DEVELOPMENT OF GRASS-ROOTS DATA COLLECTION METHODS IN RURAL, ISOLATED, AND TRIBAL COMMUNITIES

FINAL PROJECT REPORT

by

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16. Abstract

While extensive procedures have been developed for the collection and dissemination of motor vehicle volumes and speeds, these same procedures cannot always be used to collect pedestrian data, given the comparably unpredictable behavior of pedestrians and their smaller physical size. There is significant value to developing lower cost, lower intrusion methods of collecting pedestrian travel data, and these collection efforts are needed at the local or "grass-roots" level. While previous studies have documented many different data collection methods, one newer option considers the use of drones. This study examined its feasibility to collect pedestrian data and used this technology as part of a school travel mode case study. Specific information with regard to the study methodology, permissions required, and final results are described in detail as part of this report.

This study concluded that while purchasing and owning a drone requires relatively minimal investment, the initial steps required to operate a drone, along with processing time required to analyze the data collected, represent up-front barriers that may prevent widespread usage at this time. However, the use of drones and the opportunities that it presents in the long-term offer promising outcomes.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
		APPROXIMATE CONVERSIONS FROM SI UNITS		
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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EXECUTIVE SUMMARY

Transportation agencies rely on good data for planning, design, operations, and maintenance activities. While extensive procedures have been developed for the collection and dissemination of motor vehicle volumes and speeds, these same procedures cannot always be used to collect pedestrian data, given the comparably unpredictable behavior of pedestrians and their smaller physical size. As system-level pedestrian data is frequently limited, the ability of an agency to make an informed decision as to where needs are greatest is constrained. In rural, isolated, tribal, and indigenous (RITI) communities, these needs are further magnified as data may be entirely or almost completely non-existent. For these reasons, there is significant value to developing lower cost, lower intrusion methods of collecting pedestrian travel data, and these collection efforts are needed at the local or “grass-roots” level.

In 2014, the National Cooperative Highway Research Program (NCHRP) released Report 797, entitled “Guidebook on Pedestrian and Bicycle Volume Data Collection”, and identified fourteen different data collection methods ranging from manual in-field counts to automated and manual counts from video, and from laser scanners to magnetometers. While NCHRP Report 797 provided a comprehensive analysis of so many different data collection options, one additional option that was not included at the time, but has become a more popular means of collecting transportation data, is the use of drones. Given its increasing popularity, this study examined the feasibility of using this newer technology to collect pedestrian data; in particular, a drone was used for a school travel mode case study. Specific information with regard to the study methodology, permissions required, and final results are described in detail as part of this report.

This study concluded that while purchasing and owning a drone requires relatively minimal investment, the initial steps required to operate a drone, along with processing time required to analyze the data collected, represent up-front barriers that prevent widespread usage at this time. However, as the price point continues to decline and as local policies are established to allow for this type of device, it seems inevitable that the use of drones and the opportunities that it presents in the long-term will offer promising outcomes.

CHAPTER 1. INTRODUCTION

Transportation agencies rely on good data for many planning, design, operations, and maintenance activities. While extensive procedures have been developed for the collection and dissemination of motor vehicle volumes and speeds, these same procedures cannot always be used to collect pedestrian data, given the comparably unpredictable behavior of pedestrians and their smaller physical size. As system-level pedestrian data is frequently limited, the ability of an agency to make an informed decision as to where needs are greatest is constrained. In rural, isolated, tribal, and indigenous (RITI) communities, these needs are further magnified as data may be entirely or almost completely non-existent. For these reasons, there is significant value to developing lower cost, lower intrusion methods of collecting pedestrian travel data, and these collection efforts are needed at the local or “grass-roots” level.

The inherent value of good count data helps to support the need for additional walking amenities and to prioritize future improvements. It is imperative that this data be both timely and reliable so that facility use trends can be identified and contextual crash data can be captured. The data collected also serve as an opportunity to determine noteworthy pedestrian behavior such as particular travel patterns, interactions with other travel modes, and crossing behaviors.

In 2014, the National Cooperative Highway Research Program (NCHRP) released Report 797, entitled “Guidebook on Pedestrian and Bicycle Volume Data Collection”, and identified fourteen different data collection methods ranging from manual in-field counts to automated and manual counts from video, and from laser scanners to magnetometers. For this study, each of these different methods was assessed from the perspective of our RITI communities, who are challenged by both limited staffing and budget.

While NCHRP Report 797 provided a comprehensive analysis of so many different data collection options, one additional option that was not included at the time but has become a more popular means of collecting transportation data, considers the use of drones. Given its increasing popularity, this study examined the feasibility of using this technology to collect pedestrian data; in particular, a drone was used for a school travel mode case study. Specific information with regard to the study methodology, permissions required, and final results are described in detail as part of this report.

