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Locating and Costing Congestion for School Buses and Public Transportation

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16. Abstract - School and public transportation buses subjected to recurring congestion delays result in these modes becoming both more expensive to operate and often less-competitive as mobility options. Maintaining existing coverage and frequency requires increases in operating and capital expenses. Failing to maintain coverage and frequency encourages mode shifts which may exacerbate congestion in these corridors. This project combines three large datasets, 1) EDULOG school transportation routes, 2) GTFS public transportation routes, and 3) RITIS congestion data. Combined, these three datasets inform when and where publicly funded transportation vehicles are operating and allow the estimation of the delay experienced by each vehicle. The delay costs can then be calculated both temporally and spatially, allowing for identification of locations and times where mitigation strategies may be most appropriate. Strategies may include route diversion, lane dedication, signal prioritization, queue jumping and many others. This research generated a tool that calculates delay time and the relative costs of delay that schools and public transit buses experience due to congestion. Practitioners can use the tool to determine cost-effective solutions. Transit agencies, school districts, municipalities, and regional planners will benefit from this tool.

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1. INTRODUCTION

Roadway congestion creates delays and increased costs for all roadway users, including buses. When buses are subjected to congestion, operating and capital costs increase, travel time reliability decreases, and the overall competitiveness and attractiveness of these modes decreases. This research integrates three large datasets to create a practitioner tool that allows 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). This practitioner tool will allow 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. This methodology will allow practitioners to prioritize locations where treatments will be the most cost-effective and impactful.

Two different sites were chosen for comparison: 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. Both counties have transit agencies and school districts that utilize the appropriate software packages.

By combining these three datasets, the research team was able to determine when and where publicly-funded transportation vehicles are operating and to estimate the delay experienced by each vehicle. The delay costs were then calculated both temporally and spatially, allowing for identification of locations and times where mitigation strategies may be most appropriate.

2. BACKGROUND

The southeastern United States is experiencing rapid population growth in cities and towns that historically have little public transportation infrastructure. For instance, Florida and North Carolina ranked among the top 4 states in the number of new residents during a one-year period ending July 1, 2019 (Carolina Demography, 2021). 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). Much of this cost to commuters can be relieved via public transit. For example, it is estimated that the Los Angeles Transit System saves the city $1.2 to $4.1 billion every year (Anderson, 2014).

Along with congestion increases, parents and students have more choices about which schools to attend which can increase travel times and lead to mode shifts from school buses to automobiles. Parents who drop off children at schools instead of having the students ride school buses contribute to morning peak hour traffic, as well as congestion around schools (La Vigne, 2007).

With this growth and travel behavior changes comes increased travel times and delays on the local roadway infrastructure. Weisbrod, Vary, and Treyz found that, "congestion can actually shrink business market areas and reduce the scale economies" (2003). Therefore, it is imperative that urbanized areas implement efficient transportation planning practices so that urban areas can manage growth and, in turn, reduce vehicle miles traveled (VMT), recurring congestion, and travel times. Specifically, public and school transportation planning officials need to be equipped with tools to understand when and where their system is subject to congestion and understand how much that congestion costs.

When public transit services and school transportation are slowed down, or stopped in some cases, revenue miles start to drastically decrease while operational costs continue to rise. This effect correlates to the transportation system losing money and reducing efficiency, possibly resulting in a reduction of service. Additionally, if the more affluent portion of the community has the choice to sit in congestion on a public transit vehicle versus their personal vehicle, they will likely choose the comfort of their personal vehicle. The congestion that public transportation systems face does not encourage new ridership and therefore increases a car-centric mindset amongst the community.

School buses are also another factor to consider when looking at population growth and congestion. With the rapid increase in population, in conjunction with the expansion of schools, school choice, a continuation of suburban sprawl, and traffic congestion, public school buses are having to pick up their students upwards of 60 minutes before the bell time. According to the Institute for Transportation Research and Education's (ITRE) Transportation Information Management System (TIMS) group, North Carolina's earliest morning pick-up time for children riding the bus has fluctuated by nearly 30 minutes since 2010 (TIMS, 2017). Various studies have been conducted to show that this is an extreme detriment to the health of the next generation. As TIMS highlights in its own 2016-2017 North Carolina statewide 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."

Implications of congestion are widely seen across all avenues of urban planning, economics, and personal health. Common methods of dealing with congestion- building larger freeways and implementing congestion pricing, are not a viable solution because transit and school vehicles travel on secondary roads. Instead, 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. Once these hotspots and costs are identified, proper solutions can be implemented in order to mitigate these delays.

3. LITERATURE REVIEW

3.1 *What Causes Congestion*

Congestion is defined as high traffic volumes which alter the quality of service for transportation systems (Sweet, 2011). This study focuses on recurrent congestion, which is congestion caused by increased vehicle travel at peak times. Recurrent congestion differs from non-recurrent congestion, like construction and bad weather, because it is more consistent.

Recurrent congestion 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 of appropriate roadway pricing. According to the Institute of Transportation Studies, congestion occurs because roadways are free to use, and inadequate pricing often leads to exploitation of the resource.

In an effort to avoid congested roadways, users can either elect to switch departure times to avoid peak hours of traffic or to take different routes to the same destination (Sweet, 2011). Consequently, the impact of traffic congestion is not confined to only the major roads. The travelers' effort to avoid delays results in an associated delay on smaller surrounding roads (Anderson, 2014).

School travel is another cause of congestion. School pick up and drop off explains 10-15% of peak motor vehicle trips (McDonald 2005) as parents drop off and pick up their kids, resulting in an additional 4 trips per day (Victoria Transport Policy Institute (VTPI); Safe Routes to School; 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. 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 less children are reported as walking. Further, miles traveled, system cost and air pollution are reported as 2.5 times higher (VTPI, 2018).

School related congestion is also caused by the perception of risk related to walking and biking. Parents are less willing to allow their child to travel alone (La Vigne, 2007 for fear of kidnappings and traffic accidents. Even when students live within a walking distance to school some parents consider walking and biking to be dangerous. The perception of danger can be related to the high volume of vehicles traveling around the school or the erratic behavior of drivers who are frustrated by the delay. Regardless of the reason, risk discourages children from walking and biking and forces parents to drive their children to school instead. This exacerbates the congestion problem around schools (La Vigne, 2007).

3.2 *Strategies for Intervention*

Although researchers agree that congestion is an issue which must be addressed, the appropriate measures to do so are contested. Traditionally, expanding roadways was used to reduce congestion by increasing capacity. But this is not an effective long-term solution (Sweet, 2011 and ITS). An alternative to roadway expansion is subsidizing public transit. This is a publicly supported method to reduce congestion (Anderson, 2014; Parry & Small, 2009). The idea is to capture drivers who want to avoid delays by offering more frequent and affordable public transportation (Anderson, 2014). This would remove personal vehicles from traffic and consequently reduce congestion (Duy, Currie, Gruyter, Kim, & Young, 2018).

Some researchers are uncertain to what degree public transit reduces congestion. Particularly because mass transit makes up such a small share of total trips (Nelson, Baglino, Harrington, Safirova, & Lipman, 2007; Beaudoin, Farzin, & Lawell, 2018). Further, researchers believe there is latent demand to travel by personal vehicle (ITS; Beaudoin & Lawell, 2017). This implies that transferring personal vehicle users to public transit would only induce other drivers to take their place on the roadways (Beaudoin, & Lawell, 2017). Because of this, adding public transportation is considered effective only in the short run because new drivers would enter the roadways and increase congestion (Anderson, 2014; Parry, & Small, 2009**;** ITS). Researchers argue for a combination of mass transit and congestion pricing (Beaudoin, Farzin, & Lawell, 2018).

Adding busing is considered to reduce congestion related to school travel. Instead of public transportation, the focus is on adding school buses. This is thought to remove parent drivers by offering an attractive alternative. Besides adding busing, School Transport Management strategies offer a list of methods for intervention. The goal is to encourage parents, students, and staff to reduce automobile trips by using alternative modes (VTPI).

