School Travel Data Collection: Comparing the Use of Quadcopter Drones with Travel Tally Surveys

A Thesis
Presented in Partial Fulfillment of the Requirements for the
Degree of Master of Science
with a
Major in Civil Engineering
in the
College of Graduate Studies
University of Idaho
by
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May 2021

Authorization to Submit Thesis/Dissertation

This thesis of Cody S. Hodgson, submitted for the degree of Master of Science with a Major in Civil Engineering and titled " School Travel Data Collection: Comparing the Use of Quadcopter Drones with Travel Tally Surveys," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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Abstract

Travel tally surveys are administered by elementary, middle, and high (K-12) schools to collect data that measure how students arrive and leave school each day. This data can be used to determine both transportation safety and mobility needs. Collecting this data is usually accomplished by asking teachers to collect a tally in their classrooms; the data are then compiled to determine a representative result for each school. This process requires advanced planning from school administrators and teachers to ensure that information gathering is coordinated and relies on the personal input of each student. Since the age of elementary school students may be as little as six or seven years old, this approach may not always be reliable.

In this study, a new method using a quadcopter drone was examined. For comparison purposes, participatory student tally surveys and drone videos were collected on the same day at three different elementary school sites, and the results and effectiveness of each counting method were compared and analyzed. The study concluded that the survey and drone results did not always yield similar results for all modes, so an explanation as to why these deviations occurred and what it means for researchers and practitioners is discussed. Given that drone technology continues to evolve, the lessons learned from this study can be applied toward future school transportation and other mobility studies.

Acknowledgments

This work has been funded by the United States Department of Transportation's University Transportation Center program through the Center for Safety Equity in Transportation (CSET). The author would like to thank CSET for their support.

Dedication

This work is dedicated to my mother, father, brother, all my friends, and my coworkers at Welch Comer Engineering who supported and helped me throughout the duration of this research. Without their assistance and encouragement, this research would not have been possible.

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Chapter 1: Introduction

School tally surveys at elementary, middle, and high schools have been used to identify the primary travel mode of each student between his or her home and school. Based on factors such as travel distance, neighborhood safety and security, and parent or guardian schedule flexibility, each child will either walk, bicycle, travel by car, take a yellow school bus, or ride public transportation. The collection of this data, in addition to capturing travel trends over time, can be used to inform both the school and local community of potential safety and mobility needs either on school property or in the immediate vicinity of the school.

These school tally surveys have historically been administered in individual classrooms. A teacher asks a series of travel-related questions to his or her students, such as how they arrived or departed school, and students raise their hand when answering in the affirmative. The process requires the participation of teachers and students alike and assumes that the responses provided by each student is reliable. When students are of elementary school-age, it would be fair to assume that specific responses may need to be further scrutinized. Because of the potential limitations of this approach, other methods to collect student travel data are worth considering. For this research, the use of a quadcopter drone was explored as an additional and less intrusive method for collecting school travel data. The use of drones has become more accessible than ever given their lowering price point, relative ease of operation, and implementation in many transportation-related data collection efforts.

The purpose of this research was to determine if using a drone to collect student travel data would be simpler, more cost- and time-efficient, and more reliable than relying on participatory student surveys. To address this purpose, drone data and student travel tally surveys were collected and analyzed at three different elementary schools in Moscow, Idaho on the same day.

In Chapter 2, a literature review is provided describing both school travel tallies and the evolving use of drones for data collection. The methodology required to operate and fly a drone, along with the data collection and processing procedures that were developed for this study, are discussed in Chapter 3. The study results are subsequently described and analyzed in Chapter 4 and includes a description and comparison of the two different collection methods for the benefit of researchers and practitioners alike. Opportunities for future work are described in the conclusions section as part of Chapter 5.

Chapter 2: Literature Review

Travel data is most often associated with motorized vehicles. The techniques, technologies, and methods used for collecting this data have been refined over many years to make the process as efficient as possible. With the recent push and growing interest for alternative methods of (non-motorized) travel like walking and bicycling, appropriately quantifying this demand is needed to support ongoing programs and to justify the design need for new facilities. Pedestrian and bicycle data collection are a comparably new study area with multiple technologies being evaluated (Ryus et al., 2014). Research and data collection using quadcopter drones, as an example, is still quite novel despite its increasing accessibility to the general public as formal guidelines for using quadcopter drones as a routine data collection tool have not yet been formalized.

This literature review will examine several topics related to school travel and data collection. Pedestrian and bicycle data collection will be reviewed along with the technologies used to collect this non-motorized travel data. This assessment will be followed by a brief look at the Safe Routes to School program along with school travel data collection and the methods used to collect this data. Lastly, prior research using drones to collect travel data will be discussed.

Pedestrian and Bicycle Data / Data Collection

Pedestrian and bicycle travel data are not often collected by transportation agencies in the United States due to lack of resources, guidance, and perceived need or use of data. While motorized travel counting methods, techniques, and technologies have long been studied, improved upon, and utilized, non-motorized data resources have evolved in the last two decades and are still being updated and refined as new research is published (Figliozzi et al., 2014). Initial efforts to create guidance on estimating non-motorized travel data were led by the Federal Highway Administration (FHWA) in 1999 (Schwartz et al., 1999) and jointly by the Institute of Transportation Engineers and Alta Planning and Design in 2004 (Nordback et al., 2016). The FHWA published a guidebook containing several National Cooperative Highway Research Program (NCHRP)'s reports, including Report 797 and Projects 07-19 (Ryus et al., 2014) and 07-19 (2) (Ryus et al., 2017), on pedestrian and bicycle volume data collection in 2014 that described methods used to estimate non-motorized travel. The NCHRP 797 report was directed at practitioners involved in collecting non-motorized count data. The objective of this research was to provide guidance on collecting pedestrian and bicycle volume data for existing, new, and innovative technologies and methods. This data collected could then be used to fund plans to provide healthier and safer alternatives of travel.

In addition to these studies, other non-motorized counting guidelines have been adopted by state departments of transportation (DOTs) and local transportation agencies for specific purposes. As an example, the Colorado Department of Transportation (CDOT) published a non-motorized monitoring program evaluation and implementation plan in 2012 to evaluate current data collection methods to ensure that data collection was both efficient and useful for future state and local planning and design efforts (CDOT, 2016). Los Angeles County published guidelines in June 2013 on conducting bicycle and pedestrian counts to improve safety and prioritize bicycle and pedestrian improvement projects (Los Angeles County, 2013). The Idaho Transportation Department (ITD) created a toolbox for bicyclists and pedestrian counts and published it in August 2013 under the name *Toolbox for Bicyclists and Pedestrian Counts* to help communities invest in nonmotorized transportation infrastructure (ITD, 2013).

Because of the increasing demand and use of nonmotorized travel data, new research continues to evolve that focuses on streamlining pedestrian and bicycle data counting. In some cases, the effectiveness of the data collection equipment is prioritized over the creation of a guideline that describes the methods or techniques that should be used in collecting nonmotorized travel data. To understand the effectiveness of specific data collection equipment, the types of pedestrian and bicyclist data that each piece of equipment collects need to be further examined.

Common Pedestrian and Bicycle Data Collected

Los Angeles County's guidelines for conducting non-motorized counts are detailed in the report *Conducting Bicycle and Pedestrian Counts: A Manual for Jurisdictions in Los Angeles County and Beyond* (Los Angeles County, 2013). This report provides a collection sheet which gathers data on the following factors: gender, age, weather condition, direction of travel, other methods of travel such as skateboarding or rollerblading, wheelchair/special needs, bicyclists riding on sidewalks, helmet use, turning movements, and pedestrian crossing direction.

The ITD pedestrian and bicyclist toolbox recommends collecting information such as: origin and destination data, trip frequency, identifying improper use of infrastructure, and assessing the current use of existing infrastructure. ITD also recommends collection data such as: gender, age, helmet use, and direction of travel. This toolbox recommends collecting counting data between July and September to obtain peak walking and bicycling volumes. If at a high-density tourist location, ITD suggests counting twice a year so that both low and high visitation periods are measured.

The collected data recommended as part of NCHRP Project 07-19 and 07-19(2) included environmental data to determine trends in modal travel choice behavior and different weather conditions. Notably, Project 07-19(2) recommended factors such as daytime temperature separated into groups such as cold (<30°F) and hot hours (>90°F) as well as weather conditions such as rain, snow, or thunder. This report also detailed how different environmental conditions may affect data collection. It should be noted that due to location and time of year limitations, few adverse weather conditions were experienced within the testing period for this report and, as a result, little statistical evidence was found to show that these weather conditions had large impacts on data collection. A larger set of data during adverse weather conditions could potentially show a better correlation between weather and modal transportation choice.

Data Collection Methods and Technologies

Since there is not one specific guideline detailing the collection of non-motorized transportation data, the methods and technologies used vary depending on the purpose of the research as some methods may be better for collecting qualitative data, like gender or age, rather than quantitative data such as the number of bicyclists of pedestrians or direction of travel. The research methods used to collect data for research studies may not always be economically feasible to replicate, leaving these data collection methods as one-time activities for design and industry purposes.

NCHRP Projects 07-19 and 07-19 (2) evaluated a total of eleven different counting technologies and reported the research findings and conclusions on the efficacy of each technology. This research was then documented in NCHRP Report 797: *Guidebook on Pedestrian and Bicycle Volume Data Collection* (Ryus et al., 2014). This guidebook detailed the different count technologies and types of data collected when evaluating the efficiency of these technologies. As part of NCHRP Project 07-19, the collection equipment evaluated included: passive/active infrared, pneumatic tubes, inductive loops, piezoelectric strips, and radio beams. For NCHRP Project 07-19 (2), additional collection technologies were examined: thermal imaging, radar, pneumatic tubes, and piezoelectric strips. While the NCHRP Project 07-19 (2) was completed in late 2016, this project did not describe how the use of unmanned aerial vehicles (UAVs) or quadcopter drones that captured video footage for subsequently data extrapolation and processing could be incorporated. The study, however, documented the use of thermal imaging, which represents an alternative method of data collection from standard RGB video cameras that can be derived from drone video processing technologies. Previous research described how well a UAV and thermal imaging camera can detect and track pedestrians in an urban setting (Ma et al., 2016), and with the general cost of technology decreasing and quality increasing, collecting pedestrian data with higher quality thermal imaging cameras will be a feasible alternative in the future. Based on NCHRP Report 797 and Project 07-19 (2), the methods used to collect non-motorized traffic data as well as their advantages and disadvantages were summarized below. (Table 2.1)

Table 2.1: Counting Technologies Advantages/Disadvantages

Counting Technology	Advantages	Disadvantages
Manual In-Field Counts	• Cost effective • Additional information can be noted (direction, gender, behavior) • Theft proof	• Relies on data collector training, motivation, and management for accurate manual counts • Non-permanent • Inaccurate in certain cases (if too much additional information is needed) • Counting tool affects accuracy (i.e. pen and paper vs clicker)
Manual Video Counts	• Can be re-watched and zoomed for multiple counts • Additional information can be noted (direction, gender, behavior) • More cost-effective than in-field counts	• Susceptible to theft • High labor costs • Position is fixed to mounting point
Automated Video Counts	• Can be re-watched and zoomed for multiple counts • Additional information can be noted (direction, gender, behavior) • Low time-investment	• Costly • Less accuracy than manual • Limited application (cannot be used within large crowds) • Unrefined process still being researched
Inductive Loop Detectors	• Permanent system • Very accurate and precise for bicyclists • Cheaper	• Needs calibrated periodically • Bicycle Specific
Passive Infrared	• Easy to install • Cheap and common • Low time-investment • Accurate and consistent	• Background conditions can false trigger a count (mirrors, windows, reflective surfaces) • Not good for large groups • Good results depend on placement
Active Infrared	• Cheap • Large range (up to 30m)	• Cannot distinguish objects breaking beam • Not accurate for large groups
Radio Beams	• Less susceptible to theft • Accurate for low volume	• Cannot distinguish objects breaking radio signal • Not accurate for large groups
Pressure and Acoustic Pads	• Permanent • Good for walkways, trails, or sidewalks • Counts both pedestrians and bicyclists	• Installation can be difficult • Depend on direct contact • Susceptible to problems with freezing
Magnetometers	• Easy to install • Accurate in non-mixed traffic for bicyclists	• Does not perform well in mixed traffic • Does not count pedestrians
Thermal Imaging Camera	• Allows for passive counts • High accuracy	• High cost • Limited applicability • Newer counting method, still being researched
Radar	• Theft proof	• Labor intensive and intrusive install • Placement can cause over reads if vehicles encroach on sensor
Bicycle-Specific Pneumatic Tubes	• Cheap • Accurate • Passive	• Bicycle specific • Requires direct contact • Low accuracy in colder weather due to rubber stiffening
Piezoelectric Strip	• Highly accurate and precise • Passive	• Labor-intensive and intrusive to install • Does not count pedestrians

Each method of collecting non-motorized traffic data was examined based on factors including, but not limited to: ease of implementation, level of effort and cost, strengths and limitations, accuracy, and typical use.