The remainder of this report is divided into the following chapters. In Chapter 2, the methods identified by NCHRP Report 797 are summarized and examined from a RITI perspective. The parameters of using a drone for data collection are also described. In Chapter 3, the methodology required to operate a drone along with the data collection and processing procedures are explained. The study results are shared and analyzed in Chapter 4. Lastly, Chapter 5 provides the study conclusions along with opportunities for future study.

CHAPTER 2. BACKGROUND

As growing interest continues for non-motorized travel methods like walking and bicycling, appropriately quantifying demand levels is needed to support ongoing programs and to justify the design need for new facilities. Pedestrian data collection is an evolving study area with multiple technologies being evaluated.

Pedestrian travel data are not often collected in the United States due to lack of resources, guidance, and perceived need of data. While motorized travel counting methods, techniques, and technologies have 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 led by the Institute of Transportation Engineers and Alta Planning and Design in 2004 (Nordback et al, 2016). The FHWA published a guidebook that described methods used to estimate non-motorized travel; importantly, the data collected would help fund plans to provide healthier and safer alternatives of travel. The National Cooperative Highway Research Program (NCHRP) released Report 797 in 2014 to provide guidance on developing non-motorized counting programs and the report was written with practitioners in mind.

In addition to these studies, non-motorized counting guidelines have been adopted by state departments of transportation (DOTs) and local transportation agencies for specific purposes. As examples, the Colorado Department of Transportation (CDOT) published a non-motorized monitoring program evaluation and implementation plan 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 on conducting bicycle and pedestrian counts to improve safety and prioritize its bicycle and pedestrian improvement projects (LA, 2013). The Idaho Transportation Department (ITD) published the "Toolbox for Bicyclists and Pedestrian Counts" to support communities investing in nonmotorized transportation infrastructure (ITD, 2013).

Because of the increasing demand for and use of nonmotorized travel data, research efforts focus on streamlining counting methods. In some cases, the effectiveness of the data collection equipment seems to be prioritized over the creation of guidelines that describe the methods or techniques needed in collecting non-motorized travel data.

2.1. Common Pedestrian and Bicycle Data Collection Factors

Counting methods for pedestrians can be separated into various categories. The categories include continuous or coverage data, manual or automated, and existing or emerging methods. Coverage data typically refers to data that have been collected over a shorter length of time (i.e., less than a month), whereas continuous data refers to data collected over longer periods of time, such as a yearlong study. Manual studies typically require human involvement, whereas automated studies rely on technology to complete the count. Some methods have been used and adopted more frequently than others which are only now being implemented. Data collection can be administered by a local agency or contracted with a vendor specializing in this type of activity.

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" (LA, 2013). This report shares the use of a collection sheet to gather data on factors such as 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.

ITD's Pedestrian and Bicyclist toolbox recommends collecting information such as origin and destination data, trip frequency, improper use of infrastructure, and current use of existing infrastructure. ITD also recommends collection data such as gender, age, helmet use, and direction of travel. This toolbox recommends collecting count 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.

An NCHRP study, comprised of Projects 07-19 and 07-19 (2), evaluated various automated count technologies. The results were documented in NCHRP Report 797, "Guidebook on Pedestrian and Bicycle Volume Data Collection" (Ryus et al. 2014a) and in NCHRP Web-Only Documents 205 (NAS, 2014) and 229 (NAS, 2017). As part of this NCHRP study, the recommended collection data included environmental data to determine trends in modal travel choice behavior and different weather conditions. Notably, the study 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 little statistical evidence was found to show that these weather conditions had large impacts on data collection.) For the purposes of this report, any future mention of the "NCHRP study" will refer to either Report 797, NWOD 205, or NWOD 229, unless explicitly noted.

2.2. 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 depend 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.

The NCHRP study identified fourteen different counting technologies and evaluated a total of eleven different counting technologies and reported the research findings and conclusions on the efficacy of each technology. The associated guidebook described the different count technologies and types of data collected when evaluating the efficiency of these technologies. As part of the study, the collection equipment evaluated included passive/active infrared, inductive loops, radio beams, thermal imaging, radar, pneumatic tubes, and piezoelectric strips.

Based on the NCHRP study, the methods used to collect non-motorized traffic data as well as their advantages and disadvantages are summarized in Table 1. Each method of collecting non-motorized 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.

