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Accuracy Assessment and Guidelines for Manual Traffic Counts from Pre-Recorded Video Data

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Abstract

Traffic count is the fundamental data source for transportation planning, management, design, and effectiveness evaluation. Recording traffic flow and counting from the recorded videos are increasingly used due to convenience, high accuracy, and cost-effectiveness. Manual counting from pre-recorded video footage can be prone to inconsistencies and errors, leading to inaccurate counts. Besides, there are no standard guidelines for collecting video data and conducting manual counts from the recorded videos. This paper aims to comprehensively assess the accuracy of manual counts from pre-recorded videos and introduces guidelines for efficiently collecting video data and conducting manual counts by trained individuals. The accuracy assessment of the manual counts was conducted based on repeated counts, and the guidelines were provided from the experience of conducting a traffic survey on forty strip mall access points in Baton Rouge, Louisiana, USA. The percentage of total error, classification error, and interval error were found to be 1.05 percent, 1.08 percent, and 1.29 percent, respectively. Besides, the percent root mean square errors (RMSE) were found to be 1.13 percent, 1.21 percent, and 1.48 percent, respectively. Guidelines were provided for selecting survey sites, instruments and timeframe, fieldwork, and manual counts for an efficient traffic data collection survey.

Keywords

Traffic Survey, Counting Error, Transportation Planning, Total Error, Collecting Video Data, Classification Error, Standard Guidelines, Repeated Counts, Interval Error

1. Introduction

Urbanization refers to a process where many people move from rural areas to urban areas, which leads to a continuous increase in population. The United Nations in 2009 and the International Organization for Migration in 2015 both estimated that around 3 million people worldwide are moving to cities every week [1]. This increase in the number of people adds to the demand for infrastructure development for accommodation and other facilities such as recreation, education, health, etc. As a result, land is continuously being developed for purposes such as residential and industrial buildings, commercial complexes, recreational facilities, and so on. These developments require new transportation links to provide access to the existing transportation network. Consequently, trips are being added to the network by new developments and congestion is increasing all the time [2].

For this reason, traffic count survey is conducted to accurately understand the real-world traffic condition and solve the congestion problem. Traffic counting survey may be counting the number of vehicles on a road or collecting journey time information, but traffic counting survey collects many other data [3]. In another word, traffic counting involves the process of enumeration of the volume of vehicles moving along a specific roadway section, access point, or intersection. The traffic counting can be carried out in a manual and automated way. There are mainly two methods for manual counting in the current era: on-site traffic counts and counts from the pre-recorded video [4]. The on-site traffic counts refer to counting traffic on the site by trained individuals [5]. The count from pre-recorded video refers to recording traffic using video cameras and then analyzing the video footage later in the office [3]. On-site manual counting is time-consuming, difficult in unfavorable weather conditions, subject to human error, and labor intensive. To overcome these limitations, manual counting from pre-recorded video footage is a promising alternative to manual counting.

Although manual counting from pre-recorded videos is an accurate method of traffic counting and can provide total volume and classification counts, it may be prone to error and cost extra money due to inefficient traffic count survey design, human error, etc. [6] [7] [8]. Depending on the quality of the video footage, the volume of traffic, the speed of vehicles, traffic composition, and the number of lanes, each hour of video can take up to 3 hours to count [9] [10] [11]. The assessment of the manual count accuracy and providing guidelines for conducting traffic surveys have gained significant attention from the researcher in recent years. This research area aims to evaluate the accuracy and reliability of manual counts by trained individuals or video loggers and provide standard guidelines to ensure efficient video data collection. Accurate traffic counts ensure that the traffic flow analysis, delay calculation, estimation of capacity, signal optimization, project impact analysis, and other vital engineering studies represent real-world traffic scenarios [12] [13] [14]. Manual counting from video cameras or advanced Intelligent Transportation Systems (ITS) technologies allows an opportunity to provide data to transportation planners.

