RESEARCH & DEVELOPMENT

Safety of the Urban Freight System: Key Performance Indicators

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16. Abstract

Goods movement benefits the North Carolina economy by providing firms and consumers with needed materials. The freight sector has long monitored key performance indicators (KPIs) focused around delay and efficiency. This project focused on how monitoring of road safety KPIs could benefit goods movement in North Carolina. We recommend that North Carolina Department of Transportation (NCDOT) Office of Logistics + Freight (OLF) consider systematic monitoring of commercial vehicle-involved crashes across the state by focusing on overall crashes, fatalities, and severe injuries. We suggest that monitoring efforts leverage existing work based on the police crash reports. For example, the Commercial Vehicle Enforcement Resource Lab (COVERLAB) at North Carolina State University currently geocodes and presents information on commercial vehicle crashes. We recommend OLF consider augmenting currently available indicators with information on the number of commercial vehicle crashes involving vulnerable road users, i.e. pedestrians and cyclists, as this is an emerging area of concern in road safety. Additionally, we recommend that OLF track publicly available indicators on an annual basis using the database that we have provided in this report.

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Executive Summary

Goods movement benefits the North Carolina economy by providing firms and consumers with needed materials. The freight sector has long monitored key performance indicators (KPIs) focused around delay and efficiency. This project focused on how monitoring of road safety KPIs could benefit goods movement in North Carolina. We recommend that North Carolina Department of Transportation (NCDOT) Office of Logistics + Freight (OLF) consider systematic monitoring of commercial vehicle-involved crashes across the state by focusing on overall crashes, fatalities, and severe injuries. We suggest that monitoring efforts leverage existing work based on the police crash reports. For example, the Commercial Vehicle Enforcement Resource Lab (COVERLAB) at North Carolina State University currently geocodes and presents information on commercial vehicle crashes. We recommend OLF consider augmenting currently available indicators with information on the number of commercial vehicle crashes involving vulnerable road users, i.e. pedestrians and cyclists, as this is an emerging area of concern in road safety. Additionally, we recommend that OLF track publicly available indicators on an annual basis using the database that we have provided in this report. Below, an abridged list of those publicly available indicators is included, with the most recent data quantified for statewide or regional geographies.

Table 1 - Key Performance Indicators

Key Performance Indicator	Measure	Data Source	Level of Aggregation	Geography	Figure	Year
Congestion/ Mobility	Congested Hours	FHWA Urban Congestion Reports	Urban Areas	Raleigh / Charlotte	2:05: / 2:37	2019
	Travel Time Index	FHWA Urban Congestion Reports	Urban Areas	Raleigh / Charlotte	1.16 / 1.18	2019
		TTI Urban Mobility Report	Urban Areas	Raleigh / Charlotte	1.17 / 1.22	2017
	Planning Time Index	TTI Urban Mobility Report	Urban Areas	Raleigh / Charlotte	1.58 / 1.66	2017
		FHWA Urban Congestion Reports	Urban Areas	Raleigh / Charlotte	1.71 / 1.76	2019
	Delay per Traveler	TTI Urban Mobility Report	Urban Areas	Raleigh / Charlotte	42 hours / 28 hours	2017
	Change in Congestion	TTI Urban Mobility Report	Urban Areas	Raleigh / Charlotte	-0:05 / -0:30	2019
Economic Development/ Freight	Cost of Congestion	TTI Urban Mobility Report	Urban Areas	Raleigh / Charlotte	$546 M / $1.02 B	2017
	Cost of Freight Congestion	TTI Urban Mobility Report	Urban Areas	Raleigh / Charlotte	$57 M / $106 M	2017
	Value of Freight Flow	BTS State Transportation by the Numbers	States	NC	$720 B	2018

	Tons of Freight Flow	BTS State Transportation by the Numbers	States	NC	463 M	2018
	Annual Truck Delay	TTI Urban Mobility Report	Urban Areas	Raleigh / Charlotte	1.14 M hours / 2.13 M hours	2017
	Top Commodities Shipped (to/from/within)	BTS State Transportation by the Numbers	States	NC	Pharmaceuticals; Machinery; Textiles; Mixed Freight; Electronics	2018
Safety	Fatalities by Mode	BTS State Transportation by the Numbers	States	NC	Rail - 31; Transit - 1; Boat - 30; Highway 1,437	2018
	Fatalities by Person (Driver/Passenger/Bicyclist/etc.)	BTS State Transportation by the Numbers	States	NC	Driver - 53%; Passenger - 16.6%; Motorcyclist - 13.3%; Pedestrian - 15.7%; Cyclist - 1.3%	2018
Environment	Transportation Energy Use per Capita	BTS State Transportation by the Numbers	States	NC	70.6 M BTU/person	2018
	Motor Fuel Use per Capita	BTS State Transportation by the Numbers	States	NC	438 Gal/person	2018

A superb resource for North Carolina-specific data relating to commercial vehicle safety is COVERLAB produced by NC State University. Below, we have synthesized relevant metrics from this resource, which we believe to be a comprehensive, viable tool for monitoring statewide freight KPIs. Some of the graphics we present were derived from COVERLAB data, and others are infographics taken directly from the resource.

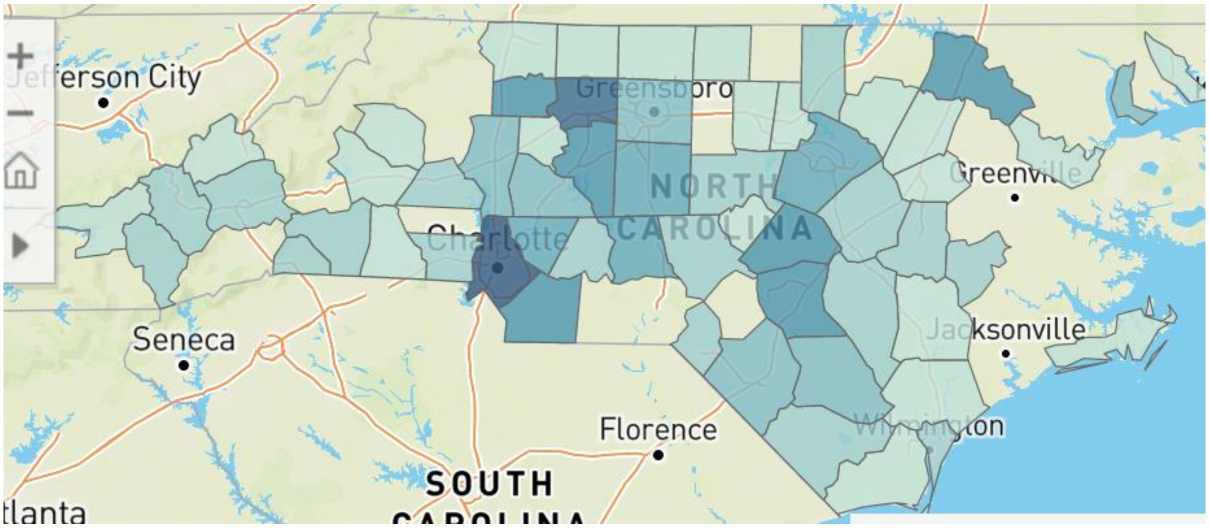

Figure 1 - 2019 Commercial Vehicle-Involved Fatalities (n=137)
Source: Image and Data – COVERLAB

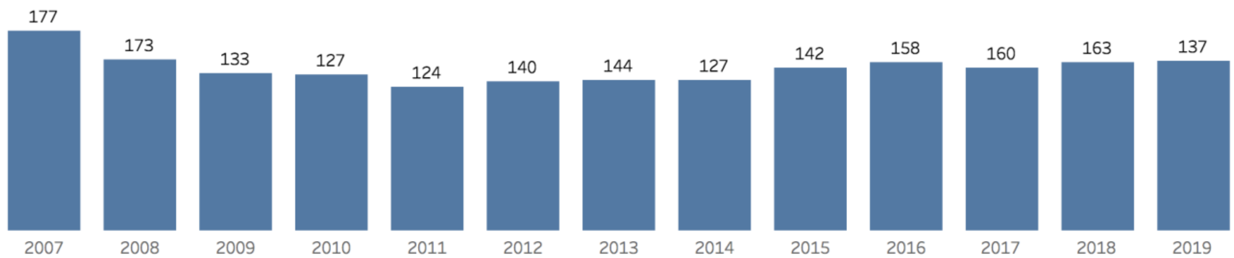

Figure 2 - CMV - involved fatalities, 2007 - 2019
Source: Image and Data – COVERLAB

Our analysis indicates the potential for increased conflicts between vulnerable road users and freight and we recommend increased monitoring of these interactions. We analyzed crashes between commercial vehicles and vulnerable road users (VRUs) and found an increasing trend. From 2007-2018 there were 33,707 crashes between pedestrians and all vehicles and 11,266 crashes between bicyclists and all vehicles during this same period. When we identify crashes between commercial vehicles and VRU's the figure is limited to 1,126 for pedestrians and 318 for bicyclists. Of these, 825 crashes with pedestrians and 251 crashes with bicyclists occurred on non-interstate roads in urban areas (Figure 3).

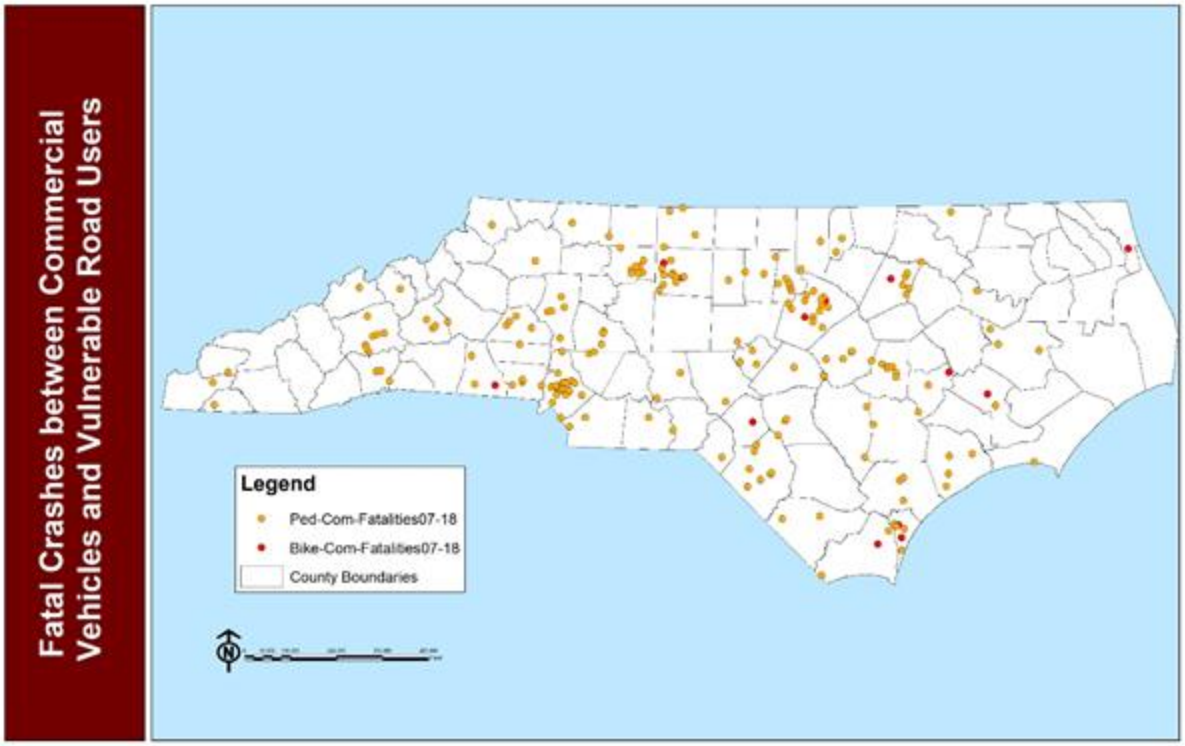

Figure 3 - VRU - Commercial Vehicle Crashes

Recommendations

We have four recommendations based on our research. These are described in Chapter 5.