Table 1 Counting Technology Advantages and Disadvantages

Counting Technology	Advantages	Disadvantages
Manual In-Field Counts	○ Ease of implementation ○ Additional information can be noted (direction, gender, behavior)	○ Relies on collector training and management ○ May lack accuracy if too much info needed ○ Can be cost-prohibitive due to staffing
Manual Video Counts	○ Can be re-watched for multiple counts ○ Additional information can be noted (direction, gender, behavior)	○ Device susceptible to theft ○ High labor costs ○ Video position typically fixed to mounting point
Automated Video Counts	○ Can be re-watched for multiple counts ○ Additional information can be noted (direction, gender, behavior) ○ Low time-investment	○ Higher cost ○ Limited application (not ideal for large crowds) ○ Data storage needs
Inductive Loop Detectors	○ Permanent system ○ User familiarity with device	○ Installation challenges ○ Limited coverage area
Passive Infrared	○ Sensors are small ○ Ease of installation ○ Portable	○ Background conditions can trigger a false count (i.e., mirrors, windows, reflective surfaces) ○ Not ideal for large groups ○ Good results depend on placement
Active Infrared	○ Ease of installation ○ Portable ○ Relatively high accuracy and precision	○ Cannot distinguish objects breaking beam ○ Not ideal for large groups / occlusion
Radio Beams	○ Portable ○ Ease of installation	○ Equipment cost ○ Cannot distinguish objects breaking radio signal ○ Not ideal for large groups
Pressure and Acoustic Pads	○ Good for walkways, trails, or sidewalks ○ Can count both pedestrians and bicyclists	○ Installation can be difficult ○ Relies on direct contact ○ Susceptible to problems with freezing
Magnetometers	○ Used primarily to count bicyclists ○ Easy to install on trails	○ Does not count pedestrians ○ Sensitivity to ferrous objects
Thermal Imaging Camera	○ Does not require light source ○ Allows for passive counts	○ Equipment cost ○ Limited applicability ○ Requires external power source
Radar	○ Does not require light source ○ Count multiple directions	○ Labor intensive and intrusive install ○ Placement can cause over reads if vehicles encroach on sensor
Bicycle-Specific Pneumatic Tubes	○ Lower cost ○ Use familiarity with device	○ Device susceptible to theft or damage ○ Requires direct contact ○ Lower accuracy in colder weather due to rubber stiffening
Piezoelectric Strip	○ Less susceptible to theft ○ Additional information can be noted (direction and speed)	○ Labor-intensive and intrusive to install ○ Not ideal for large groups
Laser Scanners	○ Typically used for indoor applications ○ Can be oriented horizontally or vertically	○ Can be affected by inclement weather ○ Limited usage ○ Requires power supply

Counting Technology	Advantages	Disadvantages
Fiberoptic Pressure Sensors	○ Method relies on weight ○ Device sensitivity can be adjusted	○ Installation costs ○ Limited application

The methods used by public agencies mirrored those described in the NCHRP report. The Idaho Transportation Department provides a list of common methodologies that can be used to conduct a bicycle or pedestrian count, and includes observation counts, mechanical reviewers, laser reviewers, video cameras, surveys, and GPS locators (ITD, 2013). By comparison, the Oregon Department of Transportation completed a 2014 study on bicycle and pedestrian data collection. Their listed 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 similar 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 (LA, 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 needs and methods that could be used to simultaneously count both pedestrians and bicycles include infrared sensors (passive and active), radio/microwave detectors, automated video (passive and active), inductive loops, and manual field data counts.

2.3. Other Data Collection Methods and Technologies

In addition to the methods identified as part of the NCHRP study, several other methods for collecting pedestrian data are available. For example, participatory surveys can 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 (NHTS, 2018) and the United Kingdom (National Travel Survey England, 2018) to gather nationwide modal transportation data. National surveys collect travel statistics of an entire nation so using this information for specific engineering design projects will likely be limited. These travel surveys are also voluntary so response rates will vary.

In 2017, a Texas A&M Transportation Institute study classified pedestrian and bicycle data sources and identified several emerging data collection methods. In addition to the methods identified from the NCHRP Report, additional methods recognizing the use of passive data collection were identified. In this case, passive sources refer to data which are collected without the active input of an individual person or traveler; these methods include, but are not limited to, the use of mobile phone positioning, global positioning systems, location-based services, and tracking apps. The authors of the study suggested that the use of passive detection methods may, in fact, be a good way to collect data that previously did not exist and that “passive crowdsourced data have the potential to overcome the shortcomings of conventional monitoring methods … walking (and bicycling) travel patterns have traditionally been more poorly understood than vehicle travel patterns, which is in part due to lack of adequate data acquisition" (Lee and Sener, 2017).

The most obvious benefit of utilizing passive data is that little to no contact with pedestrians is required. However, given the potential magnitude of data that can be collected, significant time associated with data mining, extraction, and management efforts may be required and the quality and results of this data must be carefully examined during post-processing exercises.