ITD lists its common methodologies that can be used to conduct a bicycle or pedestrian count. Their list includes observation counts, mechanical counters, laser counters, video cameras, surveys, and GPS locators (ITD, 2013). The Oregon Department of Transportation conducted a 2014 study on bicycle and pedestrian data collection. Their methods included inductive loops, pneumatic tubes, passive and active infrared sensors, magnetometers, pressure and seismic sensors, thermal imaging, radar/microwave, and manual and automated video image processing (Figliozzi et al., 2014).

Other agencies have developed bicycle and pedestrian volume data collection toolkits that recommend how this data should be collected. The Los Angeles County toolkit suggests several different counting technologies such as: pneumatic tubes, inductive loop detectors, piezoelectric strips, pressure or acoustic pads, active and passive infrared, laser scanning, radio/microwaves, active and passive video processing, magnetometers, and manual counts (Los Angeles County, 2013).

The states of Colorado and Washington have similar toolboxes that offer guidance in coordinating pedestrian and bicycle traffic counts. These toolboxes recommend similar equipment as those previous described as part of the Los Angeles County toolkit. The common methods that could be used to simultaneously count both pedestrians and bicycles are:

- Surveys
- Infrared sensors (passive and active)
- Radio/microwave detectors
- Automated video (passive and active)
- Inductive loops
- Manual field data counts

Participatory surveys can also be used to collect volume data. These surveys serve as a popular way to gather estimates of modal travel information for much larger areas. National travel surveys are implemented by some countries like the United States (McGuckin and Fucci, 2018) and the United Kingdom (Department of Transport, 2018) to gather nationwide modal transportation data. These travel surveys are voluntary so response rates vary. The data collected is not reported per city or jurisdiction, rather, these surveys collect travel statistics of an entire nation so using this information for specific engineering design projects will likely be limited.

Safe Routes to School / School Travel Data Collection

There are a select number of reports and guidelines that detail school travel data collection needs and how this data should be attained. One primary example is attributed to the Safe Routes to School (SRTS) program. This domestic program has established a methodology in the form of a student survey (Safe Routes, 2020) that is now used by schools throughout the country. The survey created by SRTS consists of a student travel tally that is voluntarily administered by each participating teacher to the students at that school. Data collected using these surveys include how the students traveled to school in the morning and how the students departed school in the afternoon. Other information gathered from these surveys also include distance traveled from home to school and the age of the children taking the survey. An example of the survey is included in Appendix A.

These surveys are then self-reported back to SRTS, and the information collected is used to identify the expected numbers of vehicles, pedestrians, and bicyclists during each school's respective drop-off and pick-up time periods. The National SRTS partnership processes/analyzes the data and reports the results from this survey. With this data, it is possible to see trends over time by school as well as modal travel choice split percentages in different weather scenarios. This data can be used by schools to create programs that incentivize non-motorized travel options or establish safe routes for already active students. These tallies have been used to support the validity of funding/projects to increase walking/biking to school; however, there are limited measures to show the efficacy of programs like SRTS. There is no national or statewide requirement to collect this data as there is no designated SRTS program any longer. SRTS programs instead are diversely funded by local funds, state funds, and transportation agencies.

This data can be utilized at a statewide level. For example, the Virginia Department of Transportation (VDOT) had published their statewide SRTS tally count to the public. VDOT reports the results of their SRTS program based on mode of travel, preferred travel mode in different weather conditions, and mode of travel used to and from school for each day of the work week (Monday to Friday) (VDOT, 2018). The information that can be derived from these results includes individual counts of bicyclists and pedestrians, as well as motorized (bus/passenger car) vehicles. The data are collected during different periods of the school day and include morning drop-off and afternoon pick-up times.

This information can be useful for many engineering purposes as these expected numbers serve as estimates for peak-hour vehicle and pedestrian volumes in these areas; however, the method has some notable drawbacks. The release of data is also not typically seen for each state, county, or city. Since these surveys are participatory and may require incentive for the teachers to participate, it is also reasonable to assume that the data collected from each school may not be entirely comprehensive. No training per se, simple on-paper instructions, are given to the teacher's administering the surveys which can lead to questions that and faulty data collected. The assumptions of this data collection approach generally assume the following:

- All schools in a district participate in the survey
- All teachers participate in the survey.
- All surveys are conducted in the same manner.
- All students correctly identify their arrival and departure travel mode.
- All students participate in the survey.

School transportation data detailing how students arrive and leave is not required at the federal, or state level for all transportation modes. This data is not required at the local level either albeit bus counts as bus users introduce income to the school. Some school districts collect transportation data to assist their communities in making safe travel choices and to participate in opportunities to secure funding for their schools. This data could be used to facilitate non-motorized modal transportation, support the safety of school zones, incorporate a SRTS program, or justify implementation of traffic calming at high density pedestrian areas. Many schools do not always consider how their students get to school or often see the benefits that the data could bring. This means that readily available data to assist in planning for non-motorized community travel programs or traffic calming design for roads frequently travelled by students is lacking.

The Use of Drones

With increased interest in non-vehicular modes of travel, the demand for good modal data at a lower cost is high. The previous methods described to collect data have limitations which are usually associated with a high operating cost or long-processing time, so a non-intrusive and passive method for data collection could prove incredibly valuable. Unmanned aircraft vehicles (UAVs) or quadcopter drones could serve as a model towards collecting non-vehicular modal transportation data due to their relatively low entry cost, ease of use, and number of vantage points over fixed camera video counts. Middle to higher-end drones are equipped with additional features that could be useful for collecting data such as a 4K resolution video capture camera, ability to create flight paths, and safety features that prevent accidents and decrease the risk associated with flying a drone in or near populated areas.

In Salt Lake City, Utah, the performance of UAVs against street-view websites and on-the-ground counts to save time and money on data collection for urban planners and designers was reviewed. This research focused primarily on the use of high-quality video produced by the drone to perform manual counts and allow for subsequent viewings. These subsequent viewings were then used to gather other user information like gender, age group, and mode of transportation. Because this research was conducted with the intent to extrapolate data manually from the video, the drone was flown at low heights (50 to 70 feet) to allow for additional detailed data on each pedestrian. The reliability of the drone data captured was compared to data collected from street-view websites such as Google Street View and Bing Streetside as well as manual traditional counts done concurrently with the UAV flight. The results of this study showed that UAV pedestrian counting can be considered a reliable alternative to on-the-ground counting as well as online street imagery counting. The study highlighted some advantages of counting via drone, such as covering larger areas or capturing video for future analysis. Some identified disadvantages included unsuitability for longer-term data collection and limited factors such as areas with flying constraints and adverse weather (Park and Ewing, 2018).

Additional pedestrian-related drone research has focused on dealing with a computing vision system to allow for detection of pedestrians through the use of low-cost RGB and thermal imaging (De Oliveira and Wehrmeister, 2018). The intended application of this study was not for traffic purposes but for search and rescue missions; thus, the need for real-time execution was needed. For most traffic engineering applications, the need for real-time execution is unnecessary and larger time periods for the video to be processed after data collection are allowable. The slower processing time with only a high-resolution RGB camera could result in more accurate results so that each frame recorded with the UAV can be analyzed. Recent studies have involved pedestrian detection and tracking focused on different methods to achieve accurate results.

A research project involving pedestrian travel data collection using a small UAV was conducted last year (Yeom and Cho, 2019). This research was concerned with detection and tracking of moving pedestrians. For this research, one automobile was used alongside twelve to thirteen pedestrians to analyze the accuracy in distinguishing different methods of transportation. Data were collected at a flight height of fifteen meters or approximately fifty feet. Visual detection of the pedestrians and automobile was done mainly through the process of frame subtraction and other noise cancellation operations to increase detection efficiency. Few pedestrians can occupy a particular region of interest thus making object detection through the use of frame subtraction valuable at low flight altitudes.

Additional research has been conducted that focuses on multiple object detection. Most of the research on multiple object detection has examined the types of video processing systems that would yield the highest accuracy. Multiple vehicles were tracked through capture from a UAV and filtering through the integration of two systems, namely image processing and Kalman Filtering (Lee and Yeom, 2019). Moving object detection was researched for a freely moving camera that used the process of background motion subtraction (Wu et al., 2017).

Thermal imaging has been used in conjunction with UAVs to detect and track pedestrians (Ma et al., 2016). Thermal imaging was used due to conditions like small target size and low contrast between the background and the target. The conditions that thermal imaging are best suited for are likely to be present for a drone being flown at high altitudes with pedestrians wearing darker clothing that could blend into shadows or asphalt; however, thermal imaging presents some difficulties like decreased resolution size and higher cost. Specific conditions, like sliding window size dependent on the height of the UAV, must also be satisfied to gather good data capture while using a thermal imaging camera. With these limitations, thermal imaging would not be appropriate for covering larger areas and would be cost-prohibitive in many cases.

As the use of drones continues to evolve as a more mainstream means of collecting non-motorized data, this research sought to specifically measure how this method could be used to facilitate the collection of school travel data. In the next chapter, the methods used to conduct such a study are described. Unique study requirements, such as protecting student privacy and anonymity, are also highlighted.

Chapter 3: Methodology

The methodology for operating and flying a drone consisted of three steps: (1) pre-flight setup, (2) data collection, and (3) data processing. For this study, all three elementary schools in the city of Moscow, Idaho with a significant student walking and bicycling population were included as data collection sites.

For the first step, initial preparations were required in order to be able to collect data in a public space. This first step was crucial to the research, as improper planning could have resulted in unsatisfactory results. After obtaining the necessary permissions from both school district administration and the respective principals at each school, data collection was conducted on December 11th, 16th, and 18th of 2019. The drone video data collected at each school was subsequently processed in order to both quantify and classify student travel mode at each location.

Pre-Flight Setup

Before collecting drone data at each school site, all potential flight areas were first evaluated to identify the key locations or points of interest that would be most beneficial for tallying each student's travel mode. Good planning during this initial stage would help during the manual evaluation analysis stage. Many factors were used to determine the key locations for collecting pedestrian, bicycle, and vehicle traffic data. To classify and count different travel modes at each school, five or more locations at each school were chosen based on the likely paths for each travel mode choice.

With these key locations determined, the position where the drone would take off (flight site) needed to be determined. The flight site was selected to mitigate altering or affecting the behavior of any travel mode but also be close enough to where objects like pedestrians are bicyclists were not represented by a few pixels in the video capture; the flight site needed to allow for a clear visual of all key areas. A pre-flight check of the area, when possible, helped to address visual conflicts in the area such as trees, light posts, and buildings that could obstruct the view from the drone's video capture. Flight sites for this study were determined using Google Earth as well as on-site visits. Coordination with those familiar with the location is highly recommended so that input on observed travel patterns to help determine flight sites and key locations can be received. For this study, coordination with each school principal and the school district superintendent occurred after the flight plan and method of data collection were finalized. Approval from the Office of Research Assurances at the University of Idaho was also obtained. These steps were completed to reflect the careful planning of this research effort and to minimize any potential danger or personal harm during the data collection process.

This study involved flying a drone near the public which required many risk assurances to be in place before collecting any data. The University of Idaho's (UI) Unmanned Aircraft Systems (UAS) committee required a flight/risk management plan to ensure the research was being done in accordance with the Federal Aviation Association's (FAA) rules for Small Unmanned Aircraft Systems (SMUAS). The flight/risk management plan requirements changed with the categorization of the proposed UAV flight.

Most drone flights are categorized as a civil operation or a commercial purpose but there are other categories such as governmental function, education purpose, or public safety operation. Flights in the civil operation category are for recreational use, while flying under the commercial purpose category usually means there is a financial benefit involved or is being used for a business. Governmental function flights involve actions undertaken by the government like national defense, firefighting, search and rescue operations, or law enforcement. Education purpose public safety operation flights are commercial flights that are done within the public that require special waivers due to not being fully covered by a Section 107 license. Civil operation and education purpose flights fall under the exception of USC 44809 of Section 107 and does not require an FAA-certified SMUAS license. Drone pilots within this classification must comply with all portions of Section 44809 when flying a drone for recreational purposes. When flying the drone for the other listed purposes, the operator of the drone must have a FAA SMUAS Section 107 license. For this research, the flight categorization was classified as a commercial flight; thus, a pilot with an FAA SMUAS Section 107 license was required by the UAS committee to fly at each site.

FAA Section 107 Pilots License

For this research, two options were available to meet the FAA Section 107 requirement. The first option was to hire a pilot from the University of Idaho who had already obtained a Section 107 license to fly the drone. The benefits of this option were that no work other than planning and scheduling would be needed to be able to fly and collect data. The disadvantages were that flights at a later notice would be difficult to arrange with the school district, visual flight observers, teachers, and parents of the student subjects. This disadvantage also would not have allowed for schedule flexibility and could have been detrimental as plans for flights can change due to unsatisfactory weather. Changes in the schedule could have also adversely affected the survey that was to be completed on the same day as the flight. It also would have added more cost to the project as the pilot would need to be paid for their work and a rescheduled date not within the blanket drone insurance period would need to be re-insured. Depending on how many flights would need to be flown, paying for a pilot could have been costly with a large number of flights but advantageous for a small amount of flights.