Executing a successful traffic data collection survey and improving accuracy in manual counts can provide efficient data representing real traffic scenarios. It will help transportation planners to deal with increasing traffic congestion; and the complex and dynamic transportation network, which is being changed with the continuous development process. This research aims to provide guidelines based on the experience of a traffic data collection survey and manual counts conducted on forty different sites for six months in the metropolitan areas of Baton Rouge, Lafayette, and Hammond in Louisiana, USA. The manuals of different agencies are also considered for providing general guidelines. The research also investigates the accuracy of manual counts conducted from pre-recorded videos.

2. Literature Review

Manual counting is considered the most accurate method of traffic counting [15] [16]. Trained individuals conduct the count with or without the help of technology, which may become prone to error [17] [18] [19]. A few research has been conducted to evaluate the error of manual counts. Zhenga and Mike (2012) [20] researched to evaluate the underlying errors of the manual count, where the authors found that the total count error is usually less than 1 percent, and classification error lies between 4 to 5 percent. The authors reported that the main reason for classification error is the failure to detect the length or form of the vehicles accurately. Moreover, increasing the speed of a media player may lead to a failure to record or classify vehicles correctly.

In the case of long-period manual surveys, Kusimo and Okafor (2016) [5] show that human error is a significant factor that leads to an error in counts. Video recording is not preferable at night because visibility is often impaired, making it challenging to detect vehicles accurately. In addition, the security factor of individuals and instruments is a question for manual counting surveys at night.

Transportation agencies often conduct short period traffic counts and then apply factors based on weekday, seasonal variation, road type, and so on to estimate AADT. Research conducted by Granato (1998) [21] shows that applying these factors can reduce the error of AADT estimates by one-quarter. Sharma (1983) [22] conducted manual traffic counts throughout the year to determine the most effective time and found that the short-period counts depend on the hour-to-hour traffic variation on the same day. The month of the year, the day of the week, and the duration of traffic counts also influence the result [23] [24] [25] [26] [27]. The authors showed that for 8 hours or less on weekdays, a period with a midpoint at 3:00 or 4:00 PM is expected to provide the most accurate volume estimates for each class of road.

Many factors may lead to the deteriorating quality of counting data, such as the selection of survey sites, the selection of time and survey instruments, the complexity of traffic movements, survey team management, the expertise of personnel conducting manual counts, and the quality of videos [4]. Therefore, proper planning before a traffic data collection survey can decrease the effect of these factors and increase the accuracy of counts. The main planning elements are selecting the sites and survey instruments, scheduling fieldwork activities, team management, and counting. It is an excellent practice to follow the guidelines of manual counting surveys to perform efficient manual counting. Guidelines give an initial idea about the procedure of fieldwork and manual counting. Different agencies and institutions have guidelines for manual counting, but those are for specific locations and conditions.

The New York State Department of Transportation (NYSDOT) [28] [29] has guidelines for performing manual counts. According to the manual, they choose random samples from all local roads to get aggregated statistics of traffic counts. Random sampling is performed uniformly from local roads to ensure samples represent all local roads and provide a consistent count. Traffic counts are conducted in 15-minute intervals, at least 48 hours of data are required while 72 hours are preferable, volume counts are done based on direction, and classification counts are conducted considering lane numbers [26] [29] [30]. NYSDOT provides equipment and manuals to local agencies to perform contractual manual counts.

The Texas Department of Transportation (TxDOT) [31] [32] has its guidelines for collecting traffic data based on different programs, such as automatic traffic-recorder volume data, accumulative count recorder traffic data, five-year count program, vehicle classification data, truck weigh-in-motion data, vehicle speed data, and border trend traffic data. According to TxDOT guidelines, it has a selected number of sites and predefined traffic data collection duration for each program; for example, an automatic traffic-recorded volume data program has 160 statewide permanent sites, and daily traffic counting duration is 24 hours and annual counting duration is 365 days [33].

According to the Center for Transportation Research and Education (CTRE) [34] at Iowa State University, a manual count is necessary when equipment for automated counting is not available or affordable. On-site automated counting methods such as pneumatic road tubes and piezoelectric sensors are faster than manual counting, but the cost of the instruments is high. According to CTRE, the typical duration of a manual count is less than a day. Standard time intervals for counts are 5, 10, or 15 minutes. Counts are typically conducted on Tuesday, Wednesday, or Thursday because Monday morning and Friday afternoon show an exceptionally high traffic volume. They use three methods to record manual counts: tally sheets, mechanical counting boards, or electronic counting boards. They recommend preparing a checklist before conducting manual counts.