An emerging technology counting method uses either GPS, Bluetooth, or Wi-Fi signals from a pedestrian's or cyclist's phone in order to track movement using the Media Access Control (MAC) address. In most cases, the MAC address is not directly linked to any personal user information. While limited research has been done with regard to the applicability of this method, studies have shown that the main drawback is lack of sample size obtained from the population and issues accounting for the total volume of foot and bike traffic. A study done by McGill University showed that during a trial run the total rate of detection for Wi-Fi signals was around 26% while Bluetooth only had a detection rate of 2%. This study concluded that if this method of pedestrian counting is expanded, then it would likely be more oriented around Wi-Fi signals rather than Bluetooth. Another study from New York University showed that future implementations of Wi-Fi and Bluetooth sensors would allow for pedestrian counts that are more accurate and can be permanently installed for much less than other counting methods. One sensor with Wi-Fi and Bluetooth capability now costs less than $100 and can be used as a stand-alone count method or as a supplement to others to improve accuracy. Along with counting, these sensors would also be able to show wait times and travelling speed which could be used to differentiate between cyclists and pedestrians (Nordback, 2016; FHWA, 2016; Lesani, 2016; Kurkcu, 2017).

2.4. Exploring the Use of Drones

With increased interest in non-vehicular modes of travel, the demand for good 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, installation challenges, or long-processing times, so a lower cost, mobile, and passive method for data collection would have advantages. Unmanned aircraft vehicles (UAVs) or quadcopter drones could serve as a model for collecting some 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 such as collecting data using a 4K resolution video capture camera, creating different flight paths, and preventing accidents and decreasing the risk associated with flying in or near populated areas with added safety features. Research and data collection using quadcopter drones is still quite novel despite its increasing accessibility to the general public as formal guidelines for using quadcopter drones as a regular data collection tool have not yet been formalized.

NCHRP Project 07-19 (2) was completed in late 2016, and this project did not describe how the use of unmanned aerial vehicles (UAVs) or quadcopter drones that captured video footage for subsequent 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, 2016), and with the general cost of technology decreasing and quality increasing, collecting pedestrian data with higher quality thermal imaging cameras could be a feasible alternative in the future.

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 a drone to perform manual counts and allow for subsequent viewings. These viewings were then used to gather information like gender, age, 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 capture detail for each pedestrian. The reliability of the drone data was compared to data collected from 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 limiting factors such as areas with flying constraints and adverse weather (Park, 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 (red, green, and blue) and thermal imaging (Candido, 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. 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 as each frame recorded with the UAV can be analyzed.

Another pedestrian travel data collection project used a small UAV and was conducted in 2019 (Yeom, 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, 2018). Moving object detection was researched for a freely moving camera that used the process of background motion subtraction (Wu, 2017).

CHAPTER 3. METHODS

The use of a drone continues to evolve as a means of collecting non-motorized data. This research further examined how it could be used to facilitate the collection of pedestrian data. As a case study, a drone was used to collect school travel data. The methods to conduct such a study will be described and unique study requirements, such as protecting student privacy and anonymity, will be highlighted.

There are a 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 program. This domestic program has established a methodology in the form of a voluntary student survey (Safe Routes, 2020) that is now used by schools throughout the country. The survey created by Safe Routes consists of a student travel tally that is administered by each participating school to students. Data collected using these surveys include how the students traveled to school in the morning and how the students departed school in the afternoon. However, since these surveys are not mandatory, it is reasonable to assume that the data collected may not be entirely comprehensive.

Many schools do not always consider how their students travel to and from school, which 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. This is particularly true in rural, isolated, tribal, and indigenous communities as the staffing and equipment resources to do so are simply not readily available.

The methods used to operate and fly a drone consisted of three steps: 1) pre-flight setup, 2) data collection, and 3) data processing. For this study, video data collected by a drone at three different elementary schools in Moscow, Idaho were analyzed. The three schools, namely McDonald Elementary, Lena Whitmore Elementary, and Russell Elementary, were selected since each had a significant student walking and bicycling population.

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, 2019. The drone video data collected at each school was subsequently processed in order to both quantify and classify student travel modes at each location.

3.1. Pre-Flight Setup

Before collecting drone data at each school site, potential flight areas were evaluated to identify the key locations or points of interest that would be most beneficial for tallying student travel mode. To classify and count the different travel modes at each school, five or more locations at each school were initially identified based on the likely paths of each travel mode choice.

The final flight site was selected to mitigate altering or affecting the behavior of any travel mode but also close enough so that objects like pedestrians and bicyclists were not represented by only 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 obstructions such as trees, light posts, and buildings. Flight sites for this study were determined using Google Earth as well as on-site visits. Coordination with those familiar with the locations also helped to determine these flight sites.

