signal which indicates when the parking brake is set.
3	Wheel Based Vehicle Speed	65265	Cruise Control/Vehicle Speed	84	Speed of the vehicle as calculated from wheel or tail shaft speed.
4	Accel Pedal Position	61443	Electronic Engine Controller	91	This parameter is intended for the primary accelerator control in an application.
5	Actual Engine Percent Torque	61443	Electronic Engine Controller	92	The ratio of actual engine percent torque (indicated) to maximum indicated torque available at the current engine speed clipped to zero torque during engine braking.
6	Fuel Level (tank 1)	65276	Dash Display	96	Fuel Level 1 represents the total fuel in all fuel storage containers. If two tanks are used see SPN 38.
7	Engine Coolant Temperature	65262	Engine Temperature	110	Temperature of liquid found in engine cooling system.
8	Transmission Current Range	61445	Electronic Transmission Controller	163	Range currently being commanded by the transmission control system. (P, R, N, D…)
9	Engine Rated Power	65214	Electronic Engine Controller	166	Net brake power that the engine will deliver continuously, specified for a given application at a rated speed.
10	Cab Interior Temperature	65269	Ambient Conditions	170	Cab interior temperature
11	Ambient Air	65269	Ambient Conditions	171	Temperature of air surrounding vehicle.
12	Trailer Weight	65258	Vehicle Weight	180	Total mass of freight-carrying vehicle designed to be pulled by truck, including the weight of the contents.
13	Cargo Weight	65258	Vehicle Weight	181	The mass of freight carried
14	Engine Trip Fuel	65257	Fuel Consumption	182	Fuel consumed during all or part of a journey.
15	Engine Fuel Rate	65266	Fuel Economy	183	Amount of fuel consumed by engine per unit of time.
16	Engine Instantaneous Fuel Economy	65266	Fuel Economy	184	Current fuel economy at current vehicle velocity.
17	Engine Speed	61444	Electronic Engine Controller	190	Actual engine speed which is calculated over a minimum crankshaft angle.
18	Vehicle Identification Number	65260	Vehicle Identification	237	Vehicle Identification Number (VIN) as assigned by the vehicle manufacturer.
19	Trip Distance	65248	Vehicle Distance	244	Distance traveled during all or part of a journey.
20	Total Vehicle Distance	65248	Vehicle Distance	245	Accumulated distance traveled by vehicle during its operation.
21	Total Vehicle Hours	65255	Vehicle Hours	246	Accumulated time of operation of vehicle.
22	Engine Total Hours of Operation	65253	Engine Hours, Revolutions	247	Accumulated time of operation of engine.

	Data parameter	PGN	PGN Description	SPN	SPN Description
23	Engine Total Fuel Used	65257	Fuel Consumption	250	Accumulated amount of fuel used during vehicle operation.
24	Brake Pedal Position	61441	Electronic Brake Controller	521	Ratio of brake pedal position to maximum pedal position. Used for electric brake applications. 0% means no braking.
25	Transmission Current Gear	61445	Electronic Transmission Controller	523	The gear currently engaged in the transmission or the last gear engaged while the transmission is in the process of shifting to the new or selected gear.
26	Differential Lock State - Central	61446	Electronic Axle Controller	564	State used which indicates the condition of the central differential lock.
27	Axle Weight	65258	Vehicle Weight	582	Total mass imposed by the tires on the road surface at the specified axle.
28	Make	65259	Component Identification	586	Make of the component corresponding to the codes defined in the American Trucking Association Vehicle Maintenance Reporting Standard (ATA/VMRS).
29	Model	65259	Component Identification	587	Model of the component.
30	Brake Switch	65265	Cruise Control/Vehicle Speed	597	Switch signal which indicates that the driver operated brake foot pedal is being pressed.
31	High Resolution Total Vehicle Distance	65217	High Resolution Vehicle Distance	917	Accumulated distance traveled by the vehicle during its operation.
32	High Resolution Trip Distance	65217	High Resolution Vehicle Distance	918	Distance traveled during all or part of a journey.
33	Trip Drive Fuel Economy	65209	Trip Fuel Information	1006	Trip drive fuel economy is equal to the distance traveled by vehicle in the drive state (engine speed greater than zero, vehicle speed greater than or equal to 2 km/h.
34	Instantaneous Estimated Brake Power	65170	Engine Information	1242	Estimate of the power developed by the engine.
35	Engine Power	65168	Engine Torque History	1247	Advertised engine power capability. Advertised power is what a customer will find on a sales sheet for an engine with a certain calibration.
36	Distance to forward vehicle	65135	Adaptive Cruise Control	1587	Distance to the preceding vehicle situated within 250 m in the same lane and moving in the same direction.
37	Adaptive Cruise Control Mode	65135	Adaptive Cruise Control	1590	This parameter is used to indicate the current state, or mode, of operation by the Adaptive Cruise Control (ACC) device.
38	Acceleration Longitudinal	61449	Vehicle Dynamic Stability Control	1810	Indicates the longitudinal acceleration of the vehicle. A positive longitudinal acceleration signal results when the vehicle speed increases, regardless of driving the vehicle forward or backward.
39	Fifth Wheel Vertical Force	61458	Fifth Wheel Smart Systems	3308	The amount of load being applied to the fifth wheel by the trailer. Zero load is indicated without a trailer.

	Data parameter	PGN	PGN Description	SPN	SPN Description
40	Fifth Wheel Lock Couple Status Indicator	64942	Fifth Wheel Smart Systems	3313	Indicates results of coupling operation to the vehicle operator. For incomplete couples' further information can be obtained from the fifth wheel error status SPN. (Successful couple detected or incomplete or bad couple)
41	Fifth Wheel Release Control	64980	Cab Message	3314	Operator input used to release the fifth wheel. (Coupler locked, coupler un locked)
42	GPS_Altitude				
43	GPS_Lat				
44	GPS_Long				
45	GPS_Speed				

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