School Traffic Trip Generation Calculator Evaluation and Data Collection

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This project focused on the collection of new data to add to the NCDOT School Traffic Calculator (STC), with a specific focus on estimates generated for vehicular rates and queue length. School travel data was collected at schools across North Carolina. This sample included schools of various types in varied geographic areas. Schools continue to be constructed at a rapid pace across North Carolina as the state experiences population growth, particularly in urban regions. Furthermore, existing schools throughout North Carolina and the U.S. continue to experience increases in child passenger pick-up and drop-off, regardless of school age or location (NHTSA, 2009). As a result, accurate estimation of school site queue length needs and trip generation rates are critical to maintaining and improving the transportation safety of North Carolina's communities.

This work is significant for NCDOT due to the potential for enhanced accuracy of school travel mode and queue length estimation. Increased accuracy in queue length needs will lead to school site design and traffic management plans that better accommodate school travel demand and corresponding needs. Effectively accommodating passenger vehicle queues will promote improved traffic safety and operations in communities throughout North Carolina with new school construction and existing schools that have difficulties with queue spillover into surrounding roadways.

The most robust estimates and updates to the calculator recommended based on this research study are drawn from the public elementary school sample (n = 13, while all other samples had seven or less observations). For this category, the existing STC high demand length estimate is comparable to the high demand length projected from the field data. To ensure a conservative estimate of queue lengths, a 95th percentile estimator was implemented in the calculator recommendations.</td></tr>
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EXECUTIVE SUMMARY

This project focused on the collection of new data to add to the NCDOT School Traffic Calculator (STC), with a specific focus on estimates generated for vehicular rates and queue length. School travel data was collected at a total of 27 schools across North Carolina. This sample included schools of various types in varied geographic areas. Schools continue to be constructed at a rapid pace across North Carolina as the state experiences population growth, particularly in urban regions. Furthermore, existing schools throughout North Carolina and the U.S. continue to experience increases in child passenger pick-up and drop-off, regardless of school age or location (NHTSA, 2009). As a result, accurate estimation of school site queue length needs and trip generation rates are critical to maintaining and improving the transportation safety of North Carolina's communities. This work is significant for NCDOT due to the potential for enhanced accuracy of school travel mode and queue length estimation. Increased accuracy in queue length needs will lead to school site design and traffic management plans that better accommodate school travel demand and corresponding needs. More effective accommodation of passenger vehicles will promote improved traffic safety and operations in communities throughout North Carolina with new school construction and existing schools that have difficulties with queue spillover into surrounding roadways.

The most robust estimates and updates to the calculator recommended based on this research study are drawn from the public elementary school sample (n = 13, while all other samples had seven or less observations). For this category, the existing STC high demand length estimate is comparable to the high demand length projected from the field data. To ensure a conservative estimate of queue lengths, a 95th percentile estimator was implemented in the calculator recommendations stemming from this research. The queue and survey data collected by the research team was used to validate the existing STC. Based on the validation results, two major computational changes to the calculator model are proposed: 1) calculating the max queue length from the 95th percentile of available data and 2) using a weighting system based on grades instructed at a school.

An on-going NCDOT research project, 2021-15: Evaluation of School Travel Patterns and Preferences, will provide further updates to the calculator. The updated calculator provided with this report is intended as an interim deliverable, and with the exception of public elementary school predictions, should not be used for school design until RP 2021-15 is complete. The specific efforts include expanding the sample size of locations with highly variable estimates, evaluating trends related to school travel, comparing loading/unloading zone techniques, and developing recommendations for modeling school locations in Synchro. In RP 2021-15, school travel data will be collected by the research team at schools across North Carolina, varying by school type and geography with a focus on school types/characteristics that have highly variable queue length estimates. This new data will be paired with existing STC data. Loading/unloading zones will also be studied to help identify and quantify the most beneficial practices. A couple of additional measures are recommended for a future update of the STC: 1) surveying a sample of schools to determine the distribution of student drivers by grade level and 2) visiting a larger sample of private/non-urban charter and urban charter schools. Both of these actions will be included in NCDOT RP 2021-15 which will further expand the sample size for the STC.

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INTRODUCTION

A school site's capacity for managing traffic during intensive, peak intervals is a traffic safety issue that has efficiency and safety implications for all modes of school travel. In North Carolina, the NCDOT Municipal School Transportation Assistance (MSTA) group reviews Transportation Impact Assessments (TIA) submitted during school site planning for public, private, and charter school systems. Each TIA includes estimates of queue length needs from the MSTA School Traffic Calculator. These estimates are derived from school-specific factors, such as type of school (e.g. Public, Urban Charter, Non-Urban Charter, Private) and student population size. NCDOT approval of proposed school site plans often depends on the projected campus storage capacity to accommodate TIA-estimated passenger vehicle queue lengths and school bus parking.

To support the school siting process, the NCDOT MSTA group developed the School Traffic Calculator (STC) to help predict the vehicle-trips that will be generated by a new school. The highly-utilized planning tool is embedded in the NCDOT approval process for proposed school sites in North Carolina. However, the STC was developed based on a relatively small school travel dataset, with less than 10 observations for both urban and non-urban charter and private schools. Additionally, the public school data used to generate the calculator's estimates were collected more than 10 years ago, yet the prevalence and demand for passenger vehicle pick-up and drop-off may fluctuate as travel behaviors change over time. Consequently, the STC needed to be evaluated and updated to ensure the accuracy of the school travel mode rate and queue length estimations. North Carolina General Statute 136-18(29a)[1] guides the work of the MSTA group.

[1] The introduction of North Carolina General Statute 136-18(29a) includes:
To coordinate with all public and private entities planning schools to provide written recommendations and evaluations of driveway access and traffic operational and safety impacts on the State highway system resulting from the development of the proposed sites. All public and private entities shall, upon acquiring land for a new school or prior to beginning construction of a new school, relocating a school, or expanding an existing school, request from the Department a written evaluation and written recommendations to ensure that all proposed access points comply with the criteria in the current North Carolina Department of Transportation "Policy on Street and Driveway Access."

LITERATURE AND DATA REVIEW

The safe arrival and departure of students to and from school is a traffic safety and operational design focus that relies on transportation infrastructure (e.g., driveways, unloading and loading zones, parking lots, walkways, etc.) on the school's campus to manage traffic during intensive, peak intervals. This includes all modes of school travel – pedestrians, bicyclists, school buses, and passenger vehicles. School travel safety research indicates that passenger vehicles account for 84% of all student travel injuries and 75% of student travel fatalities (Rhoulac, 2005). Therefore, designing school sites capable of safely managing passenger vehicle traffic is a key factor in the safety of all students traveling to and from school. Accordingly, the planning, selection, and design of a school site should reflect safety considerations for all students.

Passenger Vehicles and School Safety

Transportation safety at schools becomes a primary concern when campuses must handle a substantially greater volume of passenger vehicles than they were designed to manage (Isebrands, 2007). Passenger vehicles can impact school safety in two specific ways. First, on-site congestion can result in passenger vehicle crashes with pedestrians, as sidewalk networks may intersect with passenger vehicle queue areas and school entrances. Second, a school's capacity to store passenger vehicle traffic at peak periods directly impacts the safety of adjacent roadways due to queue spillback. Queue spillback onto roadways can reduce the function and safety of routes, particularly during afternoon pick-up due to concurrency with afternoon commute traffic and the concentration of afternoon pick-up of students (Tsai et al., 2004).

While school buses have a dedicated loading and unloading zone, child passenger pick-up and drop-off can require a significant portion of a school site's footprint to accommodate queue lengths that may be extensive, particularly during afternoon release. While the issue of adequate queue length and corresponding implications for traffic safety is generally understood by traffic engineers and planners, many school sites cannot currently accommodate the high demands of arrival and dismissal (Isebrands, 2007). This is due to the nature of planning, as forecasted travel choice can vary from actual travel behavior, select schools may experience overcrowding, and other factors such as rapid population growth within a region. A study of school traffic in North Carolina discovered that "about 50% of the schools experienced queues in the afternoon that exceeded their on-campus vehicle storage space" (Tsai et al., 2004).

School Travel Data

The National Center for Safe Routes to Schools (National Center) collects a robust dataset of student mode choice at a sample of schools in North Carolina. Homeroom teachers surveyed homeroom students to determine which mode they used to travel to and from school on the day of the survey. The dataset contains data from the tallies that schools collected, including the month and year they were collected, the teachers who completed the tallies, the teacher-reported weather, the time of day, and the number of students who used various travel modes to get to and from school.

The National Center provided the research team with data from schools that participated in the tally gathering effort for one to five years between 2007 and 2019. The research team used the tally dataset along with school population data to estimate the schools' student mode split during morning (AM) drop-off and afternoon (PM) release periods. Average mode split by grade was derived from the reported homeroom student mode choice, which was then used to estimate the total students at the school traveling by each mode. The methodology used to calculate the estimated mode split by school is outlined in the following equations.

Equation 1. Average Mode Split by Grade:

$$MS_{ia} = \frac{\sum_{x=1}^{n} \frac{Students\ in\ Class_x\ Traveling\ by\ Mode_i}{Total\ Student\ Responses\ in\ Class_x}}{n}$$

Where,
MS_{ia} = Mode split of students in grade a traveling to school by mode i
n = total homeroom classes in grade a

Equation 2. Average Mode Split by School:

$$MS_i = \frac{\sum_{a=k}^{12} MS_{ia} * MLD_a}{\sum_{a=k}^{12} MLD_a}$$

Where,
MS_i = Mode split of students at school travelling to school by mode i
a = grade
MLD = Membership of grade a on last day of month

The frequency of student school travel by mode (Figure 1) shows that the highest proportion of PM trips are made by bus (average of approximately 50% of trips), followed closely by personal vehicle trips (average of approximately 40% of trips). Non-motorized trips represent approximately 10% of trips, on average. Using this data, the schools with travel mode share significantly above the mean in the PM period are shown in Figure 2 (personal vehicle), Figure 3 (bus), and Figure 4 (non-motorized)[2].

Observations

The results of this analysis show that single family mode share at schools varies based on geography and student population. An online web application with summary statistics is available at ArcMap Online. Researchers made the following observations regarding school travel in North Carolina:

- The two most utilized modes of transportation are single family vehicles and school bus.
  - Schools with higher single family vehicle mode share had lower school bus mode share.
  - Rural schools had a higher school bus mode share than many urban schools.

[2] An ArcGIS Web Mapping Application summarizing results is available for viewing at the following website: https://ncsu.maps.arcgis.com/apps/webappviewer/index.html?id=396cd5338722429c8fa3882b238259ee

- Schools with higher rates of walking mode share are located in small town grids or within a fifteen-minute walking radius of denser single family residential developments.
- Very few schools had a bicycling mode share greater than 3%.
- No substantial changes in travel mode were noted over the time frame of the observations (2007 to 2019) available in this dataset.

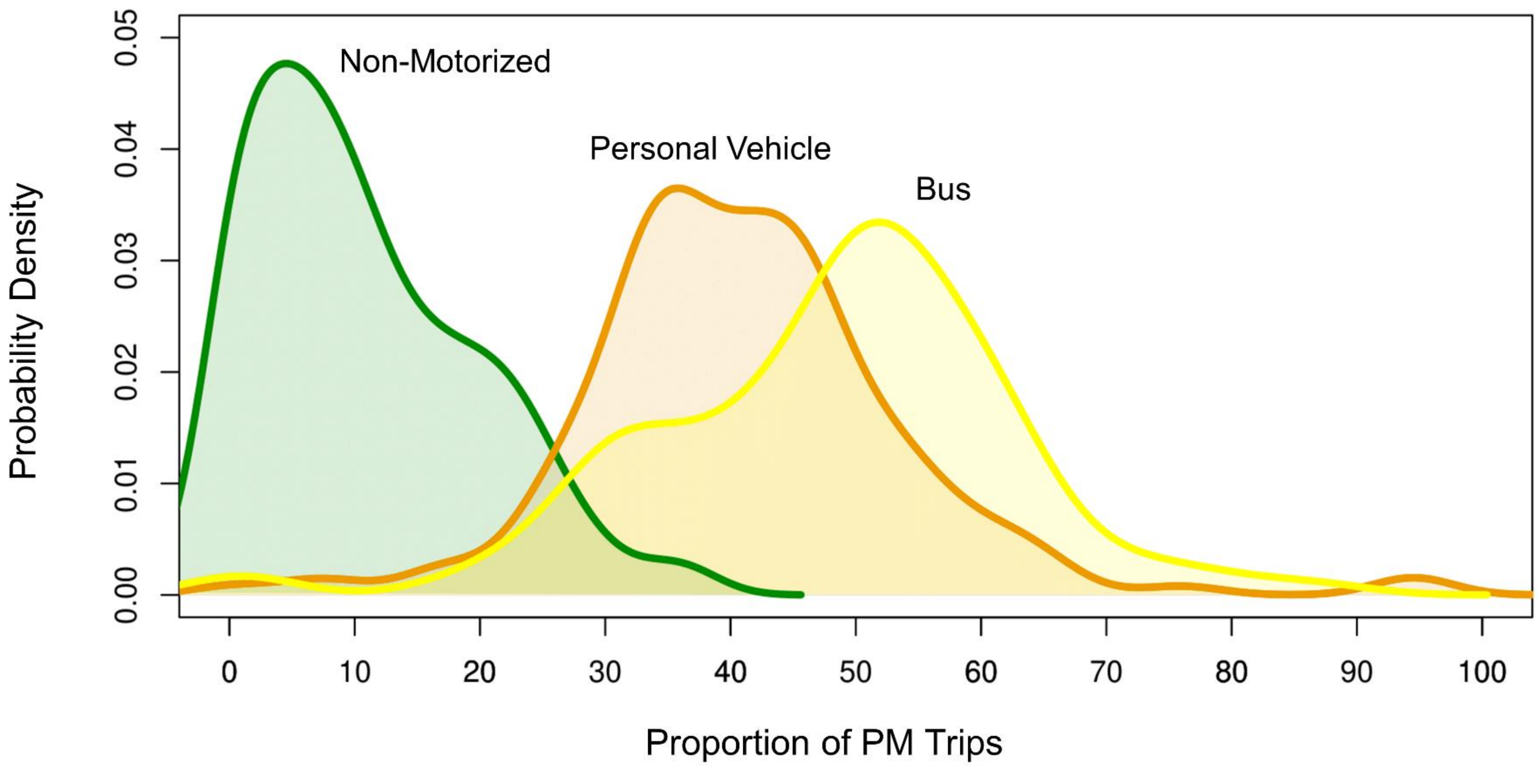

Figure 1. Frequency of Student School Travel by Mode in North Carolina [Non-Motorized, Personal Vehicle, and Bus]