Approval from the Office of Research Assurances at the University of Idaho was obtained. 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). 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.

- 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
- 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 (see Figure 1). 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 (see Figure 2). The VOs also acted as perimeter crowd control to provide more security at each site.

Figure 1 School Site Map Example

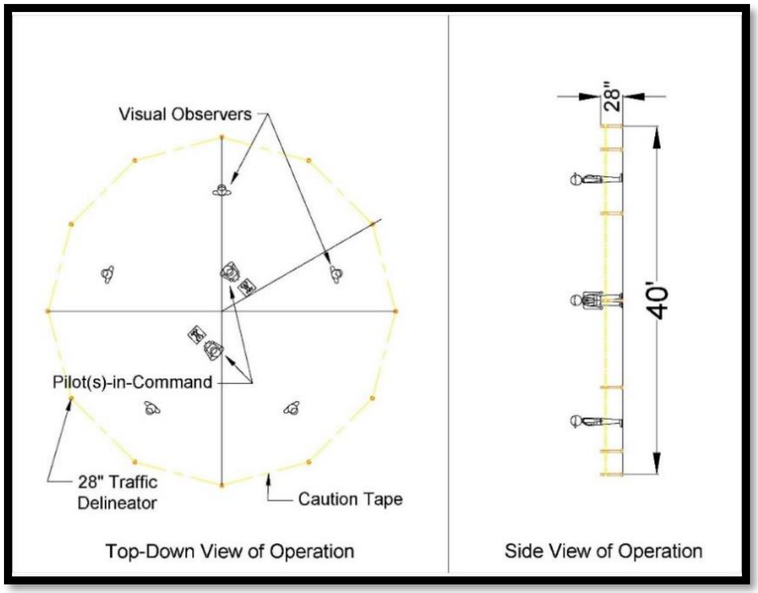

Figure 2 Flight Site Configuration

The flight plan and survey 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. This research required approval from the Moscow School District superintendent and each school principal. Follow-up 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.

These steps reflected the careful and extensive planning of this research effort required as part of a university-affiliated project.

3.2. FAA Section 107 Pilot License

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 do not require an FAA-certified SMUAS license. Drone pilots must comply with all portions of USC 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. This research effort was classified as a commercial flight so a pilot with an FAA SMUAS Section 107 license was required by the UAS committee.

Two options were available to meet the Section 107 requirement for this study. 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 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 flight plans can change due to inclement weather. It would have added more cost to the project as the pilot would need to be paid for their work and a reschedule 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. (If the test taker failed the test then a minimum wait time of 14 days was required.) 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 cost on the research effort, this second option was selected for this project.

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 resource examples freely available to the public that will help with those wishing to obtain their Section 107 license.

3.3. Drone Data Collection Procedure

For this study, a DJI Mavic Pro Platinum quadcopter drone was used for data collection purposes. This drone was chosen because of its easy accessibility, community resources, entry-level 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 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.

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 the flight site (see Figure 3).

Figure 3 Delineated Drone Flight Area (at McDonald Elementary)

To ensure anonymityof the research subjects, the drone was flown at a height where the closest subject did not exhibit any identifiable features during the video playback; this height was determined through field tests to be at a minimum of 150 feet above ground level (AGL). For this study, all flights were flown at 350 feet so that the drone was sufficiently high enough to capture all key areas of geographic interest.

3.4. In-Air Drone Procedure

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 listed below needed to be modified with on-site amendments.

- 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. After the drone returned to land, the site was broken down and all equipment removed from the flight location.

3.5. Unedited Video Manual Counts

The video data processing was divided into two distinct parts 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. Additional instructions were provided to each video reviewer (described later).

Three individuals manually counted the subjects in the unedited videos and manual counts were conducted with no recommended tally method. By not giving any rules to the reviewers, common methods could be identified and implemented as guidelines for counting the edited videos. Counting methods that resulted from the unedited videos included:

- Counting travel modes individually per viewing
- Viewing the same video multiple times
- Focusing on certain sections within the video
- Speeding up the video playback

Each person reviewed the entirety of the unedited data at least one time. Throughout the process of counting, each reviewer kept track of the amount of time it took to complete each school count. After each unedited video count, the time and the data were compiled into a spreadsheet for later analysis. With the counting methods identified, a streamlined counting process was created to increase the accuracy and consistency during future review sessions. This revised counting method would require some editing of the videos prior to review.

3.6. Video Processing and Editing

Video editing was limited to altering the view and scale, and this video processing was required for several reasons. The video directly recorded from the drone was only partly useful if available equipment like an extra-large 4k television could provide a large enough picture to distinguish subjects of interest (i.e., students) from other observable subjects (i.e., parents, other pedestrians). 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 different videos rather than one continuous streaming 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 was to combine all of the segmented videos into one single continuous 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. Color correction was not applied on the videos since this factor would have been influenced by personal preference. The contrast and brightness of each video could be adjusted by each reviewer on his or her own viewing device.