Numerous strategies can be used to reduce congestion for buses, both transit and school. Routing strategies can be both temporal (e.g., moving routes to less congested periods) and spatial (moving routes to less traveled roads). However, transit bus routes are designed with the passenger in mind, who tend to travel during peak times and along crowded corridors, the same as other travelers; school bus routes are dictated by school start times and while transportation is one factor school districts consider when planning start times, it is not the only one.

Other strategies can involve infrastructure changes. For example, buses can have signal priority at stoplights or special bus lanes to travel on. Along highways with adequate space, buses can be allowed to travel along the shoulder during peak times. These interventions may have additional construction and maintenance costs and could possibly increase congestion for other non-bus vehicles.

3.3 *Cost of Intervention(s)*

Understanding traffic congestion is important because it impacts the local and regional economy. Traffic congestion has increased significantly in the United States (Beaudoin et al., 2018) which prioritizes finding a solution. The total cost of congestion to the United States is estimated at $85 billion, or $763 per commuter, per year (USDOT, 2019).

To combat this cost, a substantial share of transportation expenditures is spent on mass transit (Nelson et al., 2007). Beaudoin et al. estimate this amount is over $18 billion per year. On a related note, Nelson et al. agree that subsidizing transit can improve traffic flow to a degree which is proportional to the level of subsidy for the service. Duy et al. (2018) agree that the net congestion impact of buses is positive and recommend combining public transportation and congestion pricing. This is important because congestion pricing can produce a welfare gain of $17.6 billion dollars annually (USDOT, 2009).

School Transport Management has many methods to reduce congestion, but they vary in difficulty and cost. Some of the less costly methods to implement include marketing and encouragement programs for parents and students. Further, behavioral changes, like parking away from school, changing event timing, and organizing a walking school bus would be more challenging but still relatively low cost. In the short term, traffic calming techniques can be combined with additional bike parking and parking management. These are more costly but improving bike and pedestrian facilities results in an 18% increase in walking and biking (McDonald, et al. 2014). The National Center for Education Statistics (2021) calculates the average expenditure per student transported to be nearly $1,000. This makes up 7.5% of total U.S. public school expenses and 12% in rural areas (VTPI). In the long-term, effective School Transport Management includes redesigning communities to be meant for families. This is accomplished by locating schools closer to neighborhoods to reduce travel distance. Reducing travel distances requires altering minimum acreage requirements, building codes, and design standards to allow a school in a residential area (Beaumont and Pianca 2000).

In conclusion, congestion is increasing and must be addressed. Adding frequent and affordable public transportation could be an effective method to reduce congestion on roadways, but this method should be considered along with congestion pricing. More research should be done to determine the impact, if any, of bus services alone in reducing congestion. Further, school travel also results in congestion. Adding school bus services is one method to reduce congestion. Another method is to use School Transport Management. While there are many possible interventions to reduce congestion, each option varies in cost and difficulty.

4. METHODOLOGY

The research team consisted of a group at North Carolina State University (NCSU) and a group at the University of Florida (UF). Both groups worked closely together throughout the project, but because the NCSU researchers were already familiar with the data and spatial analysis methods, the team opted for the NCSU group to take the lead in developing the

procedures for data cleaning and analysis based on the North Carolina site. Meanwhile, the UF group would be primarily responsible for applying the developed methodology to the Florida site. In this section, both study sites are described, but the methodology and results primarily focus on North Carolina.

4.1 Site Selection

The goal was to choose 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 uses 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.

Most medium to large public transportation providers already have GTFS feeds. All school districts in North Carolina and nine school districts in Florida utilize EDULOG. In addition, the school and transit agencies had to be willing to share basic financial information (e.g., operating and capital expenses, operating miles and hours, and vehicle replacement standards) to determine cost to the agency for each unit of delay.

Durham County, North Carolina

Durham County, North Carolina is one of the vertices of the Research Triangle, along with Raleigh and Chapel Hill. It is undergoing rapid growth, its population increasing from 233,000 to 301,000 from 2000 to the present day (Durham Open Data, 2021). The county is geographically dominated by the City of Durham; its only other incorporated areas are small extensions of Raleigh, Chapel Hill, and Morrisville from neighboring counties, with the rest of the area being unincorporated county land. Downtown Durham provides a relatively dense center, while the northern portions of the county are predominantly rural.

Durham Public Schools

Durham Public Schools (DPS) serves more than 32,000 students in both the county and the city (DPS, 2021). Pre-pandemic data from November, 2019 shows that between 18,000 to 25,000 students take school buses daily (TIMS, 2021). Utilizing a multi-tier routing system, DPS has 214 buses making 1,041 trips to/from school totalling 23,000 miles daily. This adds up to over 4 million bus miles per year and 250,000 driver payroll hours.

GoTriangle and GoDurham

GoDurham, formerly the Durham Area Transit Authority, operates 24 bus routes across Durham, many of them running out of the downtown Durham Station. This station also connects to the GoTriangle transit system to provide out-of-county routes, including express buses to downtown Raleigh and Chapel Hill. In 2019, GoDurham served 6,760,036 unlinked passenger trips and supplied 4,287,156 revenue miles (FTA, 2021).

Pinellas County, Florida

Pinellas County is one of the smallest counties in land area in Florida, located on the Gulf Coast on a peninsula just west of the city of Tampa. A population boom keeps Pinellas County increasing, with the population growing from 921,482 to 974,996 between 2000 and 2019 (US Census, 2019). With nearly 3,347.5 people per square mile, Pinellas County has the highest population density of any county in Florida, exceeding the next most dense county in Florida by nearly twice as much density. Multiple municipalities exist adjacent to each other across the entire county, with St. Petersburg being the largest of these with a population of 265,351 (US Census, 2019). Together they weave a continuous urban grid from south to north that makes Pinellas County a characteristically dense, urban area. The county's economy is influenced by its proximity to the city of Tampa and its location in the greater Tampa Bay metropolitan area.

Pinellas County Schools

The Pinellas County School District serves an enrolled student population of 99,798 as reported for the FY 19-20 (Florida Department of Education, 2021). About 27,342 (nearly 27%) of those students were transported on school buses to their corresponding schools. The school

district counts 603 school buses, 443 of which run one of 403 routes every day. An estimated 6,000,000 miles are driven by 458 bus drivers annually according to the most recent report.

Pinellas Suncoast Transit Agency

Pinellas County's own transit agency, Pinellas Suncoast Transit Agency (PSTA) currently operates 210 vehicles on 40 bus routes, 2 of which are express transit routes between Pinellas County and Hillsborough County, where Tampa is located (PSTA, 2021). The agency reports 13,615,634 million unlinked passenger trips in 2019 and supplied 13,380,238 revenue miles (FTA, 2021).

4.2 Datasets

Three datasets were used to collect vital information on the study area:

1. Regional Integrated Transportation Information System (RITIS) –archival traffic flow information on the study area 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 and in the case of Florida and North Carolina funded by FDOT and NCDOT respectively. RITIS information is not available on every road segment and furthermore is only available when there are sufficient observations. School bus routes, in particular, may often travel along non-RITIS segments, particularly as they traverse residential neighborhoods.
2. General Transit Feed Specification (GTFS) –a public data format for routing public transit on Google Maps. GTFS has standardized how transit agencies present stops, routes, calendars, and fare structures across most of the United States.
3. Education Logistics, Inc (Edulog) – a school bus routing software package used by school transportation departments across the country. Members of the research team at ITRE support the implementation of Edulog across North Carolina and work closely with software operators in over 100 districts.

4.3 Dataset Merging

Note: This section is intended to provide a relatively thorough, but general overview of the steps taken to modify each dataset for eventual merging and calculation of travel delay; Appendix A provides a more detailed description of the process.