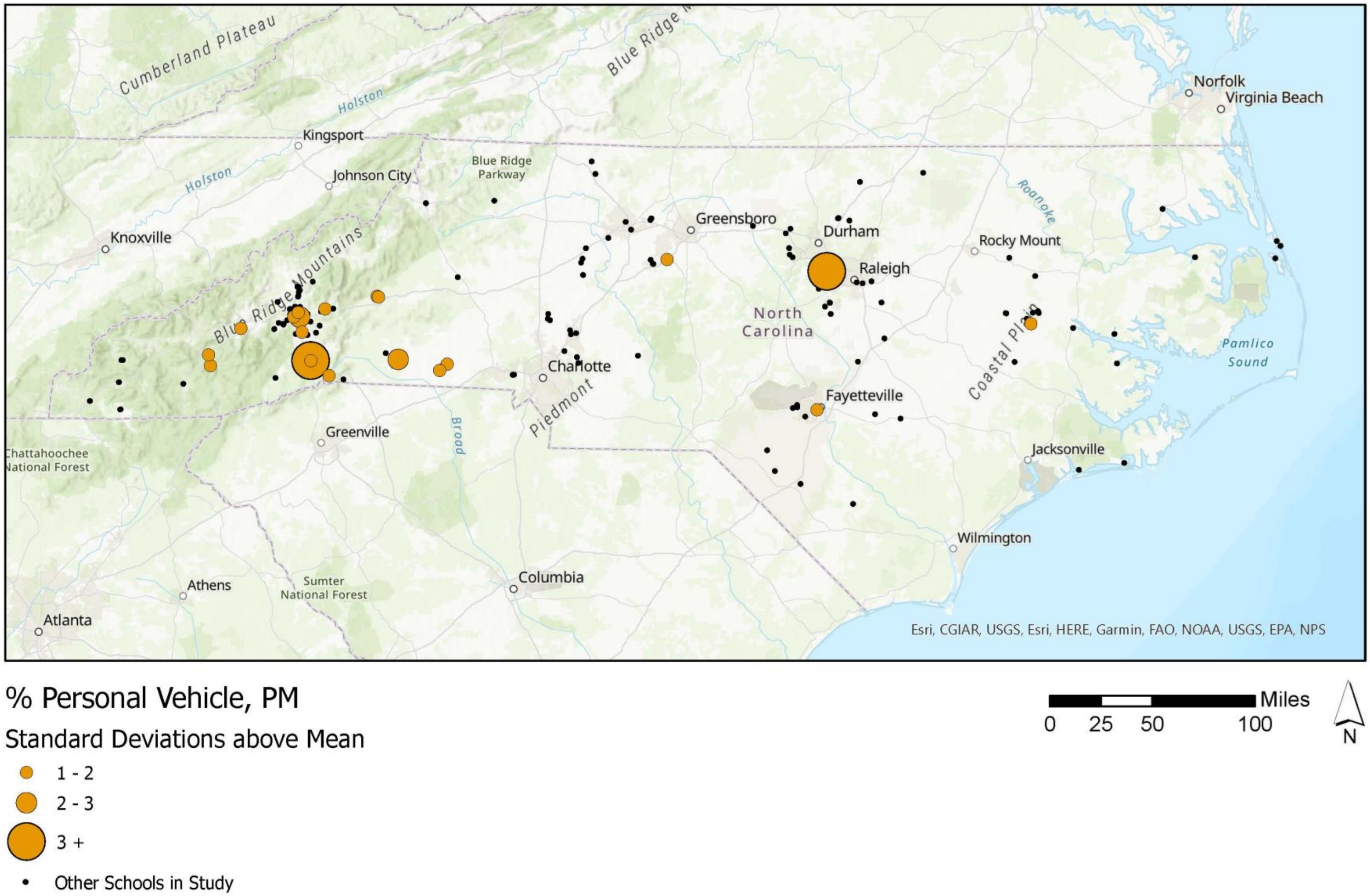

Figure 2. North Carolina School PM Personal Vehicle Travel [Schools with Student Travel Mode Share Significantly Above Mean]

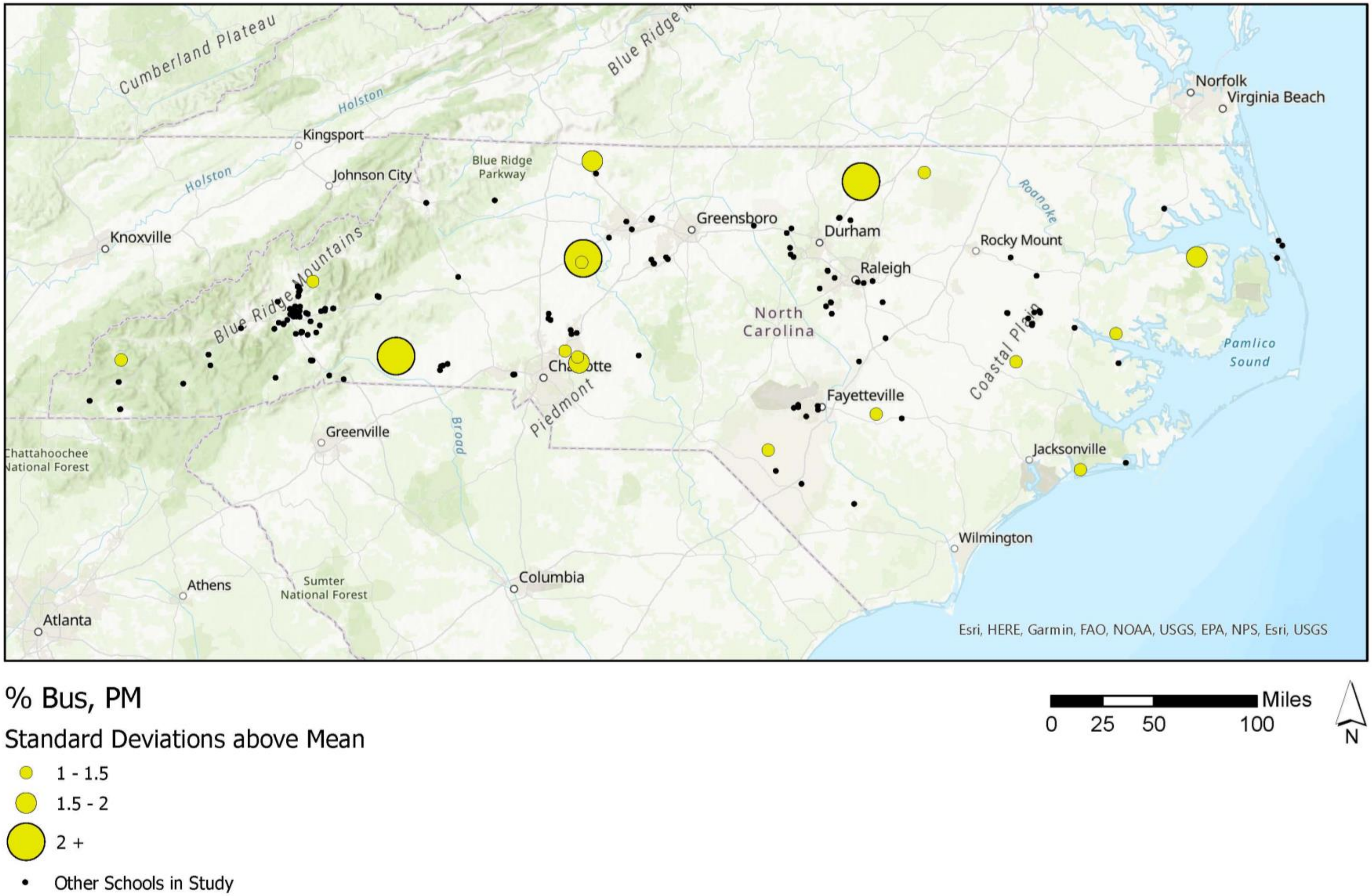

Figure 3. North Carolina School PM Bus Travel [Schools with Student Travel Mode Share Significantly Above Mean]

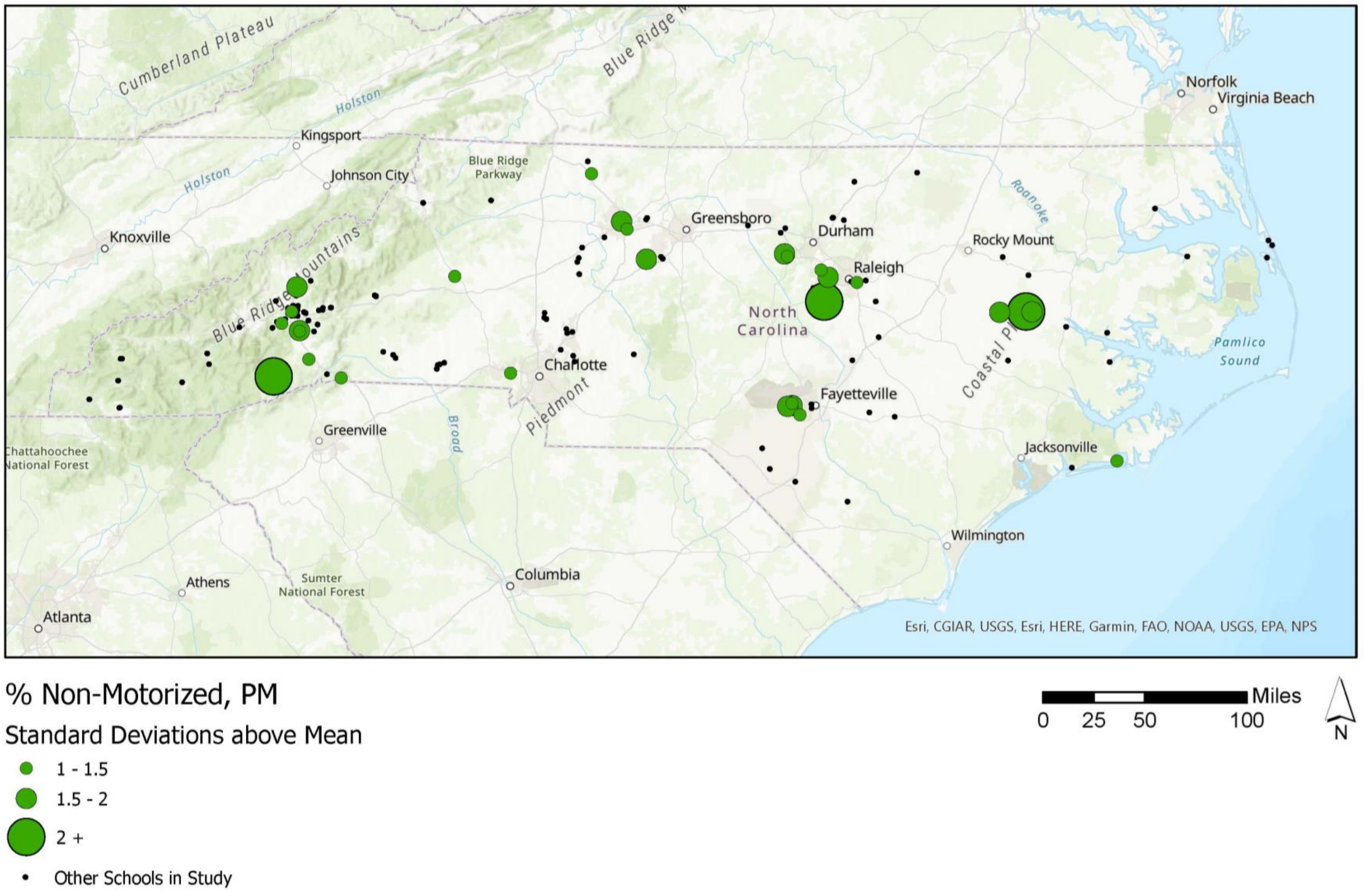

Figure 4. North Carolina School PM Non-Motorized Travel [Schools with Student Travel Mode Share Significantly Above Mean]

METHODOLOGY

School Site Identification and Sample Selection

The research team selected a geographically diverse sample of public, charter, and private schools across the state to develop a field-validated dataset. This dataset, in conjunction with records from the existing MSTA calculator, was used as the foundation for developing new data for an expanded queue and trip prediction tool.

Public schools were selected, prior to the COVID-19 pandemic, using a multi-stage sampling process. Records of public schools were extracted from the NC Department of Public Instruction (DPI)'s Educational Directory and Demographical Information Exchange (EDDIE) database. These records were combined with DPI's average daily membership data to estimate the number of students at each school. The population of public schools was further reduced using several criteria, including:

1. Only public schools teaching grades K-5, 6-8, or 9-12 (without any overlap between the categories or missing years) were sampled.
2. Only schools following the traditional calendar (as opposed to year-round or hybrid calendars) were sampled.
3. Vocational, alternative education, and hospital schools were excluded.
4. Fully or partially virtual schools were excluded.

