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Locating and Costing Congestion for School Buses and Public Transportation (Phase 2)

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1. Introduction

The impact of roadway congestion on public transit and school buses in the United States is poorly understood. Bus routes and schedules are seldom designed with much consideration to how congestion may increase travel times; school bus routes are dependent on school-opening schedules (and are increasingly subject to tiered-scheduling where schools have staggered starts to allow a single bus to serve multiple schools) and public transportation is inclined to schedule towards the congestion, since transit riders and private vehicles are often going to the same destinations.

When buses are subjected to congestion, their operating and capital costs increase, travel time increases, on-time reliability decreases, and the overall competitiveness and attractiveness of these modes decreases. In Phase I of this project, *Locating and Costing Congestion for School Buses and Public Transportation* (STRIDE Project E3), researchers from the Institute for Transportation Research and Education (ITRE) at North Carolina State University and the University of Florida explored ways to calculate the amount of travel time delay experienced by public transit and school buses. Researchers studied two locations with comparable statistics: Pinellas County, FL, a populous, primarily urban county with multiple distinct municipalities and Durham County, NC, a less populous county with a centralized core that draws passengers from suburban and rural areas on its edges.

The research team integrated three large datasets to create a practitioner tool to allow transportation planners and engineers to model the relationship between traffic flow and congestion data (via RITIS) with public transportation (GTFS) and school travel data (Edulog). The tool allowed for the spatial identification of congestion impacts affecting public transportation and school buses, along with estimates of the costs incurred by these modes resulting from congestion. By combining these three datasets, the research team determined when and where publicly funded transportation vehicles are operating and estimated the delay experienced by each vehicle. Bottlenecks, slow segments, and clogged times were identified, which could be used to develop solutions to spatially or temporally avoid congestion delays. Delay costs were then calculated to allow planning agencies, municipalities, and other entities to quantify the problem when evaluating solutions.

Phase I of the project involved an extensive amount of iterative coding and often manual fact-checking for quality control. The three datasets used were never designed to be merged (further evidence that this has been an undervalued topic) and, furthermore, may not be the relevant data sources in all communities. For example, RITIS covers few of the neighborhood roads which school buses frequent, GTFS relies on updates from local transit agencies, and Education Logistics, Inc. (Edulog) is only one of several school bus routing software platforms on the market. For these reasons, the research team instituted Phase II to further this research and attempt to devise more generalizable methodologies that could be used by stakeholders across the nation.

2. Background

Congestion is a major issue for commuters in the United States. It is estimated that the average United States commuter wastes $763 annually ($85 billion yearly, as a nation) on congestion (USDOT, 2019). While private vehicles suffer (and are the cause of) the majority of this congestion, public and student transportation also feel the effects of clogged roadways. When transit buses are slowed down by congestion, captive riders (i.e., those with no readily available alternative) see their travel times increase, while choice riders may opt to switch to private vehicles, thus increasing the congestion. Meanwhile, more and more parents and guardians are driving their children to school, contributing to morning peak hour traffic, as well as congestion around schools (La Vigne, 2007).

The Department of Justice published a report which shows that 75% of school-aged children are dropped off by car instead of walking/biking or busing (La Vigne, 2007). McDonald (2005) states that only 13% of children walk or bike to school, down 29% since 1969. This can be explained by a growth in car ownership/use in combination with urban sprawl which increases the distance needed to travel for school. Furthermore, miles traveled, system cost, and air pollution all increase as well. (VTPI, 2018). Likewise, in municipalities with increased school choice options, students may be less likely to attend their neighborhood school, necessitating either a longer bus ride or an additional car trip. Buses and private vehicles are often competing for school access during limited arrival and dismissal periods, leading to unprecedented levels of congestion.

School children may particularly feel the effects of congestion, as the school bus may pick them up over an hour or more before bell time, forcing them to wait at the side of the road in the early morning; sometimes before the sun rises. Various studies have shown that this is an extreme detriment to the health of the next generation. In North Carolina, where ITRE collects data for school buses in all 115 districts, while the median student ride time is 32 minutes, the average of the median 95th percentile ride time is 72 minutes for the 2022-2023 school year. As one ITRE team highlighted in its 2016-2017 North Carolina statewide pupil transportation report, “an early pickup might present a student with a particularly challenging start to the day” (2017). Studies show that younger students are particularly impacted; according to a study conducted by Deborah A. Temkin, et al. (2018), “Seventh and eighth grade students with later start times have significantly longer sleep durations and less daytime sleepiness than do similar students with earlier start times.” Reducing time spent on the bus may thus have benefits throughout the school day.

The implications of congestion are widely observed in urban planning, economics, and personal health. Transit agencies, municipalities, and counties need to be equipped with a reliable tool to understand: a) where congestion is occurring in their area; and b) how much that congestion costs in operational and capital funds to the public and school transportation services. When these hotspots and costs are identified, proper solutions can be implemented in order to mitigate delays.

2.1. What causes congestion?

Congestion is defined as high traffic volumes which alter the quality of service for transportation systems (Sweet, 2011). Recurrent congestion, which is congestion caused by increased vehicle travel at peak times, can be caused by an increase in the number of residents using personal vehicles on limited capacity roadways. This happens when traveling by personal vehicle is seen as the most desirable option. Increased use of personal vehicles can be exacerbated by an increased rate of car ownership and a lack, or perceived lack, of other viable options.

2.2. Cost of Congestion on Public Transportation Services

Congestion impacts the functionality, reliability and overall performance of public transportation. In rural, city, and central business district areas, congestion slows down public transit operations due to backed up vehicles on travel lanes. A study conducted by the New Jersey Department of Transportation and The U.S. Department of Transportation Federal Highway Administration (2003) found that congestion delays transit operation time by 6%, with other factors such as traffic lights, waiting for other buses to clear out the path, and boarding queued up passengers also contributing to delays. Congestion also prevents buses from operating at their maximum speed, as well as slowing down their reintegration into the moving lanes after making a stop (Begg, 2016). These delays are detrimental to not only the performance of public transit, but also detrimental to the use of this valuable service.

Public transit delay due to slower speeds increases journey times and decreases on-time performance, which ultimately decreases passenger usage of the service (Begg, 2016). The impact of congestion on bus passengers is an increase in single-passenger vehicles which only compounds the congestion problem further.

In terms of operating costs, a case study based in London found that when public transit tries to maintain service frequency, for every 10% decrease in operating speeds, there is an 8% increase in operating costs. Costs spill over to passengers' fares which leads to a 5.6% decrease in patronage. A 10% decrease in operating speeds decreases frequency of service by 10%, which decreases the passenger base by 5%. Both scenarios deter users from using public transportation (Begg).

2.3. Cost of Congestion on School Bus Services

Congestion can be particularly high around schools for short periods during the day. School pick-ups and drop-offs can explain 10-15% of peak hour motor vehicle trips, as parents make an additional four trips per day compared to bus riders (McDonald, 2005; Victoria Transport Policy Institute (VTPI); Safe Routes to School; La Vigne, 2007). The Department of Justice (2019) published a report which shows that 75% of school-aged children are dropped off by car instead of walking/biking or busing. McDonald (2005) states that only 13% of children walk or bike to school, down 29% since 1969. This can be explained by a growth in car ownership/use in combination with urban sprawl which increases the distance needed to travel for school. As distance to school increases, six-times fewer children walk, while vehicle miles traveled, system cost and air pollution all increase (VTPI, 2018). School-related congestion is also impacted by the perception of risk related to walking and biking. Parents are generally less willing to allow their child to travel alone for fear of kidnappings and traffic accidents (La Vigne, 2007). The perception of danger can be related to the high volume of vehicles traveling around the school.

School-bus-related congestion constitutes more than just a delay in school bus services as it relates to kids getting to school on time. Congestion around school zones is a result of changes in school practices and their population. Changes in the overall physical infrastructure surrounding schools such as; new school construction, the addition or elimination of busing, street layout, and traffic signs and signals surrounding a school, all contribute to school-related congestion (La Vigne, 2007). Studies have shown that extended bus rides have a negative impact on school children's health. "We found that busing children from a high-traffic neighborhood to a school 19 km away in a low-traffic environment resulted in average daily exposures two to three times higher than children walking to a local school in the high-traffic environment" (Wolfea et. al., 2021).

2.4. Phase I Case Study: Durham, NC

During Phase I of this project, the team consisted of ITRE and University of Florida (UF) researchers, with the ITRE team taking the lead on developing the procedures for data cleaning and analysis based on their familiarity with the data and spatial analysis methods (Monast et al, 2021). Durham County, NC and Pinellas County, FL were selected as the study sites; the Durham site is presented here as an example.

Researchers selected one community in Florida and one in North Carolina, that varied some in basic characteristics (e.g., size, urban/rural nature, structure of municipalities), but shared the following criteria:

1. The local public transportation is represented with a GTFS (General Transit Feed Specification) feed for fixed route public transportation,
2. The local school district utilizes EDULOG routing software,
3. The local school district is willing and able to share school bus routes, and
4. Roadway congestion is moderate to severe in at least some locations.

The first two criteria can be problematic, as transit agencies may utilize GTFS feeds differently, or not always keep them updated, while Edulog is one of many routing software programs used by school districts across the country. For this reason, it was decided that Phase II would focus on conducting the analysis using Automatic Vehicle Locator (AVL) data, which is becoming increasingly common and better reflects the real-world activities of school and public transit buses. Phase II eliminates the concern raised with the first and second criteria that was required in Phase I. In this section, we present a brief overview of the Phase I methodology, as it may be more appropriate in some municipalities. For those interested in pursuing the Phase I methodology they are advised to read the initial report for more details including a step-by-step guide in the Appendix.