The three datasets consist of spatio-temporal data that must be merged together. The temporal data was converted into tabular hourly profiles for each spatial segment. Merging the spatial data required significant geo-processing since they were based on different spatial datasets and had different network segmentation.
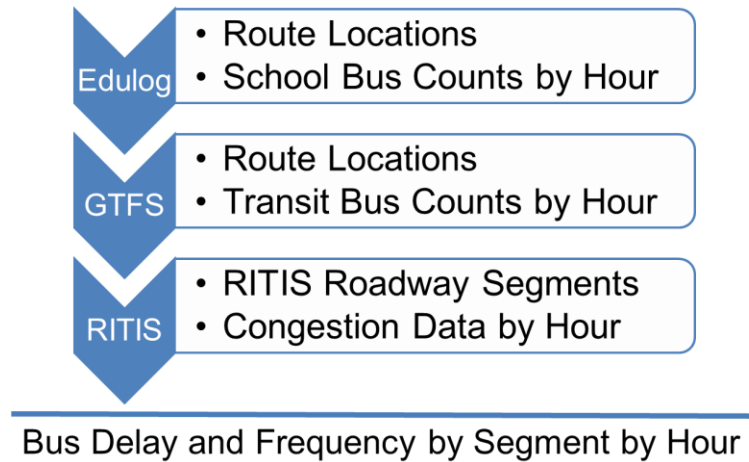
RITIS

Raw RITIS probe data includes segment name, timestamp, speed, travel time and free flow speed. This data was downloaded for October 15, 2019 to 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. This value should be 0 or greater, as vehicles only experience delay when average speed is slower than free flow.

Edulog

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 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.

To align the school bus routes temporally to the RITIS data, each route was assigned an hour based on the route start time. It was assumed that routes generally have maximum durations of 75 minutes. To assign the route to the hourly profile most closely associated with the congestion the route experiences, routes that begin between 00:00 and 00:14 of the hour were assigned to the hour, whereas routes that begin between 00:15 and 00:59 of the hour were assigned to the next hour.

Spatial bus route exports are not available from Edulog, but the software allows for tabular exports of stop coordinates and stop order as well as turn-by-turn route directions giving the intersections where turns occur. The turn-by-turn directions include intersections, but do not include municipalities. Combining the XY coordinates of known stop locations and geocoding intermediate intersections allowed the research team to "connect the dots" by a planned stop sequence using ArcPro Network Analyst. To determine the accuracy of these routes, a sample of routes were selected and compared against routes that were manually created using the turn-by-turn directions.

Some of the rules used to generate the bus routes in Edulog, such as allowing right-hand side stops only, could not be replicated within ArcPro's Network Analyst environment resulting in some discrepancies between the two methods. However, the discrepancies were minor and the amount of effort required to manually create all of the routes resulted in the research team agreeing to use the automated process. This allowed the research team to focus their efforts on the process of combining the three datasets together to create the final result.

Routes for Durham County, NC, were created using turn-by-turn directions obtained from the Edulog software. In automating the process of creating the routes between any two stop locations, a bus has many available paths of travel. However, Edulog provides a single path for the bus to follow. In order to more accurately match the automated routes to the Edulog routes, the turn-by-turn directions for each route were analyzed and XY Coordinates were generated for each intersection between known stop locations. The XY Coordinates for the intersections were then included with the XY Coordinates for the known stop locations, resulting in a more accurate representation of the bus routes that matched up well with the actual assigned routes.

However, the turn-by-turn approach could not be applied to the Pinellas County, Fl, dataset because the data does not include the municipality name. Durham, NC, has few municipalities, whereas Pinellas County, FL, has over 25 municipalities (Pinellas County, 2021). Without municipality names, geocoding intersections with common names such as 1st and Main caused false assignment to the wrong municipality which created unreliable routes. The

manual effort required to clean up the false assignments meant that this method was not going to be easily replicable. Therefore, it was decided to use the network analyst approach using only known stop coordinates for the Pinellas data.

Once these data were cleaned, they were geo-located through ESRI's geoprocessing tools. For the intersections that corresponded to actual bus stops, the calculated coordinates were overwritten with the known X- & Y-coordinates. This process was repeated for several cities: Durham, Bahama, Rougemont, Raleigh, Chapel Hill, Hillsborough, and Morrisville. Although the majority of intersections fell within Durham, Bahama, and Rougemont, some bus stops are actually located in neighboring counties so it was necessary to add the additional cities to ensure these stops were not only located but located accurately.

After geo-locating the bus stops, the routes were created through the Network Analyst tools within ESRI's ArcPro software. The street reference data used was obtained from the North Carolina Department of Transportation GIS division and is named NCRouteArcs. A network dataset was created and built. The routes were created using the Run ID for the route name and the Run Direction Position for the sequence within each Run ID. After running the Network Analyst Route solver, 1,040 routes were created.

GTFS

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.

Both GoDurham's and GoTriangle's GTFS data were collected from transitfeeds.com. The GTFS data used for GoDurham was published on October 25th, 2019 and for GoTriangle the GTFS data was published on October 21st, 2019. Using these two datasets, researchers were able to find a common date in which their system calendars aligned: Wednesday November 6th, 2019. This date is important as Wednesday represents a "normal operating day" that can be combined with the RITIS data.

The next step in processing the GTFS data is running it through an R Studio script that extracts the frequencies of each route. A script written by Santiago Toso (2021), was used as a basis to obtain the frequencies for this project.

One of the larger modifications made to Toso's R Studio script was rounding the stop times to capture the hour that has the majority of service based on the start time of the trip. After looking at the data, many of the routes had run times greater than 60 minutes. As with

the school bus data, if the start time of the route was between 00:00 and 00:14, the trip was assigned to that hour and otherwise was assigned to the next hour.

Before exploring the frequency data with the spatial data, the shapes.txt file in the GTFS dataset needed to be modified as there are often numerous shapes tied to one route. This is due to many routes having different patterns throughout the calendar year. This modification process involves importing the following GTFS files into MS Access: shapes.txt, calendars.txt, and trips.txt. Researchers used a query to find the desired service_ids and they were joined to trips.txt in a separate query. Then a query found the shape_ids active during the service_ids previously found. The final query consists of joining these active shape_ids back to the shape.txt file to only pull the active shape_ids for the study period. A table was exported with the reduced shape.txt data which replaced the original shapes.txt in the GTFS dataset. Once a frequency output was generated for the transit system and the shapes were limited to the ones for the study period, both the frequencies and the shapes were imported into GIS where the frequency export was joined to the GTFS route files using the route_id field.

Multiple attempts were made to use the Snap tool in GIS to have the GTFS routes align with the school bus routes. Due to the size of the datasets, the Snap tool could take upwards of several hours to complete. Additionally, the results were not satisfactory. Many of the GTFS nodes would miss various school bus route alignments, and therefore the future spatial joins to RITIS would not be able to calculate properly. Even through a considerable amount of manual effort to realign the Snap tool outputs, the spatial join to the RITIS data yielded inaccurate results.

Therefore, a final output for the GTFS route data was derived by using the Generate Shapes from GTFS tool and Network Analyst. The Generate Shapes from GTFS tool allows a user to create a GTFS shape based on a network dataset. This was important as it allowed researchers to obtain perfect alignment with the school by routes by using the same network dataset. The Generate Shapes from GTFS tool was used for both GoDurham and GoTriangle. Running the Generate Shapes from GTFS tool creates multiple outputs: 1. A polyline feature class estimating the routes; 2. A point feature class representing the stops; 3. A trips.txt file matching the base trips.txt file but including the shape_id. The stops created from this tool were connected using the same network dataset and process that was used to create the school bus routes. This ensured complete alignment of the transit routes with the school bus routes.