Out of 2,704 total schools in EDDIE, 1,556 public schools were eligible for data collection based on this selection process. From this sample, the following process was used to develop a reasonable distribution based on geographic location with the goal of developing a smaller, targeted sample of eligible schools:

1. North Carolina was divided into western, central, and eastern regions. The number of eligible elementary, middle, and high schools in each region was divided by the total number of eligible schools in EDDIE to determine what proportion of the 60-school sample would be drawn from each combination of region and school type.
2. Within each region, two counties were deterministically selected.
3. The eligible schools within both counties were pooled, then stratified by elementary, middle, and high school. Within each school type stratum, the final set of schools was selected by simple random sample. A selection of backup schools was also chosen in case any of the sampled schools could not be investigated.

Charter and private schools were not included in this sampling process. Schools in these two categories were selected deterministically based on each school's location and willingness to participate in the study. The traditional-calendar and non-virtual restrictions were relaxed for charter schools due to limited sample size.

Data collection efforts after March 2020 were discontinued because of COVID-19 and the resulting transition from in-person to online school instruction. As a result, the public schools sampled from Mecklenburg County were not visited and data were therefore not collected for these schools. A small number of schools were not included in the analysis in cases where the collected video footage from the schools was unusable (from camera malfunctions or inaccurate location placement) and could not be recollected. The research team sampled public schools in six counties (Franklin, Mecklenburg, New Hanover, Rowan, Wake, and Wayne) as well as nine Charter schools. The following table (Table 1) shows the 27 schools by date of collection that were collected, the date of the data collection, student population, queue length, and the number of vehicles entering and exiting the campus during the data collection period. All of the schools in Table 1 were visited during the afternoon.

Table 1. School Data Collection Information (Sorted by Collection Date)

School Name	County	Collection Date	Student Population	Attendance Method	Grades Instructed	Total Vehicles In	Total Vehicles Out	Max Queue (Vehicles)	Max Queue (Feet)
Bunn Elementary	Franklin	2/25/2020	543	ADM Estimate	K - 5	98	98	69	1733
Laurel Mill Elementary	Franklin	3/4/2020	293	Reported by School	K - 5	58	58	23	517
Edwin Anderson Elementary	New Hanover	3/10/2020	680	ADM Estimate	K - 5	101	102	62	1868
Holly Shelter Middle	New Hanover	3/2/2020	731	Reported by School	6 - 8	68	68	51	1558
Walter L. Parsley Elementary	New Hanover	3/9/2020	649	ADM Estimate	K - 5	92	94	60	1294
Charles C. Erwin Middle	Rowan	10/29/2019	869	ADM Estimate	6 - 8	96	93	65	1344
Isenberg Elementary	Rowan	10/30/2019	407	Reported by School	K - 5	84	84	40	952
West Rowan Elementary	Rowan	10/28/2019	574	ADM Estimate	PK - 5	112	112	76	2080
West Rowan Middle	Rowan	10/28/2019	672	ADM Estimate	6 - 8	117	116	56	1358
Apex High	Wake	11/19/2019	2097	ADM Estimate	9 - 12	94	93	56	1210
Apex Friendship High	Wake	1/30/2020	2572	ADM Estimate	9 - 12	138	138	70	2064
Bryan Road Elementary	Wake	12/12/2019	478	Reported by School	PK - 5	97	97	56	1454
Reedy Creek Middle	Wake	11/20/2019	813	ADM Estimate	6 - 8	145	143	77	2108
East Millbrook Middle	Wake	12/10/2019	775	ADM Estimate	6 - 8	85	84	34	840
Leesville Road Middle	Wake	12/3/2019	906	ADM Estimate	6 - 8	94	91	38	944
Lynn Road Elementary	Wake	1/22/2020	476	Reported by School	PK - 5	105	104	53	1410
Northwoods Elementary	Wake	1/23/2020	656	Reported by School	PK - 5	81	79	43	1139
Richland Creek Elementary	Wake	12/9/2019	481	ADM Estimate	PK - 5	103	105	55	1579
Wakefield Middle	Wake	2/3/2020	886	Reported by School	6 - 8	75	74	49	1238
Wakefield High	Wake	2/3/2020	1870	ADM Estimate	9 - 12	89	88	57	1701
Wakelon Elementary	Wake	12/5/2019	536	Reported by School	K - 5	79	80	45	1206
Wildwood Forest Elementary	Wake	12/4/2019	600	Reported by School	K - 5	125	122	66	1491
York Elementary	Wake	12/2/2019	411	Reported by School	PK - 5	131	130	75	1850
Eastern Wayne High	Wayne	2/11/2020	875	ADM Estimate	9 - 12	60	60	55	1121
Pinnacle Classical Academy (Lower Elem Campus)	Cleveland	5/22/2019	317	Reported by School	K - 2	157	159	107	2562
Ignite Innovation Academy	Pitt	5/23/2019	184	ADM Estimate	K - 8	15	15	14	322
Lake Lure Classical Academy	Rutherford	9/17/2019	496	ADM Estimate	K - 12	45	45	33	852

School Traffic Data Collection

After determining which schools would be sampled, the research team contacted the relevant school district offices (when applicable) to notify them of the data collection intentions and gain approval for the data collection effort. Once the school districts approved the data collection effort, individual schools were contacted approximately two weeks prior to data collection to notify them of the dates and times that researchers would be at the school to install and remove camera equipment. Vehicles that did not travel through the designated queuing area were counted as trips to the extent they were observed, but were not included in the queue length. The research team also worked with each school to gather information regarding any pertinent scheduling conflicts that could affect the data collection or result in atypical drop-off or pick-up behavior, such as holidays or special events. During the initial phone call with individual schools, the research team was able to ask about the queue length and queuing process, which allowed for ideal queue observation during data collection. A summary of the data collection process is presented in Figure 5.

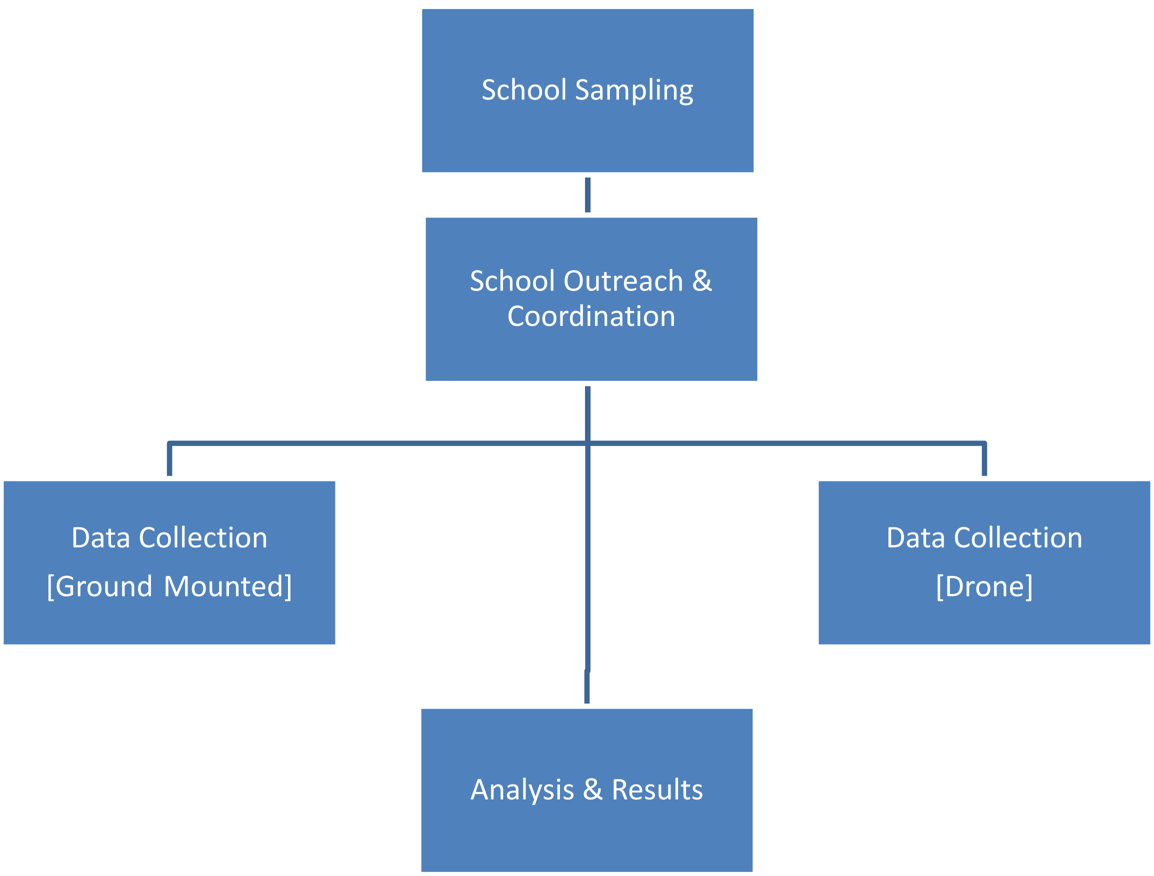

Figure 5. School Traffic Data Collection Process

A reminder email was sent to schools the day before data collection with information regarding the monitoring equipment installation process and the planned length of collection. Many schools sent email notifications to parents to inform them of the research team's presence on campus, per school or district protocol. However, no equipment was installed or removed during the drop-off or pick-up process at any schools.

The video camera installation process typically occurred during mid-morning or late afternoon, when parents and/or students were not arriving to or leaving from the school campus area. If only using static cameras for data collection, the data collection team was not on campus during the drop-off or pick-up times. However, when a drone was used for data collection at a school, research team members were on or near campus during these times to operate the drone, always at a distance from the vehicle queue.

To avoid any abnormal behavior related to the weekend plans of students or their families, data was not collected on Monday mornings or Friday afternoons. Data was most often collected on Tuesdays and Thursdays. This allowed for the installation of video cameras on Monday afternoon for the Tuesday schools, with equipment removal for these schools occurring on Tuesday afternoon or Wednesday morning. Another round of video camera installation typically occurred on Wednesday afternoon for the Thursday schools, with equipment removal for these schools occurring on Thursday afternoon or Friday morning. Once the video cameras were picked up and brought back to the research team's office from the Thursday schools, data were downloaded from the video cameras for both the Tuesday and Thursday schools. At most, three schools were observed on any given day (when proximity and schedules allowed), while most data collection days consisted of data collection at two schools.

Approval was provided for drone data collection later in the project timeline. Therefore, data at some schools was collected via a combination of drone and static cameras while only drones or static cameras were uses at others. The only time that standard ground-mounted video cameras were used to supplement drone data collection was when the research team was unsure of the extent of the vehicle queue. Most often, supplemental standard video cameras were not used because the drone could typically capture the full extent of the vehicle queue.

For ground-mounted video, static cameras were installed on either light posts or trees at or around each campus. These cameras were positioned to ensure, whenever possible, capture of the entire queue. The cameras were fixed to objects using hose clamps that are adjustable and do not require permanent changes to the environment. Each camera was initially positioned with an approximate field of view and was further calibrated after the camera was securely attached to the pole or tree.

After attaching the camera to the pole or tree, settings could be adjusted using a computer connected to the camera via ethernet. Generally, the only settings that needed adjustment were the recording schedule (depending on the arrival and departure times of students), the infrared settings (if the morning drop-off started before or during the dawn hours), and the image quality (to ensure that no faces or vehicle license plates were identifiable, while still being able to adequately observe the drop-off or pick-up process). The video recordings were stored on an SD card inserted into the camera housing. Once the camera settings were adjusted as needed, the box holding the camera batteries was closed, locked, and chained to a fixed object nearby for security purposes. This box is low profile and inconspicuous. An example of a typical camera installation is shown in the Figure 6, while Figure 7 shows the typical views from the ground-mounted cameras.