Recommendation 1 – Utilize the COVERLAB Crash Visualization Tool

Recommendation 2 – Maintain Database of Publicly Available KPIs

Recommendation 3 – Focus on VRU-Commercial Vehicle Safety

Recommendation 4 – Establish a Working Group on Freight Safety Monitoring/Data Sharing Plan

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Chapter 1 – Background and Literature

Freight Performance Measurement - Background

Goods movement has been a central element of urban areas for millennia. But the advent of online shopping and technological advances in logistics are reshaping freight in urban areas and bringing new safety concerns to the fore. North Carolina has seen increases in freight trips and will likely also see new modes for last-mile delivery introduced in coming years. For example, the move to 2-hour delivery windows in some parts of the state has increased freight volumes and changed spatial patterns. As urban freight volumes are expected to rise, levels of innovation are also rising. Governments and firms are looking for creative city logistics strategies that allow for fast, reliable, and safe freight deliveries. The resulting goods movement will impact all aspects of the transportation system including congestion, pollution, and road safety making it an opportune time to study the topic.

A first step for transportation officials in dealing with emerging problems is to assess the current situation. Once an assessment is made, goals can be put forward that shape policy funding decisions. Effectively planning in a way that achieves those stated goals involves a framework known as the “rational planning model.” The rational planning model is a foundational theory of planning that has been applied widely and forms the basis of many standard practices in transportation planning (Black, 1990). Although the model has been criticized as overly simplistic and not bound by the realities of planning practice, the rational planning model provides the overarching framework for performance measurement as a tool that agencies can use to achieve their goals (R. Ewing, personal communication, April 15, 2020). The rational planning model proceeds as follows:

Goals → Performance measures → Indicators/Data → Decisions

In response to growing demand for greater public accountability, performance measurement has been standard practice in transportation planning for decades (MacDonald et al., 2004). Many performance measures have become ubiquitous in transportation planning. Measures like vehicle miles traveled, transit ridership, mode share, delay, level of service, etc. are all familiar to transportation officials and planners.

Less commonly encountered, however, are freight performance measures. Moving Ahead for Progress in the 21st Century (MAP 21) and the Fixing Americas Surface Transportation (FAST) Acts are important enabling legislation that provide funding and frameworks for allocating those funds for surface transportation in the US. Map 21 and the Fast Act require that the Federal Highway Administration’s (FHWA) Office of Freight Management and Operations (OFMO) assist Departments of Transportation (DOTs) and Metropolitan Planning Organizations (MPOs) in their efforts to plan and monitor freight systems (Easley et al., 2017). The OFMO assists by providing data, guidance, and processes for using data to meaningfully measure freight system performance. Although the FHWA began developing freight performance measures in 2002 in response to the Government Performance and Results Act of 1993, few State DOTs and MPOs have yet to achieve successful performance-based systems (Easley et al., 2017). Below we will outline the findings from academic literature and technical reports that detail specific state projects and advances in the effort to create improved systems for measuring freight performance.

Federal Guidance

Several legislative efforts in the 1990s and 2000s put increasing pressure on government agencies such as the FHWA to monitor performance using empirical data. Examples of this include Section 1115 of MAP-21 in which a “National Freight Policy” mandates the development or improvement of tools to advance transportation system performance. Section 1115 directs transportation agencies to target federal funding in a way that reflects this measurement. Additionally, the FAST Act implemented freight funding and freight formula programs that require freight plans to demonstrate a link to performance for agencies to be eligible for funds.

Beyond the above regulations, FHWA also contributes to freight performance measurement by providing data and resources to that end. To acquire data for performance measurement, FHWA has employed several efforts including the Commodity Flow Survey, Freight Analysis Framework data, the Highway Performance Monitoring System, the National Performance Management Research Data Set, and truck parking data collection. These data sources are for highway freight performance, but the FHWA also provides data for other modes of freight as well. FHWA suggests 75 performance measures that they break into five categories: Safety; Maintenance and Prevention; Mobility, Reliability, and Congestion; Accessibility and Connectivity; and Environment. While there is a long list of suggested performance measures, a select few have been realized in practice. Below we will discuss the state of the practice in freight performance measurement, highlighting regional leaders and the measures that have gained the most attention.

Freight Performance Measures State of the Practice

Select State DOTs and MPOs have led the movement toward data-driven management of regional freight systems. Most of the academic literature and technical reports that have advanced the topic of freight performance measurement have focused on either a single State DOT or a few regions that are pioneering the practice of data-informed monitoring and decision making. US leaders in freight performance measurement, or FPM, include Minnesota, New Jersey, Texas, California, Colorado, Florida, and Oregon (Schofield & Harrison, 2007). Minnesota has proposed safety performance measures that go beyond the ubiquitous “reduce highway accidents.” Minnesota DOT (MnDOT) has moved toward using dollar costs of crashes and crash rates per mile traveled by freight mode. In an explicit effort to improve upon and further refine their performance measures, MnDOT has classified their measures accordingly:

- Developmental Measures - those for which a commitment would need to be made to set any meaningful targets.

- Emerging Measures - those for which data is available, but targets have yet to be set.
- Mature Measures - those for which data is available and targets have been set.

This is a helpful framework for considering the process of developing freight performance measures. MnDOT Office of Freight and Commercial Vehicle Operations utilize automatic traffic recorders (ATRs) and weigh-in-motion systems for measuring truck weights and identifying freight vehicles using a state-wide system. Sensors for this system collect data on truck weights and speeds throughout the state, but these systems are unable to estimate truck travel times (Liao, 2014).

DOTs have also looked outside the US for examples of successful performance management programs. Schofield & Harrison (2007) describe the use of probe cars in Japan. Probe vehicles are typically public vehicles such as buses that are equipped with location devices to obtain location and time data. Probe vehicles communicate with a network of data transceivers that send these data to be processed and accumulated. These data can be used to determine travel speeds and congestion levels. The richness of the data depends on the number of probe vehicles communicating with the network. Schofield & Harrison (2007) suggest that probe vehicles can be very useful in determining the effects of interventions on roadways, such as capacity projects or new traffic treatments.

An important contribution to the discussion of freight performance measurement came from Schofield & Harrison (2007). They highlight the elegance of a well-constructed freight performance measure with the following statement:

> “The nature of a good performance measure requires that it be easily understandable and measurable, creating new clarity that eases communication on all levels: agency to agency, planner to planner, and agency to the public.”

Pickerel & Neumann (2001) contend that difficulty in freight system management stems from the need to identify measures that are both within the purview of public agencies, meaning that the determinants of this metric are controllable by the agency, and are meaningful to private sector stakeholders. In their recommendations to Texas DOT, Schofield & Murray suggest that the most useful freight performance measures (FPMs) will be: capable of being measured; capable of capturing deficiencies; capable of measurement over time; capable of being forecast; easy to understand by decision makers/officials. The authors propose a set of FPMs for Texas that are listed below in Table 2.

Table 2 - Suggested Texas DOT FPMs

Category	Potential Indicators
Travel Time	Intercity Travel Times Average Speed on Freeways, by Route and Time of Day Major City Congestion Levels Compared to Other Metro Areas Volume/Capacity of All Vehicles on Freeway Segments
Reliability	Deviation of Travel Times or Speeds from the Average Density of Nonrecurring Delays Portion of On-Time Motor Carrier Arrivals
Economic	State Transportation Investment vs. Gross State Product
Public Impact	Emissions Freight Related Accident Rates
Infrastructure	Pavement and Bridge Quality Delay at Border Crossings

Source: Schofield & Harrison (2007)

Despite FHWA's efforts to provide data for freight system management, a persistent issue for State DOTs and MPOs is the ability to access adequate and reliable data for performance measures. Collecting data is a challenge for DOTs and MPOs as freight measures are often an afterthought when designing transportation data collection systems and protocols for even the most modern intelligent transportation systems (ITS). Another challenge they face is that some of the best data are collected from private operators that are reluctant to give up their information for competitive or privacy reasons. Geographic considerations also limit the viability of private data for performance measurement, as carriers sometimes only operate in certain regions or in specific corridors, requiring that transportation agencies aggregate multiple sources in order to have a useful dataset. Finally, the validity of private data is hard to verify, making decisions from these data circumspect (Liao, 2014).

Private freight companies can, however, be convinced to participate in freight system monitoring by providing vehicle location data that they are already collecting for their own monitoring and optimization purposes. Logistics firms are concerned with congestion because, for example, an hour of truck delay costs an estimated $88 (Schrank et al. 2012). Just as important to these companies is their ability to predict and account for inevitable delay. For this reason, they are also concerned with travel time reliability. Two survey-based research efforts asked freight carriers and planners about their top concerns with respect to operating and planning freight. The areas of overlap between the findings of both studies are concerns regarding congestion and travel reliability (Donath & Murray, 2005; Ostria, 2003). The issue of congestion was also shown to be a major concern for carriers in California by Regan & Golob (1999). Some have proposed using Global Positioning Systems (GPS) and other means of automatic vehicle location be provided to transportation agencies so that they can be aggregated into meaningful evaluations of congestion and travel speed conditions (Jones & Sedor, 2006; Turner et al., 2011). Coordinating and sharing data with State DOTs and MPOs allows private firms to participate in performance measurement so that these partnerships can lead to targeted programs and investments that mitigate congestion and unreliable travel times.

As is true in all scientific measurement, a triangulation from multiple data sources is the best practice in freight performance measurement. Turner et al. (2011) recommend a blend of private sector vehicle location data with public traffic volume data for a more nuanced measure of travel time reliability. Public traffic data might include traditional volume counts or more sophisticated data sources such as information from regional ITS or the Mobility Monitoring Program (Harrison et al., 2006). Some researchers have proposed other more state-of-the-art data collection schemes like the use of probe vehicles for dynamic monitoring of real-time travel speed and congestion information (Zhao et al., 2013; Schofield & Harrison, 2007).

Measuring Safety

Based on the above advancements in performance measurement in alignment with the motivations of the freight industry and its regulators, the most effort has been made in response to the conditions that limit freight efficiency. The performance measures that have been discussed most often in the academic literature and technical reports relate to congestion: travel times, delay, and travel time reliability. Congestion measures were mentioned in all the literature that we reviewed, although according to FHWA this is only part of the spectrum of suggested freight system monitoring. While some additional economic and environmental measures are occasionally discussed, safety is surprisingly lacking from the discussion of freight system performance. Even FHWA guidelines for freight safety measures include the value of goods lost due to crashes; further evidence of the motivations behind suggested performance measures.