Figures 1 through 3 showcase the three datasets for Durham County, while Figure 4 overlays the three datasets atop one another; it should be noted that not all RITIS segments had accessible data for the time period in question. As can be seen, the majority of public transit routes travel along RITIS segments. This is less true for school bus routes, which, by necessity, pass through residential neighborhoods, that are less likely to be monitored by the

RITIS network. These local streets might be expected to have less chronic congestion, although the system may miss congestion near the schools themselves.
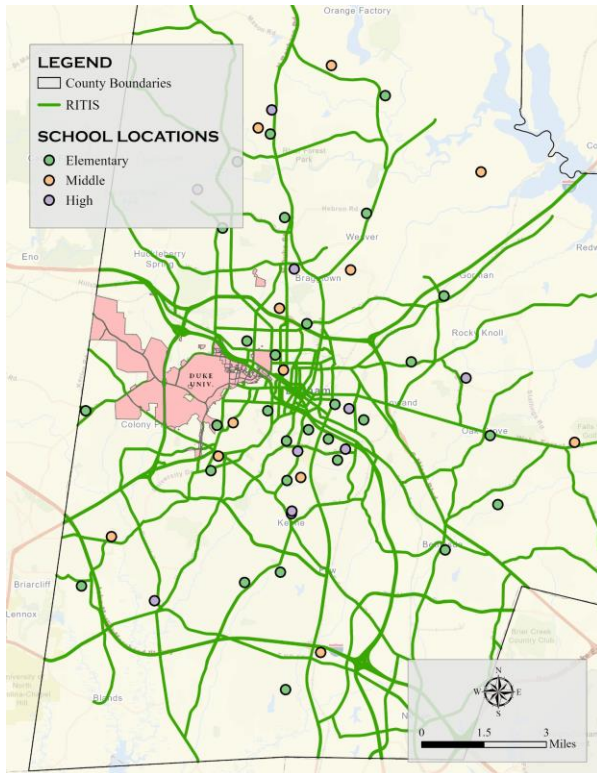
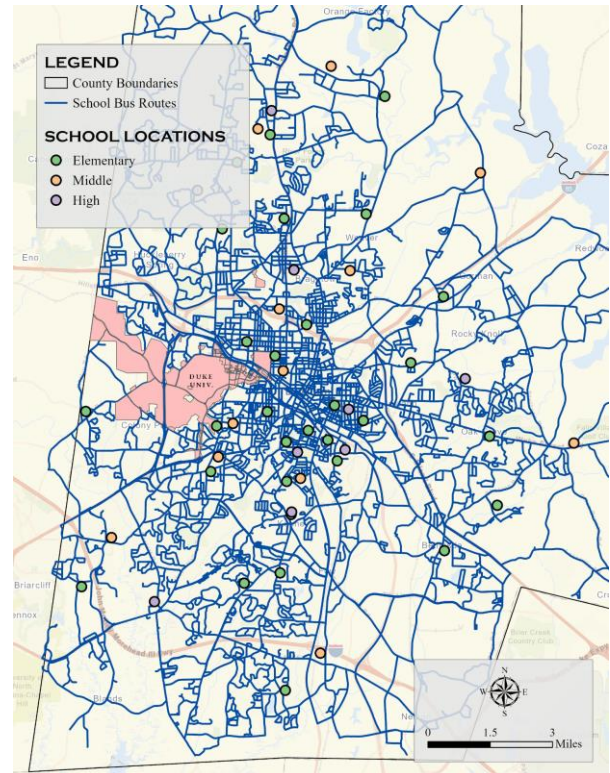

FIGURE 2: RITIS SEGMENTS IN DURHAM COUNTY

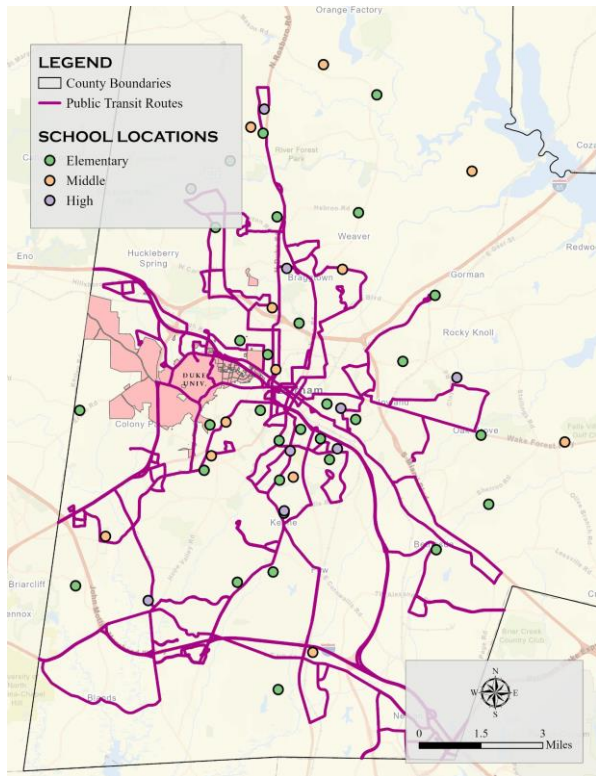FIGURE 3: SCHOOL BUS ROUTES IN DURHAM COUNTY
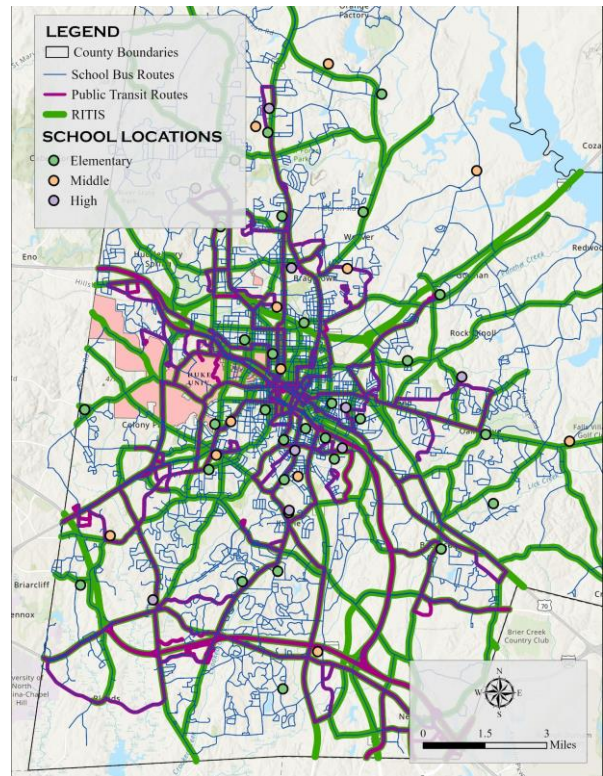
FIGURE 4: TRANSIT ROUTES IN DURHAM COUNTY

FIGURE 5: RITIS, SCHOOL BUS ROUTES, AND TRANSIT ROUTES IN DURHAM COUNTY

5. RESULTS

Using the above methodology, RITIS segments containing travel speed (and thereby travel delay when compared to free flow conditions) were aligned with school bus routes and transit routes. This allowed the research team to determine the travel delay experienced by each bus on each route segment at each hour of the day, including segment-hours with multiples of the same or different buses. These data for both study areas are presented in Table 1. The number of road miles refers to the physical miles, mapped out spatially. Route miles are much higher because a single bus may repeat the same route many times throughout the day and different routes often travel along the same road segments.

Table 1 summarizes the statistics derived from the analysis. Figures 5 – 8 show the minutes of delay by hour of the day for school buses and transit buses within Durham County (Figures 5 and 6) and Pinellas County (Figures 7 and 8). For both study areas there a significant number of bus route segments that are not coincident with RITIS segments and a large percentage of RITIS segments did not contain any congestion data. For these reasons, these numbers represent a minimum amount of delay during the days sampled.