The second option was for a member of the research team to take the Section 107 test and obtain a pilot’s license. The disadvantage for this option was the time investment necessary to study and pass the test. The test also required a fee of around $150 for every test attempt. In addition, if the test taker failed the test, then a minimum wait time of 14 days was required to retake the test. The benefits for this option were that scheduling for each flight would become easier by always having a licensed pilot readily available. The SMUAS license is good for two years at a time before the test needs to be retaken. For maximum convenience and to save initial start-up costs on the research effort, this second option was selected.

Certification for the SMUAS license was obtained by taking and passing the Section 107 drone pilot written test. This test was taken at a FAA certified testing center. To prepare for the test online resources were accessed; YouTube video lectures and online practice exams are a couple of resource examples freely available to the public that will help with those wishing to obtain their Section 107 license.

The UAS committee also required an approved flight plan to ensure the safety of the test subjects. A flight plan was created to illustrate where the drone would be flying and its flight altitude. Because the drone would be piloted around the vicinity of elementary students, the flight was categorized as a high-risk commercial flight by the UAS committee. The flight plan for a high-risk flight had several different requirements that needed to be satisfied to gain approval from the UAS committee. The UAS committee’s requirements for any high-risk flight included:

- Minimum of five visual observers (VOs) (to scan the skies for potential air traffic conflicts),
- Detailed map for each school indicating flight location,
- Time and date of flight,
- Drone registration through the FAA and insurance, and
- Written authorization from each school principal.

To properly illustrate the flight plan, separate maps were created using ArcGIS that showed the proposed flight site location at each school. Each map contained three possible sites that were deemed to be good flight locations based on the ability to capture predetermined points of interest while avoiding any undue influence on student travel (i.e., student distraction). Details on each flight site were necessary to illustrate how subject safety would be addressed and demonstrate acceptable FAA methods from the VOs and the pilot-in-command (PIC). An AutoCAD draft of the flight plan was created to show the position, direction, and spatial responsibility of each VO as well as the location of the drone at the flight site. The flight site also included protective measures to prohibit unauthorized persons to be underneath the drone while in flight. With the use of at least twelve candlestick traffic delineators and a roll of caution tape, a physical barrier was created to deter entrance by any subjects. A barrier was shaped in the form of a forty-foot diameter circle with the drone being flown directly in the middle of each site. The VOs also acted as perimeter crowd control to provide more security at each site. The UAS committee had concerns about the effectiveness of VOs scanning the skies and also the ground but because the drone would not change its position throughout the entirety of its flight duration the PIC would not need to have his or her hands on the controller at all times and could act as a fifth VO; therefore, the UAS committee permitted four visual observers and one PIC to be present during the flight and approved of their use to also provide perimeter control. With acceptance from the UAS committee on the flight plan and a modified Safe Routes to School survey completed (discussed in the next section), permission to fly could then be appropriately discussed with each school.

Modified Safe Routes to School Survey

Through consultation with a local SRTS program with experience collecting travel tally data, a best practice through alteration of the original SRTS survey was created minimize the burden of the school and teachers to collect the data. Minor modifications were made to the SRTS tally sheet to make certain that only project-relevant information was collected and to minimize the amount of work and loss of instructional time for the teachers gathering the tally data. Form details such as the date and the school name were pre-filled since these items are determined prior to when and where the data collection would be taking place. Specific line items like weather and transit travel were removed because the weather could be recorded by the research team on the day the drone was flying and because there were no mass transit vehicles picking children in Moscow, Idaho, respectively. Additional factors such as carpool and family vehicle were merged to create a "car" section that made it easier for children to distinguish during the tally count. The original tally sheet also required the tally to be conducted on two of three days, either on Tuesday, Wednesday, or Thursday, throughout the week for two periods within the day, AM or PM; which equaled a total of four different counts throughout the week. The modified tally was shortened to one specified day depending on the flight day and one specified morning data collection time. The language of the original tally was updated to ask children, "How do you plan to leave for home after school?" rather than also including questions about how the children arrived at school.

The flight plan, survey, and acceptance by the UAS committee were completed prior to any school meetings in order to demonstrate that a safe and insured method of research could be implemented. A proposed schedule, proof of insurance for each drone, proof of license, and approval from the University of Idaho's Institutional Review Board were compiled into a packet for each school. Approval for this research required approval from the Moscow School District superintendent and each school principal. Requirements from the school district superintendent and principals included a sharing of any data collected and the guarantee of data animosity to protect the identities of students. After receiving approval for the sites, the data collection effort was able to proceed.

Data Collection

A DJI Mavic Pro Platinum quadcopter drone was used for data collection. This drone was chosen because of its easy accessibility, community resources, lower entry-drone cost, high-quality 4k camera, and flight-time capabilities. It was important for the drone to have at least a 4k camera to be able to zoom in and capture each zone of interest with enough detail to distinguish subjects. The drone needed to have a sufficient flight time to allow data to be collected during one take-off and landing. A second battery was purchased to ensure that a fully charged battery would be available at the flight site in the event of any battery malfunctions and to ensure that the entire duration of the flight/recording period would be captured. Based on manufacturer specifications, the DJI Mavic Pro Platinum can fly for up to thirty minutes on one fully charged battery, and the retail cost for this model at the time of purchase was approximately $1,000. To record the duration of the flight in 4k quality, a 100GB SD card and SD card to USB converter were also purchased. Data collection followed the approved flight plan outlined in the pre-flight setup. Figure 3.1 shows the pre-flight setup that was used as well as the location of the VOs, drone, and PIC.

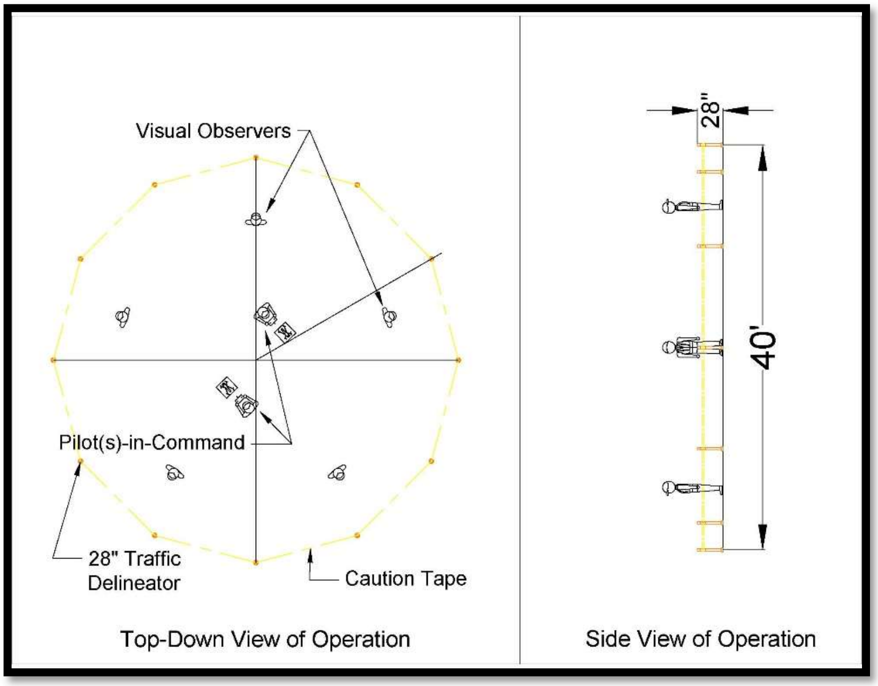
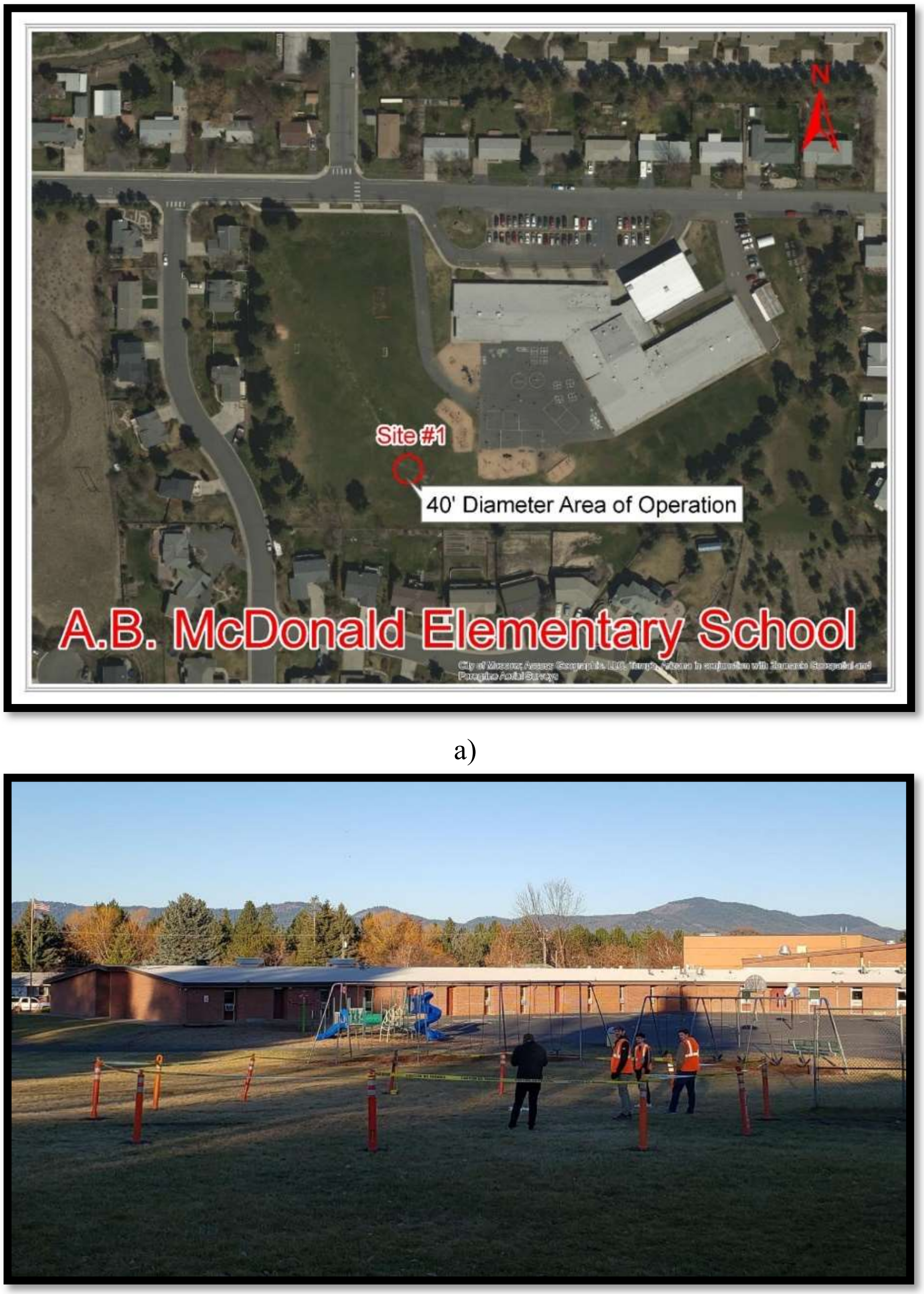


Figure 3.1: Flight Site Configuration

Once at the flight site, orange candlestick delineators were placed in a forty-foot diameter circle around the center of the drone launching point. Caution tape was used to create a physical barrier to deter subjects from entering the flight site. A breach within the flight site from unauthorized personnel would require the drone to be immediately grounded to comply with UAS guidelines and would result in data loss; for that reason, extra effort was taken to keep unauthorized personnel out of and away from the flight site. After the setup of the flight site, the drone and personal safety equipment like a small fire extinguisher and high-visibility vests were brought to flight site.



a)

b)

Figure 3.2 Example of a) School Site Map and b) Delineated Drone Flight Area (at McDonald Elementary)

<u>In-air Drone Procedure</u>

Once the drone was in the air and in position to record data, a procedure based on a list of criteria was carefully followed by the drone operator. Throughout the duration of the flight, the operator was careful to make certain that these criteria were being followed. In some instances, the criteria needed to be modified and on-site amendments made. The list of criteria to be followed is as follows:

- Fly at the determined altitude for the respective site.
- Minimize all camera and drone movement.
- Keep all areas of interest in view.
- Keep the drone within the flight site.
- Obey all FAA rules.
- Land the drone immediately if unauthorized personnel enter the flight site.

To ensure that all data were collected as part of one flight, the drone was flown during a defined afternoon dismissal period; the drone was flown for the duration of the battery life or when there were no more visible subjects. In two of the four flights, the drone was grounded after it was determined that there were no more subjects left to capture. The reasons for these difference outcomes will be discussed later in the analysis section. After the drone returned to land, the site was broken down and all equipment removed from the flight location.