When one evaluates the prominence of safety within the context of the four other performance categories, FHWA provides 18 possible measures out of the total 75 (Easley et al., 2017). This demonstrates that the federal authorities expect a reasonable proportion of transportation agencies' attention to be given to safety, among other performance concerns. Analyzing the literature beyond the policy documents provided by FHWA, we see that only one research effort, Schofield & Harrison (2007), proposed safety performance measures. This indicates that there are limited examples, aside from MnDOT's program, for transportation agencies to follow if they hope to incorporate safety considerations into their freight system monitoring. This study will help to ameliorate this issue by developing and refining new indicators of safety performance. We will explore potential data sources and measurement techniques to evaluate the current safety conditions within the State of North Carolina. Finally, we will produce recommendations and protocols for continuing to monitor safety in a way that is informative for freight planning and decision making.

Chapter 2 – KPI Matrix Assessment

Identifying Key Performance Indicators

To identify key performance indicators (KPIs) for freight system monitoring, we underwent an iterative three-stage process. First, we consulted the academic and grey literature of published journal articles and technical reports related to performance measurement of freight systems. Next, we consulted the resources that are available from federal agencies, such as the Federal Highway Administration, that provided policy guidance, best practices, and data sources for state-level freight system monitoring. Finally, we interviewed local experts to identify how they are assessing freight performance as well as to determine specific needs for future monitoring.

Lessons from Literature in Brief

The academic and grey literature relating to measuring freight performance is quite limited. Much of the literature came in response to changes mandated by Map 21 and the Fast Acts requiring performance-based transportation planning. Researchers proposed a litany of performance measures for freight planning, most of which, however, were concerned with congestion and travel time reliability. Much less attention has been given to the monitoring of freight-related safety metrics. Among those that have been suggested in the limited research are accidents, fatality rates, and insurance costs (Jones & Sedor, 2006; Harrison et al., 2006). One potential lack of focus on freight safety is the assumption that freight safety concerns are adequately addressed through broader efforts to improve highway safety. The larger field of highway safety research has produced a profusion of metrics and data sources for assessing, monitoring, and improving safety. While lessons can certainly be learned from this larger area of research, there is a need for more efforts to establish better metrics for monitoring freight-specific safety issues. For more information on freight performance measures, please see Table 1 and Appendix Items 1 and 2. A complete literature review can also be found in the appendix.

KPIs—Existing Measures and Data

As is evident in the literature, most of the attention in freight planning has been given to congestion and reliability freight measure. There is some convention, however, for measuring freight safety as well. Table 1 list accidents as an important indicator of freight safety for which we provide several specific metrics. The most common accident related metric are crash counts, as there are regular protocols for reporting crashes by responding police officers. The resulting crash reports, however, are not always digitized and easy to access, especially when trying to tease out freight-specific measures. There are several excellent resources within North Carolina, produced by the efforts of many different research centers. In Table 1, we highlight two of such efforts. First is the Commercial Vehicle Enforcement Resource Lab (COVERLAB), produced by the Institute for Transportation Research and Education at North Carolina State University. COVERLAB provides safety-related statistics for commercial vehicles in North Carolina. Their interactive data visualizations include figures for commercial vehicle-involved crashes at varying geographies and temporal scales. This is a very useful resource that can be easily integrated into regional and State freight planning efforts.

Another important indicator, novel to this study, is crashes between vulnerable road users and freight vehicles. With the help of partners at the Highway Safety Research Center at the University of North Carolina and the North Carolina Department of Transportation, we have compiled a dataset of geocoded crashes between these modes as well as characteristics of the environments around the crashes. These data can be used to describe trends in crashes between freight vehicles and vulnerable road users over time, as well as identify locations where these crashes might be happening more frequently. We will describe our analysis in more detail later in the report.

The table below details safety KPIs identified consistently in the literature, from federal agencies, and by NC freight experts. Further detail on source and data availability are available in the appendix.

Table 3 - Summary of Safety Key Performance Indicators

Indicator	Example Metrics	Best NC Data Source
Accidents	Crash Counts; Crashes by Mode; Commercial Vehicle Crashes; Commercial Vehicle Injuries; Commercial Vehicle-Vulnerable Road User Crashes	NCDOT Crash Database; COVERLAB; Bureau of Transportation Statistics;
Fatality Rates	Highway Fatalities; Commercial Vehicle Fatalities; Commercial Vehicle-Involved Fatal Crash Counts	NCDOT Crash Database; COVERLAB
Insurance Costs	Annual Cost per Truck	American Trucking Association Survey
Parking	Number of Truck Parking Spaces	Unavailable

The above resources cover many of the data needs for monitoring key performance indicators of freight safety, with a few exceptions. The literature review and interviews identified two freight indicators for which we were not able to find reliable data. Insurance costs, suggests Harrison et al. (2006), are an effective proxy for freight safety as premiums will increase as more crashes occur. The American Trucking Association (ATA) conducts annual surveys that include questions about insurance costs, however the results of the survey are proprietary and are not made available to the public. It is possible the State could license these data from the ATA and distribute them to regional transportation planners for freight system monitoring. Truck parking is another missing piece of data for freight safety monitoring that we have identified. Our interviews suggested that truck parking was a major concern to officials in North Carolina. Federal safety regulations mandate that freight operators get specified amounts of rest each day, and for this to happen in a safe way for operators and other motorists, adequate truck parking spaces need to be located along established freight corridors. We are not aware of any inventory of truck parking spaces in North Carolina. Monitoring this indicator would require establishing such an inventory as well as occasional occupancy surveys to determine whether the supply of truck parking spaces are adequate. Below, Table 4 includes a summary of data monitoring needs.

Table 4 - Summary of Data Monitoring Needs

Metrics	Potential Measures	Potential Data Sources
Truck Parking	Truck Parking Total Inventory	Survey of Municipalities; Field Studies
	Truck Parking Occupancy	Survey of Firms/Operators; Field Studies
Vulnerable Road User Conflicts	VRU-Freight Crash Counts	NCDOT Crash Database
	VRU-Freight Fatalities	NCDOT Crash Database

Chapter 3 – Quantified KPIs

3.1 COVERLAB Monitoring Tools

The best publicly available resource for monitoring freight safety in North Carolina is provided by the Commercial Vehicle Enforcement Resource Lab (COVERLAB) in collaboration with the Institute of Transportation Research and Education at NC State University. This web-based portal provides maps and data visualizations of commercial vehicle-involved crashes throughout North Carolina. Because we believe that this resource is a viable zero-cost solution for NCDOT to monitor freight system safety, we will detail below the features and basic usage of the portal.

The most rich element of the resource can be found by navigating to https://coverlab.org/visualizations/interactive-visualization/ or via their homepage by clicking on the "Data Visualizations" tab and selecting "CMV Crash Visualization." Below is an image of the site from which a wide variety of data aggregations and visualizations can be produced with ease.

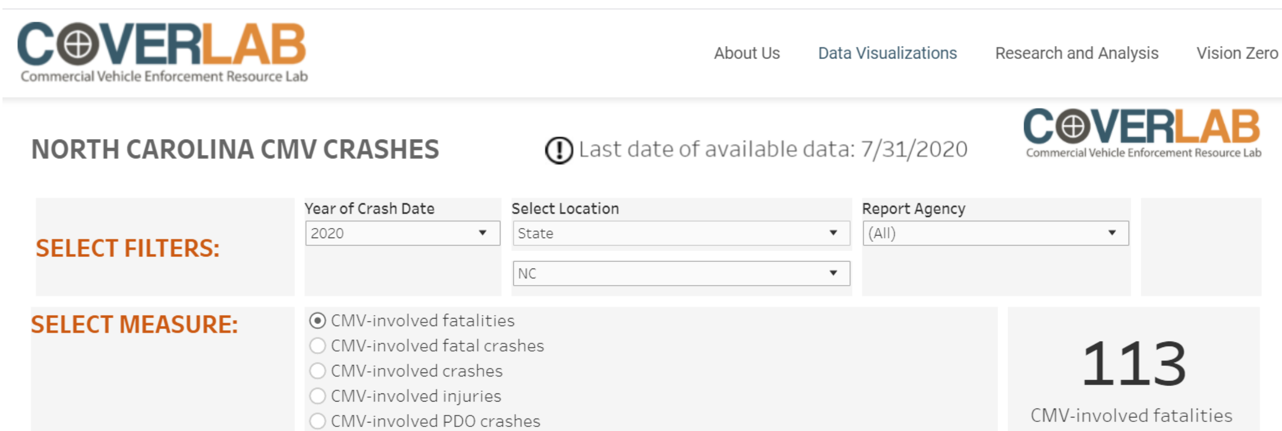

Figure 4 - COVERLAB 2020 CMV - Involved Crashes

One can select from several filters including crash year, location, and reporting agency. Crash locations, or rather aggregation levels, can include statewide, counties, troops, troop districts, LEL regions, and planning organizations.

The visualization tool includes five performance metrics that can be selected individually: commercial vehicle (CMV)-involved crashes; property damage only CMV-involved crashes; CMV-involved injuries; CMV-involved fatal crashes; and CMV-involved fatalities. These are all unique and useful metrics that are measured and reported at different geographic aggregations from 2007 to near present with this tool. The tool will produce counts, infographics, and maps of all five measures for any of the above-mentioned years. It will even produce graphics, maps and figures for specific selected geographies as well. Please see the image below for examples of the versatility of the tool.

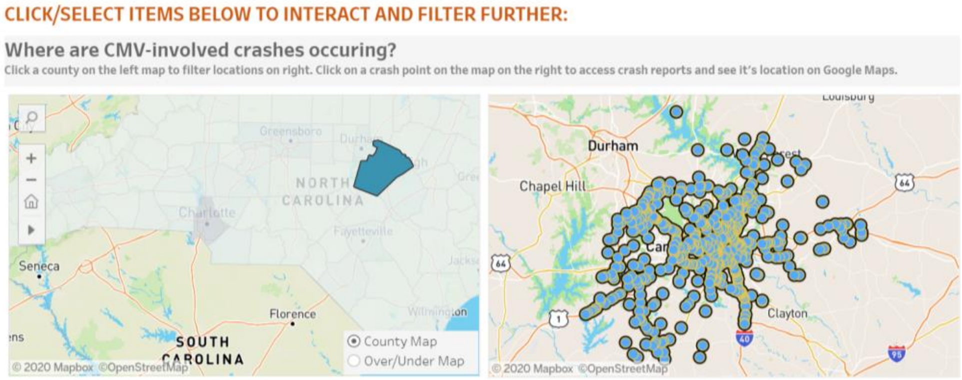

Figure 5 - CMV - Involved Crashes - Wake County, 2020

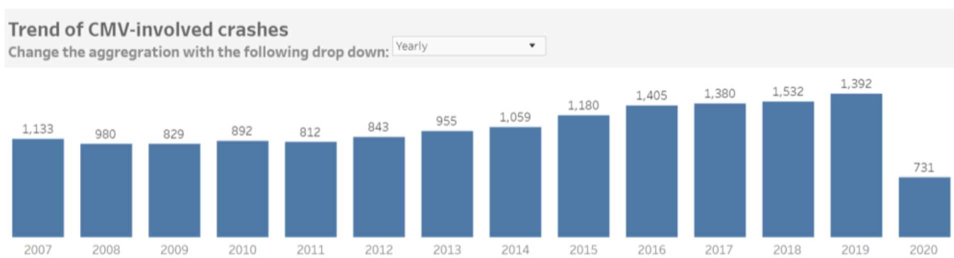

Figure 6 - Yearly Trend CMV - Involved Crashes - Wake County, 2020

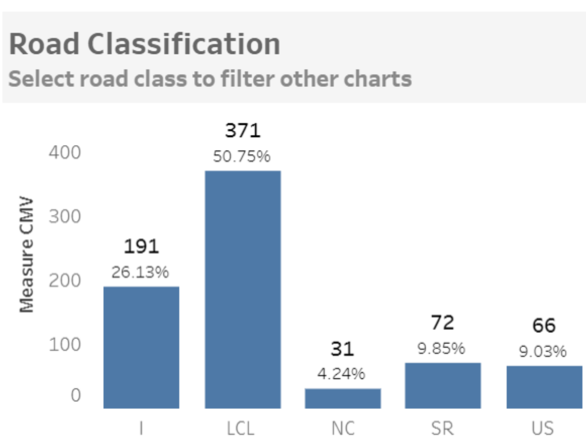

Figure 7 - CMV - Involved Crashes Road Classification Proportions - Wake County, 2020