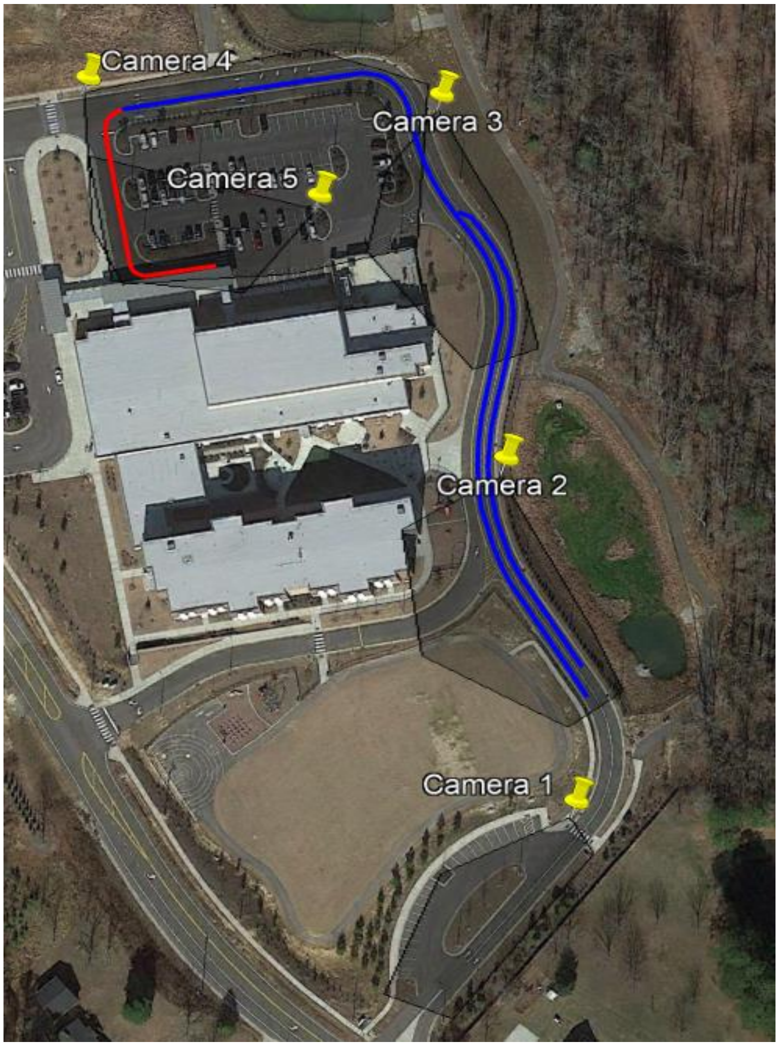

Figure 6. Typical Camera Installation

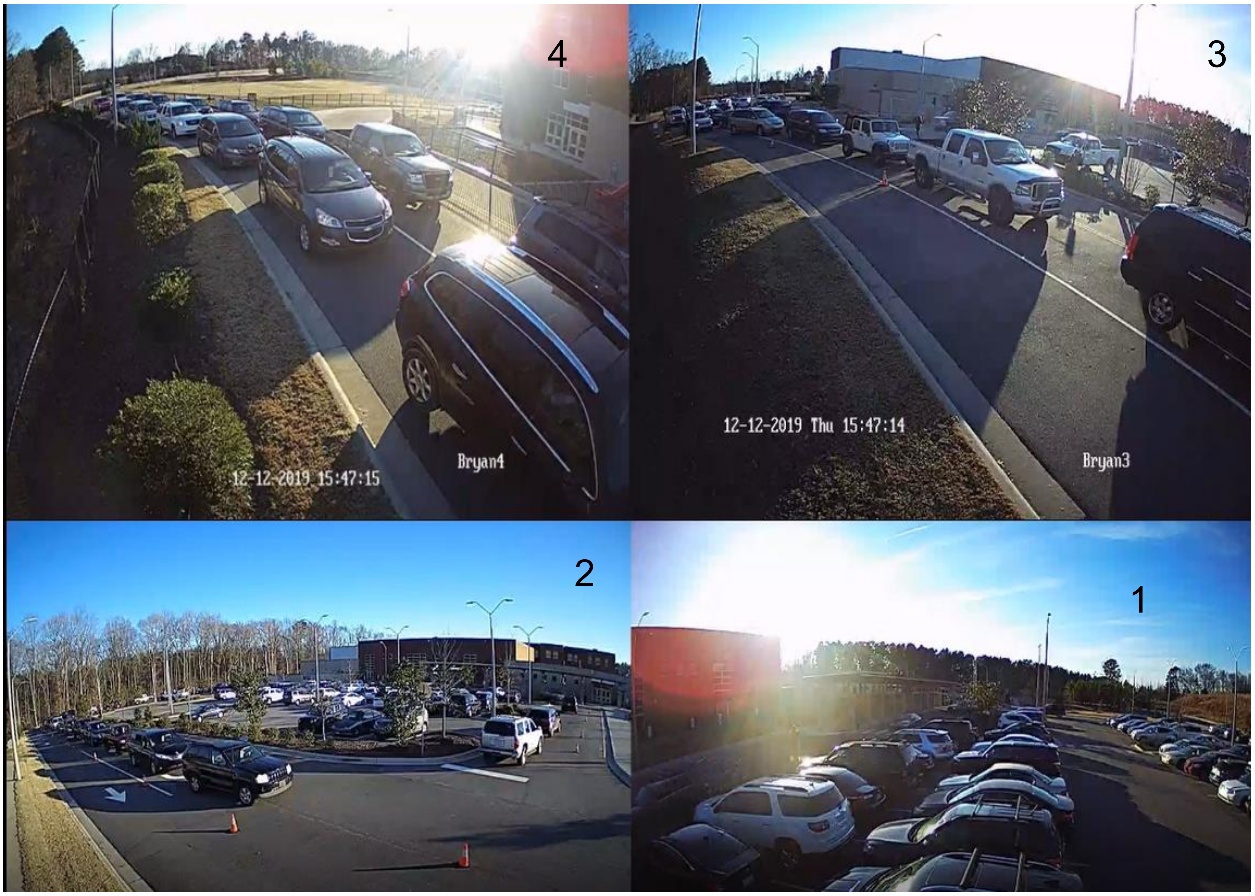

Figure 7. Typical Camera Views

When a drone was used for data collection, the data collection team selected an inconspicuous location to avoid confusion from parents, which could potentially impact the drop-off or pick-up process. The data collection team would deploy the drone as queueing began and, when possible, would not bring the drone down until the queue had completely dissipated. Each drone was tethered or connected to the ground with an FAA-licensed pilot who operated the drone throughout the duration of the data collection. Compared to ground-based cameras, drones offered substantial improvements to visual continuity. The use of drones also reduced data collection installation time. Figure 8 shows an example of the view from the drone during data collection.

Figure 8. Example Drone View

For both ground-based camera and drone data collection, efforts were made to avoid capturing identifiable information like faces and vehicle details as much as possible. In the case of drones, the research team was able to position the drones in locations farther away from the actual pick-up and drop-off locations, such as athletic fields and sidewalks.

Once data collection for a school was complete, individual video files representing separate camera views were combined into one video for analysis using physical cues in the videos to ensure accurate synchronization of the views. An online map was created for each school so the research team could document and communicate what each camera view captured. An analyst watched each video twice to fully capture entrances and then exits of the queue using timestamps. Vehicle entrances were marked when they reached the back of the queue and marked as exiting when they entered the loading zone.

After the timestamps of the entrances and exits were collected, the raw queue data were recorded for each school. The total entrances and exits were compared to identify if any errors occurred during data collection. Each school was reviewed to ensure that the difference between entrances and exits never exceeded 3 vehicles. The video data were reduced into a spreadsheet to also capture the Total In, Total Out, Max Q (cars), and Max Q (Feet) data points for each school. The spreadsheet calculated the maximum queue length based on number of vehicles. After the timestamps were collected and checked, a polygon following the path of the queue to the furthest queuing point was created in an online mapping tool to find the maximum queue length in feet.

Data collectors did not record student attendance on the day of field data collection. Estimates of student attendance were made using NC DPI records, based on the lowest monthly average daily membership (ADM) record of the school year. At the end of the project, schools were contacted to retrieve student counts on the day of data collection where available, and correction factors were generated to adjust ADM estimates to the actual attendance values.

Table 2, below, shows the correction factors estimated. Private/non-urban charter and urban charter schools were calculated as a group, rather than by grade level, due to small sample sizes. No public high schools responded to the request for records, so a correction factor of 1 was assumed. Table 3 shows the same data, but in disaggregated form.

Table 2. ADM Correction Factors (Aggregate)

Category	Sample Size	Average Correction Factor	Lower 95% CI of Correction Factor	Upper 95% CI of Correction Factor
Public Elementary	8	1.0096	0.9667	1.0525
Public Middle	2	0.9998	0.2221	1.7774
Public High	0	1.0000	N/A	N/A
Private/Non-Urban Charter	1	1.0567	N/A	N/A
Urban Charter	2	1.0115	0.7024	1.3206

N/A = Not Applicable

Table 3. ADM Correction Factors (Disaggregate)

School Name	Collection Date	ADM Estimate (Students)	Reported Attendance (Students)	Correction Factor
Laurel Mill Elementary	3/4/2020	276	293	1.0616
Harold D Isenberg Elementary	10/30/2019	406	407	1.0025
Bryan Road Elementary	12/12/2019	475	478	1.0063
Lynn Road Elementary	1/22/2020	493	476	0.9655
Northwoods Elementary	1/23/2020	601	656	1.0915
Wakelon Elementary	12/5/2019	518	536	1.0347
Wildwood Forest Elementary	12/4/2019	641	600	0.9360
York Elementary	12/2/2019	420	411	0.9786
Holly Shelter Middle School	3/2/2020	689	731	1.0610
Wakefield Middle	2/3/2020	944	886	0.9386
Pinnacle Classical Academy (Lower Elem Campus)	5/22/2019	300	317	1.0567
Pinnacle Classical Academy (Upper Campus)	5/29/2019	530	549	1.0358
Envision Science Academy	3/7/2019	703	694	0.9872

The practical effect of the ADM correction factor adjustment on queue predictions is minimal. In addition to the low magnitude of the correction factors, adjusted data only made up part of the dataset; historic calculator data that was included in the proposed STC was not affected. As a result of applying the correction factors to the proposed school traffic calculator, the predicted queue lengths decreased by 0.95% at public elementary schools, increased by 0.02% at public middle schools, and decreased by 5.36% for private and non-urban charter school grade categories PK-K, 1-10, and 12. All other categories were unaffected.

Data Collection Considerations

A variety of factors may be useful when considering whether to use ground-mounted video cameras or a drone to collect school queueing and trip information. For short-duration counts, drones can provide lower set-up costs and data processing (due to one, seamless camera view during post-processing). Drones also provide a more flexible setup with a camera angle that can be adjusted in real-time as the operational conditions change. However, for longer duration counts, ground-mounted cameras may be advantageous because they can be left unattended for an extended time period.

Grade Categorization

Every public school sampled by the research team fit neatly into a single grade category (i.e. grades K-5 for public elementary schools, or 9-12 for public high schools.) However, the private and urban charter schools generally did not; for example, one school instructed grades 3-11. To allocate those schools' queue data among the appropriate categories, a weighting algorithm was developed. For each category, the school's weight was calculated as the number of grades instructed in that category divided by the number of grades instructed by the school.

Given a school of type $s \in$ {Public, Private/Non-Urban Charter, Urban Charter}, instructing a set of grades $\{ G \in N \mid 0 \leq G \leq 12\}$ where both pre-kindergarten and kindergarten evaluate to Grade 0 and all other grades are evaluated as their numeric equivalent, the weight W for each category can be calculated as:

$$W(Public\ Elementary) = \begin{cases} \dfrac{|G \cap \{0,1,2,3,4,5\}|}{|G|} & s = Public \\ 0 & s \neq Public \end{cases}$$

$$W(Public\ Middle) = \begin{cases} \dfrac{|G \cap \{6,7,8\}|}{|G|} & s = Public \\ 0 & s \neq Public \end{cases}$$

$$W(Public\ High) = \begin{cases} \dfrac{|G \cap \{9,10,11,12\}|}{|G|} & s = Public \\ 0 & s \neq Public \end{cases}$$

$$W(Private\ or\ Non\ Urban\ Charter\ PK-K) = \begin{cases} \dfrac{|G \cap \{0\}|}{|G|} & s = Private\ or\ Non\ Urban\ Charter \\ 0 & s \neq Private\ or\ Non\ Urban\ Charter \end{cases}$$

$$W(Private\ or\ Non\ Urban\ Charter\ Grades\ 1-10) = \begin{cases} \dfrac{|G \cap \{1,2,3,4,5,6,7,8,9,10\}|}{|G|} & s = Private\ or\ Non\ Urban\ Charter \\ 0 & s \neq Private\ or\ Non\ Urban\ Charter \end{cases}$$

$$W(Private\ or\ Non\ Urban\ Charter\ Grade\ 11) = \begin{cases} \frac{|G\ \cap \{11\}|}{|G|} & s = Private\ or\ Non\ Urban\ Charter \\ 0 & s \neq Private\ or\ Non\ Urban\ Charter \end{cases}$$

$$W(Private\ or\ Non\ Urban\ Charter\ Grade\ 12) = \begin{cases} \frac{|G\ \cap \{12\}|}{|G|} & s = Private\ or\ Non\ Urban\ Charter \\ 0 & s \neq Private\ or\ Non\ Urban\ Charter \end{cases}$$

$$W(Urban\ Charter\ Grades\ K-10) = \begin{cases} \frac{|G\ \cap \{0,1,2,3,4,5,6,7,8,9,10\}|}{|G|} & s = Urban\ Charter \\ 0 & s \neq Urban\ Charter \end{cases}$$

$$W(Urban\ Charter\ Grade\ 11) = \begin{cases} \frac{|G\ \cap \{11\}|}{|G|} & s = Urban\ Charter \\ 0 & s \neq Urban\ Charter \end{cases}$$

$$W(Urban\ Charter\ Grade\ 12) = \begin{cases} \frac{|G\ \cap \{12\}|}{|G|} & s = Urban\ Charter \\ 0 & s \neq Urban\ Charter \end{cases}$$

The sum of category weights at a given school always adds up to 1. For example, the urban charter school instructing grades 3-11 introduced above would be weighted as shown in Table 4.

Table 4. Example Weighting Scheme (Urban Charter School with Grades 3 to 11)

Category	Overlap	Weight
Grades K-10	8	8/9 = 0.8889
Grade 11	1	1/9 = 0.1111
Grade 12	0	0/9 = 0.0000

RESULTS

School Traffic Data Analysis

Field data collection concentrated only on afternoon (PM) queue lengths and trip generation, following the assumption in the existing calculator that afternoon carpool queues are generally more severe than their morning (AM) counterparts. Queue length data were calculated for the same categories as the current STC:

- Public: Elementary (PK-5), Middle (6-8), and High (9-12)
- Private/Non-Urban Charter: PK-K, Grades K-10, Grade 11, and Grade 12
- Urban Charter: Grades K-10, Grade 11, Grade 12

Of the categories above, data was available for all except Urban Charter: Grade 11 and Urban Charter: Grade 12. For those categories, parameters were estimated from the existing MSTA calculator. Table 1, listed previously, contains the vehicle trips and queue lengths for each school included in the study.