The amount of congestion that transit and school buses experience was determined by merging three sets of data (Figure 1). Travel speed data was taken from the Regional Integrated Transportation Information System (RITIS), accessed with the assistance of the North Carolina and Florida Departments of Transportation. GTFS provided the routes and schedules of the public transportation systems in each county and local school districts allowed the team access to non-identifying school bus routes in the study area.

Raw RITIS probe data includes segment name, timestamp, speed, travel time and free flow speed. This data was downloaded for the period

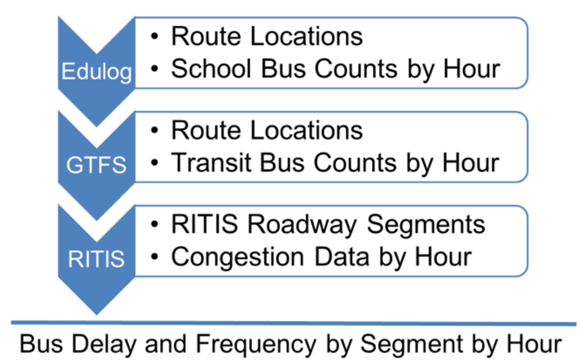

Figure 1: Methodology Conceptualization

between October 15, 2019 and November 14, 2019, to avoid major holidays and changes to school routing that may occur at the beginning of the school year. First, raw data were filtered to weekday observations on Tuesdays, Wednesdays and Thursdays, as these days of week are most representative of an average weekday. Next, average values for speed and travel time were calculated by hour of the day within the filtered dataset. Overall delay can be calculated for the entire or partial RITIS segment using the analysis length divided by the difference between average speed and free flow speed. It is important to note that RITIS does not cover all roadway segments; it tends to cover the busier segments, which are likely to suffer most of the congestion, but it may miss congestion on neighborhood streets. In addition to improving the school and public transit data, Phase II intends to simplify the congestion data criteria by utilizing Outscraper (see section 2.4)

The Edulog software is a bus route planning tool used to design daily school bus routes from start to finish. Bus route data includes planned stop sequences, projected arrival times at bus stops and expected student assignments for each bus stop and route. The Edulog software algorithm provides optimal turn by turn directions between planned stop sequences based on local settings such as travel speeds, school bus turn restrictions, no-travel segments, etc. Because of this, the data downloaded from Edulog do not include the actual roadway segments that could correspond with RITIS data, just the turning points. To align the school bus routes temporally to the RITIS data, each route was assigned an hour based on the route start time. The research team used ESRI's ArcPro Desktop software to combine the XY coordinates of known stop locations from Edulog and geocode intermediate intersections which allowed the research team to "connect the dots" by a planned stop sequence. Once these data were cleaned, they were geo-located through ESRI's geoprocessing tools. The routes were created through the Network Analysis tools within ESRI's ArcPro software.

GoDurham and GoTriangle are the two major fixed route public transit systems that operate within Durham County. Their General Transit Feed Specification (GTFS) data was used to help researchers understand the frequency of buses in Durham County as well as the spatial location of these frequencies. The final output for the GTFS route data was derived by using the Generate Shapes from GTFS and Network Analysis tools. Figures 2 through 4 showcase the three datasets for Durham County, while Figure 5 overlays the three datasets atop one another.

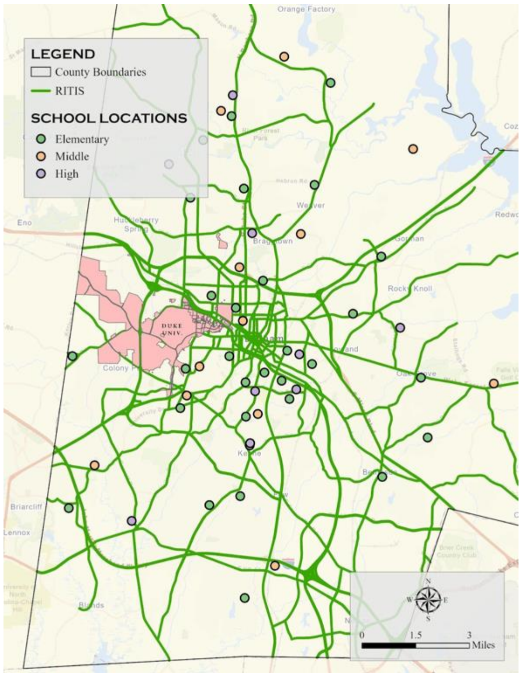

Figure 2: RITIS Segments in Durham County

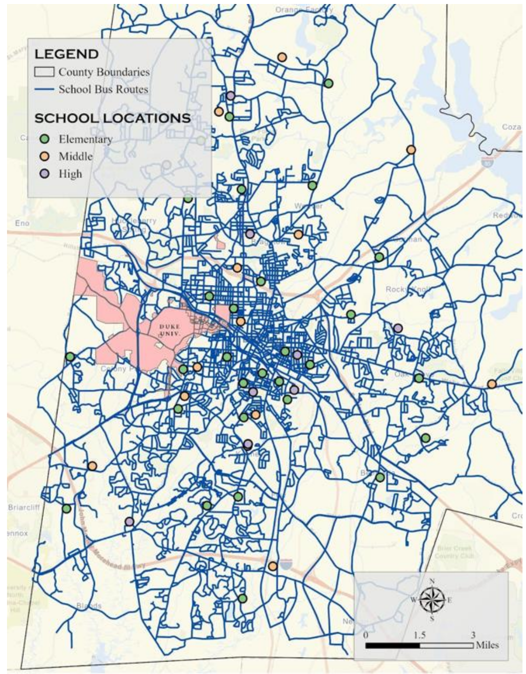

Figure 3: School Bus Routes in Durham County

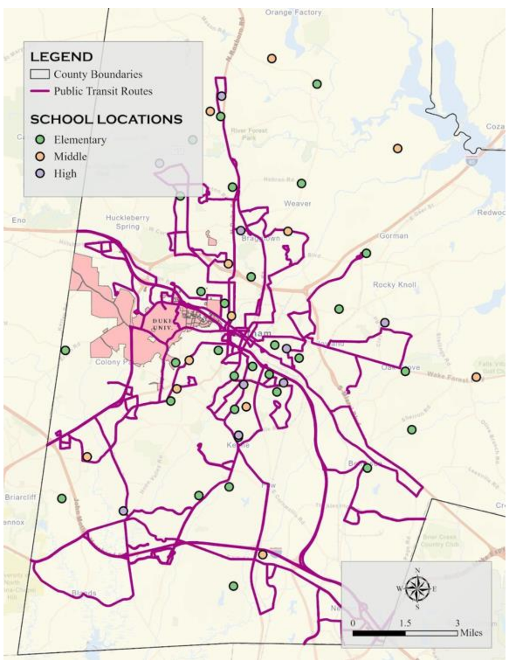

Figure 4: Transit Routes in Durham County

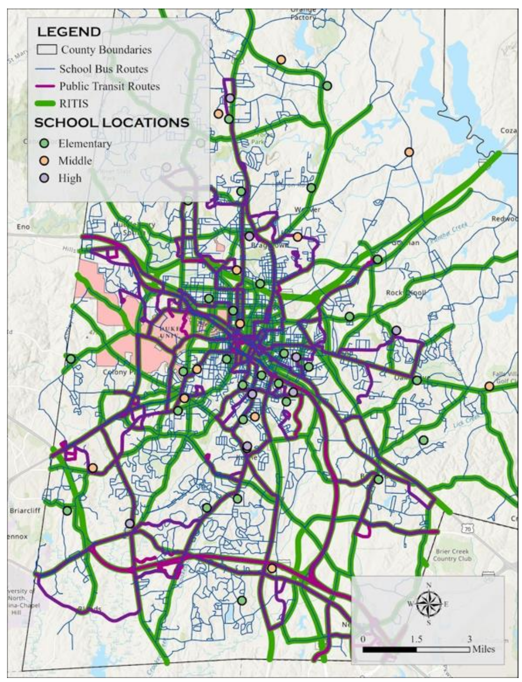

Figure 5: RITIS, School Bus Routes, and Transit Routes in Durham County

The research team in Phase I calculated the cumulative travel delay experienced by school and public transit buses for each hour of the day (Figures 6 & 7). These results represent the minimum delay during the days sampled due to some RITIS segments missing data used to calculate minutes of delay. According to these calculations, transit buses in Durham experience a minimum of 75 hours of delay on a typical weekday (Tuesday, Wednesday, and Thursday).

Assuming 250 weekdays per year, transit buses would experience at least 18,750 hours of delay per year, or 781 days. GoDurham provided an estimate of $95.89 per hour cost for capital and operational expenses, which would mean an overall congestion-related cost of $7,200 per day and $1.8 million per year.

The congestion-related costs of $1.8 million per year do not include the cost in time lost for passengers, because accurate rider count numbers per segment were not available. However, using the US Department of Transportation's recommended hourly value of time savings of $17.90 (USDOT, 2021) and if GoDurham averages 10 people on the bus when the bus is experiencing delay, this results in a societal cost of $3,360,000 per year.

Turning to pupil transportation, the 1,041 vehicle trips undertaken each day by Durham school buses experience 113 hours of delay. Expanding this to a typical school year which consists of 180 school days, results in 10,260 hours of delay, or 428 days. Researchers were unable to secure a cost per hour for operating and capital expenses from Durham Public Schools. However, using an estimated cost of $75 per hour results in a daily congestion cost of $4,240 and $763,200 per year.