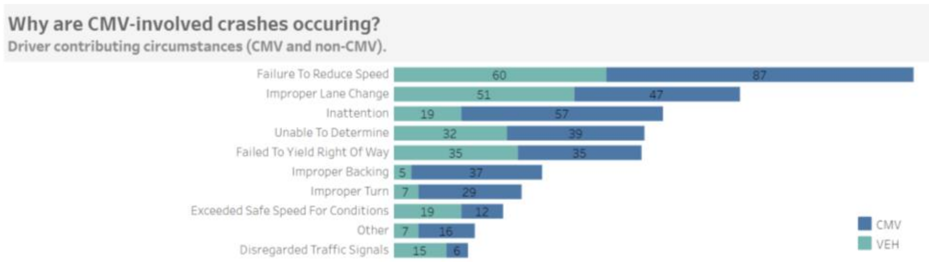

Figure 8 - Crash Reason - Wake County, 2020

Finally, in addition to the data visualization portal, COVERLAB also produces a “CMV High Crash Corridors” mapping tool for identifying where CMV crashes are happening, with respect to road segments, most frequently. This tool does not allow the user to change geography or select for specific years, but instead is intended to quickly identify problem areas within the state. Below we present an image from the mapping tool.

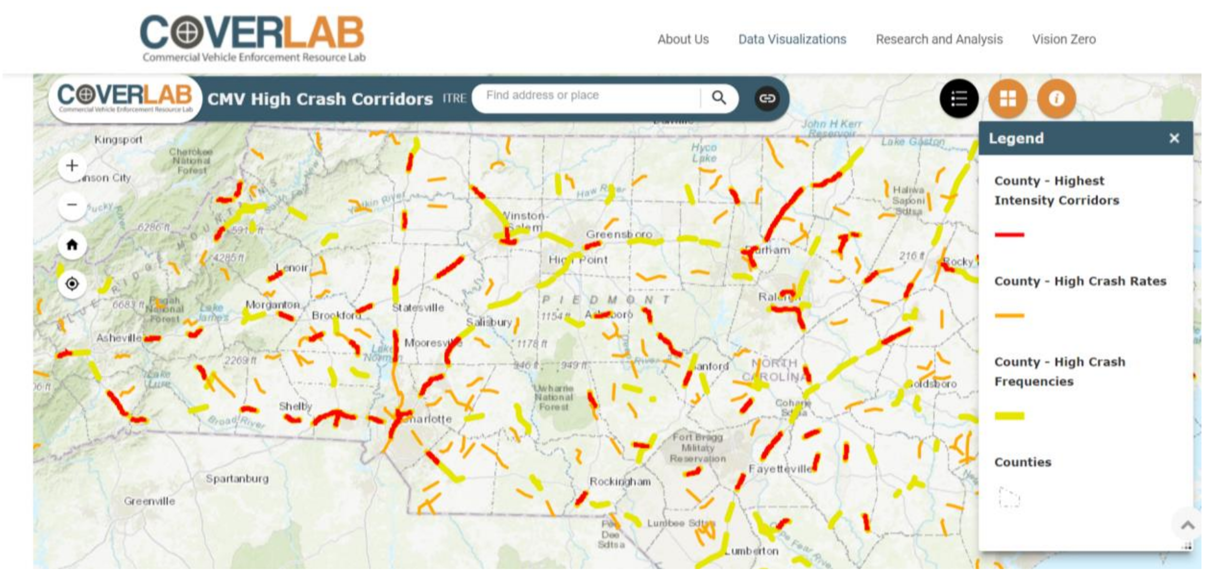

Figure 9 - CMV High Crash Corridors

3.2 Quantifying KPIs from Identified Public Data Sources

After we identified KPIs and determined the availability of data, we quantified them using existing public data sources that are regularly updated. In the below table we present quantified KPIs from public data sources with links to those data sources, the geographies at which they are quantified, the values of the KPI, and the year for which they are most recently measured. This table is slightly abridged for readability within the report, and a more detailed table with additional fields is included in the appendix.

Table 5 - Freight Key Performance Indicators

Key Performance Indicator	Measure	Link	Geography	Figure	Year
Congestion/Mobility	Congested Hours	https://ops.fhwa.d	Raleigh / Charlotte	2:05: / 2:37	2019
	Travel Time Index	https://ops.fhwa.d	Raleigh / Charlotte	1.16 / 1.18	2019
		https://mobility.tar	Raleigh / Charlotte	1.17 / 1.22	2017
	Planning Time Index	https://mobility.tar	Raleigh / Charlotte	1.58 / 1.66	2017
		https://ops.fhwa.d	Raleigh / Charlotte	1.71 / 1.76	2019
	Delay per Traveler	https://mobility.tar	Raleigh / Charlotte	42 hours / 28 hou	2017
	Change in Congestion	https://mobility.tar	Raleigh / Charlotte	-0:05 / -0:30	2019
Economic Development/Freight	Cost of Congestion	https://mobility.tar	Raleigh / Charlotte	$546 M / $1.02 B	2017
	Cost of Freight Congestion	https://mobility.tar	Raliegh / Charlotte	$57 M / $106 M	2017
	Value of Freight Flow	https://www.bts.d	NC	$720 B	2018
	Tons of Freight Flow	https://www.bts.d	NC	463 M	2018
	Annual Truck Delay	https://mobility.tar	Raleigh / Charlotte	1.14 M hours / 2.1	2017
	Top Commodoties Shipped (to/from/within)	https://www.bts.d	NC	Pharmaceuticals;	2018
Safety	Fatalities by Mode	https://www.bts.d	NC	Rail - 31; Transit -	2018
	Fatalities by Person (Driver/Passenger/Bicyclist/etc)	https://www.bts.d	NC	Driver - 53%; Pas	2018
Environment	Transportation Energy Use per Capita	https://www.bts.d	NC	70.6 M BTU/perso	2018
	Motor Fuel Use per Capita	https://www.bts.d	NC	438 Gal/person	2018

3.3 VRU-Commercial Vehicle Safety (*Section 3.3 is a product of an ongoing study funded by the Collaborative Sciences Center for Road Safety*)

3.3.1 INTRODUCTION

Trends in consumer preference and retail have led to a boom in e-commerce. Impacts of this change are felt widely but are especially apparent in the transport sector. This new model of consumption has increased the volume of heavy and light goods vehicles in urban areas including residential areas. Transportation planners, local officials, the public, and the media have been debating the impacts of our increased reliance on commercial vehicles for last-mile delivery. Researchers have analyzed congestion impacts, air pollution and greenhouse gas emissions, noise pollution, road safety, and curb management strategies to increase delivery efficiency (Allen et al., 2017; Callahan, 2019; Duhigg, 2019; Giordani et al., 2018; Ranieri et al., 2018).

Recent media coverage of the impacts of online delivery has highlighted conflicts between freight vehicles and vulnerable road users – pedestrians and bicyclists (Callahan, 2019; Haag & Hu, 2019; Gilbert, 2020). Researchers and planners have long advocated for policies and infrastructure investments that promote bicycling and walking as alternatives to automobile transport, citing reductions in externalities related to automobile travel such as air pollution, carbon emissions, congestion, and noise (Pucher & Buehler, 2017; Cavill et al., 2006; Godlee, 1992; OECD, 2004). Research suggests that targeted efforts to promote active transportation are changing travel behavior, at least in areas where these policies are present (Ogilivie et al., 2004). While we know that the potential for interactions between commercial vehicles and vulnerable road users is rising, there has been little empirical work examining safety issues specifically between these cohorts within metropolitan areas.

This study describes the spatial and temporal patterns of freight vehicle interactions with VRU in urban areas of North Carolina to provide a knowledge base and assess strategies to reduce risks for VRU and freight vehicle drivers. We focus on the following research questions:

- What are the spatial and temporal trends in VRU/freight vehicle crashes?
- What are the crass-level characteristics associated with VRU/freight crashes?

3.3.2 METHODS

3.3.2.1 Study Area

For this analysis we focus on non-interstate crashes involving vulnerable road users and commercial vehicles that occur within census-defined urban areas in North Carolina. We focus on non-interstate urban areas because the policy discussion of how to decrease dangerous interactions between VRU and freight vehicles has focused in these environments. We selected North Carolina as a convenience sample where the research team had strong knowledge of and access to road safety data. However, North Carolina represents a wide range of environments which will provide important context for broader interpretation of our results.

3.3.2.2 Data and Measurement

For the purpose of this study, we have defined vulnerable road users (VRUs) as bicyclists and pedestrians. Some authors have been more inclusive with their definition of VRUs, sometimes including motorcycles, mopeds, and other non-enclosed modes of transport (Constant & Lagarde, 2010; WHO, 2009). We believe that motorized modes are categorically different than bicyclists and pedestrians, and as such, conclusions from a combined sample would be difficult to interpret for meaningful policy or infrastructure interventions.

We define likely freight vehicles as those categorized in police crash reports as light trucks (mini-van/panel), single unit trucks (2-axel, 6-tire), single unit trucks (3 or more axels), tractor/doubles, tractor/semi-trailers, truck/tractors, truck/trailers, unknown heavy trucks, and common cargo vans. While recent innovations in last-mile delivery have greatly expanded the variety of vehicles used for commercial purposes, we limited our van category to cargo-style models that are not likely to carry passengers. This included 16 sub-models by four automakers that we identified via their vehicle identification numbers (VIN). The other vehicle type classifications are made by police officers on the scene, and do not necessarily reflect a scientific designation protocol. Previous studies have focused on large freight vehicles, typically heavy trucks (Roudsari et al., 2004; Kim et al., 2006; Ma et al., 2014; McCarthy & Gilbert, 1996; Pokorny et al., 2017). We include a broader range of commercial vehicles with the knowledge that changing delivery patterns and practices requires a broader operationalization of freight vehicles. Recent research by Lyons & McDonald (2020) shows that freight carriers are increasingly using delivery vans and other smaller vehicles for urban freight delivery.