Several schools generated queues with parallel lines of vehicles throughout some length of the queue. Additionally, some schools served afternoon carpool traffic with multiple separate loading zones. In the case where one loading zone served multiple lines of traffic, analysis proceeded similarly to a school with only a single line of vehicles. Vehicles were recorded as they entered either line of the queue or departed from the queue without specifying which line they were in, generating a combined cumulative arrival curve. The queue length in feet was generated by taking the furthest-back point in each line of the queue that cars reached and adding them together. In the case where multiple loading zones were used, the maximum queue lengths in feet from all component queues were added together, under the assumption that a length of queue equivalent to the combined maximums would be generated if only a single loading zone was available.

The queue and survey data collected by the research team were used to validate the existing STC. Based on the validation results, two major computational changes are proposed to the calculator model:

1. Calculating the max queue length from the 95th percentile of available data, rather than the mean of the sampled schools with an additional 30% safety factor, is necessary due to high variability in school queue lengths.
2. Using a weighting system based on grades instructed at a school captures the unique effects of schools not falling exactly into the STC's "grades instructed" bins.

The PM queue lengths observed by the research team, normalized to a per-student basis, are listed in Table 5.

Table 5. PM Queue Lengths

Category	PM Queue (Weighted n)	Original STC Data: Mean + 30% Safety Factor (Queue Length in Feet Per Student)	95th Percentile
Public Elem	13.000	3.578	4.501
Public Middle	7.000	2.195	2.593
Public High	4.000	1.160	1.281
Private PK-K	0.410	8.933	8.082
Private Grades 1-10	1.436	6.010	8.082
Private Grade 11	0.077	2.113	1.626
Private Grade 12	0.077	2.113	1.626
Urban Charter Grades K-10	1.000	2.249	1.730
Urban Charter Grade 11	0.000	N/A	N/A
Urban Charter Grade 12	0.000	N/A	N/A

N/A = Not Applicable

Corresponding values were generated from Version 04012021 of the existing STC by inputting test student volumes and assuming the recommended number of staff, students, and student drivers. In Table 6, the rightmost column compares the percent change in high demand length, or average queue length with a 30% safety factor, from the existing STC to the field data collected by the research team. Sample sizes are only listed for public elementary, public middle, public high, and private school Grades 1-10 because the other categories appear to be predicted from rules-of-thumb or point estimates in the existing STC calculator. Additionally, the sample sizes do not include known duplicates (one school was repeated twice in the existing STC public elementary dataset, but was not counted towards total sample size here.)

Table 6. PM Queue Length Comparison to Current Calculator

Category	Original STC Data: Mean + 30% Safety Factor (Queue Length in Feet Per Student)	Change from Original STC Data to Research Project Analysis/Data
Public Elem	3.281 (n = 23)	9%
Public Middle	2.451 (n = 7)	-10%
Public High	1.875 (n = 3)	-38%
Private PK-K	5.497	63%
Private Grades 1-10	2.848 (n = 3)	111%
Private Grade 11	4.621	-54%
Private Grade 12	2.250	-6%
Urban Charter Grades K-10	5.497	-59%
Urban Charter Grade 11	4.621	N/A
Urban Charter Grade 12	2.250	N/A

Figure 9 and Figure 10 compare the distribution of the field data to the existing STC. Figure 9 depicts the queue length cumulative distribution functions for public elementary, public middle, and public high schools, comparing existing STC datasets (red) to ITRE field data (blue). All queues are normalized to a per-student basis.

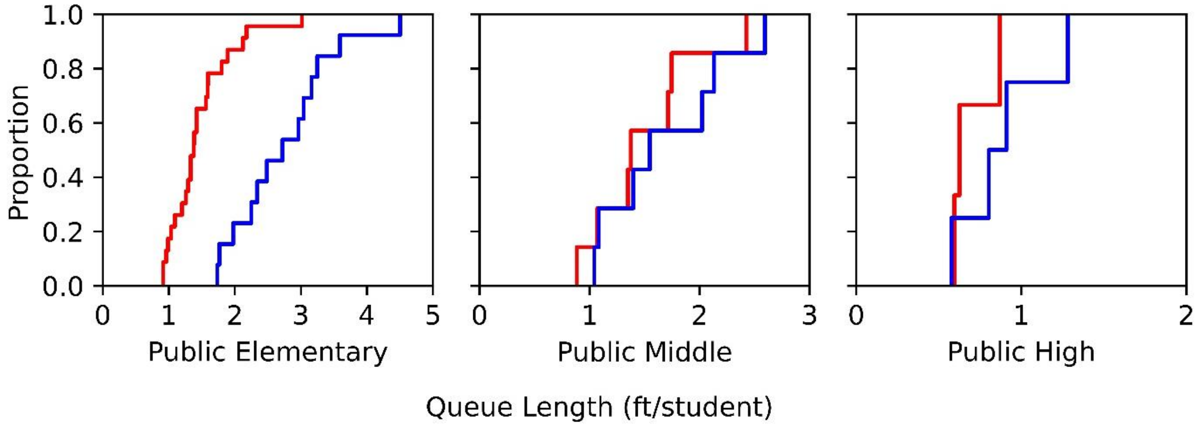

Figure 9. Cumulative Distribution Functions of Queue Length in Feet Per Student (Public Elem, Middle, and High School) [Red = STC Data and Blue = ITRE Field Data]

Figure 10 shows a similar CDF comparison for private schools. However, due to small sample sizes, all grade categories were combined.

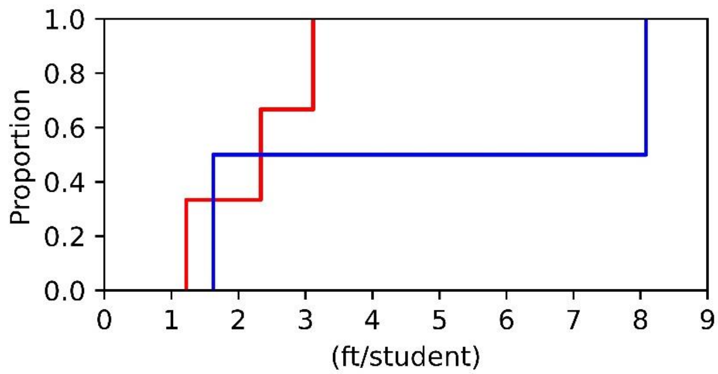

Figure 10. Cumulative Distribution Functions of Queue Length in Feet Per Student (Private Schools) [Red = STC Data and Blue = ITRE Field Data]

Kolmogorov-Smirnov two-sample tests were conducted to determine the degree of similarity between the existing STC data and ITRE field data for public elementary, middle, high, and private schools.

There was a statistically significant difference between the elementary school STC dataset and ITRE field-collected data ($D = 0.783$, $p < 0.001$). There were no statistically significant differences between the middle school STC dataset and ITRE field-collected data ($D = 0.286$, $p = 0.963$), the high school STC dataset and ITRE field-collected data ($D = 0.500$, $p = 0.657$), or the private school STC dataset and ITRE field-collected data ($D = 0.500$, $p =$

0.900). However, all of the tests above should be interpreted with caution due to very small sample sizes.

The strongest conclusions can be drawn from the public elementary school sample (n = 13, while all other samples had seven or less observations). For this category, the existing STC high demand length estimate is comparable to the high demand length projected from the field data, despite the statistically significant difference between the sample distributions. However, the high demand length algorithm itself, at least at the default 30% safety factor setting, does not appear sufficient to capture the upper end of the school queue length distribution. Two of the thirteen sampled schools have longer PM queue lengths than the existing STC high demand length.

To ensure a conservative estimate of queue lengths, a 95th percentile estimator was implemented in the calculator update. In almost all cases, this will result in the predicted queue being based off the longest-queue school in the sample.

Several parameters contribute to total trips generated:

- Number of staff
- Number of student drivers
- Number of buses
- Number of carpool vehicles

Table 7, Table 8, Table 9, and Table 10 compare the mean and 95th percentile of field data, from either queue field studies or surveys of schools, with the data in the current STC.

Table 7. Mean and 95th Percentile Data – Staff per Student

Staff per Student	Survey Weighted (n)	Existing Calculator	Survey Weighted (Mean)	Survey Weighted (95th Percentile)
Public Elem	17.000	0.118	0.146	0.202
Public Middle	4.000	0.102	0.119	0.163
Public High	4.000	0.092	0.096	0.102
Private PK-K	0.577	0.131	0.108	0.114
Private Grades 1-10	3.484	0.131	0.097	0.114
Private Grade 11	0.470	0.114	0.089	0.112
Private Grade 12	0.470	0.103	0.089	0.112
Urban Charter Grades K-10	4.735	0.125	0.118	0.135
Urban Charter Grade 11	0.188	0.114	0.125	0.134
Urban Charter Grade 12	0.077	0.103	0.112	0.112

The yellow-highlighted cells in Table 8 are unrealistically high (exceeding the practical limit of 1 car per student and in consideration of the other schools sampled) and were therefore manually adjusted down to one student driver per student in the updated calculator. The updated calculator assumes an even proportion of student drivers between 11th and 12th grade if both grades are instructed at a school; surveys are planned for the next phase of this project to determine the true split of drivers between grade levels.

Table 8. Mean and 95th Percentile Data – Student Drivers per Student

Student Drivers/Student	Survey Weighted (n)	Existing Calculator	Survey Weighted (Mean)	Survey Weighted (95th Percentile)
Public Elem	N/A	N/A	N/A	N/A
Public Middle	N/A	N/A	N/A	N/A
Public High	4.000	0.160	0.238	0.282
Private PK-K	N/A	N/A	N/A	N/A
Private Grades 1-10	N/A	N/A	N/A	N/A
Private Grade 11	0.470	0.320	0.505	0.874
Private Grade 12	0.470	0.850	0.505	0.874
Urban Charter Grades K-10	N/A	N/A	N/A	N/A
Urban Charter Grade 11	0.188	0.320	1.250	1.765
Urban Charter Grade 12	0.077	0.850	0.506	0.506

Table 9. Mean and 95th Percentile Data – PM Buses per Student

PM Buses/Student	Survey Weighted (n)	Existing Calculator	Survey Weighted (Mean)	Survey Weighted (95th Percentile)
Public Elem	16.000	0.014	0.013	0.038
Public Middle	3.000	0.022	0.012	0.013
Public High	4.000	0.016	0.011	0.014
Private PK-K	0.500	0.014	N/A	N/A
Private Grades 1-10	2.214	0.014	N/A	N/A
Private Grade 11	0.143	0.022	N/A	N/A
Private Grade 12	0.143	0.016	N/A	N/A
Urban Charter Grades K-10	4.735	0.014	0.007	0.019
Urban Charter Grade 11	0.188	0.022	N/A	N/A
Urban Charter Grade 12	0.077	0.016	N/A	N/A

Table 10. Mean and 95th Percentile Data – PM Cars per Student

PM Cars/Student	Queue Weighted (n)	Existing Calculator	Queue Weighted (Mean)	Queue Weighted (95th Percentile)
Public Elem	13.000	0.250	0.192	0.319
Public Middle	7.000	0.160	0.122	0.178
Public High	4.000	0.106	0.054	0.069
Private PK-K	0.410	0.392	0.419	0.495
Private Grades 1-10	1.436	0.263	0.276	0.495
Private Grade 11	0.077	0.347	0.086	0.086
Private Grade 12	0.077	0.136	0.086	0.086
Urban Charter Grades K-10	1.000	0.392	0.081	0.081
Urban Charter Grade 11	0.000	0.347	N/A	N/A
Urban Charter Grade 12	0.000	0.136	N/A	N/A

As with queue lengths, the updated calculator generates 95th percentile estimates for each of the above parameters. However, it should be noted that due to the combination of multiple parameters in estimating the total trips generated, the final result does not correspond neatly to a 95th percentile estimate like the queue length estimator does.

CONCLUSIONS AND RECOMMENDATIONS

Schools continue to be constructed at a rapid pace across North Carolina as the state experiences population growth, particularly in urban regions. Furthermore, existing schools throughout North Carolina and the U.S. continue to experience increases in child passenger pick-up and drop-off, regardless of school age or location (NHTSA, 2009). As a result, accurate estimation of school site queue length needs and trip generation rates are critical to maintaining and improving the transportation safety of North Carolina's communities. This work is significant for NCDOT due to the potential for enhanced accuracy of school travel mode and queue length estimation. Increased accuracy in queue length needs will lead to school site design and traffic management plans that better accommodate school travel demand and corresponding needs. More effective accommodation of passenger vehicles will promote improved traffic safety and operations in communities throughout North Carolina with new school construction and existing schools that have difficulties with queue spillover into surrounding roadways.

The most robust estimates and updates to the calculator recommended based on this research study are drawn from the public elementary school sample (n = 13, while all other samples had seven or less observations). For this category, the existing STC high demand length estimate is comparable to the high demand length projected from the field data. To ensure a conservative estimate of queue lengths, a 95th percentile estimator was implemented in the calculator recommendations stemming from this research. The queue and survey data collected by the research team was used to validate the existing STC. Based on the validation results, two major computational changes to the calculator model are proposed: 1) calculating the max queue length from the 95th percentile of available data and 2) using a weighting system based on grades instructed at a school.

To the extent possible, field data collection excluded holidays, school events, early-release days, and Fridays, but other atypical activities that the research team was unaware of may have influenced the observed values. The research project was completed during the COVID-19 pandemic. However, data collection was completed prior to school impacts from the pandemic, except for a small data collection effort specifically focused on exploring the impacts of the pandemic (which were not included in this analysis).