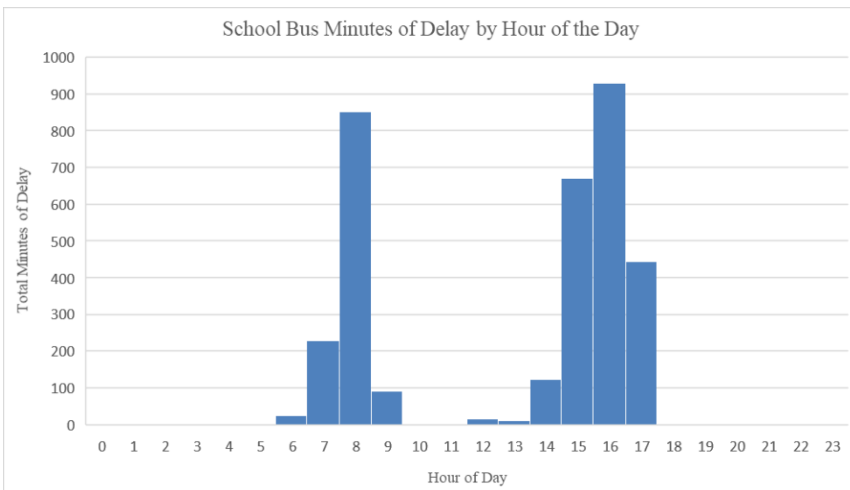

Figure 6: Durham School Bus Minutes of Delay by Hour of Day

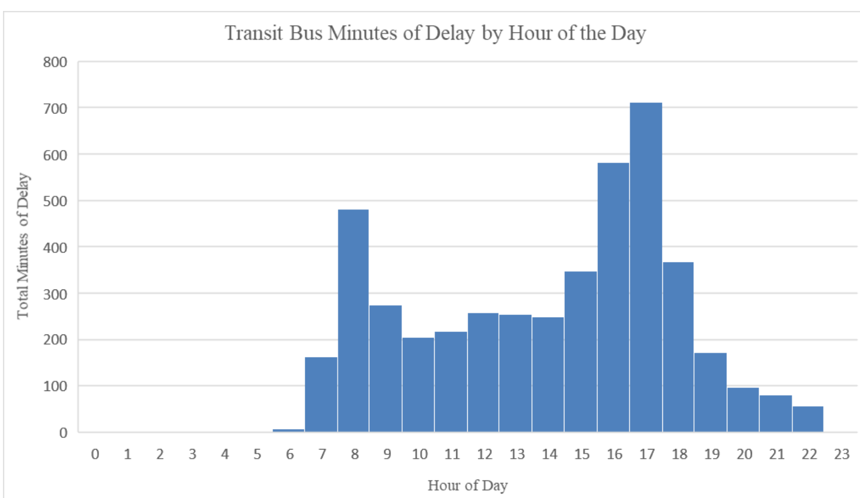

Figure 7: Durham Transit Bus Minutes of Delay by Hour of Day

The on-line mapping tool shown in Figure 8 was also developed to allow users to change time and location to better understand when and where congestion impacts school and transit buses (https://www.transitportal.org/cost_of_congestion.html). More information about this tool can be found in the technology transfer report (Monast, 2021).

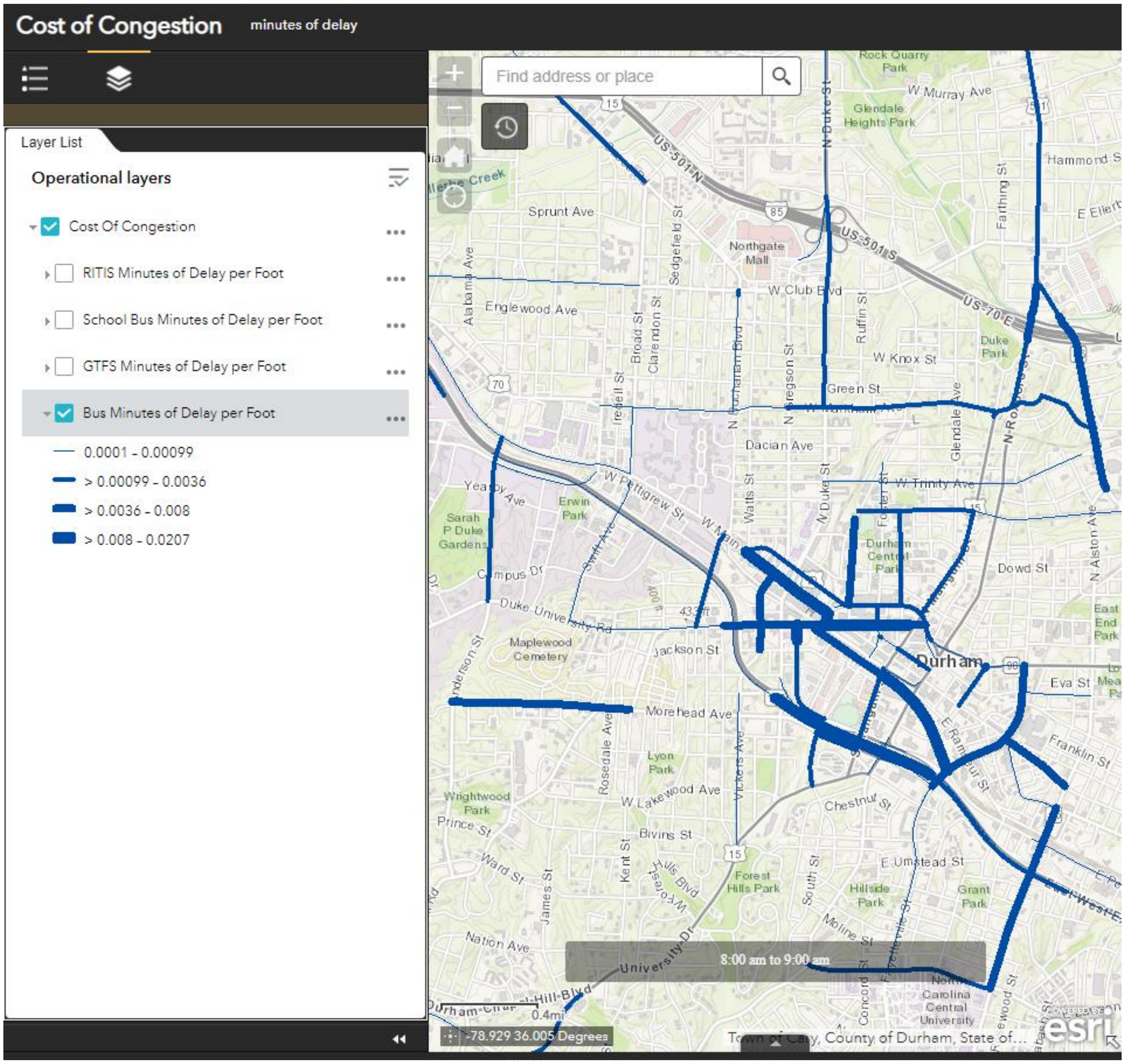

Figure 8: Cost of Congestion On-Line Mapping Tool
(https://www.transitportal.org/cost_of_congestion.html)

2.5. Solutions and Challenges

While there are many potential solutions to buses traveling through chronically congested corridors or bottlenecks, there may be valid reasons why transit buses cannot avoid when and where congestion occurs. For example, transit buses are designed to take passengers where they want to go and when they want to go, which is often in congested areas and during congested times. Transit planners cannot simply change the routes or times, without inconveniencing the passengers themselves. Likewise, school buses have to go through neighborhoods and to schools.

2.5.1. Transit Bus-Specific Strategies

It is important to note that bus delays can be affected by other issues besides congestion, such as boarding delays, lengthy dwell times, or even backup caused by other buses in particularly dense areas. Significant gains will mostly come about by addressing all the issues, including congestion (McKnight et al, 2003). Likewise, many of the solutions to combat congestion can also serve to speed up buses during off-peak hours. Some of these potential solutions include:

- Bus Rapid Transit (BRT): BRT can include various elements, but generally is designed to give buses or related vehicles greater right-of-way, often through restricted lanes and signal prioritization. BRT lanes may be entirely separated from existing roadways or may be a prioritized lane for all or part of a route.
- Signal Prioritization: Public transit buses, as well as other vehicles considered appropriate, are given priority at traffic signals (Begg, 2016). This may involve increased green times or automatic greens (signal preemption). These solutions may need to be designed to work in sync with the greater signal network to prevent unintended consequences at neighboring intersections.
- Rerouting: Generally, efficient bus planning should direct buses in the most efficient paths. However, there may be circumstances where a bus could bypass a congested bottleneck. In addition, knowledge of existing high-congestion corridors could assist transportation planners in developing alternative routes.
- Curb pull-outs and curb extensions: Curb pull-outs are designed to allow the bus to move out of the travel lane and pick up passengers at the curb (FTA, 2005). This can often delay the bus, since it may have to wait to merge back into traffic; however, it may improve overall traffic flow, reducing delay for other vehicles, including other buses. Curb extensions bring the pavement to the travel lane, reducing the bus's dwell time, while sometimes increasing the overall congestion, as traffic may build up behind the bus.
- Regulations: Municipalities can take steps to assist buses by adopting various regulations, such as limiting left turns, restricting parking during congested hours, or instituting a priority merge rule where traffic must allow a bus to reenter traffic (FTA, 2015). There may be additional costs to implementing enforcement regulations, but they may still offer significant reduction in congestion-related expenses.

2.5.2. School Bus-Specific Strategies

While school buses share many of the same issues as public transit buses, there are some unique problems they encounter. Many routes change from school year to school year, or even within the same year, as student locations and school schedules change. Significant staff power is spent just planning the basic routes, without having to further change them, particularly in smaller districts. Furthermore, safety remains the number one issue for a district’s transportation department; a longer route that allows safer loadings and unloadings or avoids dangerous turns should always be prioritized over the fastest route. The following are some strategies for reducing the impacts of congestion, although like for the transit strategies, they may be beneficial regardless of congestion:

- Bell schedule: Changing the bell schedule of a school to allow buses to travel during off-peak hours may be the simplest solution but is also the most problematic. The timing of buses is only one issue that schools grapple with when determining bell schedules. Furthermore, many districts have adopted two- and three-tiered bell scheduling, where a single driver on a single bus can make one round to take students to early opening schools and then another round for later opening schools. This reduces the number of buses and drivers needed but restricts the dispatcher's ability to manage congestion. Even on a single school campus, it may be possible to adjust the bell schedule between different grades (e.g., elementary and middle schools), thus reducing the congestion at any one time (La Vigne, 2007).
- Improving school infrastructure: At some schools, parents picking up or dropping off students creates substantial local congestion (Karly et al., 2013). Building lanes to keep buses, parent vehicles, and other vehicles separated can have benefits not just for buses but also for the neighborhood. Likewise, encouraging more students to switch from private vehicles to buses will improve the overall congestion, and the children's safety.