Our data are a sample of crashes throughout North Carolina from 2007 to 2018. Each observation in our sample represents a single crash. There are associated crash characteristics that relate to vehicles and individuals, but the observation, frequencies, and visualizations represent crashes. The sample has been limited to crashes between vulnerable road users and commercial vehicles, as defined above. We select crashes that occur on non-interstate roads within urban areas. Our sample of VRU-cargo van crashes has a more limited temporal extent, representing only 2011-2018. Because of the more recent addition of these types of vehicles to the commercial fleet, and based on our analysis of the data, we expect that our sample contains most of this type of accident occurring in North Carolina. The data come from digitized crash reports that have been geocoded by the Institute for Transportation Research and Education at North Carolina State University. The data include crash-specific variables that measure aspects of the individuals involved, the vehicles, the crash site and immediate surroundings, and the conditions at the time of the crash. From 2007-2018 there were 33,707 crashes between pedestrians and all vehicles and 11,266 crashes between bicyclists and vehicles during this same period. When we identify crashes between commercial vehicles and VRU's the figure is limited to 1,126 for pedestrians and 318 for bicyclists. Finally, we selected only VRU-commercial vehicle crashes that occurred on non-interstate roads in urban areas, leaving 825 crashes with pedestrians and 251 crashes with bicyclists. There were an additional 51 crashes between qualifying cargo vans and VRU's that met all the above criteria.

3.3.2.3 Analysis:

Descriptive Analysis

We begin by exploring the data using descriptive analysis. We use crosstabulations and pivot tables to observe patterns and associations between specific variables of interest. Given the limited size of our sample, some relationships will not demonstrate significant relationships in inferential models, but trends and associations can still provide meaningful context. Next, we map crashes to observe spatial patterns for certain crash types. We map crashes between VRU's and commercial vehicles for the two largest North Carolina regions: Charlotte, and Raleigh/Durham/Chapel Hill. Finally, we conduct a time series analysis of monthly VRU-commercial vehicle crashes to determine if there is a significant trend over the study period and how it varies monthly and seasonally.

Modeling

We estimate two logistic regression models to assess the determinants of crash severity in crashes between VRUs and commercial vehicles. To add nuance to our understanding of the determinants of crash severity, we estimate the same model using two different outcome variables: severe crashes and fatal crashes. Severe crashes are those in which the VRU was classified in the crash report as a "Suspected Serious Injury" or "Killed." Fatal crashes are those in which the VRU was classified as "Killed." Given the fact that crash reports are completed on the scene or shortly thereafter, it is possible that some crashes categorized as "Suspected Serious Injury" could have resulted in a subsequent fatality, where the victim later died as a result of injuries from the crash. We select our logistic regression model using a stepwise model selection process considering model fit, face validity, and significance of relationships as criteria for inclusion of independent variables.

3.3.3 RESULTS

3.3.3.1 Descriptive Analysis

We start by presenting crosstabulations of variables of interest with crash severity. Figure 10 describes crash counts by hour of the day for each level of crash severity. This crosstabulation of crash hour and crash severity indicates that there is a higher frequency of minor crashes in the 12-hour period from 8:00 AM to 8:00 PM. More serious crashes involving suspected serious injuries or fatalities are more evenly spread throughout the 24-hour period, with the distribution most even for fatal crashes.

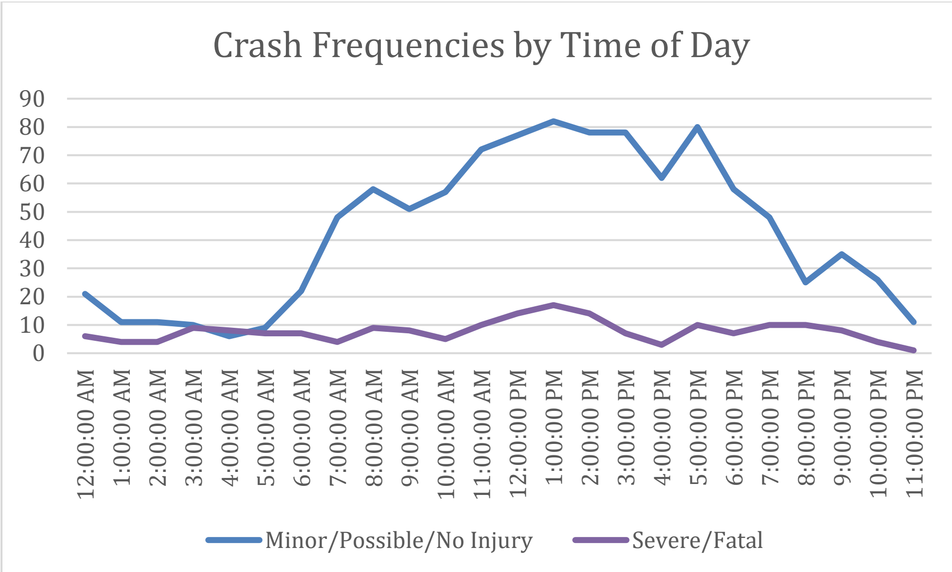

Figure 10 - Crash Severity by Crash Hour

Below, Figure 11 describes yearly crash counts by crash severity. We see two peaks in total crashes, first in 2008 and next in 2014. This does not conform with our expectation that as urban freight and home deliveries have increased there would be a corresponding increase in VRU-freight vehicle crashes.

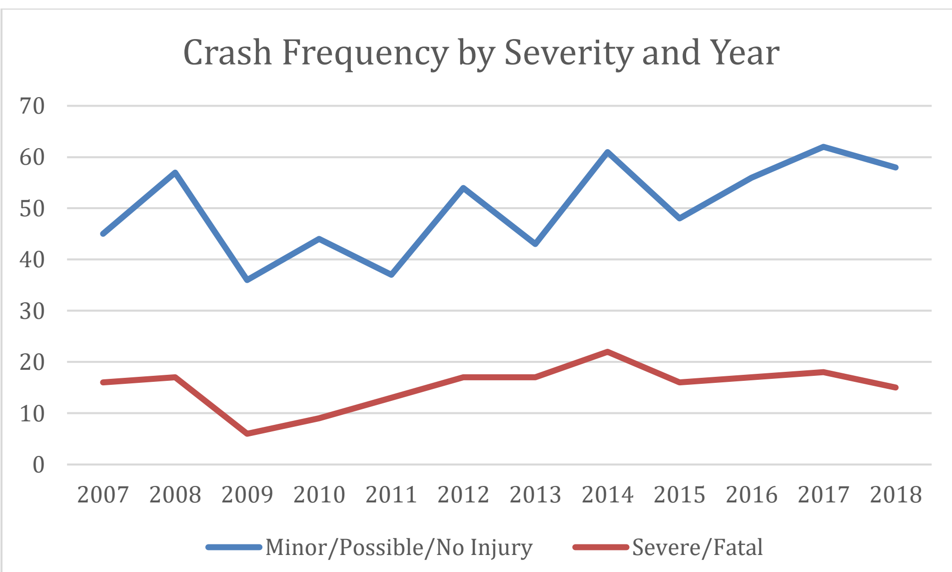

Figure 11 - Crash Severity by Year

3.3.3.2 Spatial Analysis

We map VRU-commercial vehicle crashes for the two largest regions in North Carolina below. We have shaded census tracts by population density and freight jobs to explore whether there are observable patterns in crash frequency for areas with high freight-producing economic activity or high general trip-producing activity. We use the Work Area Characteristics subset of Longitudinal Employer-Household Dynamics (LEHD) Origin Destination Employment Statistics to determine the number of freight-producing jobs per census tract. Of the 20 employment categories provided by the LEHD data, we include jobs from the following four categories: Manufacturing; Wholesale Trade; Retail Trade; and Transportation and Warehousing. Below, Figures 12 and 13 depict VRU-commercial crashes for the Charlotte region of North Carolina.

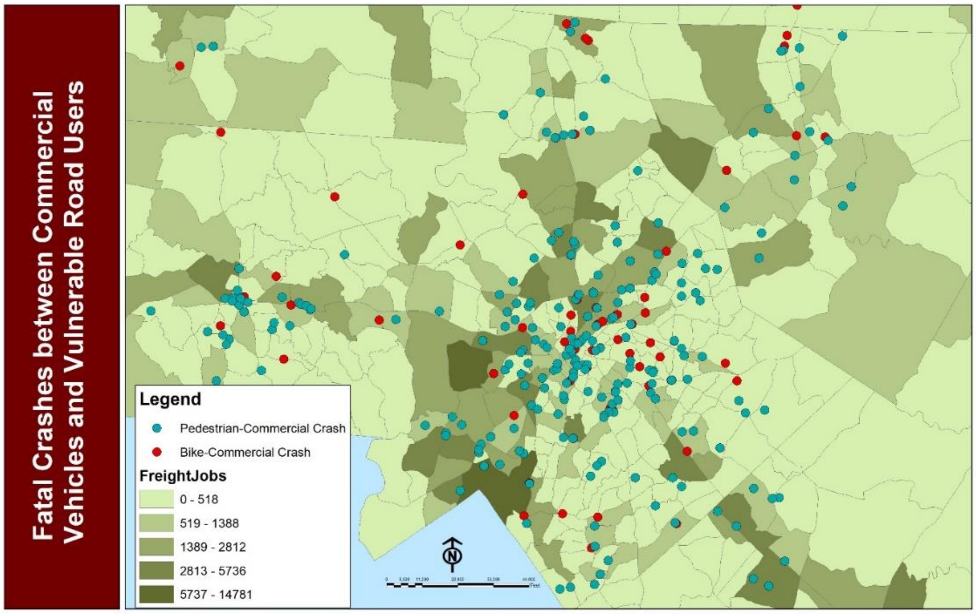

Figure 12 - Charlotte VRU - Commercial Crashes and Freight Jobs

The census tracts with the highest levels of freight jobs are dispersed around the periphery of the Charlotte region. However, we see that the highest density of VRU-commercial vehicle crashes occurs in the center of the region. There does not appear to be a spatial pattern indicating that freight jobs are associated with crashes in this region.

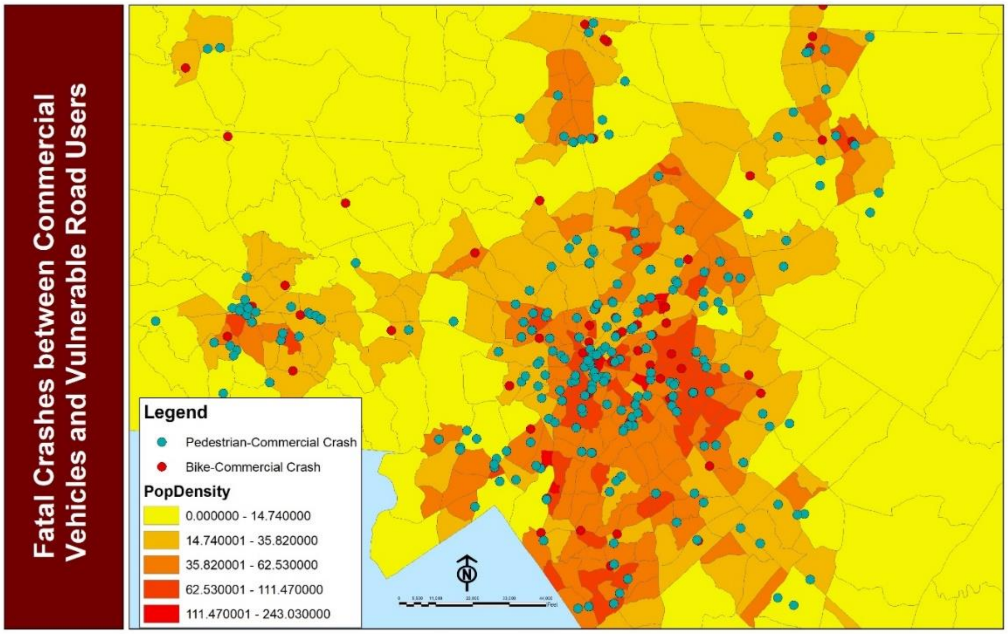

Figure 13 - Charlotte VRU - Commercial Crashes and Population Density

We see that population density is higher near the center of the region. There appears to be a spatial relationship between crash density and population in Charlotte. It is important to note, however, that this apparent relationship is not proven statistically, however. We are simply stating that there is an apparent association visible in this map. Below, Figures 14 and 15 explore these patterns for the Raleigh/Durham/Chapel Hill (Research Triangle) region.