3.7. Cordon Boundary Survey

For the edited videos, specific areas of interest were prioritized over 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 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 crossed over the frame boundaries. Since travel paths associated with each transportation mode had previously been observed, cordon boundaries could appropriately be established. Focusing on these boundaries reduced background distractions for the reviewers, and zooming in on specific areas distinguished the subjects more clearly than before.

To increase the focus of these cordon boundary areas using the Adobe software, a keyframes tool was 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 of the keyframe could also be adjusted. This was used to rearrange the orientation of the viewport to utilize the longitudinal direction of a monitor.

3.8. Edited Video Manual Counts

The edited videos were viewed by each reviewer and included an additional set of instructions. The instructions were developed based on the feedback provided by the reviewers during the assessment of the unedited videos. The instructions provided to each reviewer consisted of the following:

- Only count students, do not include parents. (Distinguish between 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 reviewer boundary.
- Only count for cars when the student 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 reviewer was also given a graphic for each school. As noted on each graphic, cordon boundaries were identified and associated with each mode of travel (see Figure 4 for an example).

Figure 4 McDonald Elementary Cordon Lines and Boundaries

CHAPTER 4. RESULTS

This chapter describes the results based on the drone flights at each school. For the video reviews, the raw data include outcomes from both the unedited and edited videos. Three reviewers examined both the unedited and edited videos, and one additional reviewer examined only the unedited video. On-site challenges as well as difficulties reported by the video reviewers will be fully described.

4.1. Unedited Video

After the drone videos were collected for each of the three schools, four individuals reviewed the videos and, to the best of their abilities, determined the mode of travel for each child departing the school. The videos were unedited; in other words, they represented the images captured directly from the drone. During this process, the reviewers were also asked to provide input as to how the counting process could be streamlined to improve efficiency and accuracy. The reviewers 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.

4.1.1. McDonald Elementary

The results from McDonald Elementary were inconsistent amongst all reviewers. The reviewers provided feedback on their experience by using the unedited video and took note of areas where this task was difficult. One aspect noted by the reviewers was a car pickup area where a large portion of students entered vehicles not fully captured by the video due to height restrictions mandated by the FAA. Because this was the largest area covered by the school, the reviewers had trouble distinguishing between parents and students at farther distances (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 views 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 contrast between students and the background to be limited.

Table 2 McDonald Elementary (Unedited Video)

	Bus	Car	Ped	Bikes	Total	Time (Hours)
Reviewer #1	29	45	62	4	140	1.5
Reviewer #2	53	38	88	3	182	2.0
Reviewer #3	47	13	88	4	152	2.5
Reviewer #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 site from the northeast while the drone was in the air capturing footage. According to Section 107 rules, 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.

4.1.2. Lena Whitmore Elementary

The bus and bicycle results for Lena Whitmore using the unedited video were generally consistent. These results can be attributed to the fact that there was only one bus 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 recorded areas continuously got darker later into the afternoon. One 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 reviewers. 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 and, in some cases, larger groups of students who were farther away obstructed other students making assessment difficult. Some positive aspects of this flight site were that key school exit locations were easily viewed based on the flight height of the drone.

Table 3 Lena Whitmore Elementary (Unedited Video)

	Bus	Car	Ped	Bikes	Total	Time (Hours)
Reviewer #1	22	22	76	2	122	1.0
Reviewer #2	22	57	111	2	192	2.0
Reviewer #3	19	38	96	2	155	3.0
Reviewer #4	21	47	114	0	182	1.5

4.1.3. Russell Elementary

The Russell Elementary results were the most consistent of all the schools, particularly the results among reviewers 2, 3, and 4. The major difference between reviewer 1 and the others was the significant difference in pedestrian counts. Because this school had the smallest video capture area, the drone was easily able to capture the entirety of the perimeter at a high flight altitude and high camera angle so that groups of students were more distinguishable. On the other hand, 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 these hillsides, 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 in order to capture the school bus pickup area as well as the school exits and a large crosswalk area. These elevation changes also limited drone flight height; for flights within the United States, drone flight height is limited to 400 feet AGL (above ground level). 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 Russell Elementary (Unedited Video)

	Bus	**Car**	**Ped**	**Bikes**	**Total**	**Time (Hours)**
Reviewer #1	68	6	40	0	114	1.0
Reviewer #2	71	9	83	1	164	1.5
Reviewer #3	71	13	81	1	166	2.5
Reviewer #4	71	9	72	1	153	1.3

Feedback reported by the reviewers for this school focused on how these results could be counted more consistently. A positive listed for this site was that the bus pickup area was fully captured and was close enough for reviewers to be able to distinguish between parents and students. However, obstructions were present at these bus pickup areas and made counting more difficult.