Modified Safe Routes to School Survey Data Collection Procedure

Student tally survey data collection was conducted on the same day as the drone flights. The modified SRTS tally sheet is included in Appendix B. The tally form was distributed to each school a minimum of one full workday prior to the scheduled flight. This was done to make sure that the teachers had enough time to read over the survey and ask questions, if necessary. The surveys were handed to the principal who then distributed the form to individual teachers, with the number of surveys directly proportional to the number of teachers teaching at the beginning of the school day. The instructions on the form asked teachers to conduct the tally at the beginning of their class on the day of the flight. Students were asked how they planned to leave school for home after the school day and the teacher read off the options listed on the tally to let the children know their options. A second reading of these options preceded the performed count; the teacher counted the number of students that raised their hands when they heard the option that best matched their response. The student could only vote for one travel mode, so the number of tallies should have equaled the number of students present in each class. After the full tally was conducted, the surveys were turned into the office and collected by the principal to later be retrieved by the research team for analysis.

Data Processing

The video data processing was divided into two different steps which examined both an “unedited” version and “edited” version. The unedited videos consisted of a manual review with no editing to the videos, while the edited version, based on lessons learned, consisted of videos which were zoomed in to target specific viewing areas and additional reviewing instructions for each data collection reviewer.

Unedited Video Manual Counts

The unedited manual counts were viewed with no recommended tally method. Three different individuals manually counted the subjects within the videos. By not giving any rules to the counters, common methods could be identified and implemented as guidelines to counting the edited videos. Common counting methods that resulted from this unedited manual count included:

- Counting travel modes individually per viewing
- Multiple viewings of the same video
- A focus on certain sections within the video
- Speeding up the video playback

Each person counted the entirety of the unedited data one time. Throughout the process of counting, each counter kept track of the amount of time it took to complete each school count. After each unedited video count was completed for each school, the time and the data were compiled into a spreadsheet for later analysis. With common counting methods identified, a new counting method was subsequently created in an attempt to increase the accuracy and consistency of the results. The new counting method required some editing of the videos to support the common counting methods listed above.

Video Processing and Editing

Video editing for the edited counting method was limited to altering the view and scale of each video. Video processing was necessary for the edited manual counting process for several reasons. The video directly recorded from the drone was only partly useful in the case of available equipment like an extra-large 4k television that could provide a large enough picture to distinguish subjects of interest (i.e., students) from other observable subjects (i.e., parents, other pedestrians). The video was also subject to user error if any of the criteria in the in-air drone flight section was not met at any time during the video collection. Because the video files were quite large, the drone divided the video into four gigabyte (GB) files to prevent data corruption in case an error occurred while recording. As a result, longer duration timed flight data collection videos were separated into usually three different videos rather than a continuous streaming one video. This issue could be resolved using a simple video editing and processing software application.

The video editing software used to mitigate for the described effects was Adobe Premiere Pro. Through Adobe Premiere Pro, many of the disadvantages could be corrected for and assisted the user as part of the edited video counting. The first step to solving these disadvantages was to combine all videos into one single video. With only one viewing, user concentration could be better maintained throughout the duration of the video. Merging these videos was easily done by dragging and dropping the videos within the software's video editing timeline. A simple joining of these videos could then be performed to create one large section of videos rather than three separate ones.

Color correction was not done on the videos since this factor would have been influenced by personal preference. The contrast and brightness of each video could have been adjusted by each reviewer on his or her own viewing device.

Cordon Boundary Survey

For the edited videos, specific areas of interest were more important than others. The objective within each area of interest was to create survey boundary lines (i.e., cordon lines) within the video frame to simplify the count and subject classification process. The key locations assigned a during the pre-flight setup could be framed and used to track, tally, and classify the objects moving into and out of the frame. These frames could be used as cordon lines as different transportation modes cross over the frame boundaries. Due to an already known travel path associated transportation mode, cordon boundaries were established with each travel mode choice in mind. After the video was recorded, focusing in on these boundaries would allow for more accurate counts of subjects by reducing background distractions. Increasing the focus by zooming in to these videos also allowed for subjects to be distinguished more clearly.

To increase the focus of these cordon boundary areas using the Adobe software, a keyframes tool is used. Keyframes can be edited into the cordon boundaries by adjusting the zoom factor in the video editing tab. The video can then be exported to show the area of interest; however, by zooming into the area of interest, alterations to the camera position are amplified within the viewing window. This is a large disadvantage because the cordon boundaries will often move outside of the boundaries with small camera adjustments. An effective method of making sure that the viewing window stays within the cordon boundaries is by utilizing the keyframe animation tool.

If the drone significantly moved during the in-flight data recording (typically associated with strong winds), then video stabilization methods were needed to adequately focus on each area of interest. The keyframe animation was used to reduce excess motion generated during the video capture. The process of applying keyframe animations included assigning keyframes at different times during the video so that the animation would pan from one keyframe to the next. The drawback to this tool was that it was time consuming to implement in the video; however, when done correctly, the video would have the appearance of being a stable stationary shot. Within this same editing tab, the angle that the keyframe could also be adjusted. This was used to rearrange the orientation of the viewport to utilize the longitudinal direction of a monitor. After the editing was completed, data processing using the edited videos commenced.

Edited Manual Counts

The edited videos were viewed by each counter and included an additional set of instructions. The instructions were developed based on the feedback provided by the counters during the first round of video reviews. The instructions provided to each counter consisted of the following:

- Only count students, do not include parents. (Work to best ability to distinguish if parent or student.)
- Make a count just as students are about to exit the frame in the counting boundary. (Counting boundaries will be represented by a RED line in the figures below for the pedestrian and bicycle travel modes.)
- Do not count pedestrians/bicyclists that enter the frame over the counter boundary.
- Only make counts for cars where the student(s) is seen entering the car.
- If students are seen exiting the frame, they will be counted as a pedestrian, regardless of parent accompaniment.
- Use of the 2x playback speed in the video player is recommended.

The counter was also given a figure of each school (Figures 3.3 - 3.5). As noted on each figure, cordon boundaries were identified and associated with each mode of travel.

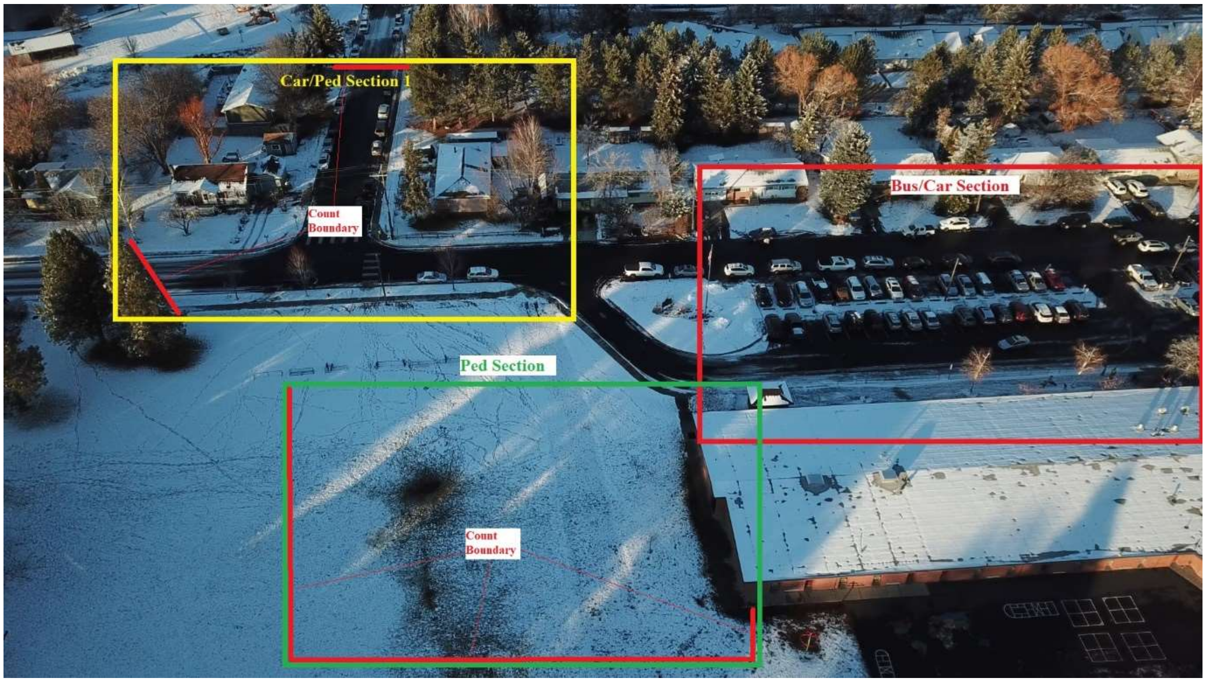


Figure 3.3: A.B. McDonald Elementary Cordon Lines and Boundaries

Figure 3.4: Lena Whitmore Elementary Cordon Lines and Boundaries

Figure 3.5: Russell Elementary Cordon Lines and Boundaries

Chapter 4: Results and Analysis

This chapter will describe the results of the drone flights at each school and the results of the school tally survey. For the video reviews, the raw data results will include outcomes from both the unedited videos and edited videos. Three reviewers counted both the unedited and edited videos; one additional counter was only able to count the unedited videos. Because the analysis of the counts did not require each counter to watch each version of the videos, all available count data results were reported. On-site challenges as well as difficulties reported by the counters reviewing the videos will also be described.

Unedited Video

After the drone videos were collected for each of the three schools, four individuals were enlisted to review the videos and, to the best of their ability, determine the mode of travel for each child departing the school. The videos used were unedited; in other words, they represented the images captured directly from the drone. During this process, the enlisted individuals were also asked to provide input as to how the counting process could be streamlined to improve efficiency and accuracy. The counters also reported their aggregate time spent and noted their counting techniques. Specific techniques included isolating individual travel modes during each viewing, viewing each video multiple times for accuracy, focusing on certain sections within each video, and speeding up the video playback during periods of no or limited activity.

McDonald Elementary

The results from McDonald Elementary were inconsistent amongst all counters. The counters provided feedback on their experience with counting by using the unedited video and took note of areas where there was difficulty in counting that could have caused this variation between results. One difficulty noted by the counters was a car pickup area where a large portion of students entering vehicles were not fully captured due to constraints of the capture area being limited and due to height restrictions mandated in the FAA or narrow allowable drone capture area. Because this was also the largest area covered by the school, the counters had trouble distinguishing between parents and students at farther distances away from the drone (i.e. walking out of the upper frame). Other issues experienced at this site included sight obstructions like overhangs and trees that not only blocked view but created shadows which made it harder to observe students. Since these videos were recorded around 3:30 PM in late December in northern Idaho, the natural light from these videos began to decrease throughout the capture, causing the constant between students are the background to be limited and increasing difficulty for counters.

Table 4.1: McDonald Elementary (Unedited Video)

	Bus	Car	Ped	Bikes	Total	Time (Hours)
Counter #1	29	45	62	4	140	1.5
Counter #2	53	38	88	3	182	2.0
Counter #3	47	13	88	4	152	2.5
Counter #4	33	59	121	0	213	1.0

One near-problem encountered while flying at McDonald was that a local Moscow hospital helicopter approached the flight sight from the northeast, while the drone was in the air capturing footage. According to Section 107, the drone must immediately descend and give right of way to larger aircraft if close to the helicopter's flight path. This encounter happened during the data collection activity, but did not affect the results as the event happened just prior to school dismissal.

Lena Whitmore Elementary

The bus and bicycle results for Lena Whitmore using the unedited video were consistent. These results can be attributed to the fact that there was only one bus was observed during the data collection period and both the bus pickup area and the bike rack were relatively close to the flight zone. The difficulties encountered during video counting were similar to those at McDonald. Some obstructions like trees blocked views of pickup areas and darker recorded areas continuously got darker later into the afternoon. One dark area at Lena Whitmore was a blacktop asphalt near the bike racks and school bus pickup area, which made students wearing darker clothes blend into the background and cause trouble for the counters. The angle of the drone used at this location was less than the other sites because the flight site was farther away from some of the key viewing areas. This led to smaller images of the students on the video; in some cases, larger groups of students who were farther away obstructed other students making assessment difficult. One positive aspect of this flight site was that key school exit locations were easily viewed based on the flight height of the drone.

Table 4.2: Lena Whitmore Elementary (Unedited Video)

	Bus	Car	Ped	Bikes	Total	Time (Hours)
Counter #1	22	22	76	2	122	1
Counter #2	22	57	111	2	192	2
Counter #3	19	38	96	2	155	3
Counter #4	21	47	114	0	182	1.5

Russell Elementary

The Russell Elementary results were the most consistent of all the schools, particularly the results among counters 2, 3, and 4. The major difference between counter 1 and the others was the significant difference in pedestrian counts. Because this school had the smallest captured surface area, the drone was easily able to capture the entirety of the perimeter at a high flight altitude and high camera angle to provide extra distinguishability between groups of students at distances. The school was dominated by steep hillsides, which limited flight site locations as the site needed to provide a reasonably level forty-foot diameter area of operation. Because of the school's geography, the flight site location was restricted to the middle of the school area, and consequently, a large portion of car pickup areas were not captured. The decision to not capture this area was made to be able to capture the school bus pickup area as well as the school exits and a large crosswalk area. These elevation changes limited drone flight height; for flights within the United States, drone flight height is limited to 400 feet above ground level (AGL). As an example, if the flight site is 100 feet below the area of interest, the maximum height the drone will be able to capture the area of interest is 300 feet, rather than 400 feet. Flight sites at areas with high slopes should be positioned to have no more than a fifty-foot elevation difference between the site's highest ground elevation; to ensure that at least 350 feet is provided for the drone to adequately capture the areas of interest.*)*

Table 4.3: Russell Elementary (Unedited Video)

	Bus	Car	Ped	Bikes	Total	Time (Hours)
Counter #1	68	6	40	0	114	1
Counter #2	71	9	83	1	164	1.5
Counter #3	71	13	81	1	166	2.5
Counter #4	71	9	72	1	153	1.3

Feedback reported by the counters for this school listed positives as well as negatives for how these results could be counted consistently. A positive listed for this site was that the bus pickup area was fully captured and was close enough for counters to be able to distinguish between parents and students. It was also noted, however, that obstructions were present at these bus pickup areas that made counting more difficult.