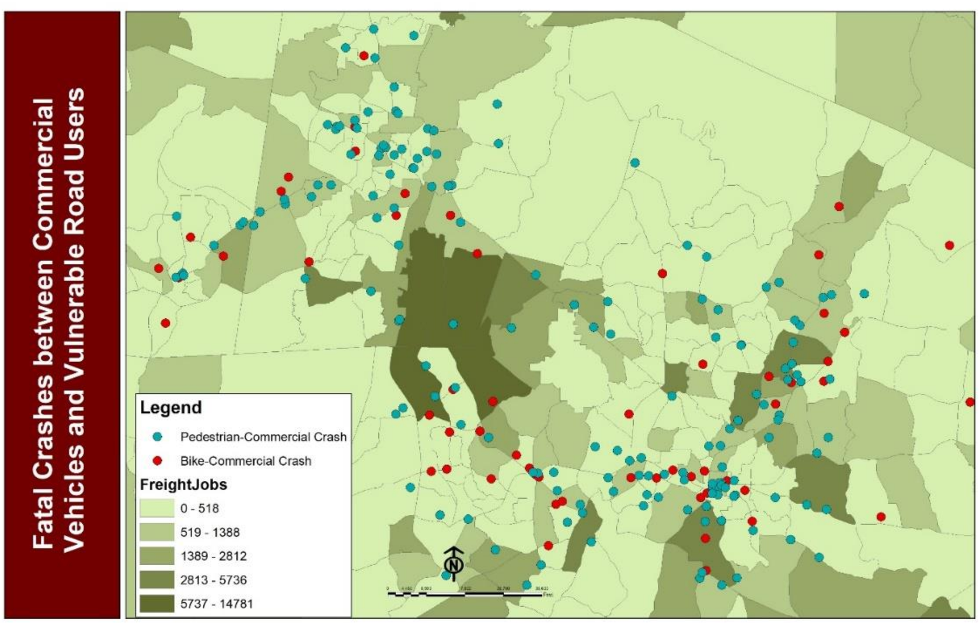

Figure 14 - Raleigh/Durham/Chapel Hill VRU-Commercial Crashes and Freight Jobs

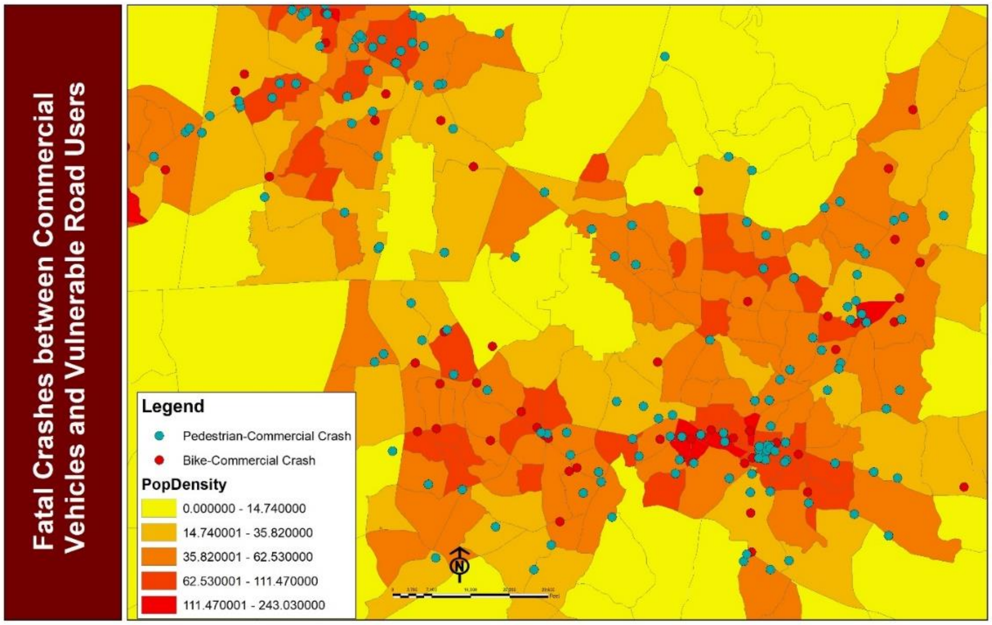

Figure 15 - Raleigh / Durham / Chapel Hill VRU - Commercial Crashes and Pop Density

Like what we observed in the Charlotte region, the Research Triangle region seems to display little or no spatial relationship between freight jobs and VRU-commercial crashes. We do observe an apparent association between population density and crashes.

3.3.3.3 Time Series Analysis

We plot the time series of VRU-freight crash counts per month in Figure 16 below. One can observe a somewhat irregular seasonal trend in these crashes, with dramatic peaks around 2016 and continuing higher peaks in the following years. The R package "forecast" identifies the overall trend as well as the seasonal variation to predict crash counts for 20 months past the end of the data. Figure 16 depicts the time series plot of monthly crash counts as well as a forecast for monthly crash counts through 2022. The overall trend is significant (t=2.79, p=0.01), suggesting a 2% increase in crashes per year. This 2% increase is much smaller than what was observed by McDonald et al. (2019). Beyond the overall trend however, none of the yearly variation was significant.

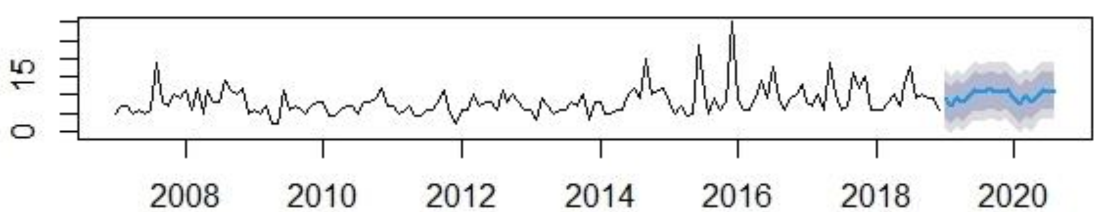

Figure 16 - VRU - Commercial Vehicle Crash Frequency by Month (Preliminary)

3.3.4 CONCLUSION AND LIMITATIONS

This paper examines crashes between vulnerable road users (VRUs) and commercial vehicles. We define VRUs as pedestrians and bicyclists and commercial vehicles as large trucks and cargo vans. We analyze data taken from police crash reports and geocoded for the entire State of North Carolina. Our data represent all VRU-commercial vehicle crashes from 2007 to 2018. We analyze the data using descriptive statistics, mapping, time series analysis, and logistic regression. The mapping indicates little to no spatial association between VRU-commercial vehicle crashes and freight-producing jobs. We do see, however, some apparent association between population density and clustering of crashes. Our time series analysis indicated that over the 12-year study period, there has been a statistically significant increase in these crashes. The increase predicted by the time series model is approximately 2% per year, with slight deviations from that trend that did not prove to be significant.

Chapter 4 – Lessons from Interviews

To achieve a more nuanced understanding of the state of freight planning and measurement in North Carolina, we interviewed key informants that are participating in local and regional freight planning efforts. We interviewed three individuals from two different planning agencies and reviewed documents that further detailed the topics from our interviews. We conducted semi-structured interviews with 10 questions that covered the state of freight planning in North Carolina, current practices for monitoring freight safety, problems that the informants observed with the freight system, and suggestions for future freight monitoring practices. In the below paragraph we succinctly synthesize our findings from these interviews. The interview questions and edited interview notes can be found in the appendix.

We started interviews by asking informants how they saw their agencies' role in planning for freight as well as how they collaborated with other regional actors. We found that, at least with the agencies that we covered, there was a robust framework for interagency collaboration over freight. An example of this collaborative freight planning process in North Carolina is the Greater Charlotte Freight Mobility Plan (GCFMP) published in 2016. The GCFMP is unique, not only in its pioneering of a regional effort to vision, measure, monitor, and improve freight mobility, but also in its coordination with an exhaustive set of stakeholders. Contributors to the GCFMP process included representatives from federal agencies, state (North Carolina and South Carolina) DOTs, five different MPOs, local governments, local economic development organizations, and private industry. The plan, according to one our informants, was an 18-month project that was an outgrowth of Charlotte's Connect Our Future Initiative that identified freight as a major priority for improving economic development. The GCFMP identified the existing freight network, detailed bottlenecks in the system, and suggested policy solutions to the issues it established. An additional unique feature of the plan, according to one informant, was its acknowledgement that land use was an important factor in planning for a successful freight system. Measurable effects of the GCFMP are difficult to assess at this point, but our interviews indicated that the plan has a significant effect on the way that officials are framing and understanding the regional freight planning process. Our informants consistently referenced the plan when asked about the state of freight planning and the ways they are working to monitor and improve freight conditions. A critique that we noticed of the plan, apparent in our interviews both explicitly and implicitly, was that the collaboration that existed in the process of producing the plan did not continue past its publication. The plan was often referenced when informants discussed how they work with other actors to plan and monitor the freight system, but there was little evidence that interagency collaboration on freight was ongoing.

The freight system has undergone a significant amount of pressure associated with the increase in e-commerce activity, according to our informants. The officials attributed issues with congestion and safety to an increase in home deliveries made by box trucks and vans. The freight system is also changing in terms of the prominence of truck shipments. Much of the share of freight tonnage has shifted from rail to truck, according to our informants, as the latter mode is more cost effective and flexible to the needs of agents on the supply chain. Despite the clear pressure associated with changes happening in the freight system, our informants did not feel that there was a corresponding increase in attention being given to the issue. In fact, we were told by one official that they had observed a lack of awareness of transportation issues in general by land use planners, but the problem is even more acute with respect to freight issues. A specific problem that is currently not addressed by land use planning that affects the freight system is accommodating the physical constraints of larger freight vehicles. The technical aspect of providing space, whether it be for safely moving through an urban environment or parking spaces for unloading. Our informant suggested that tickets associated with violating parking regulations have become an expected “cost of doing business” for freight carriers.

Chapter 5 – Freight Monitoring Recommendations

From this research effort we can comfortably make four recommendations for monitoring freight safety KPIs in North Carolina to provide a pathway for better assessment and management of the freight system. Below we outline each recommendation and our assessment of what it will take to achieve the recommendation in a manner that is prudent and sustainable.