This research aimed to measure demand for student drop-off and pick-up, which is most directly expressed in terms of the queue length and trips generated. However, student drop-off and pick-up activities can also occur in locations other than the areas designated by the school, such as nearby parking locations, curbs, and other areas that students can walk to and from campus to avoid the queuing process. The research team counted trips generated in this manner as much as possible but due to the nature of these unapproved activities, some of this travel was likely unobserved and is therefore not included in the project data.

An on-going NCDOT research project, 2021-15: Evaluation of School Travel Patterns and Preferences, will provide further updates to the calculator. The updated calculator provided with this report is intended as an interim deliverable, and with the exception of public elementary school predictions, should not be used for school design until RP 2021-15 is complete. The specific efforts include expanding the sample size of locations with highly variable estimates, evaluating trends related to school travel, comparing loading/unloading zone techniques, and developing recommendations for modeling school locations in Synchro. In RP 2021-15, school travel data will be collected by the research team at schools across North Carolina, varying by school type and geography with a focus on school types/characteristics that have highly variable queue length estimates. This new data will be paired with existing STC data. Loading/unloading zones will also be studied to help identify and quantify the most beneficial practices. A couple of additional measures are recommended for a future update of the STC: 1) surveying a sample of schools to determine the distribution of student drivers by grade level and 2) visiting a larger sample of private/non-urban charter and urban charter schools. Both of these actions will be included in NCDOT RP 2021-15 which will further expand the sample size for the STC.

Several future research ideas were identified during this research project. One idea is to further understand and estimate the impacts of vehicles/students who did not travel through the designated queuing area (which could be the result of various school and community factors). Estimates of student drivers by grade and school permitting designations would also be beneficial. Investigations of travel behaviors at schools that have queue lengths that are insufficient to accommodate the demand (i.e., over-capacity) may be useful to better understand how travel behavior may be impacted (which could include mode shift or using alternative drop-off/pick-up locations). Additional student data, such as the distance from the school, mode options, and other built-environment factors could provide useful insights into school travel.

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APPENDIX A: SCHOOL OUTREACH

School Outreach Template

Hello,

My name is ______ and I am contacting you on behalf of the Municipal and School Transportation Assistance Calculator Validation Team. Your school has been selected for data collection to re-calibrate the Municipal and School Transportation (MSTA) Calculator. The MSTA Calculator provides estimates about a school's projected vehicle queue length at school pick-up and drop-off based on maximum student population and other school characteristics. Data required to re-calibrate the current MSTA Calculator is a combination of school operation characteristics and observations of pick-up and release times. We are reaching out to your school to collect preliminary school characteristic data through an online questionnaire as well as schedule a day for Institute of Transportation Research and Education (ITRE) staff to install camera equipment at your school site to collect observational data.

School Travel Questionnaire
We are asking a representative from our partner schools (principal, asst. principal, or other administrator) to complete a questionnaire and participate in a short phone call in order to accurately collect school operations characteristics. Linked below is our current MSTA School Traffic Operations Questionnaire. You are welcome to complete this questionnaire independently or during a short follow-up phone call with the assistance of an ITRE team member. Of note, questions can be skipped if necessary and edited afterwards. Overall, it should take about 15 minutes to fill out the questionnaire. MSTA School Traffic Operations Questionnaire

Scheduling Questionnaire / Site Plan Review
We are also requesting time to engage in a short phone call with your school transportation specialist in order to clarify questionnaire responses, gather more information about your school's pick-up and drop-off operations, and learn more about upcoming special events or other activities that may impact the pick-up and drop-off observation component of this project. Please identify blocks of time that your school transportation specialist is available to speak within the next week and we will schedule our call accordingly. We will also be discussing ideal dates in May to install camera equipment to collect observational data.

Data Collection Field Visit
Two ITRE staff members will be in contact with you to schedule a visit to your school within the next few weeks to collect data. Please inform these field staff of any special events like field trips or after school activities that may affect the length of the pick-up or drop-off queue.

Thank you and please let me know if you have any questions.

District Outreach Template

Hello [Administrative Official],

This is _____ and I am contacting you on behalf of the Municipal and School Transportation Assistance Calculator Validation Team at the Institute for Transportation Research and Education (ITRE). The Municipal and School Transportation Assistance (MSTA) Calculator provides estimates about a school's projected vehicle queue length at school pick-up and drop-off based on maximum student population and other school characteristics. Attached is the NCDOT/ITRE letter of collaboration outlining the project purpose and key contacts. Please be aware that due to staff change, the PI is currently Dr. Daniel Findley. Data required to re-calibrate the current MSTA Calculator is a combination of school operation characteristics and observations of pick-up and release times.

The research study is composed of three elements: a school travel questionnaire that is completed by a school administrator, a site plan review where school staff inform ITRE of any operations characteristics that may not have been reported in the questionnaire, and a queue observation study where ITRE field staff install research cameras on a school campus to observe the maximum queue length for morning and afternoon pick-up and drop-off cycles. The project is NC State University IRB approved. Observation cameras are set at a low enough resolution that distinguishing characteristics and license plate numbers are not detectable.

Are there any special authorizations from the district office that are required to sample schools in your county that are a good fit for the study? If your county is willing to work with us, would it also be possible to obtain some type of memo, email, or other document from the school district's office that we could share with principals demonstrating that the project has support from the district administration?

Thank you and please let me know if you have any questions.

APPENDIX B: USER GUIDE

This section of the report serves as a user guide for the draft School Traffic Calculator. An expanded discussion of the design assumptions and decisions made during the update to the STC back-end is also provided.

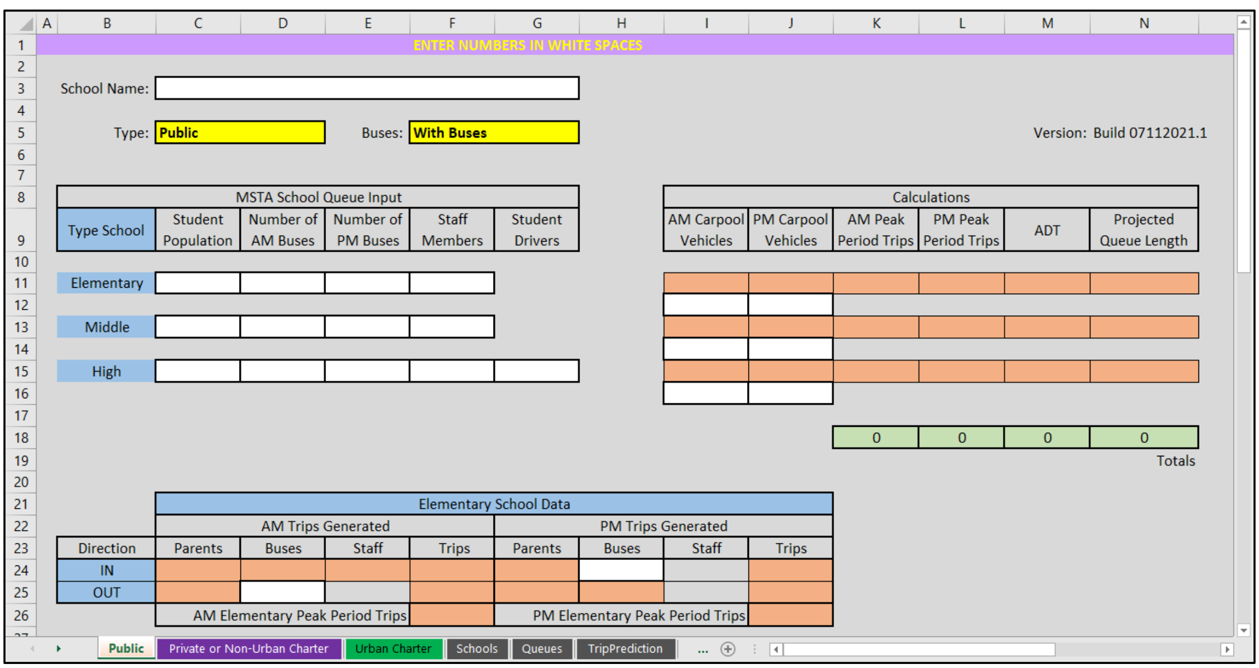
The portion discussing the user-interface pages is also broadly applicable to the current NCDOT version of the School Traffic Calculator, although minor cosmetic differences exist between the two models.

User Interface

Almost all analyst interaction with the STC occurs on the *Public, Private or Non-Urban Charter*, or *Urban Charter* calculation tabs. These spreadsheets require either predicted student population, predicted number of AM carpool vehicles, or predicted number of PM carpool vehicles as an input. Three outputs are produced:

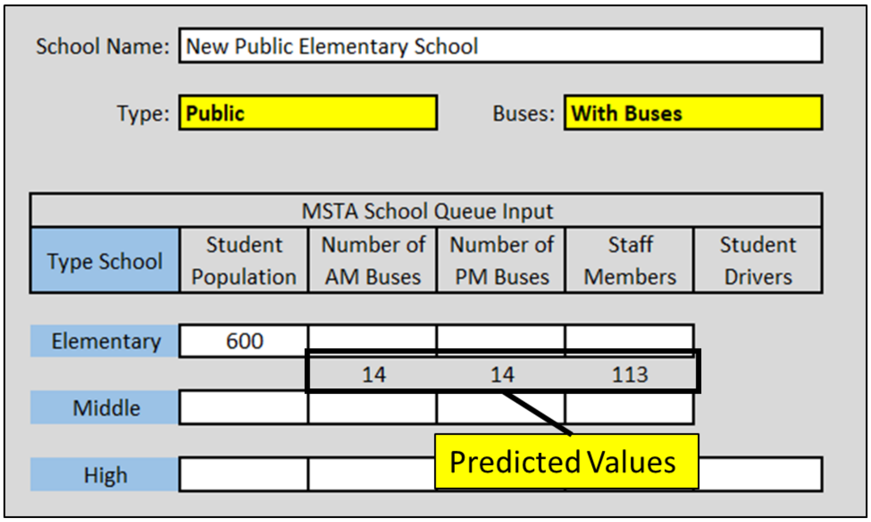
- The predicted maximum carpool queue length, in feet;
- The predicted number of trips generated by the school during the AM peak period;
- The predicted number of trips generated by the school during the PM peak period.

The layout of the tabs is best displayed by example. Consider the design of a new 600-student public elementary school. Buses will be provided. Based on these inputs, the *Public* tab should be selected.

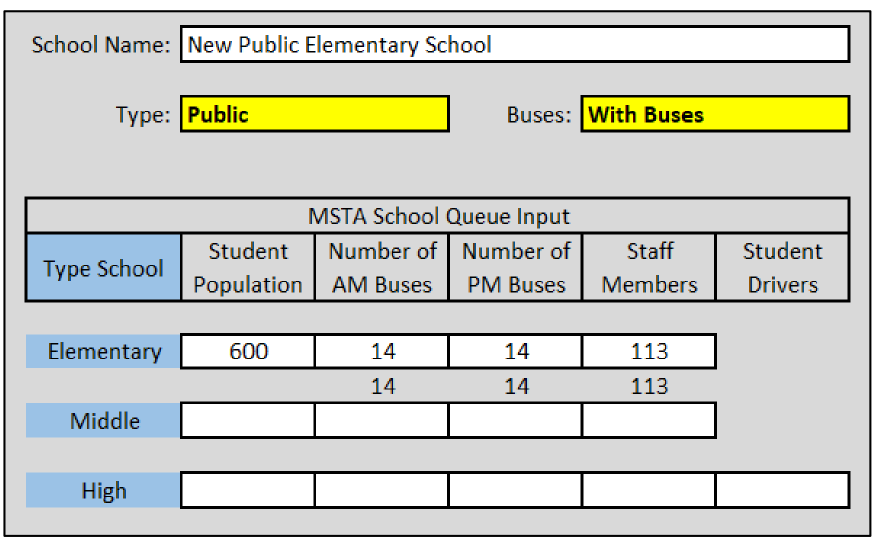


The top left of the page contains input blocks for student population, number of buses, number of staff members, and number of student drivers. Of these, the only value the analyst must know initially is the student population. If the student population is unknown, it can be estimated based on the predicted number of AM or PM carpool vehicles, using the input boxes under the "Calculations" section. Inputs are divided by grade type; elementary school data (K-5) is entered on the first row, middle school data (6-8) is entered on the second row, and high school data (9-12) is entered on the third row. If a school fits into more than one category (e.g. a school instructs kindergarten through eighth grade), multiple rows should be used, with the total student population divided between both, or all three, rows depending on predicted grade split.

After entering the student population, predicted values are generated for the other parameters.



If information about these parameters is available, it should be entered; otherwise, the predicted values can be used. None of the fields in a grade type row should be left blank if that row's student population has been completed.



The "Buses" drop-down option is provided as a data-entry convenience, but does not impact the calculations. If it is known that a school does not provide buses, this option can be adjusted to change all bus predictions to zero.

School Name:	New Public Elementary School				
Type:	**Public**		Buses:	**Without Buses**	

MSTA School Queue Input					
Type School	Student Population	Number of AM Buses	Number of PM Buses	Staff Members	Student Drivers
Elementary	600	14	14	113	
		0	0	113	
Middle					
		0	0		
High					
		0	0		

The section below, *Elementary School Data*, must be filled out to ensure an accurate peak period trip estimate. The number of parents (carpool), bus, and staff trips to and from school are calculated, generating a total number of trips in the morning and afternoon. Most of these cells auto-calculate. However, the number of "Out" bus trips must be entered by the user. This value represents the number of buses that arrive in the morning, but do not stay on campus all day (i.e. they leave to serve another school or park somewhere off-campus after dropping off students.)