Durham, NC				Pinellas, FL			
	RITIS	Edulog	GTFS		RITIS	Edulog	GTFS
Road Miles	372	1,130	464	Road Miles	957	2,131	967
-Overlap with RITIS		178	220	-Overlap with RITIS		793	785
Route Miles		27,661	16,336	Route Miles		38,475	35,113
-Overlap with RITIS		5,093	8,418	-Overlap with RITIS		20,046	28,730
Minutes of Daily Vehicle Delay		3,392 (57 hours)	4,524 (75 hours)	Minutes of Daily Vehicle Delay		10,056 (167 hours)	7,205 (120 hours)

TABLE 1: THE NETWORK RESULTS FOR DURHAM COUNTY (LEFT) AND PINELLAS COUNTY (RIGHT).
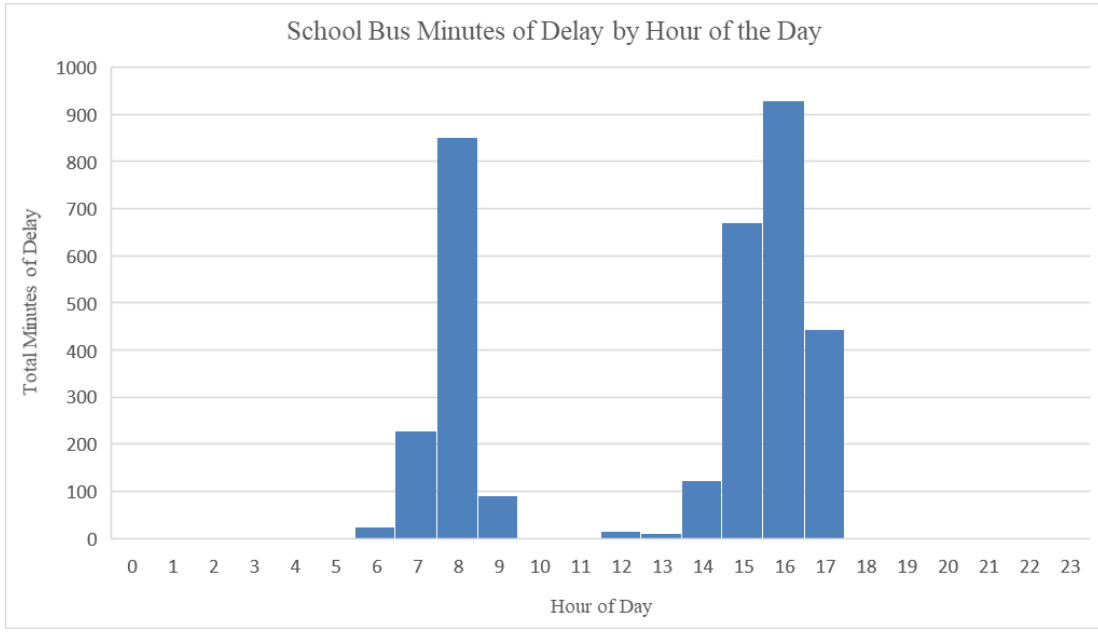
FIGURE 6: DURHAM SCHOOL BUS MINUTES OF DELAY BY HOUR OF DAY
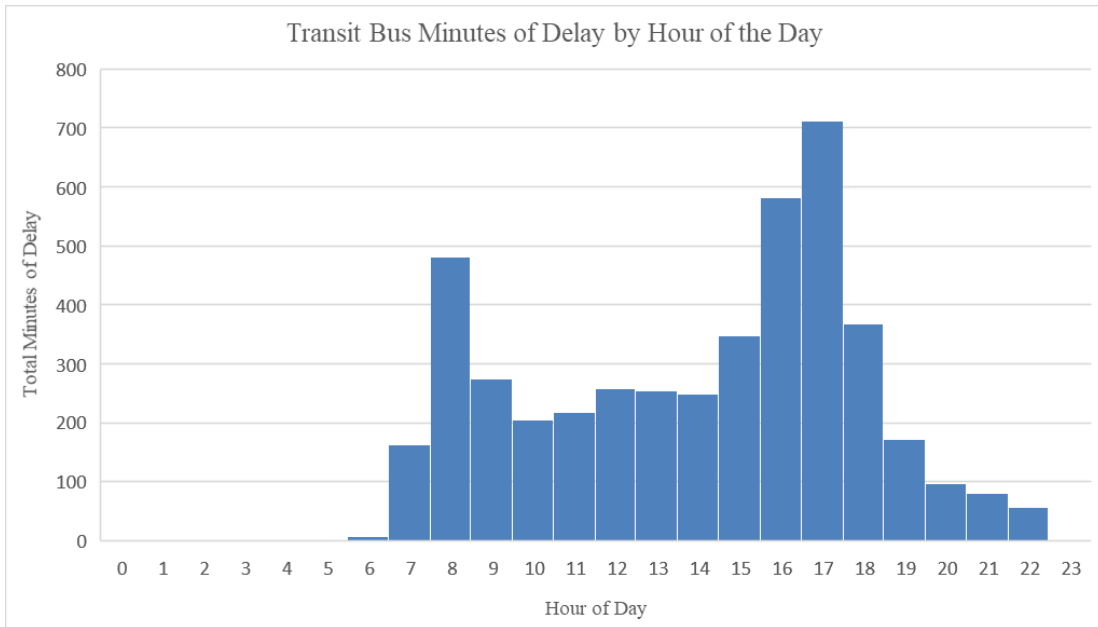
FIGURE 7: DURHAM TRANSIT BUS MINUTES OF DELAY BY HOUR OF DAY
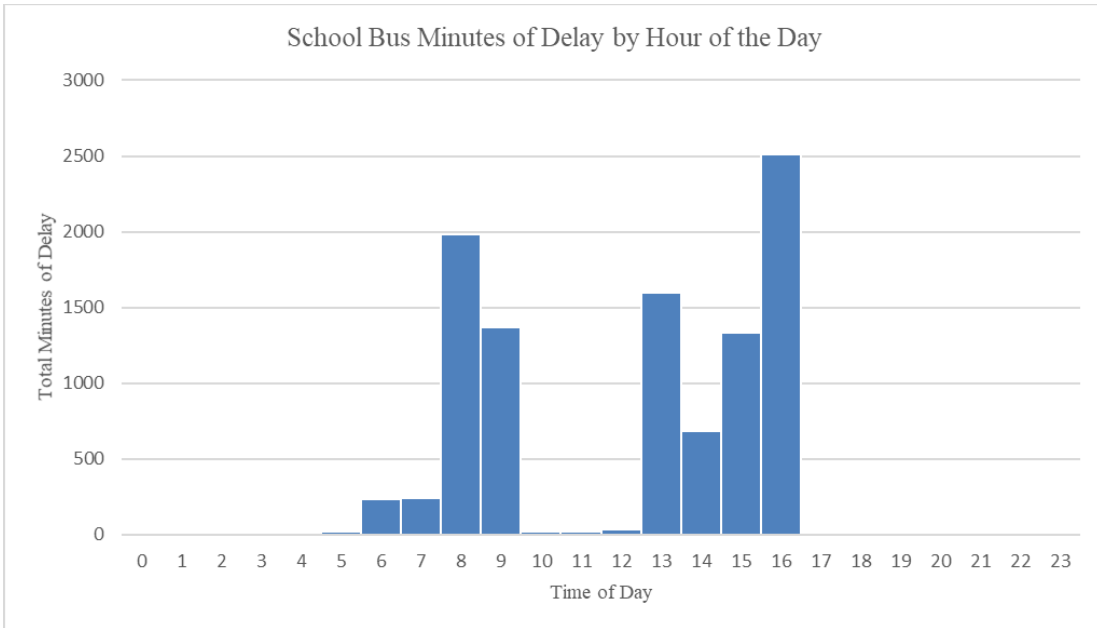
FIGURE 8: PINELLAS SCHOOL BUS MINUTES OF DELAY BY HOUR OF DAY
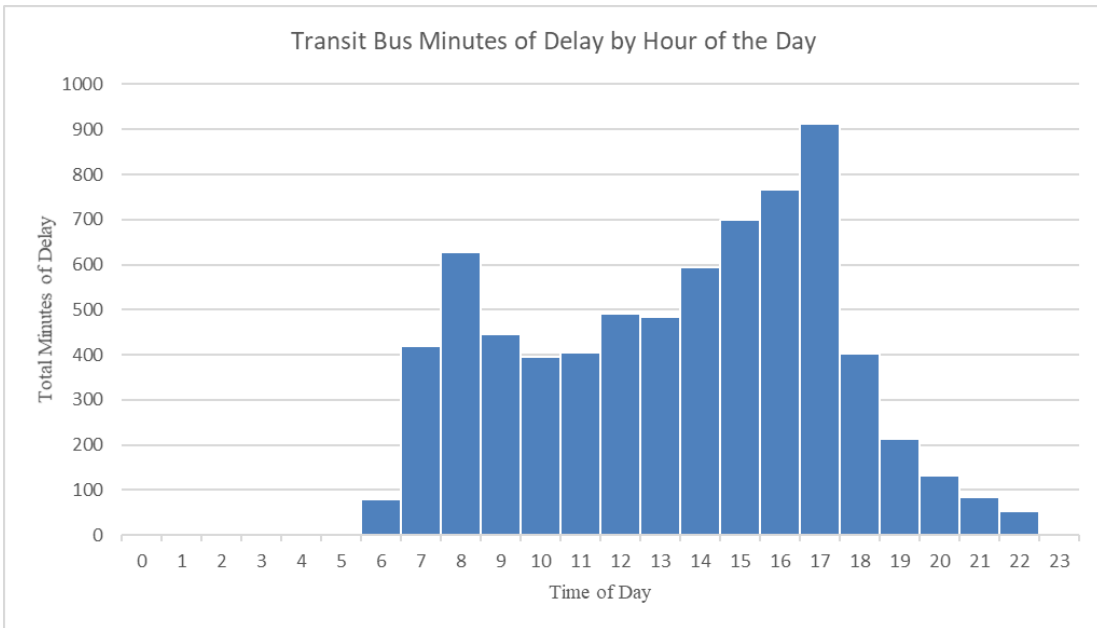
FIGURE 9: PINELLAS TRANSIT BUS MINUTES OF DELAY BY HOUR OF DAY