The results for the unedited videos showed that there was a large deviation between results for the counters in most cases. The goal for this first stage of analysis was to compare the count totals, means, and standard deviations. The standard deviation was important to this research as it showed which schools and travel modes had the largest variation between counters and directly related to the effectiveness of the captured data for that scenario. These values helped to develop alternative counting methods using the edited videos. When comparing the standard deviations amongst the school data, this result did not allow for a direct comparison between schools because their totals and means varied. For this reason, the coefficient of variation was calculated to be able to compare these deviations between the schools as it represents the ratio between the mean and standard deviation (Table 4.4)

Table 4.4: Unedited Video Statistical Analysis

		Bus			Car		
		Mean	**St. Dev**	**Coefficient of Variance**	**Mean**	**St. Dev**	**Coefficient of Variance**
Unedited Videos	**A.B. McDonald**	40.5	11.36	0.28	38.75	19.26	0.50
	Lena Whitmore	21	1.41	0.07	41.00	14.85	0.36
	Russell	70	1.41	0.02	10.75	4.03	0.37
		Ped			**Bike**		
	A.B. McDonald	89.75	24.17	0.27	2.75	1.89	0.69
	Lena Whitmore	101	19.58	0.19	1.5	1	0.67
	Russell	69	19.92	0.29	0.5	0.58	1.15

At first glance the school and travel mode with the highest standard deviation value for all modes was A.B. McDonald with a standard deviation value of 24.17 for the pedestrian mode; however, the coefficient of variance was calculated to be only 0.27 which is not the maximum value calculated on the table. This value indicates that although the standard deviation was high, it is closer than other counts to the mean. The mode with the highest coefficient of variance was the bike mode at Russell with a maximum of 1.15. This also makes sense as these numbers are much smaller and thus the sample size is not sufficiently large enough to be statistically analyzed. The largest coefficient of variance between the other modes of travel was 0.50 for McDonald's car counts. The car counts had the largest variance between the counters for each school, and this result indicates that the mean and standard deviation between the car counts were quite large. To illustrate the standard deviation and the mean collected from this unedited data collection method, the probability mass function for each school's travel mode was plotted to directly compare the areas which best captured each travel mode (Figures 4.1–4.4).

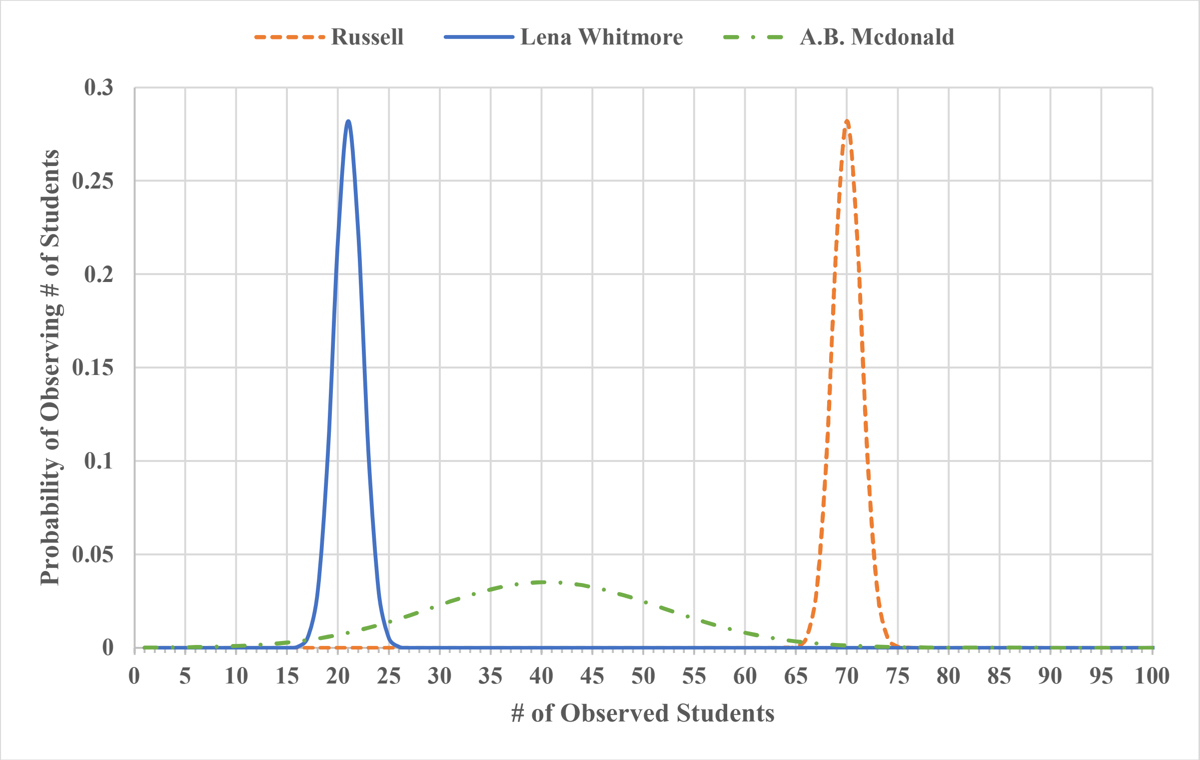


Figure 4.1: Bus Observations PMF (Unedited Video)

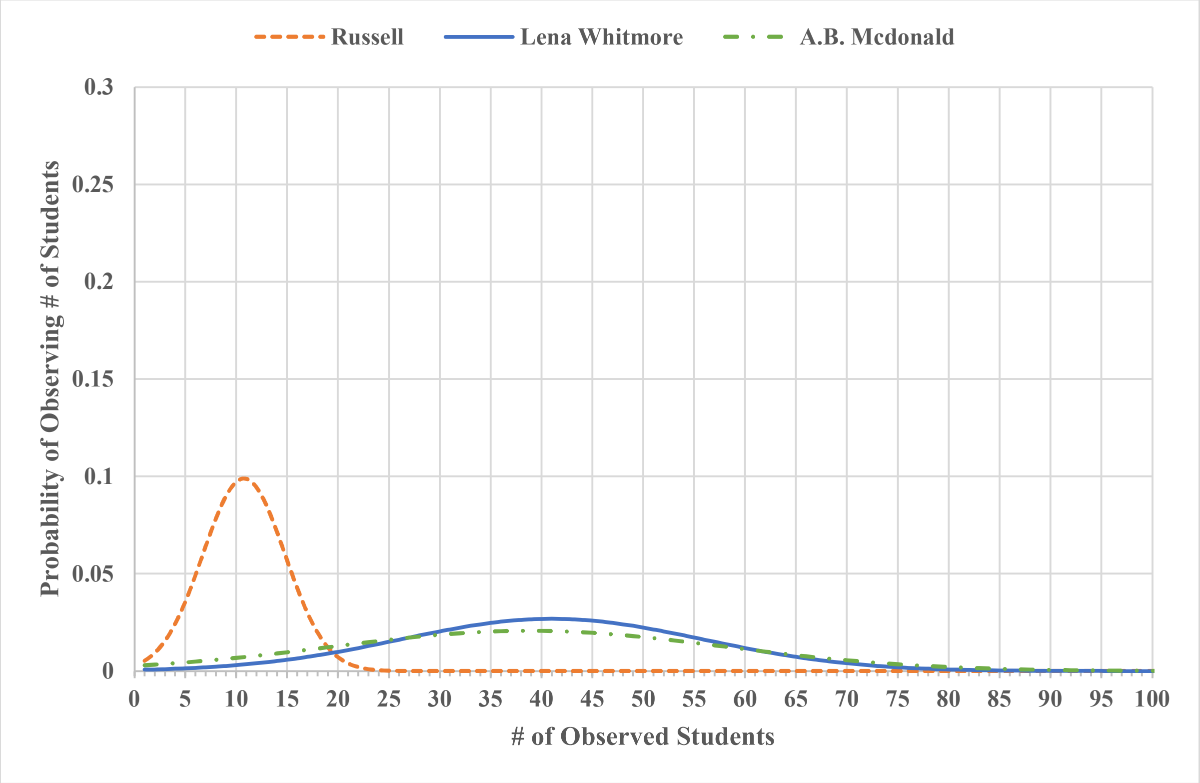


Figure 4.2: Car Observations PMF (Unedited Video)

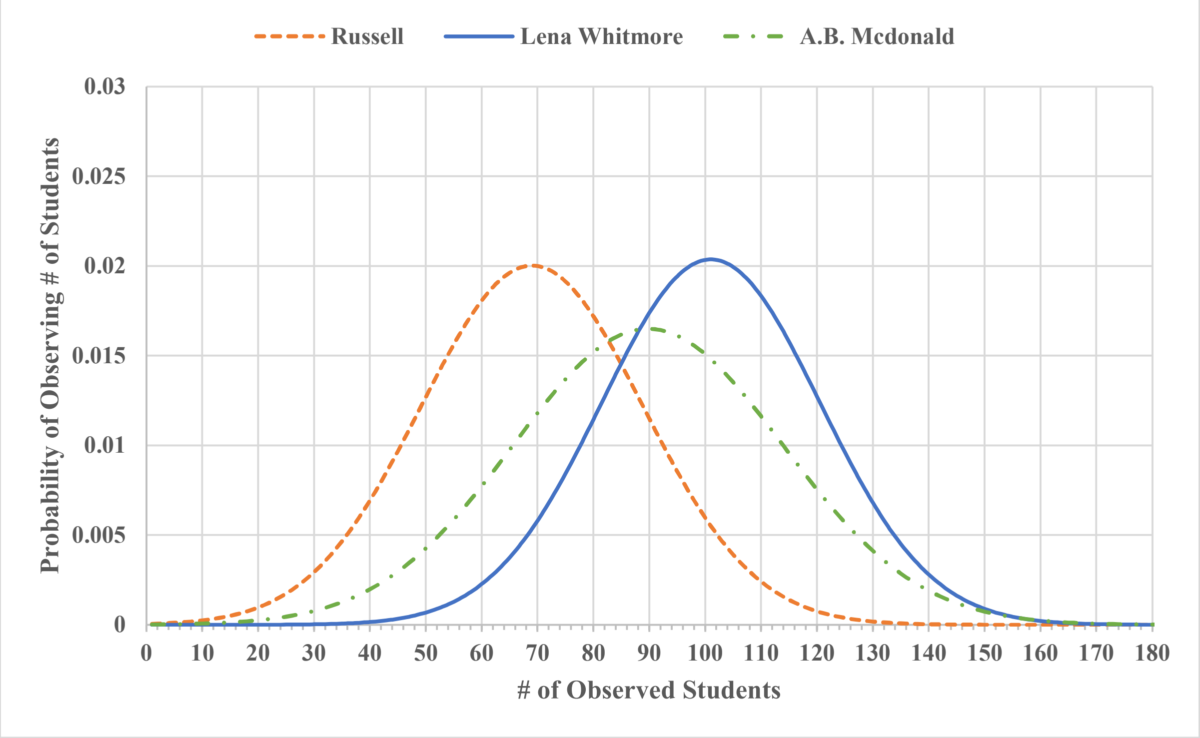


Figure 4.3: Ped Observations PMF (Unedited Video)