The Florida Department of Transportation (FDOT) [13] [35] [36] has a manual for collecting traffic data. According to the manual, traffic data may include daily counts, directional factors, speeds, vehicle classification, weight, and truck factors, depending on the location of a site. The manual recommends conducting short-duration counts. FDOT has 300 continuous traffic data collection sites, where traffic data is collected from January through December.

The Minnesota Department of Transportation (MnDOT) [37] has 32,000 traffic data collection sites. The typical duration of data collection is 48 hours. MnDOT has 1200 vehicle classification data sites. In addition, they have more than 240 counting sites operated by the Regional Traffic Management Center operates for volume data collection only. They use different data collection technologies, such as automated traffic recorders and weigh-in-motion.

The National Cooperative Highway Research Program (NCHRP) [38] [39] [40] [41] has produced guidelines in three parts for a traffic survey: planning a program, implementing a program, and adjusting counts. Planning a program includes specifying the data collection purpose, identifying data collection resources, selecting general count locations, determining count timeframe, and considering available counting methods and technologies. Implementing the program includes obtaining permission from site owners, selecting counting devices, inventorying, and preparing devices, training staff, installing, and validating equipment, calibrating devices, maintaining devices, managing count data, cleaning and correcting count data, and applying count data. NCHRP recommends short-time counts if time is short and sufficient equipment is unavailable for long-duration counts [39] [42] [43]. It recommends counting classified traffic, pedestrian, and bicycle volumes individually.

The Oregon Department of Transportation (ODOT) [44] has guidelines for intersection counts, peak hour counts, and old counts. According to their guidelines, the intersection count should provide the volume and classification of vehicles, where the typical count duration is 16 hours. A duration of 3 hours is preferred for peak hour counts, whereas 16 hours of count is recommended for multiple peak hours. According to ODOT, three to five years old data can be used to minimize the cost if no significant development occurs. They also have several guidelines for the time of the traffic survey. Urban areas typically require collecting counts on a weekday afternoon, especially in summer but may include weekends for high recreation areas, areas experiencing lunch hour peaks, or high reverse direction flows during the day.

Although different agencies have guidelines for traffic data collection survey, those are specific to for their regions and cannot be applied in other regions. Therefore, a standard guideline addressing these issues can be good material for transportation planners to conduct video data collection surveys and manual counts.

3. Methodology

The methodology of this research is addressed in four parts: Traffic video data collection survey, conducting manual counts, estimation of error and providing general guidelines based on the experience of this study and literature review. The steps are shown in **Figure 1**.

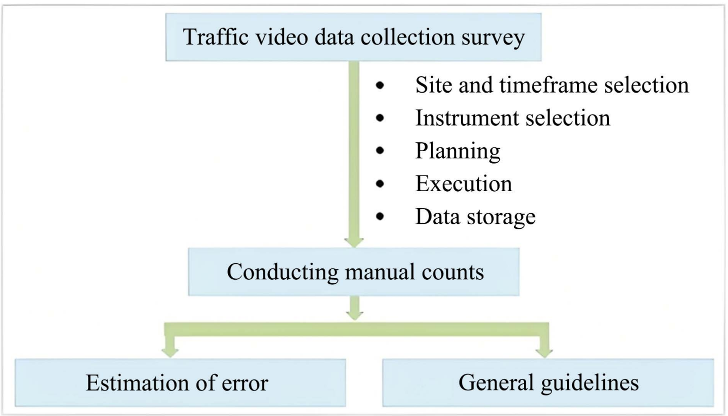

Figure 1. The research approach of manual counting and guidelines.

3.1. Traffic Video Data Collection Survey

3.1.1. Site and Timeframe Selection

The traffic survey was conducted in the metropolitan areas of Baton Rouge, Lafayette, and Hammond in Louisiana, USA. A total of forty strip malls were selected from these metropolitan areas for the video data collection survey. First, a sampling frame of all strip malls in the survey area was established. Then each strip mall was characterized as having either a high or low surrounding land use diversity, population density, and traffic intensity, which resulted in each site being categorized into 1 of 8 groups. Five sites were randomly selected from each group, resulting in 40 sites being selected for a traffic survey.