An on-line mapping tool (Figure 9) was also developed to allow users to change time and location to better understand where and when congestion impacts school and transit buses. The map can be accessed via www.transitportal.org/cost_of_congestion.html. More about this tool can be found in the technology transfer report.
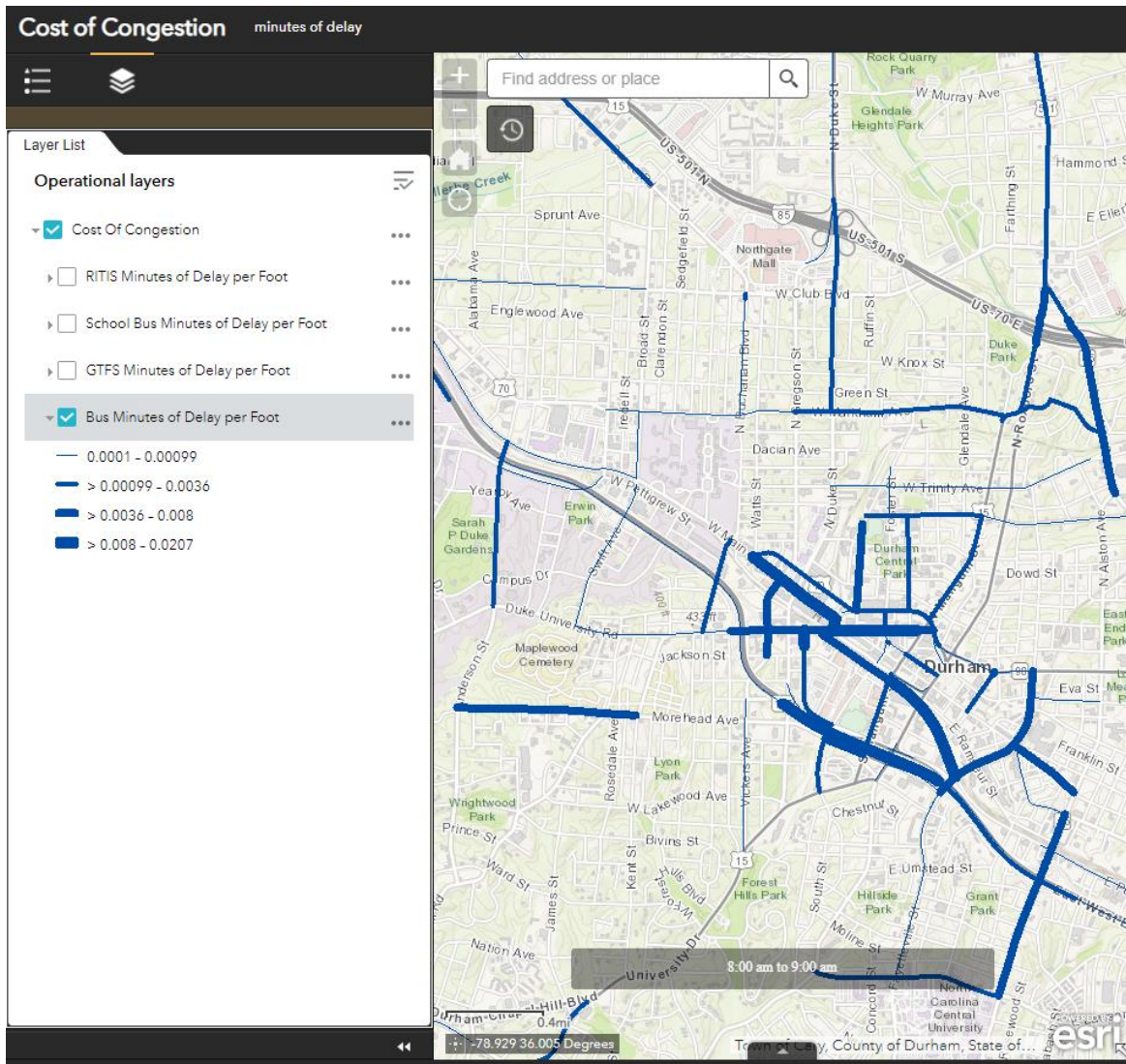
FIGURE 101: COST OF CONGESTION ON-LINE MAPPING TOOL

6. ANALYSIS

6.1 Transit

According to these calculations, transit buses in Durham experience 75 hours of delay on RITIS segments on a typical Tuesday/Wednesday/Thursday day. Assuming that on average Mondays and Fridays are not likely to be less congested than midweek days and multiplying by 250 non-holiday weekdays per year, this would total to transit buses experiencing at least 18,750 hours of delay per year, or 781 days. Using GoDurham's estimate of $95.89 per hour cost for capital and operational expenses, this would mean an overall cost of $7,200 per day and $1.8 million per year.

Applying the operating cost of $95.89 to Pinellas County, the recurring daily delay of 120 hours results in a daily cost of $11,500 and a yearly cost of $2.875 million.

This figure does not include the cost in time lost for the passengers, since the research team did not have accurate rider count numbers per segment. However, using the US Department of Transportation's recommended hourly value of time savings of $17.90 (USDOT, 2021) and assuming that 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.

6.2 School Buses

The 1,041 vehicle trips undertaken each day by Durham school buses experience 113 hours of delay. Expanding this to the 185 school days in a year, this results in 20,900 hours, or 871 days. The 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, a figure that was verified as reasonable by school transportation staff, results in a daily cost of congestion of $8,475 and $1.5 million per year. Applying the same cost to Pinellas County school buses results in a minimum cost of $12,525 per day over $2.3 million per year.