	Elementary School Data							
	AM Trips Generated				PM Trips Generated			
Direction	Parents	Buses	Staff	Trips	Parents	Buses	Staff	Trips
IN	273	14	113	400	168			168
OUT	273			273	168	14		182
	AM Elementary Peak Period Trips			673	PM Elementary Peak Period Trips			349

If this value is not known, the most conservative option is to enter the full number of "In" buses. This will generate the largest number of peak period trips and corresponding ADT. In most cases, bus trips make up a very small percentage of total trips in and out of a school. As with the previous section, these cells should not be left blank, or the total trip volume will be underestimated.

	Elementary School Data							
	AM Trips Generated				PM Trips Generated			
Direction	Parents	Buses	Staff	Trips	Parents	Buses	Staff	Trips
IN	273	14	113	400	168	14		182
OUT	273	14		287	168	14		182
	AM Elementary Peak Period Trips			687	PM Elementary Peak Period Trips			363

The upper-right of the page displays the results of the calculator. The predicted number of peak period trips, ADT generated by the school, and projected queue length are provided in the row of green cells below the table.

Calculations					
AM Carpool Vehicles	PM Carpool Vehicles	AM Peak Period Trips	PM Peak Period Trips	ADT	Projected Queue Length
273	168	687	363	1163	2174
		687	363	1163	2174
					Totals

At the base of the page, a standalone tool is provided for estimating the number of cars passing the school per minute during the peak hour of traffic. It is not affected by other calculations on the page.

Roadway ADT	Peak-Hour Traffic Volumes		
	15% of ADT	Major Direction	Minor Direction
500	75	45	30
	Split	60%	40%
	Cars / Min.	0.8	0.5
	0	0	0
	Split	60%	40%
	Cars / Min.	0.0	0.0

AASHTO: On rural roads with average fluctuation in traffic flow, the 30th highest hourly volume is typically 15 percent of the ADT.

Use a 60/40 split unless additional information is available.

The design of the *Public, Private or Non-Urban Charter*, and *Urban Charter* tabs are generally similar. However, the private and non-urban charter tab provides the option to omit pre-kindergarten and kindergarten students from the carpool queue. In some cases, parents of these students will park and walk their students in, bypassing the carpool line. This option should only be selected if sufficient parking spots are provided to serve the pre-kindergarten and kindergarten parents, and it is expected that they will actually use them. The example below shows a private elementary school where PK/K students have been dropped from queue calculations.

Type: Private or Non-Urban Charter

Version: Build 07112021.1

PK & K Park and Walk: Yes

MSTA School Queue Input					
Grade Level	Student Population	Number of AM Buses	Number of PM Buses	Staff Members	Student Drivers
PK & K	50	0	0	10	
				7	
Grades 1-10	300	0	0	40	
				39	
Grade 11					
Grade 12					

Calculations					
AM Carpool Vehicles	PM Carpool Vehicles	AM Peak Period Trips	PM Peak Period Trips	ADT	Projected Queue Length
22	26	53	52	116	0
130	160	300	320	660	2562
		353	372	775	2562

Totals

Back-End Design

In most cases, the sampled schools' metadata, queue lengths, trip generation surveys, and associated calculations do not need to be viewed by the analyst. However, some familiarity with the design paradigm used to structure the STC back-end may provide analysts with a greater understanding of how the calculator's queue length and trip generation predictions are derived.

The back-end is made up of a *Schools, Queues, TripPrediction, ADMCorrectionFactor,* and *Calculations* tab. The first four tabs form a relational database containing data gathered during RP 2019-27, along with data from the previous version of the School Traffic Calculator. The calculations tab aggregates data from all of the sampled schools and interfaces with the public, private/non-urban charter, and urban charter spreadsheets.

<u>Schools Database</u>

The schools sheet contains one record for every school in the School Traffic Calculator.

- sch_ID: A unique identifier used within the STC
- School Name
- EDDIE School ID: A shorthand code taken from the NC DPI EDDIE database; not necessarily unique for multi-campus schools.
- Address
- County
- School Type: Either Public, Private/Non-Urban Charter, or Urban Charter.
    - The NC DPI EDDIE database was used to separate schools visited during RP 2019-27 into public and charter categories. Charter schools were divided into non-urban or urban categories based on the 2010 Census Urban Areas map (1). No private schools were included in the STC update.
        - The previous MSTA School Traffic Calculator used the 2013 North Carolina Urbanized Area Boundaries map (2). Based on discussion with MSTA staff, charter school characterization is location-dependent, and may not correspond to geographic location.
    - Schools extracted from the previous School Traffic Calculator already had school types assigned.
- MSTA Project: Either RP 2019-27, indicating collection by the research team, or Historic, indicating the school was extracted from the previous School Traffic Calculator.
- Removed From Sample: Indicates a school was initially sampled or had data collected during RP 2019-27, but was removed from the sample before data collection could occur or scrubbed afterwards due to further information indicating it violated the sampling frame rules.
    - Only two schools were flagged. One was dropped from the sampling frame before data collection could occur because permission to visit the campus could not be obtained. The other was included in an e-mail survey, but the results were scrubbed because the school had a year-round schedule.
- Notes

The image below shows the upper-left corner of the *Schools* spreadsheet.

sch_ID	SchoolName	EDDIESchoolID	Address	County	SchoolType
1	Millbridge Elementary School	800366	155 Ed Deal Rd, China Grove, NC 28023	Rowan	Public
2	West Rowan Elementary	800406	480 Mimosa St, Cleveland, NC 27013	Rowan	Public
3	Winget Park Elementary	600588	12235 Winget Rd, Charlotte, NC 28278	Mecklenburg	Public
4	Lake Wylie Elementary	600436	13620 Erwin Rd, Charlotte, NC 28273	Mecklenburg	Public
5	Dorothy J. Vaughan Academy of Technology	600475	8601 Old Concord Rd, Charlotte, NC 28213	Mecklenburg	Public
6	Reid Park Academy	600517	4108 W Tyvola Rd, Charlotte, NC 28208	Mecklenburg	Public
7	Harold D Isenberg Elementary	800358	2800 Jake Alexander Blvd N, Salisbury, NC 28147	Rowan	Public
8	Hawk Ridge Elementary	600406	9201 Bryant Farms Rd, Charlotte, NC 28277	Mecklenburg	Public
9	Rama Road Elementary	600512	1035 Rama Rd, Charlotte, NC 28211	Mecklenburg	Public

Over time, one school can occupy multiple addresses, or one address can host multiple schools. For example, a campus may be used as a middle school for a few years, the school move to a new campus, and an elementary school move into the same building(s). The research team attempted to manually remove any cases where this occurred from the final sample out of concern that they would result in correlated observations. Most of the observations dropped from the previous School Traffic Calculator were removed because the school metadata was ambiguous, and there was no way to rule out the possibility of "duplicate" sampling.

<u>Queues Database</u>

Queue records represent a unique combination of school, queue line, and collection date. Data in this tab were either gathered by field data collection or extracted from the previous School Traffic Calculator.

The following fields are provided for each record:

- sch_ID: The school's unique identifier number. Links the queue record to the appropriate school record on the Schools tab.
- Short Description: Generally the school's name, but may also include descriptions such as "Front Queue" or "Side Queue" at schools with multiple queues.
- AM/PM: Indicates whether the queue was measured during morning drop-off or afternoon pick-up.
- Multi Queue: Indicates whether the queue is part of a multi-queue school.
  - The research staff counted schools as having multiple queues if students loaded from spatially separated pick-up locations (i.e. one pick-up zone on the side of the school, and one pick-up zone at the front of the school.) A single pick-up zone where the queue had multiple lines was counted as a single queue.
  - No records of single or multiple queue status were available for queues extracted from the previous School Traffic Calculator.
- Collection Date: Lists the date when field data was collected.
- School Year: Calculated during post-processing; contains the two years that the school year falls into (i.e. 2018-2019 represents the August 2018 – May 2019 school year.)
- Student Population: Lists the number of students present at school on the day the queue data was collected.
- Pop Collection Method: Indicates the method used to capture the student population.

    - The populations of all schools visited during RP 2019-27 were estimated using Average Daily Membership records from NC DPI. ADM records from all months in the collection school year were compared, and the month with the lowest student membership was selected.
    - The method used to estimate student population in the previous School Traffic Calculator is unknown. Based on discussion with MSTA staff, it appears that data collectors checked with the front office on the day they collected data at each school, obtaining the number of students actually present on that day directly. Compared to this method, ADM is likely to overestimate student populations.
- Grades Instructed: The grades instructed by the school at the time the queue was collected. Generally determined by reviewing EDDIE records, reviewing survey data for schools that responded, and checking the school's website.
    - For many locations, it was difficult to determine to a high degree of confidence whether the school instructed pre-kindergarten students or not. The draft STC combines kindergarten and pre-kindergarten groups for most analysis purposes to reduce the effects of this uncertainty on results.
- Total Vehicles In: The total number of carpool vehicles entering the queue.
- Total Vehicles Out: The total number of carpool vehicles exiting the queue after pick-up or drop-off. This value is close to or equal to the total vehicles in; minor differences may occur due to measurement error or vehicles entering or leaving the queue.
- Max Queue (Vehicles): The maximum number of vehicles in the queue.
    - The updated School Traffic Calculator bases queue predictions on the maximum queue length in feet, normalized to a per-student basis. The maximum queue in vehicles was collected for backwards compatibility with the previous version of the School Traffic Calculator.
- Max Queue (Feet): The maximum length of the queue.
    - The maximum length in feet may not occur at the same time as the maximum number of vehicles due to queue shockwaves (i.e. vehicles may be departing the queue at a faster rate than they arrive, but the queue shockwave has not reached the back of the queue yet.)
- Notes

The image below shows the upper-left corner of the *Queues* spreadsheet.

sch_ID	ShortDescription	AM/PM	Multi Queue	CollectionDate	SchoolYear	StudentPopulation	PopCollectionMethod
2	West Rowan Elementary	PM	No	10/28/2019	2019-2020	574	ADM Estimate
7	Harold D Isenberg Elementary	PM	No	10/30/2019	2019-2020	406	ADM Estimate
13	West Rowan High School	PM	No	10/20/2019	2019-2020	1058	ADM Estimate
15	Charles C Erwin Middle School	PM	No	10/29/2019	2019-2020	869	ADM Estimate
24	York Elementary	PM	No	12/2/2019	2019-2020	420	ADM Estimate
27	Bryan Road Elementary	PM	No	12/12/2019	2019-2020	475	ADM Estimate
30	Abbotts Creek Elementary School	PM	No	12/4/2019	2019-2020	865	ADM Estimate
31A	Laurel Mill Elementary (Front Queue)	PM	Yes	3/4/2020	2019-2020		
31B	Laurel Mill Elementary (Side Queue)	PM	Yes	3/4/2020	2019-2020		
31	Laurel Mill Elementary	PM	Yes	3/4/2020	2019-2020	276	ADM Estimate

Trip Prediction Database

The trip prediction database contains bus, staff, and student driver data based on an email survey sent to schools, along with records reconstructed from the previous School Transportation Calculator.

The following fields are provided for each record:

- sch_id: The school's unique identifier number. Links the queue record to the appropriate school record on the Schools tab.
- School Name: The school's name.
    - Database links are based on the sch_id field, not the name field, so there is no guarantee that the school name is exactly identical among spreadsheets.
- Timestamp: The date and time the school survey was submitted by school administrators back to the research team.
- School Year: This field is similar to the School Year field in the "Queues" sheet.
- Attendance Fields (PK/K, 1, 2, ... , 11, 12): Indicates the student attendance by grade.
    - Data for schools surveyed by the research team was gathered from NC DPI records.
      Grade breakdowns for schools in the historic STC were not available; however, total student population was. An even distribution among all grades was assumed unless more detailed information was available in the school records.
- Pop Collection Method: This field is similar to the Pop Collection Method field in the "Queues" sheet.
- Program: Describes the calendar type for the school.
    - All schools surveyed by the research team were either classified as Regular Calendar or Year Round schools.
        - Only one Year Round school was surveyed. It was later dropped from the final calculations to maintain consistency with the original sampling frame rules, which restricted sampling to traditional-calendar schools, but is retained on the data spreadsheet in case future updates expand the model to account for the effects of year-round scheduling.
    - School records extracted from the previous STC were labeled as Unknown, since no corresponding calendar records were available.
- School Staff: The self-reported number of staff members serving at the school.
- AM Buses: The number of buses serving the school in the morning.
- PM Buses: The number of buses serving the school in the afternoon.
- Student Drivers: The total number of student drivers, across all grades, attending the school.
    - For private/non-urban charter and urban charter schools: Attendance by grade is used to split the student drivers up into 11^{th} and 12^{th} grade "bins." The draft STC divides student drivers among grades 11 and 12 equally, or assigns all drivers to one grade if the other is not served by the school.
    - For public schools: Student drivers are calculated on a student driver per high school student basis.
- Notes

The image below shows the upper-left corner of the *TripPrediction* spreadsheet.

sch_id	School Name	Timestamp	School Year	PK/K	1	2	3	4
74	Aberdeen Elementary	HistoricData	HistoricData	118	118	118	118	X
75	Alexander Wilson	HistoricData	HistoricData	100	100	100	100	100
76	Altamahaw-Ossipee	HistoricData	HistoricData	100	100	100	100	100
77	Archdale Elementary	HistoricData	HistoricData	78	78	78	78	78
64	Envision Science Academy	2019/05/01 12:56:59 PM AST	2018-2019	75	76	80	80	79
66	Maureen Joy Charter School	2019/05/03 9:30:15 AM AST	2018-2019	63	63	66	73	74
63	Bradford Preparatory School	2019/05/07 12:26:18 PM AST	2018-2019	92	99	108	115	128
70	Oxford Preparatory School	2019/05/08 4:19:44 PM AST	2018-2019	X	X	X	X	X
68	Pinnacle Classical Academy (Lower Elem Campus)	2019/05/09 10:23:19 AM AST	2018-2019	109	104	87	X	X
67	Lake Lure Classical Academy	2019/05/10 4:31:12 PM AST	2018-2019	29	27	38	41	44
69	Pinnacle Classical Academy (Upper Campus)	2019/05/10 4:37:23 PM AST	2018-2019	X	X	X	84	90
62	Alpha Academy	2019/05/11 12:20:06 PM AST	2018-2019	81	112	99	93	63
71	Research Triangle High School	2019/05/14 4:17:48 PM AST	2018-2019	X	X	X	X	X
72	Youngsville Academy	2019/05/16 4:40:35 PM AST	2018-2019	60	54	59	56	40

ADM Correction Factor Database

The ADM correction factor spreadsheet compares the attendance reported by schools to the attendance at those locations estimated from NC DPI average daily membership records. Correction factors are also provided to apply the difference in reported attendance and ADM estimates to other schools visited during RP 2019-27.