4.2. Unedited Video Analysis

The results for the unedited videos showed that there were discrepancies between reviewers in many 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 reviewers and directly related to the effectiveness of the captured data for that scenario. These results 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 compare these deviations between the schools as it represented the ratio between the mean and standard deviation (Table 5).

Table 5 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	11.4	0.28	38.8	19.3	0.50
	Lena Whitmore	21.0	1.4	0.07	41.0	14.9	0.36
	Russell	70.0	1.4	0.02	10.8	4.0	0.37
		Ped			Bike		
	A.B. McDonald	89.8	24.2	0.27	2.8	1.9	0.69
	Lena Whitmore	101.0	19.6	0.19	1.5	1.0	0.67
	Russell	69.0	19.9	0.29	0.5	0.6	1.15

The results for the unedited videos showed that the standard deviation was quite large in some cases. The school and travel mode with the highest standard deviation value for all modes was A.B. McDonald with a standard deviation value of 24.2 for the pedestrian mode. The coefficient of variance was calculated to be 0.27 so although the standard deviation was high, it was closer to the mean than some of the other counts. The mode with the highest coefficient of variance was bicycles at Russell with a maximum of 1.15. These overall counts were much smaller and thus the sample size was not sufficiently large enough to be analyzed. The largest coefficient of variance between the other modes of travel was 0.50 for McDonald's car counts.

The counts with the highest coefficient of variation were from the car and bike observations. Bike counts, in hindsight, seemed to be a relatively easy task for manual counts because of its smaller sample size compared to the other travel modes, but external bike users entering the frame were 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 and affected the count results).

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 reviewers was 5.2 hours. This gap between the hours spent counting these videos could be caused by 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. This range was expected to narrow with further enhancements to the counting procedure.

The process of using the unedited videos resulted in inconsistent results between the reviewers. This was attributed to potential factors ranging from limited instruction given to the reviewers to the reviewers potentially omitting or overlooking data during their counts. Because of this range of results and reviewer feedback, procedural adjustments were necessary to increase the desired accuracy and precision of the counts.

4.3. Edited Video

The edited videos were reviewed based on refined methods described in Chapter 3. The videos were edited using Adobe Premiere Pro but limited to 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 reviewers could vary and affect the results.

4.3.1. McDonald Elementary

When using the edited videos for McDonald, the count results of all travel modes were significantly more consistent, especially the pedestrian counts. Overall, through visual inspection of the results, the use of the edited videos sought to improve the precision of the count results. The time taken to count these videos also decreased from an average of 1.8 hours to 1.4 hours (Table 6).

Table 6 McDonald Elementary (Edited Video)

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

4.3.2. Lena Whitmore Elementary

All travel modes representing Lena Whitmore became more precise amongst the reviewers, however, the car counts still varied. This could be partially due to the obstructions near the car pickup location. Also, far away areas were reported as difficult to count because of the angle of the drone, and grouping at far distances concealed some students. The average time to count these videos decreased from 1.9 hours to 1.4 hours (Table 7).

Table 7 Lena Whitmore Elementary (Edited Video)

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

4.3.3. Russell Elementary

The Russell Elementary results remained the most consistent amongst the reviewers. The largest deviation was shown in the pedestrian counts where the first reviewer recorded significantly more pedestrians than the second and third reviewers. This was noted in the reviewer's report as a travel path for students that was near a cordon boundary but was actually represented by a subset of pedestrians who were traveling to a portable classroom for after-school activities. The average amount of time to count this school's data also declined from 1.6 hours to 1.2 hours (Table 8).

Table 8 Russell Elementary (Edited Video)

	Bus	Car	Ped	Bikes	Total	Time (Hours)
Reviewer #1	74	14	94	1	183	1.0
Reviewer #2	75	20	75	1	171	1.0
Reviewer #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 McDonald, Lena Whitmore, and Russell, respectively. The decrease in time spent examining the videos effectively translated into increased counting efficiency for the reviewers.

However, the time required to edit the video for each school was roughly 1.5 hours, offsetting much of the time savings experienced by the reviewers. Additional time was also required for video processing, which took up to four hours for each video.

4.4. Edited Video Analysis

The statistical analysis conducted previously was repeated for the edited video for comparison purposes (see Table 9). Based on the edited video counts, the standard deviation and the coefficient of variance decreased. This indicates that each school's travel mode averages calculated by the reviewers started to approach the respective population mean (i.e., the true possible quantity of the travel mode observed by the drone).