7. DISCUSSION

The methodology developed for this research was able to produce temporal and spatial results showing where and when school and transit buses are impacted by recurring congestion and to convert the congestion into daily and annual capital and operating costs. By understanding exactly where and when congestion creates delay for bus modes and quantifying

the extent and costs of these delays, planners and policymakers can pursue mitigation strategies. Practitioners can use this research to prioritize locations where mobility solutions should be deployed to have the greatest impact on decreasing transit and school bus service provider costs and increasing levels of service. These strategies include re-alignment of routes or school bus entrances, informing land use planning policies, establishing bus lanes, implementing queue jumping, or developing other planning, operating or technological solutions. Transportation providers may also use the research to support changes in operational and capital budget requests.

Considerable effort has been devoted to identifying the most appropriate techniques to combine the three key datasets while also balancing the need for the methods to be replicable at other time periods and in other jurisdictions.

There are some limitations to address. First, the school routes are based on planned service, may not align with how the service was actually delivered, and do not include summer routes. Second, generating the school bus routes was time-consuming and their accuracy differed between the study sites due to data limitations. Third, although some agencies will have access to more granular data, the RITIS congestion data available to the researchers is only available for major roadway segments and even then is sometimes missing congestion data on some segment-hours, resulting in underestimations of the impact of congestion. Fourth, the transit network data has limitations such as not including ADA paratransit or other demand response modes, not accounting for schedule padding due to existing congestion, and is unable to account for the impact of congestion of fixed guideway services. Fifth, existing congestion mitigation treatments such as bus on shoulder interventions are unaccounted for, although these strategies are rare at these sites. Finally, the methodology does not address the possibility that the buses themselves may cause some of the congestion.

8. UNADDRESSED ISSUES / FUTURE RESEARCH

This project was intended as a proof of concept that it is possible to calculate the costs of congestion on school districts and transit agencies using existing data sets. With that goal met, future research should be conducted to further refine the process, make it more accessible to even small agencies, and explore issues that were beyond the scope of this project. These questions include:

1. How much delay is on segments that do not match with RITIS data?
2. How is congestion already incorporated into routing and scheduling, such as using alternative routes and schedule padding?
3. How many riders experience the delay and what is their value of time?

4. How do we account for existing treatments to help the buses avoid congestion (e.g. bus on shoulder or dedicated bus lanes)?
5. How often do actual routes differ from scheduled routes (e.g., afternoon school routes)?
6. How can we include other times (e.g., summer school routes and weekend transit congestion)?
7. How do we incorporate demand response transportation?

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Appendix A: Combining Travel Speed, School Bus, and Transit Bus Datasets

This procedure is based on using travel speed/congestion data from Regional Integrated Transportation System (RITIS), school bus route and timing from Edulog Inc. software, and transit bus frequency and route data from General Transit Feed Specification (GTFS). All three are some of the most used systems in the industry; although different datasets or different versions of these may necessitate changes to the following instructions, the overall steps should be similar.

1. Network dataset
   a. A network dataset is required to create the School Bus and Transit routes. Note that the <u>Split Line at Point</u> tool, used in a later step, has an issue where the line can sometimes be split at random locations instead of or in addition to at the point. Based on research, a workaround is to run the <u>Integrate</u> tool and it is recommended to do this to the road reference layer before creating the network dataset.
2. School Bus Routes: The following steps are based on data downloaded from Edulog. If a different software is used, some of the fields and/or processes might be a little different.
   a. Create intersection field.
   b. Populate Intersection field based on data from Edulog. This was done in three steps.
      i. The initial intersection was calculated based on two fields in the Edulog dataset:
         1. Run Direction Action
            a. A: Arrive
            b. D: Depart
            c. S: Straight -- removed
            d. R: Right turn
            e. L: Left turn
            f. U: U-turn
            g. Blank
         2. Run Direction Street Or Stop Desc
            a. Contains a street name or intersection depending on the value in the Run Direction Action field
      ii. The initial intersection was calculated using the following if/then/else statement
            =IF(U2="S","",IF(ISBLANK(U2),V2,IF(ISBLANK(U1),V1,CONCATENATE(V1," & ",V2))))
      iii. In some cases, the above if/then/else statement calculated the same intersection in two successive stops. When geocoding these intersections,

the geocoding tool would randomly pick one or the other resulting in an odd order and sometimes incorrect route. This was solved by removing the duplicate intersections using the following if/then/else statement.

=IF(U2="S","",IF(ISBLANK(U2),V2,IF(ISBLANK(U1),V1,IF(V2=V1,"",CONCATENATE(V1," & ",V2)))))

    iv. The final iteration cleans up the intersections by removing text within '()' as the geocoder had difficulty locating intersections that contain this text. The following if/then/else statement removes text within and including parentheses.

=IF(ISERROR(SEARCH("(",X2)>0),X2,LEFT(X2,SEARCH("(",X2)-1))

    v. The final result is going to show congestion by hour of the day. The Edulog dataset provides a run start time. An assumption was made that a typical run would last about 75 minutes. Therefore, a run that starts between 00:00 and 00:14 would be assigned the current hour and any run that starts after 00:15 would be assigned the next hour.

        1. Create a new field named Run_Hour
        2. Calculate the hour based on the BEGIN RUN TIME field

c. Geocode the final intersection field using ESRI's geocoding service or similar.

d. Calculate the XY Coordinates from the intersections that were geocoded in the previous step.

e. The Edulog dataset provides XY Coordinates for known stops. In this step, overwrite the XY Coordinates from the previous step with the known XY Coordinates.

f. Create the School Bus Routes using Network Analyst
    i. Set the stops to be the Bus Stop layer was created in Step 2.b
    ii. Use the Network Dataset that was created in Step 1

g. Prep the dataset for merging
    i. Run the Split Line At Point to using the Network Dataset junctions
        1. Input Features: School Bus Route layer
        2. Point Features: Network Dataset Junctions
        3. Output Feature Class: An appropriately named feature class that describes the tool and input parameters to easily identify the process.
        4. Search Radius: 10 ft

3. Transit Routes (GTFS)

a. Open the Generate Shapes from GTFS tool to obtain new GTFS stops that align with the network dataset
    i. Input file is the PSTA GTFS dataset
    ii. Give a unique name for the lines and the stops – save them in a safe place
    iii. Also save the trips.txt file in a safe place – this will be used later
    iv. Transit Mode:

1. I just used "Bus (GTFS 3)"
   v. Network Options:
      1. Select the network dataset that was used for the school bus routes
      2. Select the transit mode. If none was created, go back into the network dataset in the GDB and create one.
      3. Use defaults for the remaining fields
   vi. Run
   vii. Outputs from the Generate Shapes from GTFS is a lines and a stops file. Check your lines file for straight lines. A few straight lines are ok and can be fixed later, but there shouldn't be an excess.
   viii. Stops are the more important file
   ix. It is helpful to check my stops file with the **original** GTFS shapefile that can be obtained through the GTFS Shapes to Features tool. Stops should follow the routes.
   b. Use Network Analyst to create a GTFS line based on the stops that align with the network dataset
      i. Analysis > Network Analysis > Set the data source to the same network dataset used for the school bus routes > Route
      ii. Click on Route in the Contents pane > Network Analyst Tab > Route > Import Stops
         1. Input Network Analyst Layer: Route
         2. Sub Layer: Stops
         3. Input Locations: Stops file created from Generate Shapes
         4. Properties:
            a. Name = shapeID
            b. RouteName = ShapeID
            c. Sequence = Sequence
         5. Default all other values
         6. OK
         7. Run (Next to Import Stops)
      iii. These results should match very closely to the original GTFS shapefile obtained from the GTFS Shapes to Features tool. If they don't, you may need to check the network dataset, or the parameters used along the way. If it appears to be an issue with commuter routes (longer runs with fewer stops), you may need to add in pseudo stops along the route to trick the tool into routing properly.
   c. Join the new route to the trips.txt output in the Generate Shapes from GTFS tool and join in the frequency data