Recommendation 1 – Utilize the COVERLAB Crash Visualization Tool
The COVERLAB platform developed by ITRE provides strong visualization tools for monitoring commercial vehicle road safety. This tool can be used without any cost and is straightforward to use, requiring little to no staff training. Our overview of the web portal should act as an easy starting point from which NCDOT staff can become familiar with the tool. While NCDOT could maintain a spreadsheet or database from figures produced by the tool, the data visualizations are very helpful in displaying KPI trends and mapping occurrences of KPIs. The versatility of the tool will require little if any maintenance of the data by NCDOT staff if the tool remains available and accessible to the public. If NCDOT were to adopt only one KPI monitoring practice as a product of this report, we would suggest that it simply utilize this existing resource to monitor freight safety KPIs going forward. Specifically, we would suggest that NCDOT maintain a record of statewide figures for the five KPIs provided by the Crash Visualization Tool. Other state, regional, and local agencies can also use this tool by selecting specific geographies of concern. We also suggest that NCDOT consult the High Crash Corridors tool to ensure that agency efforts to focus on areas of greatest concern are, indeed, being applied to the appropriate corridors.

Recommendation 2 – Maintain Database of Publicly Available KPIs
Building on the efforts of this project, we recommend that NCDOT continue to monitor KPIs from the publicly available data sources that we have identified, linked, and quantified in the table included in this report. We recommend that staff use the modest database that we have compiled here and build upon it by updating KPIs as new figures are released. The baseline established in this report will be more meaningful as additional data become available and trends can begin to be noticed. We also suggest that NCDOT incorporate metrics from proprietary data sources or others that were not included in this report. A single KPI database, especially if it is similar to the scope of what we have provided in this report, will not be particularly onerous to maintain, but will help staff to continue monitoring the safety of the freight system as conditions change.

Recommendation 3 – Focus on VRU-Commercial Vehicle Safety
Our review of the literature as well as our analysis of the empirical data suggest that vulnerable road users (VRUs) are often neglected when considering freight safety KPIs. We have identified crashes between VRUs and commercial vehicles and cross tabulated them among many characteristics for a nuanced understanding of how these characteristics interact and how specific types of crashes are varying in frequency over time. We suggest that NCDOT continue to monitor these trends by maintaining our dataset. While we do not necessarily assume that continued refinement of the regression models and time series analysis are necessary, it should

prove useful to maintain the dataset so that specific crash types and frequencies can be monitored.

Recommendation 4 – Establish a Working Group on Freight Safety Monitoring/Data Sharing Plan

A challenge that we found in conducting our analysis, with concerted effort, could become an asset for NCDOT. There are several different entities working on measuring and monitoring safety of the road system. While they do not all necessarily have a freight focus, they are working to collect data and maintain databases that have the potential to have a meaningful impact on NCDOT's ability to monitor the safety of the freight system. The specific entities that we suggest NCDOT contact for the establishment of a freight safety monitoring working group include the Commercial Vehicle Enforcement Resource Lab also at NC State, the Highway Safety Research Center at UNC, and the City and Regional Planning program at the University of North Carolina at Chapel Hill. We see the purpose of this working group to collaborate on a data sharing plan, as our process of acquiring data from some of these entities has uncovered many overlapping data collection and maintenance efforts. We believe that the formation of this group would benefit both NCDOT by clarifying exactly what data exist and where, but the entities themselves would also benefit from such a discussion.

REFERENCES

Allen, J., Bektaş, T., Cherrett, T., Friday, A., McLeod, F., Piecyk, M., ... & Austwick, M. Z. (2017). Enabling a freight traffic controller for collaborative multidrop urban logistics: Practical and theoretical challenges. *Transportation Research Record*, 2609(1), 77-84.

Al-Ghamdi, A. S. (2002). Pedestrian–vehicle crashes and analytical techniques for stratified contingency tables. *Accident Analysis & Prevention*, 34(2), 205-214.

Baltes, M., R. (1996). Factors Influencing Nondiscretionary Work Trips by Bicycle Determined from 1990 U.S. Census Metropolitan Statistical Area Data. *Transportation Research Record*, pp. 96–101.

Caldwell, H., & Sedor, J. (2002). The freight story: A national perspective on enhancing freight transportation (No. FHWA-OP-03-004).

Callahan, P. (2019, September 5). Amazon pushes fast shipping but avoids responsibility for the human cost. *The New York Times*, retrieved from https://www.nytimes.com/2019/09/05/us/amazon-delivery-drivers-accidents.html

Cavill, N., Kahlmeier, S., Rutter, H., Racioppi, F., & Oja, P. (2008). Economic analyses of transport infrastructure and policies including health effects related to cycling and walking: a systematic review. *Transport Policy*, 15(5), 291-304.

Clifton, K. J., Burnier, C. V., & Akar, G. (2009). Severity of injury resulting from pedestrian–vehicle crashes: What can we learn from examining the built environment?. *Transportation Research Part D: Transport And Environment*, 14(6), 425-436.

Constant, A., & Lagarde, E. (2010). Protecting vulnerable road users from injury. *PLoS Medicine*, 7(3).

Conway, A., Tavernier, N., Leal-Tavares, V., Gharamani, N., Chauvet, L., Chiu, M., & Bing Yeap, X. (2016). Freight in a bicycle-friendly city: Exploratory analysis with new york city open data. *Transportation Research Record*, 2547(1), 91-101.

Dablanc, L., & Ross, C. (2012). Atlanta: a mega logistics center in the Piedmont Atlantic Megaregion (PAM). *Journal Of Transport Geography*, 24, 432-442.

Dablanc, L., Giuliano, G., Holliday, K., & O'Brien, T. (2013). Best practices in urban freight management: Lessons from an international survey. *Transportation Research Record*, 2379(1), 29-38.

Duhigg, C. (2019, October 10). Is Amazon Unstoppable? *The New Yorker*, retrieved from https://www.newyorker.com/magazine/2019/10/21/is-amazon-unstoppable

Dumbaugh, E., Li, W., & Joh, K. (2013). The built environment and the incidence of pedestrian and cyclist crashes. *Urban Design International*, 18(3), 217-228.

Dumbaugh, E., Rae, R., & Wunneberger, D. (2009). Examining the relationship between community design and crash incidence (No. SWUTC/09/167173-1). Texas Transportation Institute.

European Conference of the Ministers of Transport. National Policies to Promote Cycling. Organisation for Economic Cooperation and Development, Paris, 2004.

Gao, J., & Ozbay, K. (2017). A Data-Driven Approach to Estimate Double Parking Events using Machine Learning Techniques. Transportation Research Board's 96th Annual Meeting. Washington, DC.

Gilbert, B. (2020, July 29). 10-year-old killed in crash with Amazon delivery van in Bay Area. *Business Insider*, retrieved from https://www.businessinsider.com/10-year-old-killed-in-crash-with-amazon-delivery-van-2020-7

Giordani, I., Archetti, F., Djordjevic, D., & Sormani, R. (2018). Towards sustainable urban logistics: the evolution of digital marketplace. *Transport and the City*, 75.

Giuliano, G., Kang, S., & Yuan, Q. (2018). Using proxies to describe the metropolitan freight landscape. *Urban Studies*, 55(6), 1346-1363.

Godlee, F. (1992). Transport: a public health issue. *BMJ: British Medical Journal*, 304(6818), 45.

Haag, M. & Hu, W. (2019, October 28). 1.5 Million Packages a Day: The Internet Brings Chaos to N.Y. Streets. *The New York Times*, retrieved from https://www.nytimes.com/2019/10/27/nyregion/nyc-amazon-delivery.html

Hutchings, D., Best, N., & Mahmuti, M. (2013). Global perspective on retail: online retailing. A Cushman & Wakefield Research Publication, London.

Kaplan, S., Vavatsoulas, K., & Prato, C. G. (2014). Aggravating and mitigating factors associated with cyclist injury severity in Denmark. *Journal Of Safety Research*, 50, 75-82.

Kim, J. K., Kim, S., Ulfarsson, G. F., & Porrello, L. A. (2007). Bicyclist injury severities in bicycle–motor vehicle accidents. Accident Analysis & Prevention, 39(2), 238-251.

Lee, C., & Abdel-Aty, M. (2005). Comprehensive analysis of vehicle–pedestrian crashes at intersections in Florida. *Accident Analysis & Prevention*, 37(4), 775-786.

Lyons, T. & McDonald, N. (2020) Innovative Strategies in Last-Mile Urban Freight Delivery: A systematic review of the literature. Working Paper.

Ma, Y. (2014). City logistics in China–an empirical study from an emerging-market-economy country (Doctoral dissertation, Technische Universität).

Ma, M., Ma, Y., Liu, L., & Shi, L. (2014). Severity Analysis of Motor Vehicle-Bicycle Crashes. In CICTP 2014: Safe, Smart, and Sustainable Multimodal Transportation Systems (pp. 2605-2613).

Manson, J., Cooper, S., West, A., Foster, E., Cole, E., & Tai, N. R. (2013). Major trauma and urban cyclists: physiological status and injury profile. *Emergency Medicine Journal*, 30(1), 32-37.

Martinez, K. L. H., & Porter, B. E. (2006). Characterizing red light runners following implementation of a photo enforcement program. *Accident Analysis & Prevention*, 38(5), 862-870.

McCarthy, M., & Gilbert, K. (1996). Cyclist road deaths in London 1985–1992: drivers, vehicles, manoeuvres and injuries. *Accident Analysis & Prevention*, 28(2), 275-279.

McDonald, N., Yuan, Q., & Naumann, R. (2019). Urban freight and road safety in the era of e-commerce. *Traffic Injury Prevention*, 20(7), 764-770.

McGowan, J. (2019). How Has the Growth of E-commerce Sales Affected Retail Real Estate?.

Nicaj, L., Stayton, C., Mandel-Ricci, J., McCarthy, P., Grasso, K., Woloch, D., & Kerker, B. (2009). Bicyclist fatalities in New York City: 1996–2005. *Traffic Injury Prevention*, 10(2), 157-161.

OCDE/OECD (1998) Safety of vulnerable road users. Paris: Organisation for Economic Co-Operation and Development. DSTI/DOT/RTR/ RS7(98)1/Final DSTI/DOT/RTR/RS7(98)1/ Final. http://www.oecd.org/dataoecd/24/4/ 2103492.pdf

Ogilvie, D., Egan, M., Hamilton, V., & Petticrew, M. (2004). Promoting walking and cycling as an alternative to using cars: systematic review. *BMJ*, 329(7469), 763.

Park, K., Ewing, R., Sabouri, S., & Larsen, J. (2019). Street life and the built environment in an auto-oriented US region. Cities, 88, 243-251.

Pokorny, P., Pritchard, R., & Pitera, K. (2018). Conflicts between bikes and trucks in urban areas—A survey of Norwegian cyclists. *Case Studies on Transport Policy*, 6(1), 147-155.

Pucher, J., & Buehler, R. (2009). Integrating bicycling and public transport in North

America. *Journal of Public Transportation*, 12(3), 5.

Pucher, J., & Buehler, R. (2017). Cycling towards a more sustainable transport future.

Ranieri, L., Digiesi, S., Silvestri, B., & Roccotelli, M. (2018). A review of last mile logistics innovations in an externalities cost reduction vision. *Sustainability*, 10(3), 782.