3. Phase II Case Study: Methodology

3.1. Introduction

In Phase I, the research team focused on the process of estimating the cost of congestion on school and public transportation. To estimate the impact congestion has on the operating budgets of school and public transit systems, it was necessary to calculate the frequency of school and public transit buses. This required a significant amount of trial and error resulting in a process that would be very difficult to replicate. The focus of Phase II is to develop a tool around the methodology described below that would automate and simplify the process developed in Phase I. This tool will be made up of a set up scripts contained within an ESRI ArcToolbox which can be shared with transportation planners that have access to ESRI's ArcPro Desktop software.

School bus data has its own unique issues, separate from the fixed-route, fixed-schedule transit systems. First of all, transportation planners must map out new routes every year, as the locations of students, and even schools, change; it is also possible that schedules are amended during the year, particularly as schools with alternate schedules (e.g., year-round schools) come in and out of session. Secondly, since many students assigned to a bus stop may not actually take the bus, the *performed* bus route is often different from the *planned* bus route. Additionally, school bus drivers may have knowledge of local conditions and alter their routes accordingly to increase efficiency and/or safety.

The research team has wide experience working with school districts across North Carolina and for this project spoke with several of the leading vendors in the school bus routing industry (EDULOG, Tyler Technologies, Bus Planner, Synovia, Where's The Bus and Safe

Fleet). These software vendors all supply the location of bus stops and turns, but do not directly provide the roadway segments between them, which is necessary for this project. With technological advances, more districts are using Automatic Vehicle Locator (AVL) systems to manage driver payroll hours, view the real-time location of a bus and to identify stops that may have been missed by the driver. Some school systems may also have student swipe cards or other methods for tracking actual daily ridership at the student level.

The availability of AVL data is growing throughout both school and public transit industries and the goal in Phase II was to take advantage of the simplicity of this dataset. To build a robust GIS tool that could be used by school and public transit professionals, it was first necessary to develop a single standard schema for both school and public transit datasets. In developing the schema, the research team incorporated some of the data already collected as part of creating a Google Transit Feed Specification (GTFS). Additional fields were included with considerations to future research. Table 1 shows the fields included in the input schema along with a brief definition and datatype of each field; the last columns show whether each field is optional and if it is included in the GTFS schema.

Field Name	Definition	Datatype	Optional	GTFS
AVL_ID	Unique value for each XY Coordinate	Int		
Date	Date of service	Date		
TimeStamp	Time when AVL_Lon & AVL_Lat data are collected	Time		
AVL_Lon	Longitude of the bus location	Double		
AVL_Lat	Latitude of the bus location	Double		
Agency_ID	Identifies a school/transit agency	varchar(50)		X
Agency_Name	Full name of school/transit agency	varchar(100)	X	X
Trip_ID~	Identifies a trip	varchar(50)		X
Route_ID	Identifies a route	varchar(50)		X
Stop_ID	Identifies a stop	varchar(25)	X	X
Stop_Seq	Order of stops for a particular trip	Int		X
Direction	Direction of travel	bit(1)		X
Boardings	Number of passengers boarding bus at a stop	Int	X	
Alightings	Number of passengers exiting bus at a stop	Int	X	
Load	Current number of passengers	Int		
Capacity	Maximum number of passengers	Int	X	X

Table 1: Proposed school and public transit AVL data schema.

The focus of this research is to build a tool that determines where school and public transit are most affected by high congestion corridors. The tool is made up of two parts:

- Part 1 — Determine the travel and free-flow speeds along each road segment by hour of the day;
- Part 2 — Calculate the frequencies of school and public transit routes along the same segments from Part 1 and calculate the congestion impacts.

The tool is based on congestion data obtained from Outscraper (See Section 2.4) and school and public transit route data (See Section 2.5). Part 1 of the tool requires a single input feature layer: a road reference layer of the study area. Part 2 of the tool requires the road reference layer, the congestion data obtained from Outscraper and school and public transit data formatted to the schema defined above.

3.2. Study Area

Datasets matching the schema defined above were created from the datasets used in Phase I. The study area used to develop the methodology described below is shown in Figure 9 and is a subset of the study area used in Phase I.

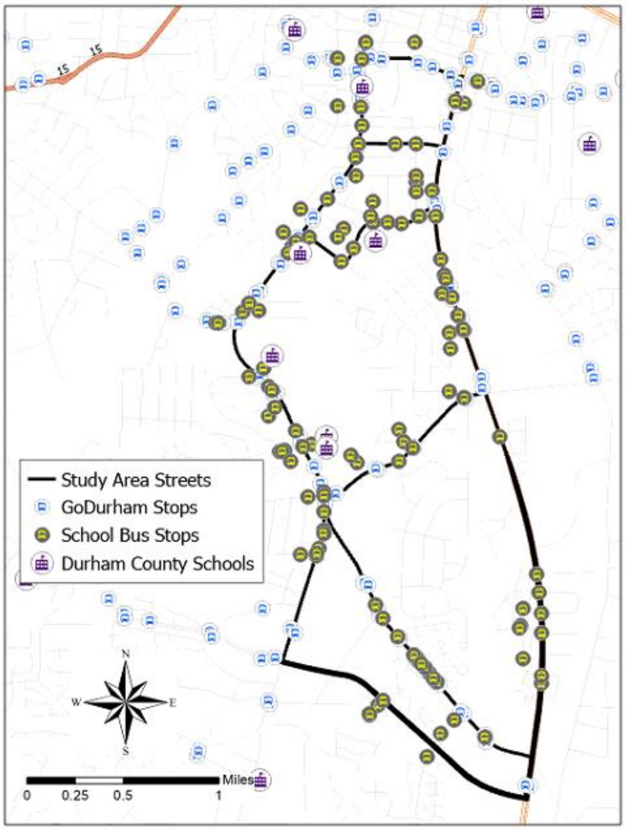

Figure 9: Study area used to develop the methodology for Phase II.

3.3. Road Reference Layer

A road reference layer for the study area of interest is used to create a network dataset for the study area. This network dataset is used to create the school and public transit routes. This is important when combining the three datasets together to calculate the final congestion data metrics. The three feature layers are split at every intersection to ensure they have the same segmentation. Figure 10 highlights the importance of splitting routes at intersections.

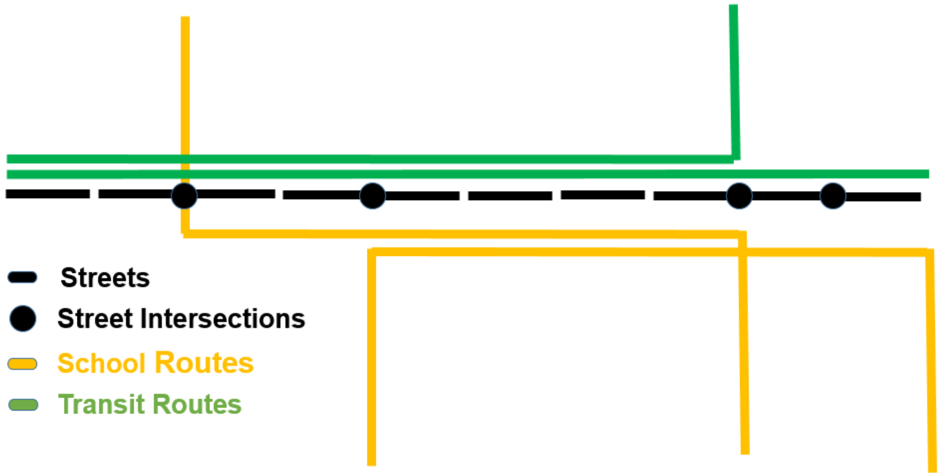

Figure 10: Comparison of school and public transit routes with road reference layer. Due to the overlapping nature of these three layers, it is important that each is split at street intersections.

3.4. Congestion Data

The data informing congestion levels can be derived from numerous sources with varying degrees of accuracy and a multitude of caveats. In Phase I of the study, Regional Integrated Transportation Information System (RITIS) data was utilized to determine congestion impacts on school and public transportation. RITIS data provided archival traffic flow information such as the estimated harmonic mean speed, historic average speed for any hour of the day and week, and the associated reference speed (free flow). This data originates from aggregated vehicle GPS devices or Location Based Service data that is collected by a third party (spatial features with congestion data were provided by NCDOT). One of the issues observed in Phase I with the RITIS dataset was the sparsity of road segments with congestion data. This sparsity resulted in a significant number of streets being excluded from the results. School bus routes may often travel along non-RITIS segments, particularly as they traverse residential neighborhoods. One of the goals for Phase II was to find a more comprehensive congestion dataset that would be more widely inclusive of school bus data.