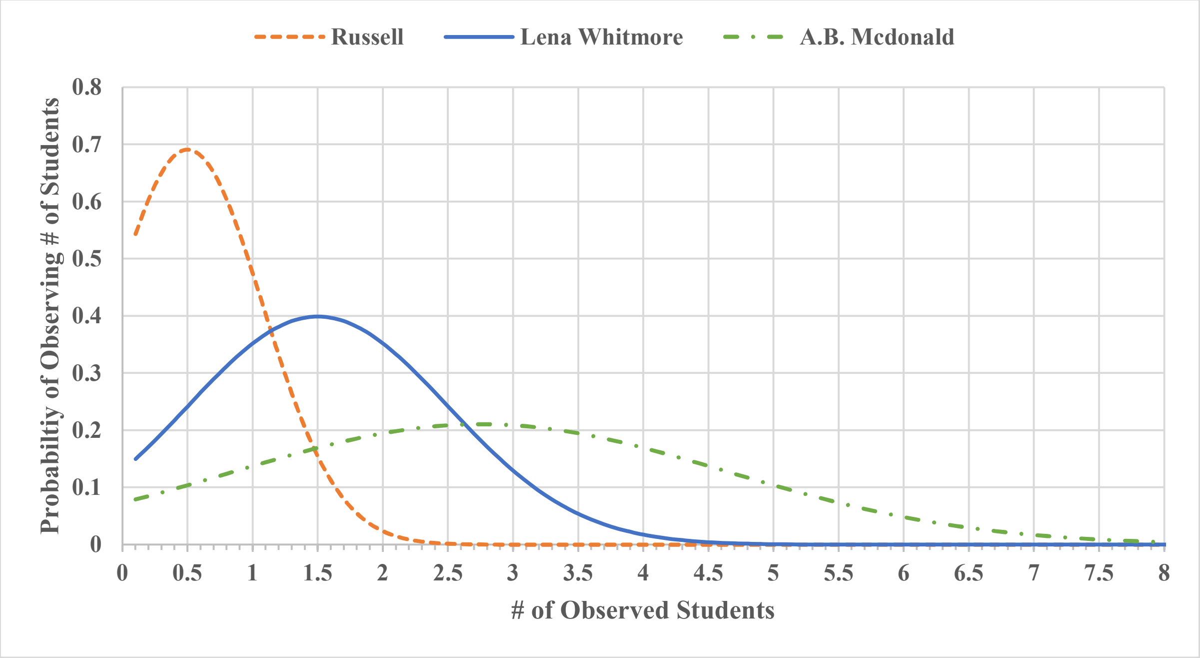


Figure 4.4: Bike Observations PMF (Unedited Video)

Unedited Video Analysis

Based on these PMF graphs, the varying accuracy and precision of the counts could be examined. The results with the lowest standard deviation amongst the counters were represented by the bus observations at Russell and Lena Whitmore. This outcome could be attributed to the bus pick up areas being closer to the flight site. The pedestrian counts were also tightly distributed despite the larger sample sizes; although the standard deviations were high, these distributions were fairly close to each mean. The results where the outcomes were poor included the car observations at Lena Whitmore and McDonald as well as the bus observations at McDonald. The pedestrian counts might have been better if the video were modified to help solve the issues reported by the counters.

The results for the unedited videos showed that the standard deviation is quite large amongst the counters. The counts with the highest coefficient of variation came from the car observations and bike observations. Bike counts in hindsight seemed to be a relatively easy task to do within the manual counts because of its smaller sample size compared to the other travel modes.
Bike observation is believed to be not exact because of external bike users entering the frame and being incorrectly accounted for. (As an example, at Lena Whitmore, three bike users from the nearby middle school entered and exited out of one of the associated cordon boundaries). This could reduce the accuracy of the count as miscounts would be made by not being able to distinguish bikers entering the frame versus bikers coming from the elementary school.

The time that it took to complete all three of these school counts was between 3.5 hours to 8.0 hours; the average amongst the counters was 5.2 hours. This gap between the hours spent counting these videos could be caused from a wide variety of reasons. Added time could have been spent on the videos to achieve a more confident and accurate count; alternately reviewers could have rushed through the videos without pausing to yield more variable results. This range was expected to decrease with further enhancements to the counting procedure.

Overall, the unedited videos showed inconsistency between the counters. This was attributed to potential factors ranging from limited instruction given to the reviewers to the reviewers potentially omitting or overlooking data during their count. Because of this range of results and reviewer feedback, procedural adjustments were necessary to increase the desired accuracy and precision of the counts.

Edited Video

The edited videos were reviewed based on the instructions described earlier. The videos were edited using Adobe Premiere Pro but was limited to only modifying the frame to focus on areas of interest (i.e., cordon boundaries) and combining the video segments (which had been automatically separated by the drone's video storage software). No color alteration was done for the videos even though the videos were quite dark because personal visual preference amongst counters could vary and affect the results in a negative way.

A.B. McDonald saw a large increase in accuracy when using the edited videos, as counts in all travel modes became significantly more accurate, especially the pedestrian counts. Overall, through visual inspection of the results alone, the edited videos looked to improve the counts dramatically. The time taken to count these videos also decreased from an average of 1.8 hours to 1.4 hours (Table 4.5).

Table 4.5: A.B. McDonald Elementary (Edited Video)

	Bus	Car	Ped	Bikes	Total	Time (Hours)
Counter #1	50	28	104	3	185	1.3
Counter #2	55	28	101	3	187	1.5
Counter #3	51	22	103	4	180	1.5

All travel modes within Lena Whitmore became more accurate amongst the counters; however, the car counts still varied quite a bit. This could be partially due to the obstructions near the car pickup location. Also, areas that were far away were reported to be difficult to count because of the angle of the drone, as grouping at far distances concealed some students. The average time to count these videos decreased from 1.9 hours to 1.4 hours (Table 4.6).

Table 4.6: Lena Whitmore Elementary (Edited Video)

	Bus	**Car**	**Ped**	**Bikes**	**Total**	**Time (Hours)**
Counter #1	22	48	100	4	174	1.0
Counter #2	21	61	102	3	187	1.3
Counter #3	19	52	96	2	169	2.0

The Russell Elementary results remained the most consistent amongst the counters. The largest deviation was shown in the pedestrian counts where counter #1 counted significantly more pedestrians than counters 2 and 3. This was noted in the counter's report as a travel path for students that was near a cordon boundary was actually represented by a subset of pedestrians who were traveling to a portable classroom for after-school activities. This average amount of time to count this school's data also declined from 1.6 hours to 1.2 hours (Table 4.7).

Table 4.7: Russell Elementary (Edited Video)

	Bus	**Car**	**Ped**	**Bikes**	**Total**	**Time (Hours)**
Counter #1	74	14	94	1	183	1.0
Counter #2	75	20	75	1	171	1.0
Counter #3	71	17	79	0	167	1.5

The average time taken to count each school by using the edited videos decreased by 19.0%, 24.4%, and 25.3% for A.B. McDonald, Lena Whitmore, and Russell, respectively. This decrease in time spent in processing the videos effectively increased the efficiency of the counting system. It should be noted that the time to edit the videos for each school was roughly 1.5 hours, which quickly increases the overall processing time back to the unedited average value. This time can be decreased by properly following the six criteria mentioned in the data collection process. This time does not include the video processing time needed, which required up to four hours per video.

Edited Video Analysis

The results for the edited videos show that the edited video counts reduced the standard deviation amongst the counters when compared to the unedited results. The same statistical analysis was done for these results for comparison purposes.

Table 4.8: Edited Video Statistical Analysis

		Bus			**Car**		
		Mean	**St. Dev**	**Coefficient of Variance**	**Mean**	**St. Dev**	**Coefficient of Variance**
Edited Videos	**A.B. McDonald**	52.00	2.65	0.05	26.00	3.46	0.13
	Lena Whitmore	20.67	1.53	0.07	53.67	6.66	0.12
	Russell	73.33	2.08	0.03	17.00	3.00	0.18
		Ped			**Bike**		
	A.B. McDonald	102.67	1.53	0.01	3.33	0.58	0.17
	Lena Whitmore	99.33	3.06	0.03	3.00	1.00	0.33
	Russell	82.67	10.02	0.12	0.67	0.58	0.87

In almost all cases, the coefficient of variance decreased when using the edited videos. This indicates that each school's travel mode averages calculated by the counters started to approach the respective population mean (i.e., the true possible quantity of the travel mode observed by the drone). To compare the results between the edited and unedited videos, PMF graphs for the edited video results were created to visually illustrate the change in standard deviation and mean. The PMF graphs for the edited videos are shown below. (Figure 4.5–4.8)

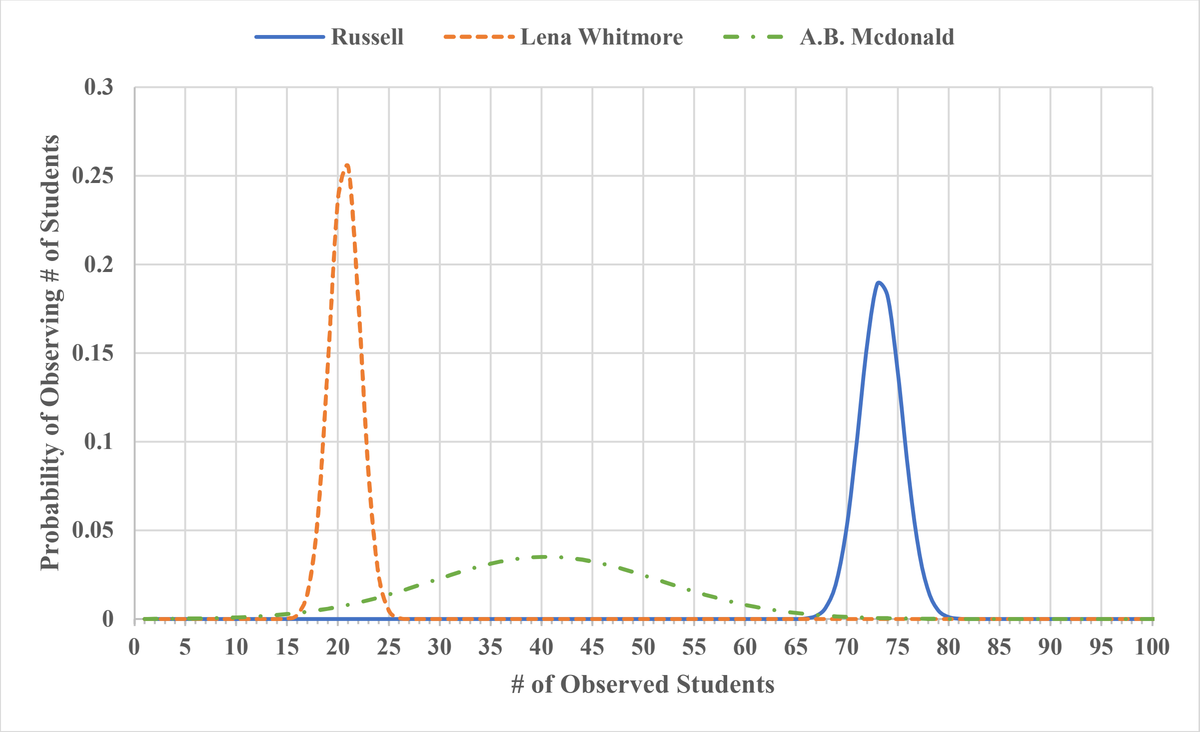


Figure 4.5: Bus Observations PMF (Edited Video)

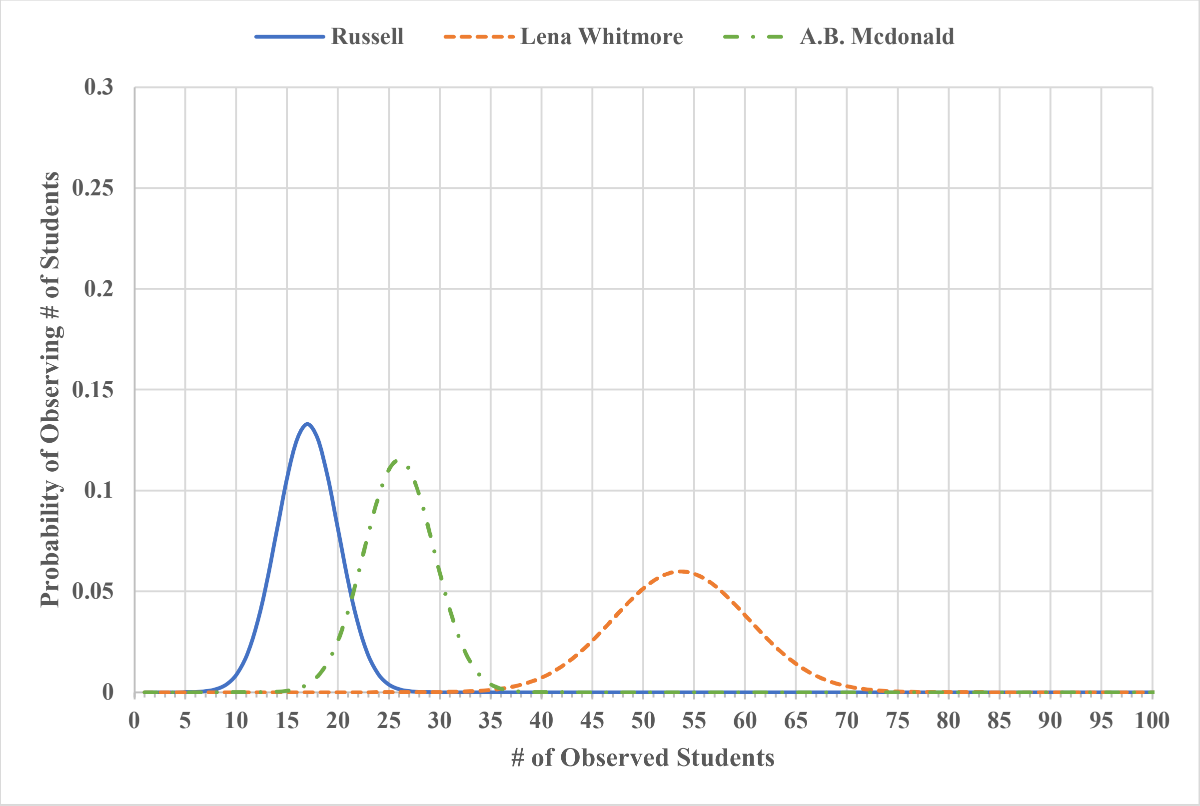


Figure 4.6: Car Observations PMF (Edited Video)