Average daily membership data was collected from NC DPI records for all schools, and the lowest ADM over the school year was taken as an approximation for school attendance. At the end of the RP 2019-27 project timeline, schools where queue data had been successfully collected were contacted, and schools were asked to provide exact attendance records. The reported records include a mix of head counts and Principal’s Monthly Record data, and are best interpreted as a slightly more accurate estimate than the ADM records.

Correction factors were generated for public elementary, public middle, private and non-urban charter, and urban charter schools to adjust the ADM estimates. No public high schools responded to the request for records, so a correction factor of 1 was assumed.

Student population records were present in two locations in the calculator: the queues database, and the trip prediction database. All student populations in both, with the exception of historic records inherited from the existing MSTA calculator, were updated using the correction factors. Where actual attendance data was available, it was applied to the queue database only, since the survey was generally filled out on a different day than the school was visited to collect queue data.

sch_ID	School Name	EDDIE School ID	School Type	Grades Instructed	Collection Date	ADM Estimate	Reported Attendance	Correction Factor
31	Laurel Mill Elementary	350330	Public	K - 5	3/4/2020	276	293	1.0616
7	Harold D Isenberg Elementary	800358	Public	K - 5	10/30/2019	406	407	1.0025
27	Bryan Road Elementary	920349	Public	PK - 5	12/12/2019	475	478	1.0063
18	Lynn Road Elementary	920488	Public	PK - 5	1/22/2020	493	476	0.9655
34	Northwoods Elementary	920520	Public	PK - 5	1/23/2020	601	656	1.0915
22	Wakelon Elementary	920597	Public	K - 5	12/5/2019	518	536	1.0347
20	Wildwood Forest Elementary	920618	Public	K - 5	12/4/2019	641	600	0.9360
24	York Elementary	920628	Public	PK - 5	12/2/2019	420	411	0.9786
60	Holly Shelter Middle School	650343	Public	6 - 8	3/2/2020	689	731	1.0610
43	Wakefield Middle	920594	Public	6 - 8	2/3/2020	944	886	0.9386
68	Pinnacle Classical Academy (Lower Elem Campus)	23A000	Private_or_NonUrbanCharter	K - 2	5/22/2019	300	317	1.0567
69	Pinnacle Classical Academy (Upper Campus)	23A000	UrbanCharter	3 - 11	5/29/2019	530	549	1.0358
64	Envision Science Academy	92Y000	UrbanCharter	K - 8	3/7/2019	703	694	0.9872

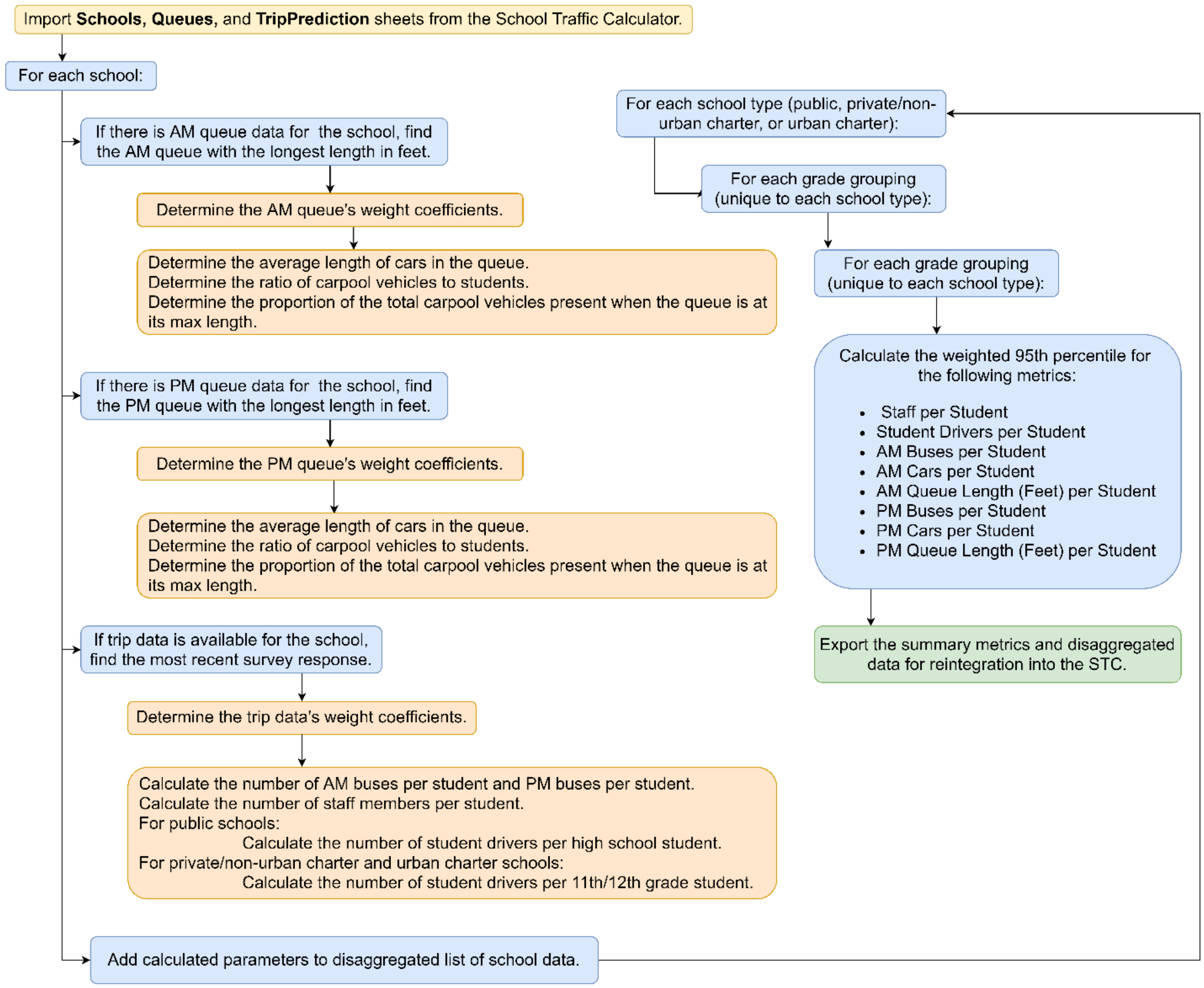
Category	Sample Size	Avg CF	Lower 95% CI	Upper 95% CI
Public Elementary	8	1.0096	0.9667	1.0525
Public Middle	2	0.9998	0.2221	1.7774
Public High	0	1.0000	N/A	N/A
Private/Non-Urban Charter	1	1.0567	N/A	N/A
Urban Charter	2	1.0115	0.7024	1.3206

Calculations Spreadsheet

The calculations spreadsheet contains the following summary metrics for each combination of school type and grade level:

- Staff per Student
- Student Drivers per Student
- AM Buses per Student
- AM Cars per Student
- AM Queue Length (Feet) per Student
- PM Buses per Student
- PM Cars per Student
- PM Queue Length (Feet) per Student

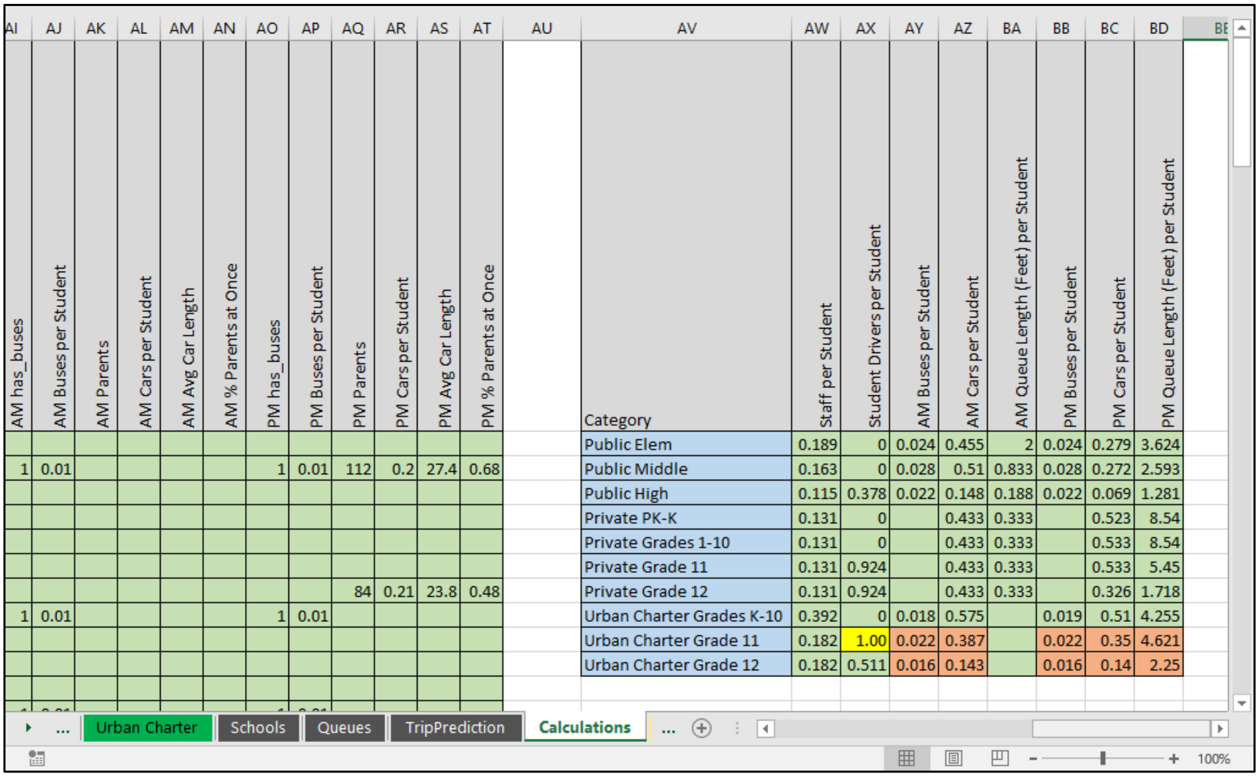
Individual statistical weights, along with the component variables used to calculate the metrics above, are also displayed for each school. Data aggregation is performed using an external script, rather than inside the workbook itself. The diagram below outlines the “behind-the-scenes” data analysis and aggregation process:



The following assumptions were made during data aggregation:

- Schools that did not have records for total number of carpool parents, average car length, and the ratio of carpool vehicles to total number of students (i.e. all components of a measured queue) were not used in calculating the average queue length per student in feet.
- Unrealistically high ratios (i.e. a ratio of student drivers to students greater than 1.00, or a ratio of carpool cars to students of greater than 1.00) were adjusted to 1.00.

The image below shows the upper-right corner of the *Calculation* spreadsheet, including the summary metrics. Note the yellow-highlighted cells; these represent unrealistically high ratios that were corrected to 1.00. The orange-highlighted cells represent values that were not available in the ITRE dataset; as a result, they were estimated from the current MSTA calculator and will be updated in future research.



AM has_buses	AM Buses per Student	AM Parents	AM Cars per Student	AM Avg Car Length	AM % Parents at Once	PM has_buses	PM Buses per Student	PM Parents	PM Cars per Student	PM Avg Car Length	PM % Parents at Once
1	0.01					1	0.01	112	0.2	27.4	0.68
								84	0.21	23.8	0.48
1	0.01					1	0.01				

Category	Staff per Student	Student Drivers per Student	AM Buses per Student	AM Cars per Student	AM Queue Length (Feet) per Student	PM Buses per Student	PM Cars per Student	PM Queue Length (Feet) per Student
Public Elem	0.189	0	0.024	0.455	2	0.024	0.279	3.624
Public Middle	0.163	0	0.028	0.51	0.833	0.028	0.272	2.593
Public High	0.115	0.378	0.022	0.148	0.188	0.022	0.069	1.281
Private PK-K	0.131	0		0.433	0.333		0.523	8.54
Private Grades 1-10	0.131	0		0.433	0.333		0.533	8.54
Private Grade 11	0.131	0.924		0.433	0.333		0.533	5.45
Private Grade 12	0.131	0.924		0.433	0.333		0.326	1.718
Urban Charter Grades K-10	0.392	0	0.018	0.575		0.019	0.51	4.255
Urban Charter Grade 11	0.182	1.00	0.022	0.387		0.022	0.35	4.621
Urban Charter Grade 12	0.182	0.511	0.016	0.143		0.016	0.14	2.25

Section References:

(1) North Carolina Department of Transportation. (n.d.). *https://connect.ncdot.gov*. map. https://connect.ncdot.gov/projects/planning/TPB%20Documents/MPO_UZA_MAP_2013.pdf.

(2) Census Bureau. (2018, November 9). *2010 Census Urban Areas*. www.nconemap.gov. https://www.nconemap.gov/datasets/nconemap::2010-census-urban-areas