The following sources for traffic data were assessed:

- Mapbox
- ArcGIS Traffic Data
- Outscraper
- HERE
- googletraffic

The following metrics were used in this assessment:

- Satisfactory data source outputs (minutes of delay, data types, format, etc.)
- Ease of use (exportable, user-interface simplicity)
- Cost
- Origin of traffic data (smartphone location data, Mapbox application data)

This review indicated that Google Maps is the most ubiquitous of the traffic data sources and could be scraped using proprietary tools. While open-source options exist for scraping Google Maps traffic data, Outscraper provided the simplest interface for capturing the necessary data in a usable format. In addition, the Outscraper tool provides an API for connecting to a web-application, providing a direct linkage to congestion data. This API could be utilized in the future development of a Cost of Congestion web-mapping application. In addition, no other traffic data source allowed users to create an account and access data without using additional proprietary software

3.4.1. Outscraper - Google Maps Traffic Data Scraper

Outscraper - Google Maps Traffic Extractor provides congestion data for Phase II of the study. Outscraper is a proprietary tool that captures historic Google Maps data and outputs specified congestion data in an excel document with the following fields: The fields marked with an asterisk (*) were utilized in the research team's analysis.

Traffic Data Dictionary

Columns names and descriptions for Google Directions.

- road - name of the route. *
- distance - distance between two points in meters. *
- distance_label - label of the distance that you would see on Google Maps.
- duration - average duration of the trip in minutes.
- duration_min - minimum duration of the trip in minutes.
- duration_max - maximum duration of the trip in minutes.
- road_distance_timing - represents the traveling speed on each segment of the road. It indicates what time (seconds) it takes to pass certain distances of the trip (meters). Can be used to calculate the speed. *
- origin - starting point.
- origin_coordinates - starting point coordinates. *
- destination - destination point.
- destination_coordinates - destination point coordinates. *

Data is available from 2001 in all countries covered by Google Maps.

Start and end coordinates (or intersections) of the study area road segments are formatted for submission to the software with coordinate pairs entered in a batch query. Time frame and time interval are submitted in accordance with the desired range and the output congestion data is exported. The output data schema does not allow for a user-defined primary key and therefore, only the input coordinate queries link the congestion data back to the original road segments.

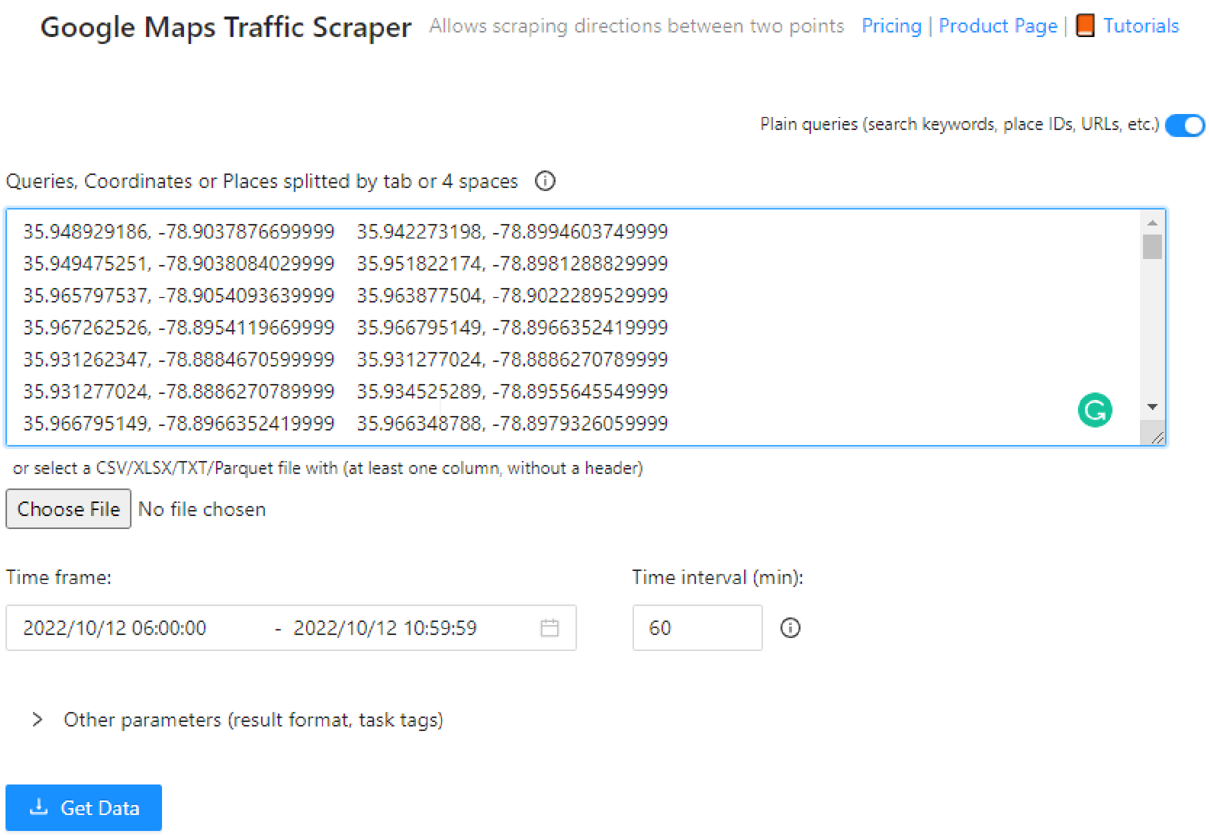

Figure 11: Screenshot of Outscraper Interface

To estimate free-flow traffic (FFT), road segments were evaluated using the Outscraper tool with the time frame set to 0:00am - 1am (1 hour). This assumes that traffic congestion is at its minimum during this hour. The final congestion dataset is then joined back to the road segments data creating a record for each hour in the dataset, for each segment. FFT data for each road segment is joined to each record in the study period dataset as a separate column.

The Outscraper tool provides the time it takes to travel each segment from each out. To calculate the minutes of delay, it is necessary to first calculate the travel speed for the congestion hours and the free-flow hour. The travel speed was calculated by dividing the length of the segment by the travel time provided by the Outscraper tool. If the road reference layer contains a speed attribute, the research team recommends using this attribute rather than estimating the free-flow speed using the 12am hour. Using the travel speed for each hour of the analysis and free-flow periods, minutes of delay per vehicle is calculated using the following formula:

$$MD_n^i = \left(\frac{1}{\frac{TS_n^i}{l^i}} - \frac{1}{\frac{FFS_n^i}{l^i}} \right) * 60$$

Where

$$MD_n^i = Minutes\ of\ Delay\ for\ hour\ n\ and\ segment\ i$$
$$TS_n^i = Travel\ Speed\ (mph) for\ hour\ n\ and\ segment\ i$$
$$FFS_n^i = Free\ Flow\ Speed\ (mph)\ for\ hour\ n\ and\ segment\ i$$
$$l^i = \frac{length\ (ft)}{5280} = length\ (mi)\ of\ segment\ i$$

One limitation in this method is that it assumes school and public transit buses travelling at the free flow speed throughout their routes and does not consider time spent at stops which results in an overestimation of the minutes of delay the buses experience. Future research could address this issue by adjusting the free flow speeds based on the number of stops within each segment of the route.

3.5. School and Public Transit Data

School and public transportation operations offer similar types of service with fixed stop times and locations which are served on a daily basis. Therefore, a single data schema can be applied to both school and public transit datasets and a single methodology can be created to analyze the two datasets. This methodology is described below.

Using the previously defined network dataset, both the school and public transit routes are created using associated stop data. This ensures the school and public transit routes are coincident with the congestion-related features. Then, using the network dataset junctions, the school and public transit routes are split at each intersection. This results in the same segmentation that was used in determining the congestion information. The frequency of school and public transit routes for each segment are calculated and joined to the congestion data feature layer. Figures 12 through 14 show the frequency of school, public transit, and school + public transit buses during the 7am hour.