Time selection refers to selecting the survey's season, day, and hour. Spring or fall is suitable for traffic surveys because the schools remain closed, and people travel during summer. During winter, the weather may affect the regular traffic. Therefore, the early fall was selected for conducting the traffic survey. The entire survey was conducted before the COVID-19 pandemic. Businesses generally have steady customer demand throughout the weekdays, except for Fridays, mainly Friday afternoons. Thus, Monday through Thursday was selected for the survey days. The survey was conducted for two consecutive days for each site to capture the total diurnal and day-to-day variation in traffic at a site. The hours of the survey were selected based on the opening and closing hours of strip malls and the convenience of camera installation. Most strip malls' average hours are 8 am to 6 pm. Therefore, the survey duration is 8 am to 6 pm, 10 hours daily for each site.

3.1.2. Instrument Selection

The resolution, battery life, and weather factors were considered for the selection of suitable cameras to get good-quality video data. The resolution is vital because good-resolution video enables individuals to recognize, and report counts confidently. In this study, the minimum resolution of the cameras was 480 pixels (frame size 480 × 640 pixels), which ensured a good quality video. The battery backup time was selected based on the duration of the recording time. Since this project required recording videos continuously for about 36 hours, the minimum battery backup of cameras was 40 hours. The weather factors were also considered for the selection of the cameras. It was ensured that the cameras were able to operate in bad weather, for example, rain and fog. In this research, three types of cameras were selected primarily for their properties but also due to their availability. The configurations of these cameras are shown in Table 1.

Table 1 shows the properties of Scout Video Collection Camera, Counting Camera, and CountCam2 Traffic Recorder.

The cameras were used based on the number of sites, number of entrances and exits, and availability. A typical view of the cameras while installed in the survey sites are shown in Figure 2.

(a) (b) (c)

Figure 2. Three types of cameras used in this study as installed in the survey sites. (a) Scout Video collection camera; (b) Counting Camera; (c) CountCam2 Traffic Recorder camera.

Table 1. Table type styles (Table caption is indispensable) [45] [46] [47].

Camera Name	**Scout Video collection**	**Counting Camera**	**CountCam2 Traffic Recorder**
Manufacturer	**Miovision**	**CountCam**	**CountingCars**
Weight (lbs)	28 lbs	13 lbs (approx.)	2 lbs (approx.)
Resolution (pixels)	640	480 × 640	480 × 640
Storage (GB)	64 GB and extendable	Extendable	64 GB SDXC internal storage
Duration of recording (hrs)	55	Adjustable	50
Video format	.mp4	.mp4	.mp4
Display (inch)	5.5	6.5	Connectable to smartphone
Battery life (hrs)	72	48	50
Waterproof	yes	yes	yes
Operation temperature (˚F)	−40 to 140	N/A	Withstands summer heat and winter cold
Installation time (minutes)	5	5	5

3.1.3. Planning of Survey

The planning includes preparing a checklist, scheduling fieldwork, and a field-worker management plan. A checklist was prepared before the survey work to ensure all the instruments were available prior to the survey date. On the survey day, instruments were loaded in the vehicle according to the checklist to avoid missing instruments. In addition, a checklist also helps with the management of instruments, for example, the charging level of cameras. The checklist prepared for this study is shown in **Table 2**.

Scheduling fieldwork involves selecting the actual survey day, site preference, site travel plan, and survey team management. All forty sites were scheduled for survey based on the distance from the survey office, the number of entrances and exits, and the availability of instruments. A single site was selected for a survey day when the site had several entrances and exits and required the installation of all the available instruments. Similarly, a group of sites was selected for a survey day when the available instruments were sufficient to cover the sites with few entrances and exits. Moreover, the distance between the sites and the survey office was also considered for successful installation of the cameras before 8 AM.