<ol type="i">
Locate the trips.txt output from Generate Shapes from GTFS and bring it into GIS as a .csv
Join to your route file via the "name" and the "Shape_id" in trips. This will allow us to obtain the original route_id from the GTFS data
<ol type="1">
Export the new joined data to a new feature class

Dissolve the new feature class based on the route_id – you should now have a unique record for each route_id that follows the streets network close to perfectly.
Load in your frequency data in .csv format
Use the Make Query Table tool to create a new file that contains the frequency for each hour of the day for each route
<ol type="1">
The inputs are 1. The dissolved routes file and 2. The frequency .csv
The expression should join the route_ids from the two files. For example: Routes_Dissolve.RouteID_TEXT = trips_per_hour_GoDurham_20191021_RT.route_id
Run the tool

<ol type="a" start="4">
Use the Split Line at Point tool to obtain the same segmentation across layers
<ol type="i">
Input features: routes feature class with the frequencies
Point features: ND junctions
Search Radius: 10ft
Run the tool
Confirm the tool did split between the ND Junctions. If not, go back and create a copy of the route feature class. With this copy, use the Integrate tool mentioned above.

Using the RITIS centroids, join the split routes to the TMC centroids.
<ol type="i">
Target features: split route feature class
Join features: TMC centroids
Match option: Intersect - You may also want to try Closest and/or Within a Distance. Results may vary depending on your splits and network dataset.
Search Radius of 10 ft

Run two dissolves in order to get the final output:
<ol type="i">
Dissolve 1:
<ol type="1">
Dissolve fields are TMC, Route_id, and Arrival_hour
Sum "n"

Dissolve 2:
<ol type="1">
Dissolve fields are TMC and Arrival_hour
Sum "n" again

<ol type="1" start="4">
General Traffic Flow (RITIS)

a. The RITIS layer was provided by a 3rd party and it was unknown what layer was used to create the polylines. And, unfortunately, they did not line up with the School and Transit routes. To match the segmentation of the School and Transit routes, the RITIS layer needed to be adjusted. This was done in a two-step process.

b. Prep the feature layer for merging
   i. Run the Snap tool to align the RITIS segments with the vertices of the Network Dataset Junctions. Make sure to create a new feature layer as this tool modifies the existing feature layer.
      1. Input Features: The RITIS dataset
      2. Snap Environment
         a. Features: Network Dataset Junctions
         b. Type: Vertex
         c. Distance: 25 ft
   ii. Run the Snap tool again, this time to align with the Network Dataset itself.
      1. Input Features: The RITIS dataset
      2. Snap Environment
         a. Features: Network Dataset
         b. Type: Edge
         c. Distance: 25 ft

c. Calculate the Minutes of Delay for every TMC segment.
   i. The original data was provided in the following column format.

tmc_code	hour	Speed	FFS	travel_time

   ii. From this table, two tables were created and transposed to join into the spatial RITIS feature layer. This seems to add unnecessary steps, but the process described in the School Bus section does not create a TMC record for every hour of the day, only those in which there is a bus count. The steps that follow will create the congestion data for every hour, but will need to be transposed before creating the final dataset.
      1. Travel Speed: Two formulas were used to copy the data into this spreadsheet in the required format.
         a. TMC ID: *=OFFSET('TMC N & P'!A1,(ROW(A1)*24)-1,0)*
         b. Travel Speed for each hour of the day: *=INDEX('TMC N & P'!$C:$C,ROW(C1)*24-26+COLUMN(C1))*
      2. Free Flow Speed (FFS): Same formulas as above, except pointing to the column containing the free flow speed.
      3. Export each of these tabs to their own .csv file and add them to GIS. From there, they are joined to the RITIS layer, first the travel speed and then the free flow speed.

4. Add the additional fields to calculate the minutes of delay. For each column, the delay 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

$TS_n^i =$
$Travel\ Speed\ (mph) for\ hour\ n\ 0..23\ and\ TMC\ segment\ i{=}1..1{,}011$

$FFS_n^i = Free\ Flow\ Speed\ (mph)\ for\ hour\ n$
$\qquad\qquad = 0..23\ and\ TMC\ segment\ i = 1..1{,}011$

$l^i = \dfrac{length\ (ft)}{5280} = length\ (mi)\ of\ TMC\ segment\ i = 1..1{,}011$

5. After the Minutes of Delay have been calculated, the data needs to be transformed using into the following columns. Additional fields will be added by the software. The JoinField is based on concatenating the TMC ID with the Hour and used to join in the data from the School and Transit feature layers. Similar fields will need to be calculated for those feature layers.

TMC ID	Hour	Minutes of Delay	JoinField

6. To create the data in the above format, the Transpose Fields tool will be utilized.
   a. Input Table: RITIS feature layer containing the minutes of delay by column for each hour of the day.
   b. Fields to Transpose: Every column that contains the minutes of delay is transposed. See the example below
      i. Field: F12AM_MD
      ii. Value: 0
   c. Output Table: Appropriately named table
   d. Transposed Field: Hour (name of the field that contains the hour 0 .. 23)
   e. Value Field: RITISMinDelay (name of the field that contains the minutes of delay for each hour)
   f. Attribute Fields

<div style="margin-left:3em">

     i. TMC: required to create the join to join in the attribures from the school and transit feature layers.

     ii. Shape: required to export the transposed dataset as a feature layer.

7. Add the JoinField and calculate it to be the concatenation of the TMC ID and Hour (i.e. 125N04801 + 0 = 125N048010).

8. Add additional fields to hold the school and transit counts and minutes of delay calculations.

     a. SB_Count

     b. SB_Delay

     c. TRN_Count

     d. TRN_Delay

</div>

5. Combining the datasets

   a. To combine the datasets, they all need to have the same segmentation. This was done with the following steps. The steps to do this for each layer are described above.

     i. The TMC ID of each RITIS segment needs to be joined to the School and Transit route layers. This was done in two steps.

       1. Run the <u>Feature To Point</u> tool on the segmented and snapped RITIS feature layer. This will convert each line segment to the centroid.

         a. Input Features: The RITIS layer after the <u>Snap</u> and <u>Split Line At Point</u> tools have been run

         b. Output Feature Class: An appropriately named feature class that describes the tool and input parameters to easily identify the process.

         c. Inside: Checked – This ensures the centroid is located on the polyline feature

       2. Run the Spatial Join tool to attach the TMC ID from the RITIS centroids to the School and Transit feature layers.

         a. Target Features: School and Transit feature layers after the <u>Split Line At Point</u> tool has been run.

         b. Join Features: The RITIS centroid feature layer created in the previous step.

         c. Output Feature Class: An appropriately named feature class that describes the tool and input parameters to easily identify the process.

         d. Join Operation: Join one to one

         e. Keep All Target Features: Checked

         f. Match Option: Intersect

         g. Search Radius: 10 ft

3. After the TMC ID's have been joined to the School and Transit layers, two dissolves will next be performed.
    a. Dissolve by TMC, Run Hour, and Run ID (three field dissolve, no statistics)
    b. Dissolve by TMC, Run Hour and count Run ID (two field dissolve, one statistic). The format of the output from running this tool matches the final format. Add a field named FieldJoin and calculate similar to Step & in the RITIS section
4. The final step is to join the second dissolved school and transit layers using the JoinField field. Then, calculate the count of buses to the fields created in Step 8 in the RITIS section.
5. After updating the bus counts, calculate the minutes of delay for school and transit buses multiplying the minutes of delay by the number of buses. An additional column is created to sum the minutes of delay for school buses to the minutes of delay for transit buses.