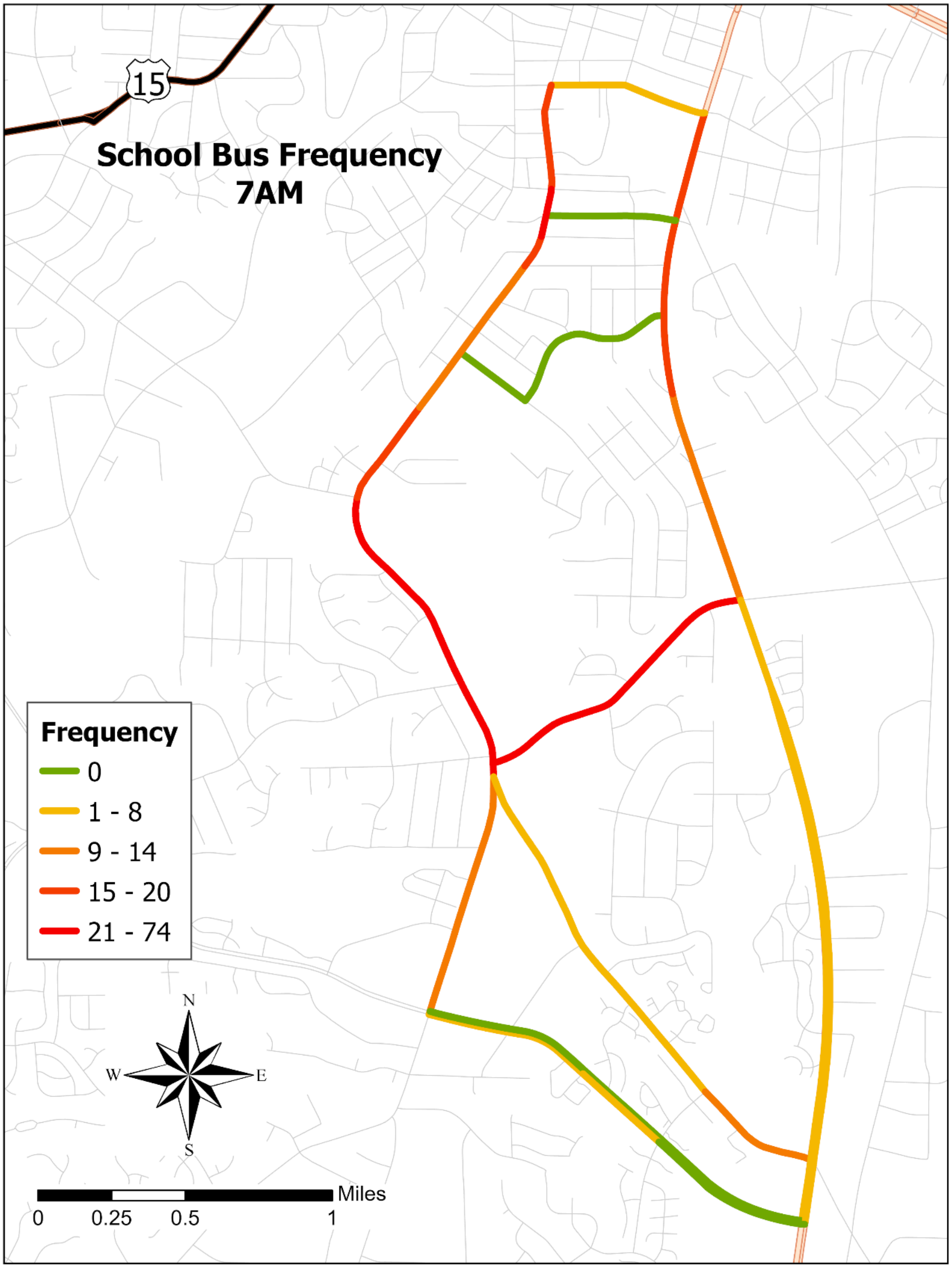

Figure 12: School bus frequency by corridor at 7am.

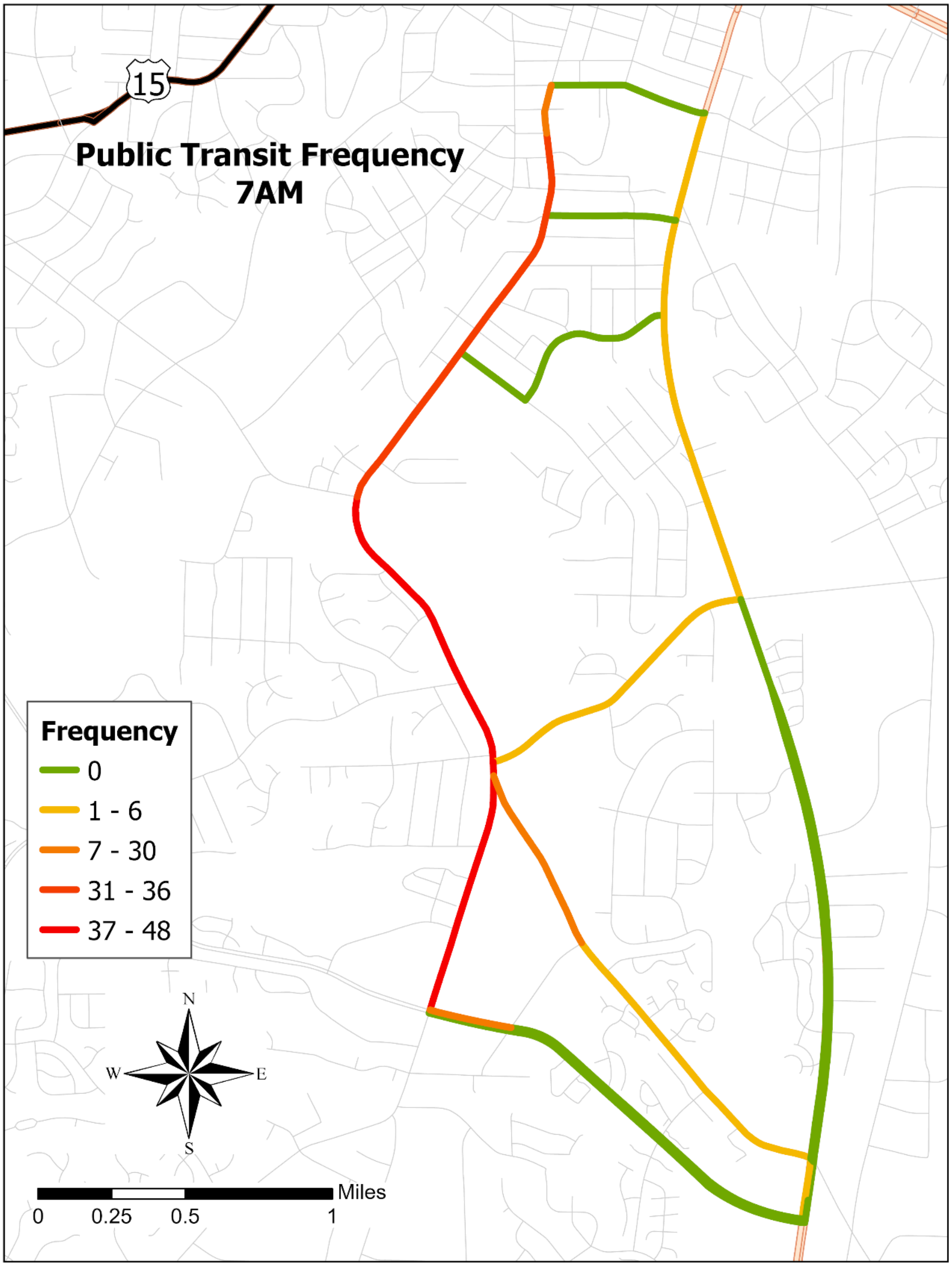

Figure 13: Public transit frequency by corridor at 7am.

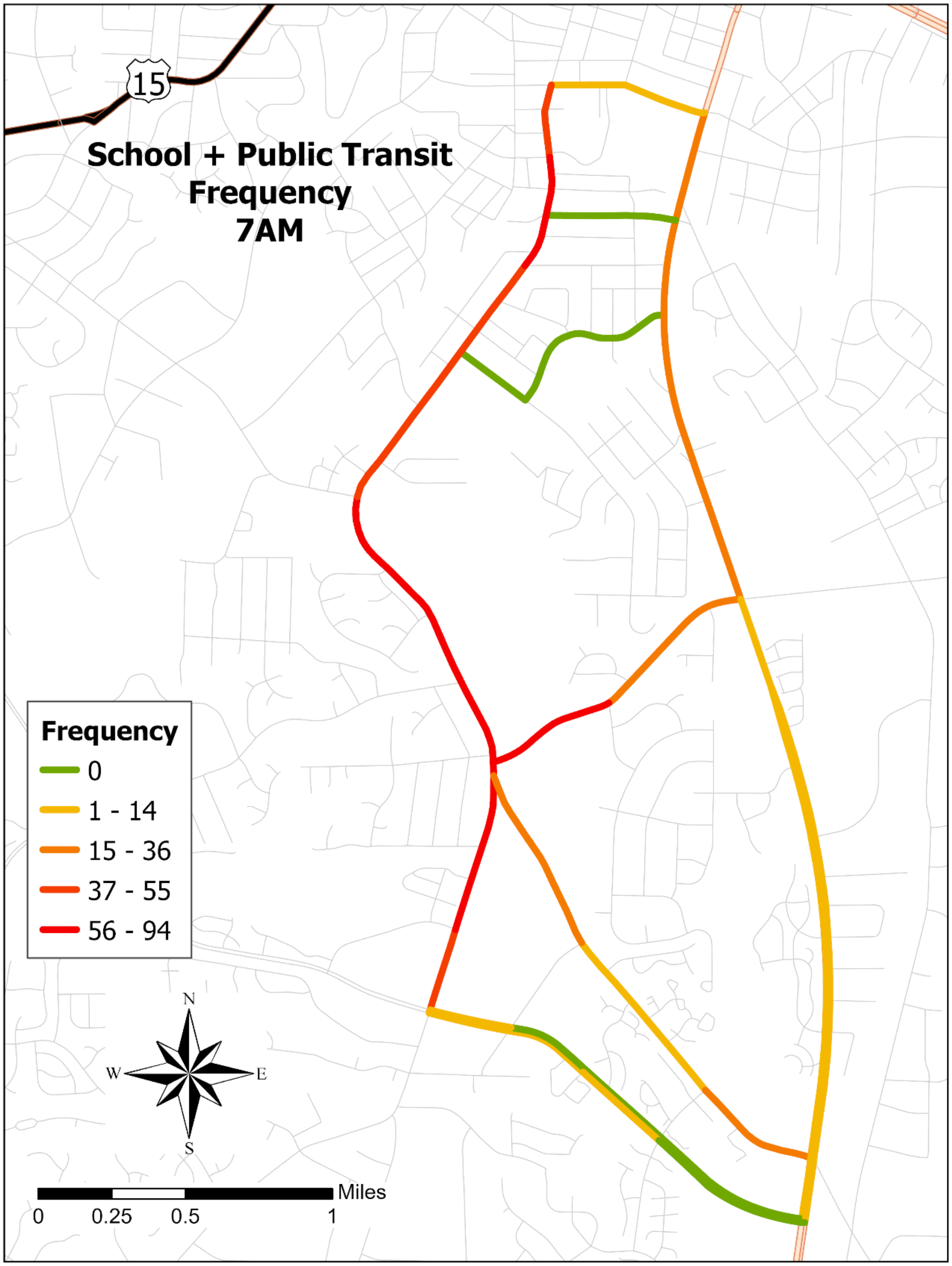

Figure 14: School + public transit frequency by corridor at 7am.

Combining the minutes of delay calculated above and the school and public transit frequency calculated in this step, the cumulative minutes of delay can be calculated using the following formula:

$$CM_n^i = MD_n^i * TF_n^i$$

Where

CM_n^i
$= Cumulative\ minutes\ of\ delay\ for\ hour\ n\ and\ segment\ i$
$MD_n^i = Minutes\ of\ Delay\ for\ hour\ n\ and\ segment\ i$
$TF_n^i = Bus\ Frequency\ for\ hour\ n\ and\ segment\ i$

See Figure 15 for a flow chart of the step-by-step process to tag the congestion data feature layer with the frequency counts of school and public transit routes.