Survey team management involves distributing tasks to individual workers. In this study, seven student workers were involved in the fieldwork, and individual workers were responsible for individual tasks. For example, a student worker was responsible for checking the availability of instruments and charging before survey day; and loading instruments in the survey vehicle according to the checklist on the survey day. During the survey, some members were responsible for finding suitable spots for the camera installation, and some were responsible for installing and retrieving the cameras. After the survey, an individual was responsible for downloading video data from the cameras and uploading them to the server.

Table 2. Prepared checklist for fieldwork.

Instrument Name	Number required	Status	Check		Remark
			yes	no	
Camera					
Fully charged battery					
Traffic boxes					
Plastic pole					
Steel pole					
Steel angle					
Metal straps					
Wheel measurer					
Hammer					
Drill machine					
Safety vast					

3.1.4. Execution of Fieldwork

The fieldwork was conducted according to the plan prepared at the survey office. This study calculated and tested that it takes 30 minutes to load all the instruments in a vehicle. So, the survey team reached the office 30 minutes before departing to ensure that all the instruments were loaded in the vehicle according to the checklist. When the team reached a survey site, the first task was to find suitable spots to install the cameras, where the team preferred existing poles, such as electricity or telephone poles, because the existing poles give better support to the camera. Steel angles were used to support a 2-inch diameter camera pole when no existing pole existed. Two steel angles were driven into the ground to support each side of the pole and secured with clamps. The average mounting height of the cameras was 10 feet because it was tested and found in this study that this height generally prevents a vehicle in a closed lane from obscuring the view of a vehicle in the farther lane.

Figure 3 shows a typical successful installation of camera conducted in this study. A few factors were checked during the camera installation:

1) The battery's charge level was checked to ensure it could record the whole duration.

2) The installation angle of the camera was checked so that the camera covered a full view of the entrance or exit.

3) The clarity of the camera lenses was checked to ensure clear video footage.

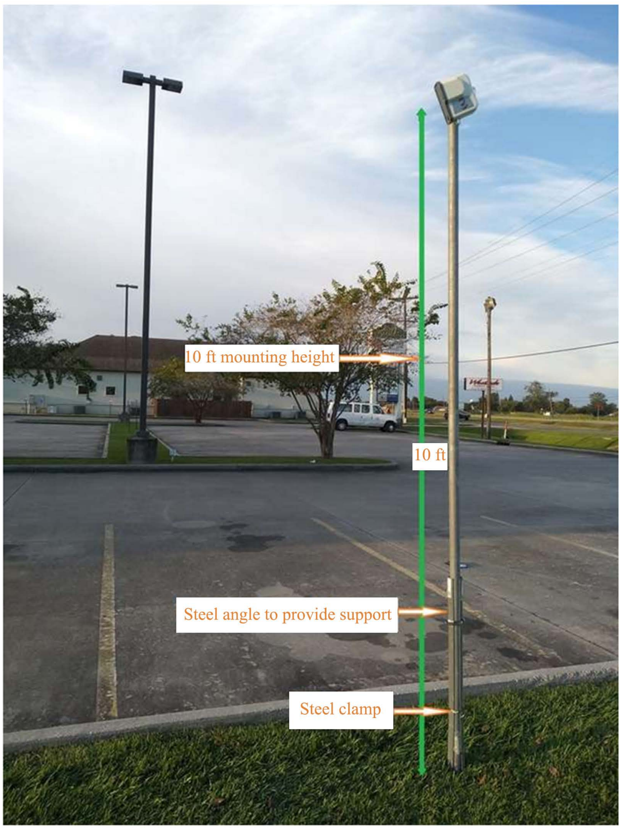

Figure 3. A successful installation of camera.

4) A real-time clock (for example, a smartphone clock) was shown in front of each video camera so that it could record the time. This task aimed to find the difference between the camera clock and the real-time clock. This time difference was adjusted when manual counting was conducted.

5) It was ensured that the camera did not record the adjacent traffic movement because this movement can distract individuals while conducting counts. A typical view of camera footage is shown in Figure 4.

The cameras were retrieved on the following day of installation after 6 PM. While retrieving the cameras, it was checked whether they had successfully saved all the video data. A check was conducted to ensure all the instruments were retrieved and loaded in the vehicle. When the survey team reached the office, video data was retrieved from the cameras and uploaded to a server. Finally, a check was performed for the availability of instruments for the next-day survey.