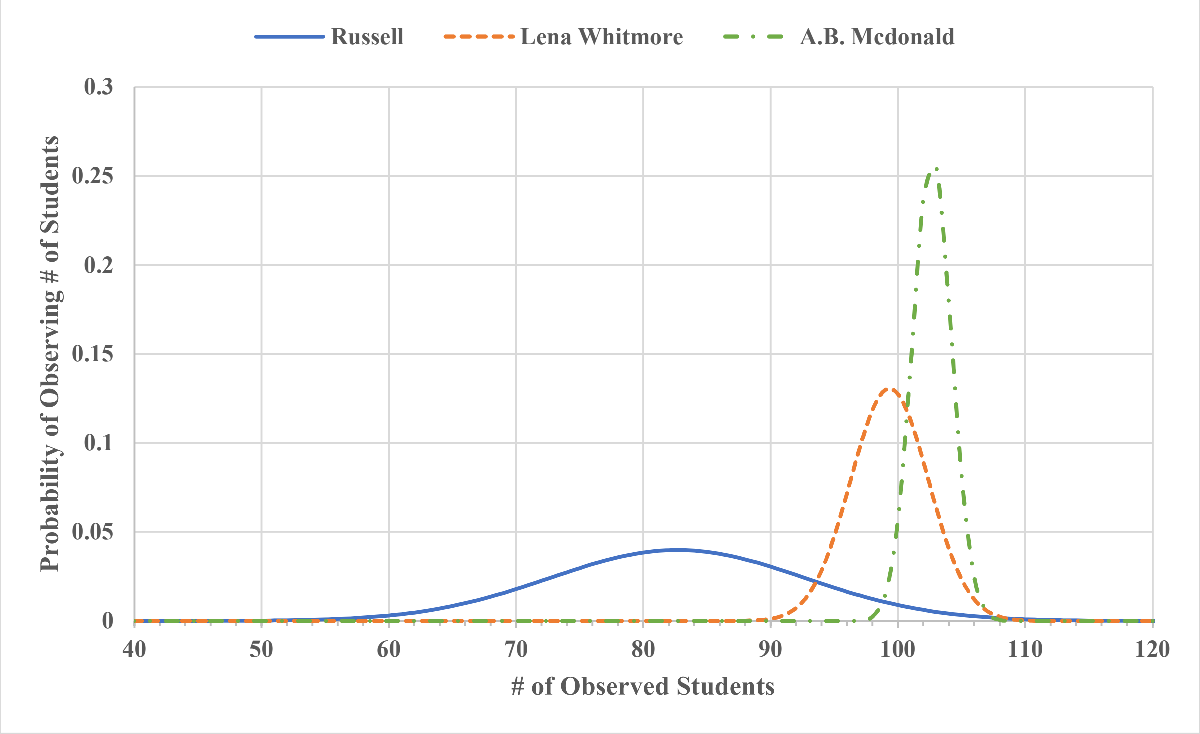


Figure 4.7: Ped Observations PMF (Edited Video)

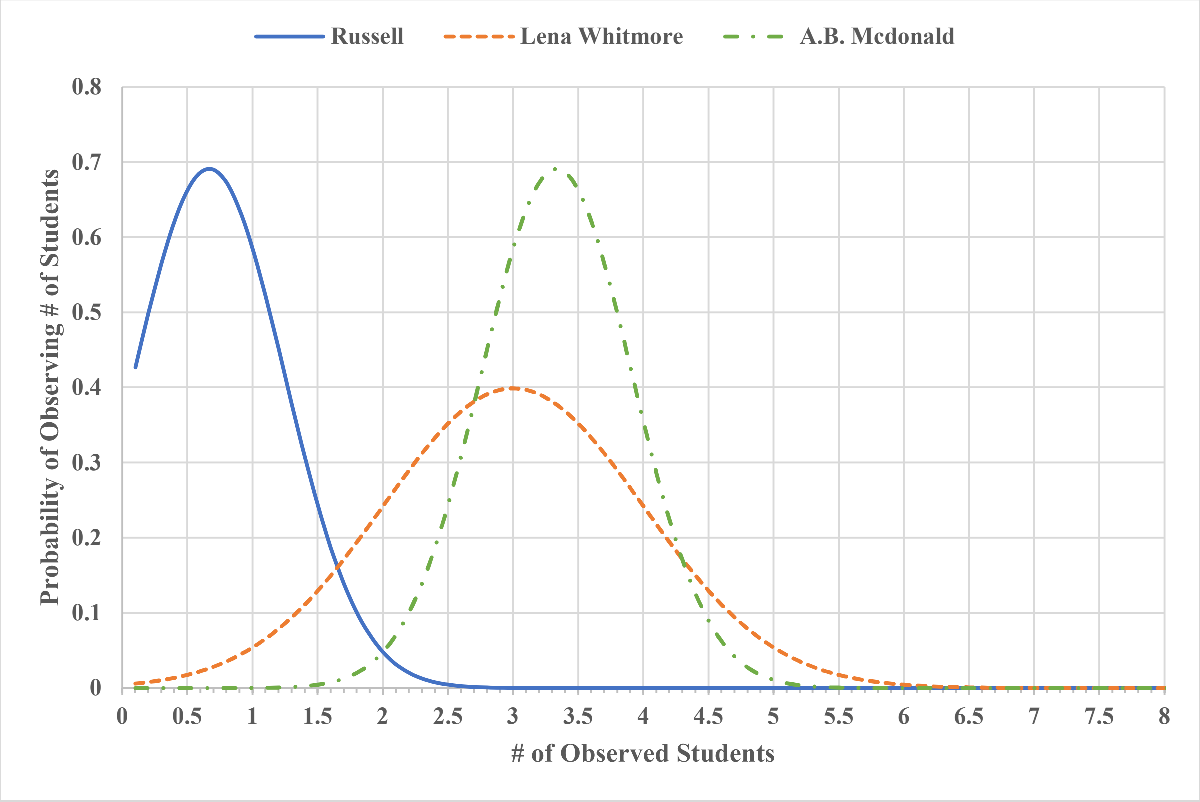


Figure 4.8: Bike Observations PMF (Edited Video)

Although the edited video results were shown to be visibly more accurate than the unedited results, this outcome alone could not prove that the editing and post processing of the video produced a result that was statistically significant in terms of the data collected. For this reason, a Levene's statistical test was done to compare the results of the two counting methods.

The Levene test is commonly used to compare values and determine if the change between them is or is not statistically significant. This test was conducted at the 10% significance level between the unedited and edited data to determine if their respective results were significantly different. The standard deviation was being tested to see if the accuracy of the counters statistically increased. (Table 4.9)

Table 4.9: P-values for Levene's Statistical Test (10% Significance Level)

	Bus	**Car**	**Ped**	**Bike**
A.B. McDonald	**0.069***	**0.059***	**0.023***	1.000
Lena Whitmore	0.692	0.284	0.136	0.116
Russell	0.725	0.776	**0.099***	1.000
* Instances of Null Hypothesis Rejection H_0: The population variances are equal				

The bolded values indicate a rejection of the null hypothesis, with the results of this test showing a significant improvement in the results at McDonald and Russell Elementary for the pedestrian data and additionally for the bus and car count at McDonald Elementary. This makes sense as these results were inconsistent in the unedited count and the standard deviation and coefficient of variation decreased significantly. This result also shows that the edited video results showed the most improvement over unedited videos at sites with larger areas captured by the drone. McDonald showed the most improvement and had the most area captured in the drone; second to McDonald was Lena Whitmore which also coincidentally had the second-best improvement from unedited to edited results.

The results that did not show a significant change were the bike counts at every school as well as the bus counts at Lena Whitmore and Russell. This intuitively makes sense because these counting areas in the video capture were close to the flight site and had a small number of users, thus making it easy to count even with no alteration to the video. These results also show that the edited version is more useful in different scenarios and slightly unnecessary in other areas.

A hybrid between the two counting methods could significantly reduce the amount of video processing time while also increasing the overall accuracy of the count by selectively using the edited approach when meeting a certain criterion. A list of criteria for when to use the unedited video and edited video was created to help improve the efficiency of the process. (Table 4.10)

Table 4.10: Video Analysis Choice Benefits

Unedited	Edited
• Close to the flight site • Mostly unobstructed • Low quantity • Low frequency • Small Observable Areas (0 - 3 Acres)	• Farther away from the flight site • Obstructions present • High Quantity • High Frequency • Large Observable Areas (3 – 5 Acres)

Student Tally Survey Results

The survey data for each school were collected on the same day as each flight. The data were collected by the teachers that had classes in the morning and, in theory, represented the total population of the school. The time associated to collect this per school was around two to three days; this included the time needed to schedule the count and inform teachers of the study, printing and distributing the surveys to each teacher collecting the data, and the data collection period itself. The distribution of the survey to the teachers and collecting them after being filled out relied on the principal or office staff to accomplish; in two cases, the surveys were not collected by the school employees on the same day as the flight. The surveys were distributed for the teachers to review at least one day prior to data collection to allow the teachers to ask questions if necessary. As an example, one school had emailed a list of questions from teachers the day before flying at the school. These questions were answered prior to survey data collection.

To summarize the SRTS tally data, the results from each teacher were compiled and then aggregated for each school. A total of seventeen teachers participated at McDonald, twelve at Lena Whitmore, and seven at Russell Elementary. Based on the number of enrolled students at each school, school tally response rates ranged from a low of 72.8% (134 out of 184 students) at Russell Elementary to 92.6% (338 out of 365) at McDonald Elementary.

Table 4.11: Modified Safe Routes to School Tally Results

	Bus	Car	Ped	Bikes	After-School/ Other	Total*
McDonald	92	161	55	6	24	**314 (338)**
Lena Whitmore	26	97	71	6	35	**200 (235)**
Russell	54	44	27	1	8	**126 (134)**
*** ## = (Total) – (After-School/Other) (##) = Total**						

Since the student tally required participation by elementary school-aged children, the response by a six- or seven-year-old child may have been affected by the responses of their peers; this assumption is not meant to be malicious but simply a reflection of child behavior. Additionally, school tally results could also have been affected by students who did not clearly distinguish between walking or getting picked up in a car. Other potential sources that may have contributed to the anomalies in the data include:

- Number of surveys incorrectly quantified.
- Not all classes began in the morning.
- Video counts incorrectly counted.
- Not all students left immediately at afternoon dismissal.

To directly compare the school tally results with the data that had been compiled by the drone videos, the after-school/other category which had been part of the school tally was removed. While the drone video tallies consistently yielded a higher percentage of pedestrians than car riders, the school tally results attribute more students to car-riding than walking. In this case, the drone results could have been affected by many factors. The drone may have missed a crucial area within its data collection. As an example, in the case of McDonald, it was later noted that a large student pickup area was not captured within the available periphery of the drone. Alternately, students may have walked several blocks away to a waiting car-driving parent or guardian. In other words, while the drone observer would have counted this child as a pedestrian, the school tally would have recorded this child as a car-rider. For this reason, car and pedestrian tallies were summed together. The drone and tally count could then be compared by their mode split percentages, for each mode of travel at each school was calculated. The results of this analysis are shown in Table 4.13).

Table 4.12: Cumulative Percentage Drone vs Survey Results

		Bus	Car + Ped	Bike
A.B. McDonald	**Drone**	28%	70%	2%
	Tally	29%	69%	2%
Lena Whitmore	**Drone**	11%	84%	2%
	Tally	13%	85%	3%
Russell	**Drone**	36%	63%	2%
	Tally	43%	56%	1%

These results suggest that both methods are consistent in terms of mode split. In terms of the mode split, the percentage of students who either rode the bus or a bicycle were consistent, regardless of the school or the data collection method; however, individual car and pedestrian mode split percentages were difficult to sufficiently determine with the use of the drone. Future work could be done to better distinguish the pedestrian and bicycle mode split percentages.

Chapter 5: Conclusions

School travel tally data has historically provided parents, schools, school districts, and the local community with valuable data that can be used to make informed decisions with regard to potential and future transportation infrastructure and safety improvements. The collection effort, typically administered in classrooms, requires participation from teachers and students alike, and the responses from by younger elementary school-aged may or may not always be representative of actual conditions.

The genesis for this study was to determine if drones could be used as a more efficient and less intrusive means of collecting the same information. As drones have become more mainstream and less cost-prohibitive, its usage has steadily increased in a wide range of transportation-related applications. The results show that it is possible to use a low-budget drone as a means of collecting school travel data and increase the efficiency of the data collection review process when some video editing steps are taken to improve system efficiency.