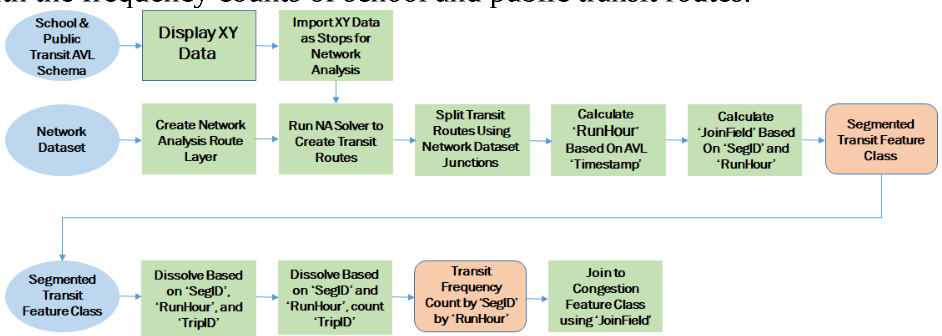

Figure 15: Workflow to calculate the school and public transit route frequencies.

3.6. *Outputs*

After calculating the minutes of delay per vehicle and the cumulative minutes of delay experienced by school and public transit vehicles, the results can be visualized by hour of the day. Figures 16 through 19 show the minutes of delay calculated during the 7am hour for the study area:

A. The minutes of delay per vehicle;
B. The cumulative school bus minutes of delay;
C. The cumulative public transit minutes of delay; and
D. The cumulative bus minutes of delay (school + public transit).

Note: In the maps below, several segments show zero minutes of delay. Depending upon the segment, this could be due to one of two factors: 1) The free-flow speed is equal to the travel speed at 7am; or 2) No school or public transit buses traveled through the corridor during the 7am hour.

To determine the actual costs of these delays, individual agencies and school districts should use their specific hourly operating costs. These costs are most noticeable in salaries for drivers or vehicle attendants, but can have ripple effects on mechanics, dispatchers, and others who may be delayed due to delayed buses. Fuel costs are likely to go up as well, particularly for internal combustion vehicles, as they spend more time idling. The greatest costs are likely to be passed on to the passengers who lose time; the USDOT (2021) recommends a value of time savings of $17.90 per hour. This value of time is often used as a potential benefit when engineers propose increasing highway capacity, believing that it will reduce congestion and save time. However, transit agencies seldom utilize these calculations. For school buses, while the value of time for students on the bus is not often monetized, long bus rides are a frequent issue with parents and guardians, as well as school boards.