Table 9 Edited Video Statistical Analysis

		Bus			Car		
		Mean	St. Dev	Coefficient of Variance	Mean	St. Dev	Coefficient of Variance
Edited Videos	A.B. McDonald	52.0	2.7	0.05	26.0	3.5	0.13
	Lena Whitmore	20.7	1.5	0.07	53.7	6.7	0.12
	Russell	73.3	2.1	0.03	17.0	3.0	0.18
		Ped			Bike		
	A.B. McDonald	102.7	1.5	0.01	3.3	0.6	0.17
	Lena Whitmore	99.3	3.1	0.03	3.0	1.0	0.33
	Russell	82.7	10.0	0.12	0.7	0.6	0.87

Although the edited video results were shown to be 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 is statistically significant. This test was conducted at the 10% significance level between the standard deviation of the unedited and edited data to determine if their respective results were significantly different (Table 10).

Table 10 P-Values for Levene's Test (10% Significance Level)

	Bus	Car	Ped	Bike
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 pedestrian count results at McDonald and Russell Elementary and additionally for the bus and car count at McDonald Elementary. These results were inconsistent in the unedited count and the standard deviation and coefficient of variation decreased significantly using the edited video. 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.

The results did not show a significant change with 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 show that the edited version was more useful in different scenarios but somewhat unnecessary in other cases.

A hybrid processing approach 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 suggested list of criteria as to when the unedited or edited video should be used was created to help improve the efficiency of the overall process (see Table 11).

Table 11 Video Analysis Choice Benefits

Unedited	**Edited**
Close to the flight site	Farther away from the flight site
Mostly unobstructed	Obstructions present
Low volumes	Higher volumes
Low frequency	High frequency
Smaller observable areas (< 3 acres)	Larger observable areas (3 to 5 acres)

CHAPTER 5. CONCLUSIONS

Many different data collection options exist to collect pedestrian travel data, but the limited staffing and financial resources available to rural, isolated, tribal, and indigenous communities suggest that any method used must be relatively easy to implement with negligible financial cost. Previous studies have provided guidance on the methods that are currently available but have not included the use of drones. For this reason, the study examined the feasibility and promise of using a drone to collect pedestrian data and used this tool as part of a school travel mode activity.

This study concluded that while purchasing and owning a drone requires relatively minimal investment, the initial cost and the steps required to operate and fly a drone, along with the potential processing time required to analyze the data collected, represent up-front barriers that would prevent the widespread use of drones at a "grass-roots" level at this time. However, as the price point continues to decline and local policies are established and refined to allow for this type of device to be used, it seems inevitable that the use of drones and the opportunities that they present in the long-term will offer positive outcomes.

The use of drones has steadily increased in a wide range of transportation-related applications, and the results from this study show that it is possible to use a low-budget drone as a means of collecting pedestrian and school travel data. Additional efficiencies can be gained if the data collection review process includes some video editing measures. The benefits of using a drone include factors such as being less intrusive and collecting data in a relatively anonymous manner while real-world conditions are captured.

It is necessary to point out that operational limitations were primarily influenced by the capabilities of the drone 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 (i.e., developing a pre-flight plan and seeking agency approval) to ensure personal safety. Under the auspices of a university study, these additional process steps proved to be both resource and time-consuming. For small communities who choose to administer this type of activity on their own, it is conceivable that some of these institutional steps would be omitted.

A few post-research improvements were noted that could improve upon the methods and results of the study. Drone lens attachments, like a wide-angle lens, could be utilized to add more capture area and potentially collect better data. Another potential change would be to simultaneously use two drones recording in opposite directions of each other. 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 in part 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 for a level of transparency that would not be possible if foliage was present. 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 take advantage of increased visibility and light exposure. Using Table 11 as a decision-making tool on whether to use the unedited or edited counting process could decrease the total 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 will 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. Further research and development of standards and guidelines for drone data collection will improve the data collecting process as pedestrian data needs continue to evolve over time, particularly in local communities where both staffing and financial resources are limited.

5.1. COVID-19 Impacts

As noted earlier, weather and surface condition are key contributors to good data collection when a drone is to be used. For this study, the research team had intended to collect a second set of data in the late winter or early spring to not only reassess the refined data collection methods but also to measure changes in travel patterns by school students due to warmer weather conditions that would be more conducive for walking and bicycling behaviors.

The impacts of the COVID-19 pandemic canceled these plans. Since in-person schooling was not allowed for the remainder of the 2020 calendar year, it was not possible to collect a follow-up set of school travel data during the Spring time period as the elementary schools were closed and students were limited to at-home learning. However, the key takeaways and findings from this study are not affected by this impact, and the comparison of school travel patterns during different time periods of the academic year is suggested as an area for future study.

CHAPTER 6. REFERENCES

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