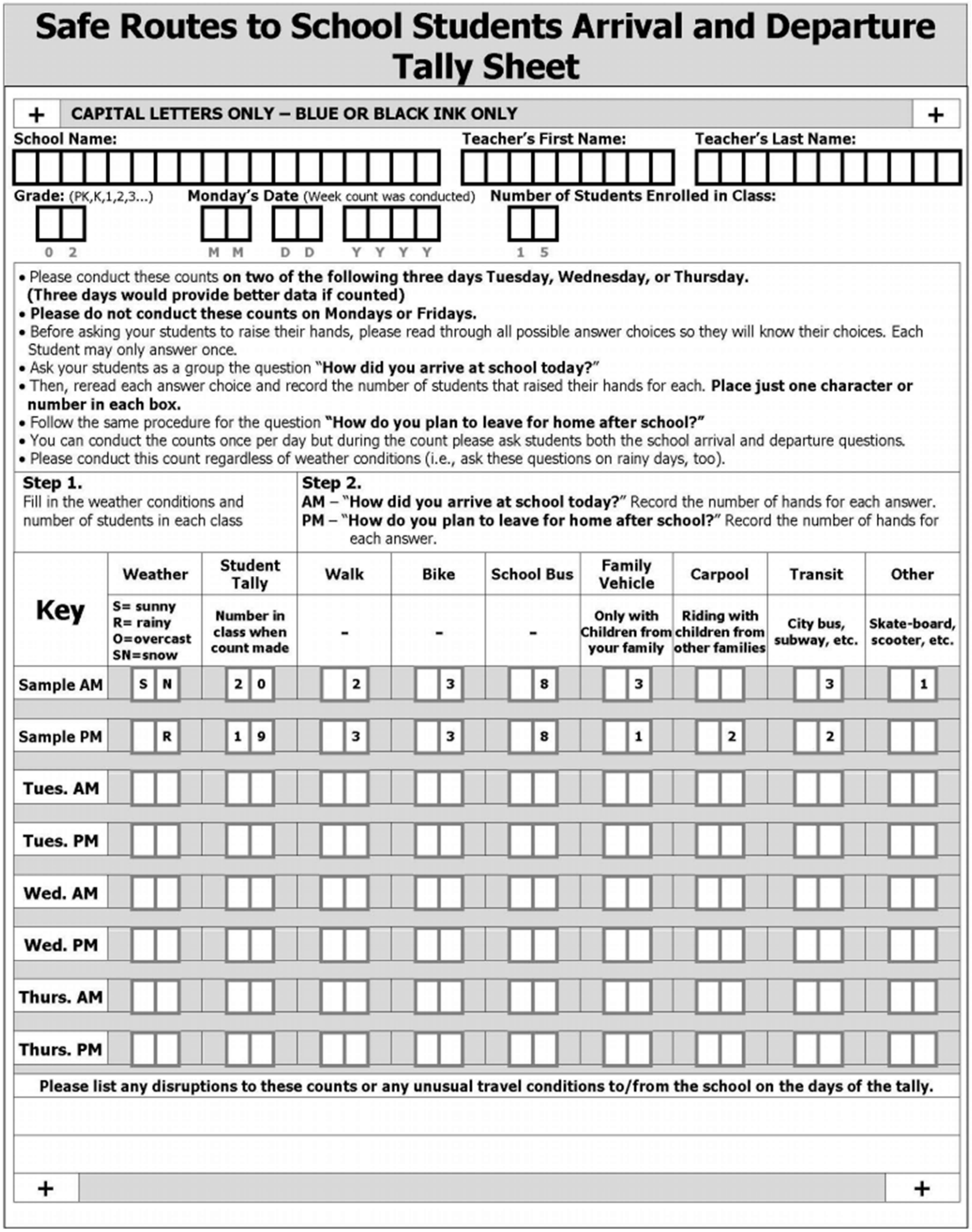
While this study provides an important baseline and a foundational protocol, it revealed potential limitations from both the school tally survey and the use of drones that were unique to each method. The use of drones to collect school travel data, although advantageous in some areas, could not be proven to be a better alternative for collecting data. The potential benefits included the factors: drones were less intrusive and were able to collect data in a relatively anonymous manner, real-world conditions were captured, the data need not need to rely on the student population. Conversely, study limitations were primarily influenced by the capabilities of the drone or drone operations and included: limited geographic scope due to drone height limitations and camera field-of-view restrictions, obstructions (such as trees, roof awnings, etc.), constrained data collection period, extra processing steps, and an extensive pre-flight setup process to ensure personal safety. Students who participate in after-school programs would not be accounted for with this approach.

Post-research, a few improvements were noted that could have positively affected the methods and results of the study. Drone lens attachments, like a wide-angle lens, could have been utilized to add more capture area and potentially capture more students. Another potential method to capture more data would be to simultaneously use two drones recording in opposite directions of each other. These solutions could also be used to better distinguish pedestrians and car users within the school area to determine individual mode split percentages.

One issue encountered during the recording process was lack of natural lighting that made darker areas like blacktop asphalt difficult to count. This was due largely because the data collection period began at the beginning of December when natural light diminished near the dismissal period of school (around 3:30 PM); however, an advantage in flying in December was that the trees had already shed their leaves which allowed a level of transparency in what would otherwise be considered visual obstacles. An ideal time to capture data would be after trees abscise their leaves in the fall and before the end of November; or prior to trees budding in the late spring to increase visibility and light exposure. Using Table 4.11 as a decision-making tool on whether to use the unedited or edited counting process could potentially decrease the amount of video processing time.

As drone technology continues to evolve with better cameras and longer-lasting batteries that could be used to extend flight times, it is anticipated that future research efforts would yield better and more robust results. There are also opportunities to automate the counting process by using refined artificial intelligence that is already present for traffic volume studies. The use of thermal imaging could also be incorporated with passive video counting software. Further research and development of standards and guidelines for drone data collection will improve the data collecting process as school transportation data needs continue to evolve over time.

Appendix A - Safe Routes to School Travel Tally Sheet



Safe Routes to School Students Arrival and Departure Tally Sheet

CAPITAL LETTERS ONLY – BLUE OR BLACK INK ONLY

School Name: **Teacher's First Name:** **Teacher's Last Name:**

Grade: (PK,K,1,2,3...) 0 2

Monday's Date (Week count was conducted) M M D D Y Y Y Y

Number of Students Enrolled in Class: 1 5

- Please conduct these counts **on two of the following three days Tuesday, Wednesday, or Thursday. (Three days would provide better data if counted)**
- **Please do not conduct these counts on Mondays or Fridays.**
- Before asking your students to raise their hands, please read through all possible answer choices so they will know their choices. Each Student may only answer once.
- Ask your students as a group the question "**How did you arrive at school today?**"
- Then, reread each answer choice and record the number of students that raised their hands for each. **Place just one character or number in each box.**
- Follow the same procedure for the question **"How do you plan to leave for home after school?"**
- You can conduct the counts once per day but during the count please ask students both the school arrival and departure questions.
- Please conduct this count regardless of weather conditions (i.e., ask these questions on rainy days, too).

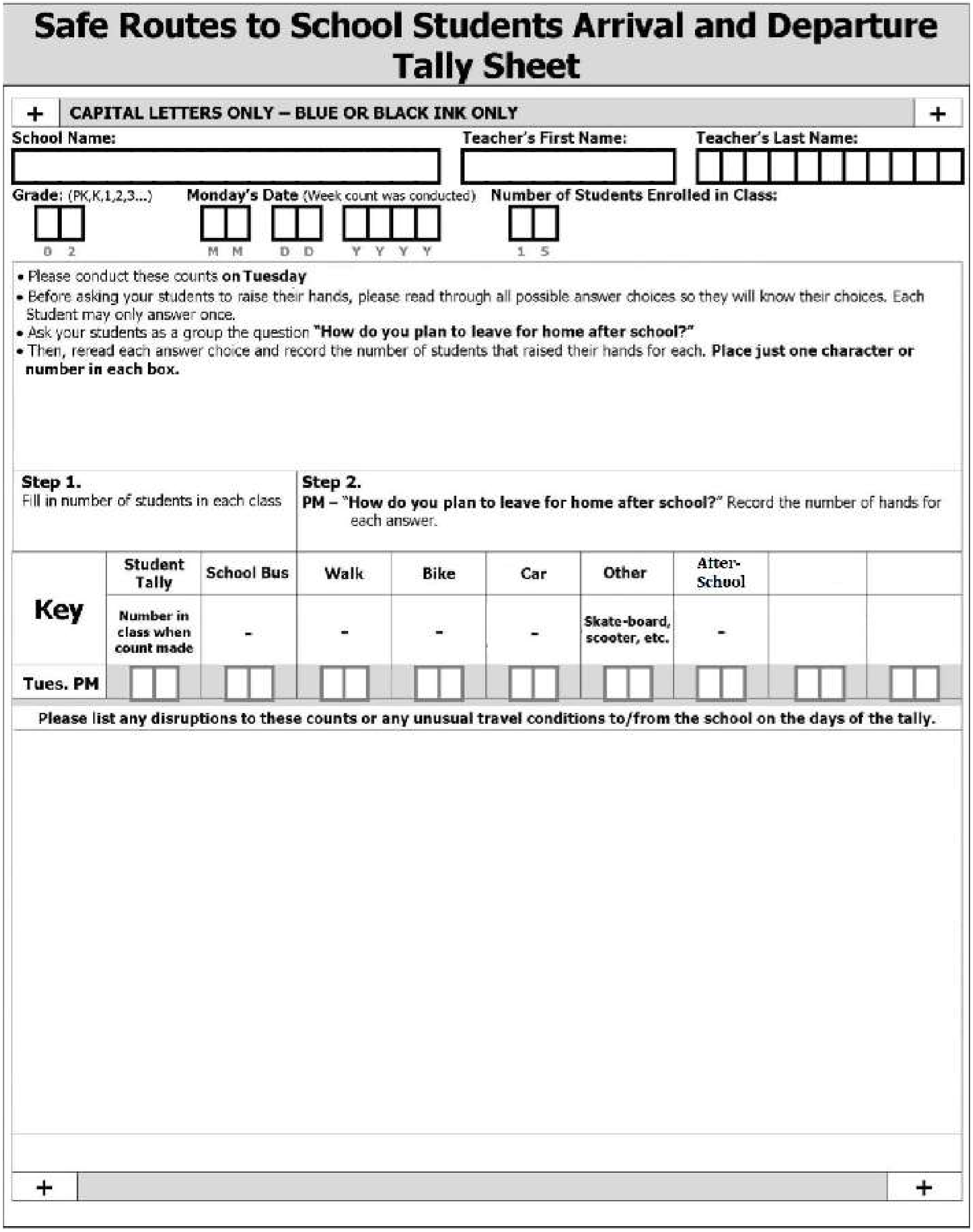
Step 1.
Fill in the weather conditions and number of students in each class

Step 2.
AM – "**How did you arrive at school today?**" Record the number of hands for each answer.
PM – "**How do you plan to leave for home after school?**" Record the number of hands for each answer.

Key	Weather	Student Tally	Walk	Bike	School Bus	Family Vehicle	Carpool	Transit	Other
	S= sunny R= rainy O=overcast SN=snow	Number in class when count made	-	-	-	Only with Children from your family	Riding with children from other families	City bus, subway, etc.	Skate-board, scooter, etc.
Sample AM	S N	2 0	2	3	8	3		3	1
Sample PM	R	1 9	3	3	8	1	2	2	
Tues. AM									
Tues. PM									
Wed. AM									
Wed. PM									
Thurs. AM									
Thurs. PM									

Please list any disruptions to these counts or any unusual travel conditions to/from the school on the days of the tally.

Appendix B - Modified Safe Routes to School Travel Tally Sheet



Safe Routes to School Students Arrival and Departure Tally Sheet

\+ **CAPITAL LETTERS ONLY – BLUE OR BLACK INK ONLY** +

School Name: ☐

Teacher's First Name: ☐

Teacher's Last Name: ☐☐☐☐☐☐☐☐☐☐☐

Grade: (PK,K,1,2,3...) ☐☐ 0 2

Monday's Date (Week count was conducted) ☐☐ ☐☐ ☐☐☐☐ M M D D Y Y Y Y

Number of Students Enrolled in Class: ☐☐ 1 5

- Please conduct these counts **on Tuesday**
- Before asking your students to raise their hands, please read through all possible answer choices so they will know their choices. Each Student may only answer once.
- Ask your students as a group the question **"How do you plan to leave for home after school?"**
- Then, reread each answer choice and record the number of students that raised their hands for each. **Place just one character or number in each box.**

Step 1.
Fill in number of students in each class

Step 2.
PM – "How do you plan to leave for home after school?" Record the number of hands for each answer.

	Student Tally	School Bus	Walk	Bike	Car	Other	After-School		
Key	Number in class when count made	-	-	-	-	Skate-board, scooter, etc.	-		
Tues. PM	☐☐	☐☐	☐☐	☐☐	☐☐	☐☐	☐☐	☐☐	☐☐

Please list any disruptions to these counts or any unusual travel conditions to/from the school on the days of the tally.

\+ +

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