Roudsari, B. S., Mock, C. N., Kaufman, R., Grossman, D., Henary, B. Y., & Crandall, J. (2004). Pedestrian crashes: higher injury severity and mortality rate for light truck vehicles compared with passenger vehicles. *Injury Prevention*, 10(3), 154-158.

Seiniger, P., Gail, J., & Schreck, B. (2015). Development of a test procedure for driver assist systems addressing accidents between right turning trucks and straight driving cyclists. *In 24th International Technical Conference on the Enhanced Safety of Vehicles (ESV*), Gothenburg, Sweden.

Sze, N. N., & Wong, S. C. (2007). Diagnostic analysis of the logistic model for pedestrian injury severity in traffic crashes. Accident Analysis & Prevention, 39(6), 1267-1278.

Visser, J., Nemoto, T., & Browne, M. (2014). Home delivery and the impacts on urban freight transport: A review. *Procedia-Social and Behavioral Sciences*, 125, 15-27.

WHO/OMS (2009) Global status report on road safety: time for action. Geneva: World Health Organisation, http://whqlibdoc.who.int/publications/ 2009/9789241563840_eng.pdf.

Zegeer, C. V., Stutts, J. C., Huang, H., Zhou, M., & Rodgman, E. (1993). Analysis of elderly pedestrian accidents and recommended countermeasures. *Transportation Research Record*, 1405, 56-63. Transportation Research Board, Washington, D.C., 2018.

Appendix

Acronyms:

KPI – Key Performance Indicator
DOT – Department of Transportation
MPO – Metropolitan Planning Organization
VRU – Vulnerable Road User
CV – Commercial Vehicle
OLF – Office of Freight + Logistics
COVERLAB – Commercial Vehicle Enforcement Resource Lab
FHWA – Federal Highway Administration
OFMO – Office of Freight Management and Operations
FPM – Freight Performance Measurement
ATR – Automated Traffic Recorder
ITS – Intelligent Transportation System
GPS – Geographic Positioning System
ATA – American Trucking Association
VIN – Vehicle Identification Number
LEHD – Longitudinal Employer-Housing Dynamics
GCFMP – Greater Charlotte Freight Mobility Plan
ITRE – Institute of Transportation Research and Education
HSRC – Highway Safety Resource Center

Appendix Table 1: Key Performance Indicators from Literature

Authors	Year	Article	Indicator	Measurement	Details
Jones & Sedor	2006	Improving the Reliability of Freight Travel	Speed		
			Reliability	Fill Rate	The percentage of orders delivered "on time"
			Security	Delay	Actual delivery day minus confirmed delivery day
			Visibility		
			Profitability		
			Return on Investment		
			Congestion	Delay	Delay per person or per vehicle
			Mobility	Travel Time	The time it takes for a vehicle to travel between two points
			Safety		

			Economic Development		
Lomax et al.	2003	Selecting travel time reliability measures	Travel Time Reliability	Statistical Range	An estimate of the range of transportation conditions (congestion) that can be experienced
				Buffer Time Measures	The effect of irregular conditions--the extra time that must be allowed to achieve the destination reliably
				Tardy Trip Indicators	How often a traveler will be "unacceptably" late
Texas Transportation Institute and Cambridge Systems	2006	Travel time reliability: Making it there on time every time	Travel Time Reliability	90th/95th percentile Travel Times	How bad delay will be on the heaviest travel days
				Buffer Index	Extra buffer or time cushion that travelers must add to ensure reliable on time arrival
				Planning Time Index	Like buffer index but includes free-flow travel time

Harrison et al.	2006	Developing Freight Highway Corridor Performance Measure Strategies in Texas	Travel Time	Peak Period Travel Time	
				Delay	Hours of delay per 1000 vehicle mile
			Reliability	Delay	Hours of incident-related delay
				Percent of on-time arrivals	
				Travel Time Reliability	Ratio or variance to average minute per trip in peak periods in metro areas
			Cost	Cost of highway freight per ton-mile	
				Fuel consumption per ton mile	

				Maintenance cost of connector links	
			Safety	Accident Rates	Number of accidents in given geography and/or period of time
				Fatality Rates	
				Insurance Cost	
			Highway Condition	Condition	Lane-miles of high-level highway requiring rehabilitation
					NHS intermodal connectors condition
					Percent of roads/bridges with surface/condition classified as good
					Number of at grade railroad crossings
					Overpasses with vertical clearance restrictions
					Weight-restricted bridges
					Intersections with inadequate turning radii
			Economic Impact	Infrastructure Return	Contribution of investment to GDP
					Net present value of improvements/ Benefit-cost ratio of highway improvements
			Industry Productivity	Capacity	Average length of haul
					Average load
					Percent of VMT empty
					Annual miles per truck
Margiotta et al.	2015	Freight Performance Measure Approaches for Bottlenecks, Arterials, and Linking Volumes to Congestion Report	Congestion	Total Delay	Actual vehicle hours experienced minus the vehicle hours at free-flow speeds
				Mean Travel Time Index	The mean travel time over the highway section divided by the travel time that would occur at the reference speed
				Planning Time Index	

				80th Percentile Travel Time Index	The 80th percentile travel time divided by the travel time that would occur at the reference speed

Appendix Table 2: KPIs and Data Sources:

Key Performance Indicator	Measure	Data Source	NC Data Available	Link	Data Type	Updated	Frequency
Congestion/Mobility	Congested Hours	FHWA Urban Congestion Reports	Yes (Raleigh)	https://ops.fhwa.d	PDF Report	2019	Annual
		INRIX Scorecard	Yes (Select Cities)	https://inrix.com/s	PDF Report	2019	Annual
	Travel Time Index	FHWA Urban Congestion Reports	Yes (Raleigh)	https://ops.fhwa.d	PDF Report	2019	Annual
		FHWA Significant Corridors	No	https://ops.fhwa.d	PDF Report	2005	One-off
		FHWA Conditions and Performance Report	Yes (Select Cities)	https://www.fhwa	PDF Report	2019	Annual
		Texas Transportation Institute Urban Mobility R	Yes (Select Cities)	https://mobility.tar	Interactive, web-b	2019	Annual
		INRIX Scorecard	Yes (Select Cities)	https://inrix.com/s	PDF Report	2019	Annual
	Planning Time Index	FHWA Urban Congestion Reports	Yes (Raleigh)	https://ops.fhwa.d	PDF Report	2019	Annual
	Average Operating Speed	FHWA Significant Corridors	No (National)	https://ops.fhwa.d	PDF Report	2005	One-off
	Buffer Index	FHWA Significant Corridors	No (National)	https://ops.fhwa.d	PDF Report	2005	One-off
	Daily percent of VMT in congestion	FHWA Conditions and Performance Report	Yes (Select Cities)	https://www.fhwa	PDF Report	2019	Annual
	Annual Hours of Delay per Capita	FHWA Conditions and Performance Report	Yes (Select Cities)	https://www.fhwa	PDF Report	2019	Annual
	Average Length of Congested Conditions	FHWA Conditions and Performance Report	Yes (Select Cities)	https://www.fhwa	PDF Report	2019	Annual
	Delay per Traveler	Texas Transportation Institute Urban Mobility R	Yes (Select Cities)	https://mobility.tar	Interactive, web-b	2019	Annual
	Change in Congestion	Texas Transportation Institute Urban Mobility R	Yes (Select Cities)	https://mobility.tar	Interactive, web-b	2019	Annual
Economic Development	Cost of Congestion	Texas Transportation Institute Urban Mobility R	Yes (Select Cities)	https://mobility.tar	Interactive, web-b	2019	Annual
	Value of Freight Flow	Bureau of Transportation Statistics State Trans	Statewide (Aggregat	https://www.bts.d	PDF Report	2019	Annual
	Tons of Freight Flow	Bureau of Transportation Statistics State Trans	Statewide (Aggregat	https://www.bts.d	PDF Report	2019	Annual
	Top Commodoties Shipped (to/from/within)	Bureau of Transportation Statistics State Trans	Statewide (Aggregat	https://www.bts.d	PDF Report	2019	Annual
Safety	Fatalities by Mode	Bureau of Transportation Statistics State Trans	Statewide (Aggregat	https://www.bts.d	PDF Report	2019	Annual
	Large Truck-Involved Injuries	Federal Motor Carier Safety Administration Lar	No (National)	https://www.fmcs	Tabular	2017	
	Large Truck-Involved Pedestrian Fatalities	Federal Motor Carier Safety Administration Lar	No (National)	https://www.fmcs	Tabular	2017	Annual
	Large Truck-Involved Bicycle Fatalities	Federal Motor Carier Safety Administration Lar	No (National)	https://www.fmcs	Tabular	2017	Annual
	Large Truck-Involved Fatal Crashes	Federal Motor Carier Safety Administration Lar	Statewide (Aggregat	https://www.fmcs	Tabular	2017	Annual
	Fatalities by Person (Driver/Passenger/Bicyclist/etc)	Bureau of Transportation Statistics State Trans	Statewide (Aggregat	https://www.bts.d	PDF Report	2019	Annual
Efficiency	Transportation Energy Use per Capita	Bureau of Transportation Statistics State Trans	Statewide (Aggregat	https://www.bts.d	PDF Report	2019	Annual
	Motor Fuel Use per Capita	Bureau of Transportation Statistics State Trans	Statewide (Aggregat	https://www.bts.d	PDF Report	2019	Annual

Appendix Item 3: Data Hyperlinks

Federal Highway Administration Urban Congestion Report - https://ops.fhwa.dot.gov/perf_measurement/ucr/reports/fy2019_q4.pdf

INRIX Scorecard - https://inrix.com/scorecard/#:~:text=Welcome%20to%20the%20INRIX%20Global,comparisons%2C%20and%20incident%20congestion%20impacts.

Federal Highway Administration Significant Corridors - https://ops.fhwa.dot.gov/freight/freight_analysis/perform_meas/fpmtraveltime/traveltimebrochure.pdf

Federal Highway Administration Conditions and Performance Report - https://www.fhwa.dot.gov/policy/23cpr/pdfs/23cpr.pdf

Texas Transportation Institute Urban Mobility Report - https://mobility.tamu.edu/umr/congestion-data/

Bureau of Transportation Statistics State Transportation by the Numbers - https://www.bts.dot.gov/sites/bts.dot.gov/files/states2020/North_Carolina.pdf

Federal Motor Carrier Safety Administration Large Truck and Bus Crash Facts - https://www.fmcsa.dot.gov/safety/data-and-statistics/large-truck-and-bus-crash-facts-2017#A5

Appendix Item 4: Semi-Structured Interview Questions

1) Who do you see (organization, agency, decision-makers etc.) as primarily responsible for monitoring the freight system?

2) What changes have you observed in urban freight activity in your region?

3) Have you noticed any change in the amount of attention given to urban freight by planners or leaders?

4) What problems do you see associated with urban freight now or in the future?

5) How is your organization monitoring urban freight?

6) What kind of collaboration, if any, is your agency participating in with respect to coordinated planning for urban freight?

7) you know of any private-public collaboration happening with respect to urban freight?

8) What do you see as key indicators of safety in the urban freight system?

9) Beyond safety, what should be other foci of urban freight monitoring?

10) Who else should we speak to for this inquiry?