3.1.5. Data Storage

The concerning factors for data storage are accessibility, capacity, and safety. This study involved collecting a considerable volume of video data that needed huge capacity and accessibility by multiple individuals simultaneously to conduct manual counts. Thus, the server at Intelligent Transportation System (ITS) Lab in Louisiana Transportation Research Center (LTRC) was used for storing the data. The server is secured, has a large capacity, and is accessible by multiple people simultaneously. The retrieved video data from cameras was stored on the server.

3.2. Vehicle Counting

After collecting the video data, manual counting was conducted by trained individuals. This research followed a few rules for conducting the manual count as follows.

1) The time interval of counts was selected as 5 minutes because it allows counts to be aggregated in any multiple of 5 minutes.

2) The rules for counting arriving and departing vehicles were fixed by deciding that as soon as the front of a vehicle passes an imaginary reference line on the access road of a strip mall, it is counted as an arrival or departure.

(a) (b)

Figure 4. The position and view of a camera: (a) The camera is mounted 10 ft in height at the entrance of a strip mall; (b) The covered view by the camera.

3) The number of arriving and departing vehicles was counted separately.

4) The vehicles were classified into six classes: Car, Motorcycle, Cycle, Pedestrian, Transit, and Others. As shown in **Table 3**, a spreadsheet template was used to record all manual counts.

3.3. Estimation of Error

Different errors can occur while conducting manual counts, which can be classified into three classes: total count error, classification error, and interval error. There is no ground truth count for manual counts, but repeated counting for a sample of sites can be considered to produce ground truth counts. The first count can be compared with the repeated counts to estimate errors. In this research, a few sites were randomly selected for conducting repeated counts.

3.3.1. Total Count Error

Total count error is defined as the difference between the number of counted vehicles and the actual number of vehicles for an interval of time. After that the total error for all intervals can be summed to get the total count error for the whole survey time. It can be expressed as the Equation (1). If the equation provides positive number, the error is an undercount and if the number is negative the error is overcount. The average percentage error is taken to get the average percent error.

$$e^{\text{total}} = \Sigma_i \left(C_a - C_m \right), \tag{1}$$

where,

i = interval number;

e_{total} = total count error;

C_a = Actual total count; and

C_m = Manual counts.

Table 3. Sample manual counts sheet.

Site Name: Date: Time:													
Camera details: No of Entrances:													
Time Start (hr:min:sec)	Time End (hr:min:sec)	Entry Details						Exit Details					
		Counts in every 5 min interval						Counts in every 5 min interval					
		Car	Motorcycle	Cycle	Ped.	Transit	Others	Car	Motorcycle	Cycle	Ped.	Transit	Others
8:00:00	8:04:59												
8:05:00	8:09:59												
8:10:00	8:14:59												
8:15:00	8:19:59												
-	-												
17:55:00	17:59:59												

A suitable statistic is to present average total error is the root mean square error (RMSE) or the percent root mean square error (% RMSE). It expresses the average error between estimated and observed values. The percent root means square error (% RMSE) of the total manual count from all sites over all time intervals can be estimated from the Equation (2).

$$\%\text{RMSE of total counts} = \sqrt{\frac{\sum_{i,k}^{I,K}\left(\frac{N_{a,k,i}-N_{c,k,i}}{N_{a,k,i}}\right)^2}{I\times K}}\times 100 \qquad (2)$$

where,

i = a time interval;

I = total number of time intervals at site k;

k = a site;

K = total number of sites;

$N_{a,k,i}$ = actual count of vehicles at site k in time interval i; and

$N_{c,k,i}$ = counted vehicles at site k in time interval i.

3.3.2. Classification Error

The classification error defines the difference between the actual classified counts and the counted vehicles for a particular vehicle class and time interval. Total number of classification errors can be expressed as the Equation (3).

$$e^{\text{classification}} = \Sigma_i^j \left|C_a^{\text{class}} - C_m^{\text{class}}\right|, \qquad (3)$$

where,

$e^{\text{classification}}$ = total classification error;

i = interval number;

j = vehicle class;

C_a = Actual classified count; and

C_m = Manual counts.