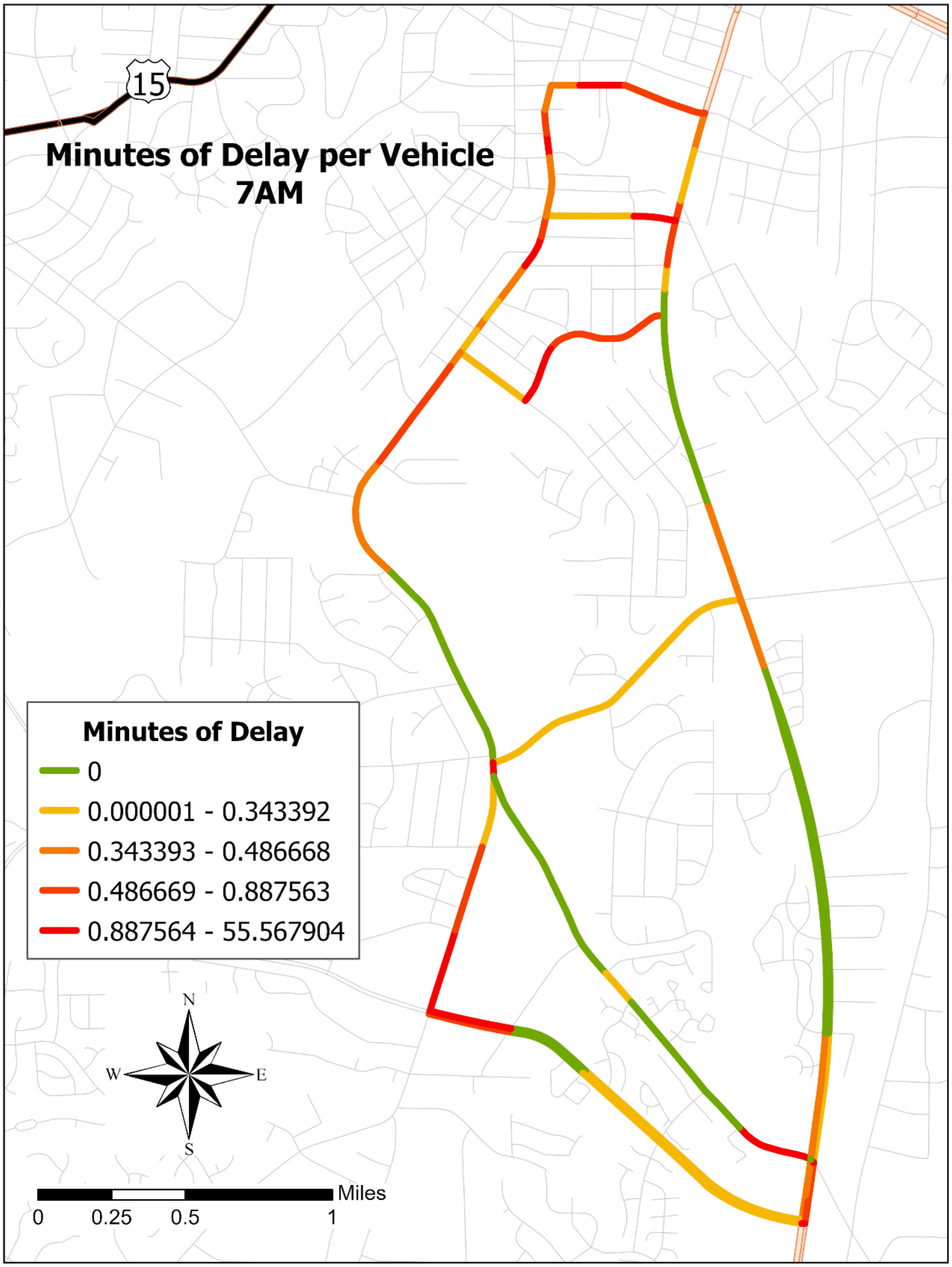

Figure 16: A. Minutes of delay per vehicle

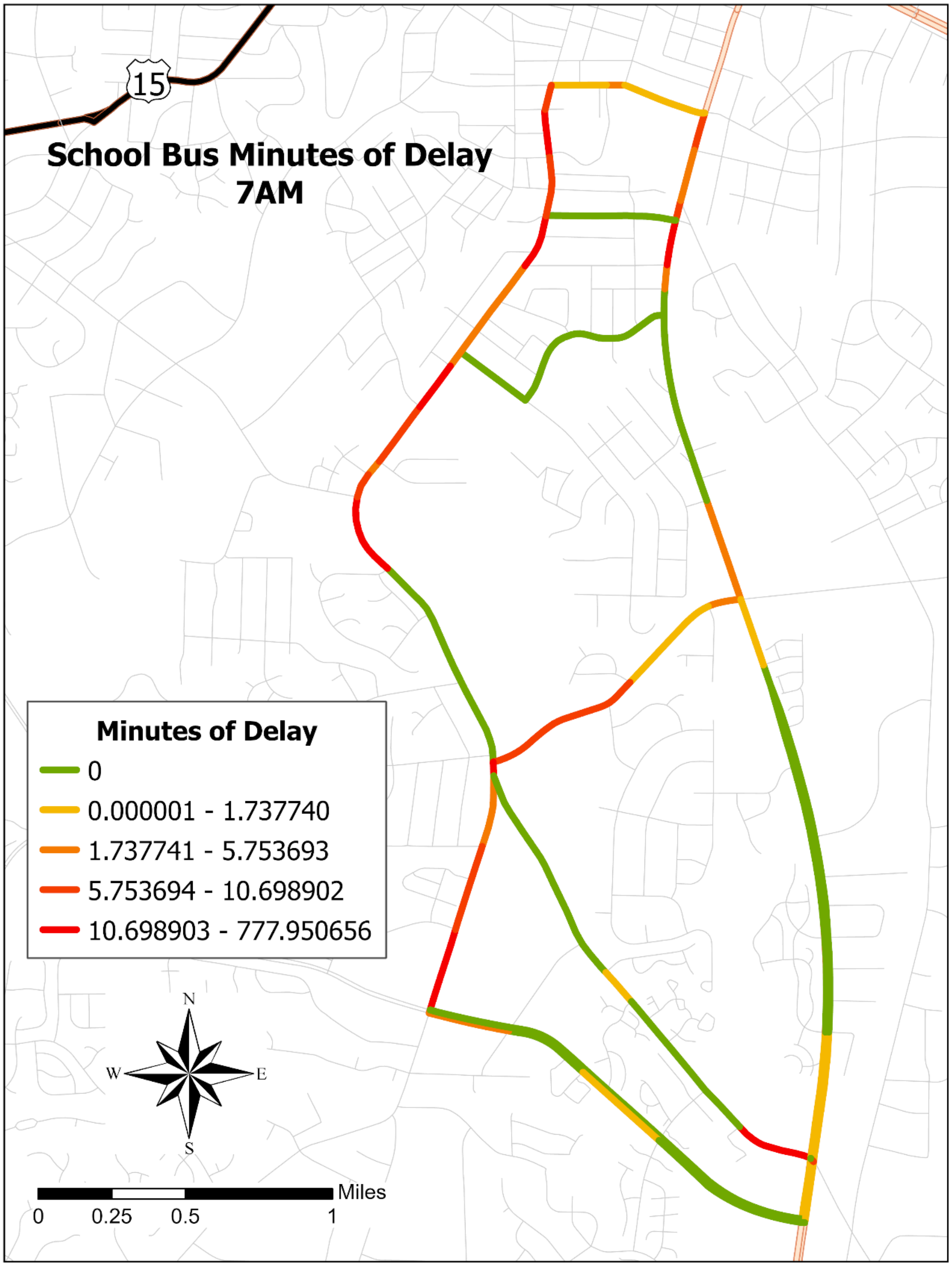

Figure 17: Cumulative school bus minutes of delay

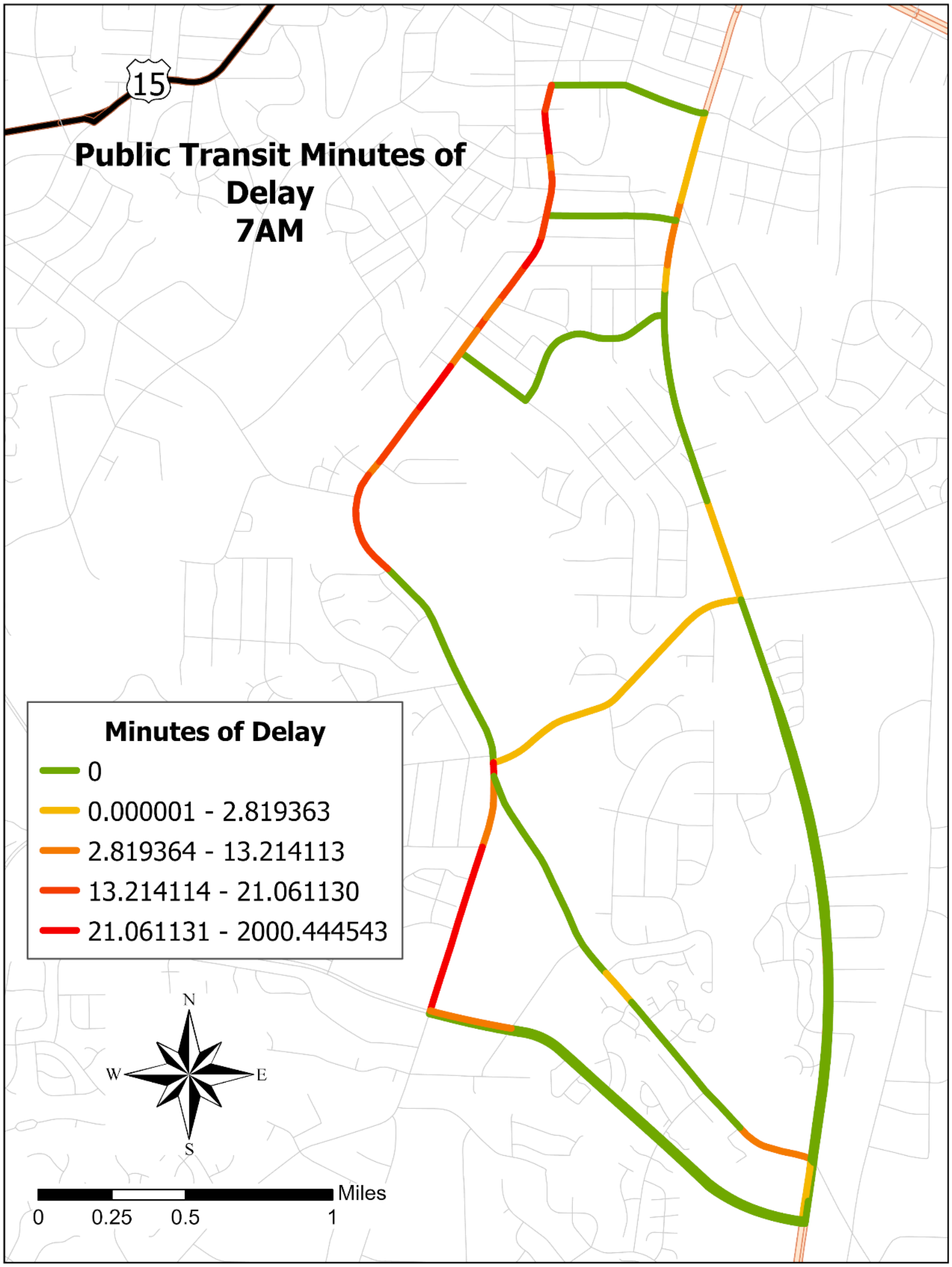

Figure 18: Cumulative public transit bus minutes of delay

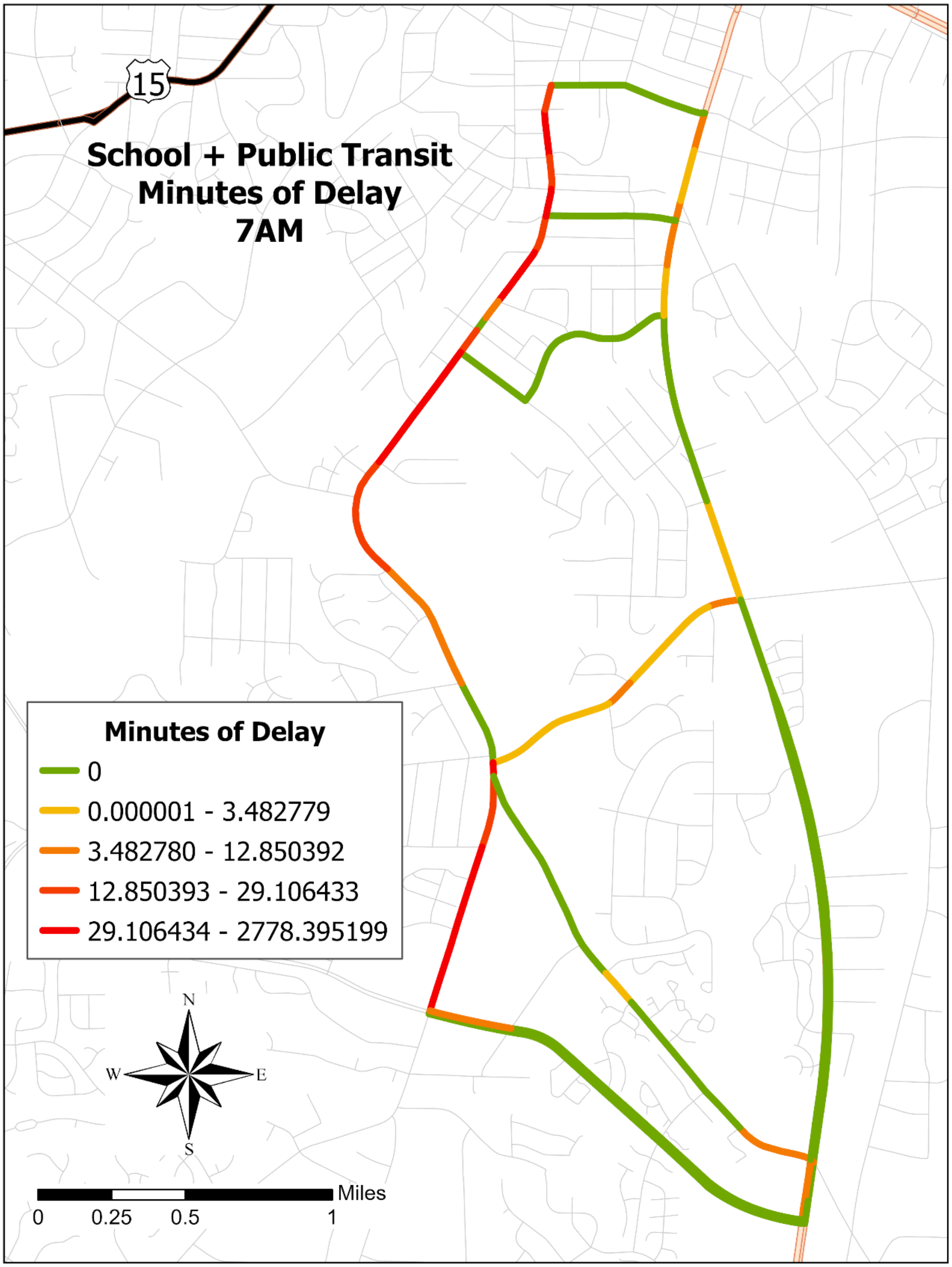

Figure 19: Cumulative bus minutes of delay (school + public transit)

4. Conclusions

The methodologies described in this report were used to build a practitioner's tool to assist transit agencies, school districts, cities, planning organizations, and other entities in understanding when and where high traffic congestion corridors exist. With this knowledge, transit professionals can begin to understand the direct and indirect costs associated with this congestion and then develop methods to minimize these costs. An output from the tool is the minutes of delay experienced and the hypothetical examples shown in Figures 16 through 19 highlight which road segments and intersections are most impacted by congestion delays. Local agencies could take various steps to mitigate the effects of congestion along these corridors or at specific intersections. For example, dedicated bus lanes, signal priority or signal preemption at these intersections might noticeably increase bus speed and improve reliability.

Future research could assess the potential for real-time congestion analysis using the Outscraper API and AVL data from school and transit buses. This technology could be used to develop a network of bus prioritization across a municipality or county and further improve reliability and public perception. Other research may include a more in-depth analysis of the cost of congestion to passengers (including students) potentially calculating more precise figures using demographic and/or income data.

Every situation may be different. But the toolbox created here can arm local practitioners with additional data that may not be otherwise available. Combining this data with local knowledge from the agencies, including the drivers, can help inform plans to make transit and school buses quicker and more effective at transporting passengers. Besides reducing costs for the agencies, this can make these modes a more reliable and preferable choice for current and potential riders.

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