A classification error occurs due to the placement of a count in a different vehicle class. It is assumed that classification error increases with the increase of vehicle classes because more vehicle classes require more subdivisions in counts. Equation (4) can be used to estimate the percent RMSE of classification counts.

$$\%\text{RMSE of class counts} = \sqrt{\frac{\sum_{i,k}^{I,K}\left(\frac{\sum_v^V\left(N_{a,k,i,v}-N_{c,k,i,v}\right)}{N_{a,k,i}}\right)^2}{I\times K}}\times 100 \qquad (4)$$

where,

i = a time interval;

I = total number of time intervals at site k;

k = a site;

K = total number of sites;

v = a vehicle class;

V = total vehicle classes;

$N_{c,k,i,v}$ = counted vehicles at site k in time interval i for vehicle class v;

$N_{a,k,i,v}$ = actual count of vehicles at site k in time interval i for vehicle class v; and

$N_{a,k,i}$ = actual count of vehicles at site k in time interval i.

3.3.3. Interval Error

Interval error occurs when a count is placed into a different time interval than the one to which it belongs. So, for a single time interval, for example, 5 minutes, it can be defined as the difference between the actual count of vehicles and the counted vehicles. Then the errors for all time intervals are summed to get the total interval count error. Total interval error can be estimated using Equation (5).

$$e^{\text{interval}} = \Sigma_i \left| C_a^{\text{interval}} - C_m^{\text{interval}} \right|, \quad (5)$$

where,

e^{interval} = total interval error

i = interval number

C_a = Actual interval count

C_m = Manual counts

Formula (6) can be used to calculate the percent RMSE of interval counts.

$$\%\text{RMSE of interval counts} = \sqrt{\frac{\sum_{i,k}^{I,K}\left(\frac{n}{N_{a,k,i}}\right)^2}{I \times K}} \times 100 \quad (6)$$

where,

i = a time interval;

I = total number of time intervals at site k;

k = a site;

K = total number of sites;

n = the number of misreported vehicles at site k at time interval i, which actually belongs; to a time interval (i + 1); and

$N_{a,k,i}$ = actual count of vehicles at site k in time interval i.

3.4. Benefit-Cost Analysis

The actual benefit of conducting a traffic count survey is unknown, but it is recognized that the actual benefit must at least equal or exceed the cost of conducting the survey. Thus, the hours were taken to collect video data, and manual counts were converted to monetary value and assumed to be the minimum benefit as well as the cost of the survey. For video data collection, the working hours taken to conduct fieldwork were estimated and then converted to a monetary value using the payment rate of 10 dollars per hour. The time taken to process videos at each site was considered to estimate the cost of manual counts. In this research, it was found that it took 21 minutes to count an hour of a video file manually. This proportion was used to estimate the actual hours taken to count videos from all sites. The total counting time was converted to a monetary value by applying a payment rate of 10 dollars per hour. Since the cost of cameras and computers is a long-term investment, this factor was disregarded for the Benefit/Cost (B/C) analysis. The following formula was used to estimate the benefit-cost ratio (B/C) ratio for the traditional method [48].

$$\begin{aligned} B/C &= \frac{\text{Benefit}}{\text{Cost}} \\ &= \frac{\geq\left(\Sigma_{K}^{k}\text{wokring hours for collecting videos} + {}_{K}^{k}\text{hours for conducting manual counts}\right)}{\left(\Sigma_{K}^{k}\text{wokring hours for collecting videos} + {}_{K}^{k}\text{hours for conducting manual counts}\right)} \\ &\approx \frac{\geq\left(\Sigma_{K}^{k}\text{cost for collecting videos} + {}_{K}^{k}\text{cost for conducting manual counts}\right)}{\left(\Sigma_{K}^{k}\text{cost for collecting videos} + {}_{K}^{k}\text{cost for conducting manual counts}\right)} \end{aligned} \tag{7}$$

k denotes a site.

K denotes the total number of data collection sites.

4. Results

4.1. Estimation of Counting Time

Manual counting is time-consuming when it is conducted on a real-time clock. Modern media players can increase the speed of a video by 16 times more, saving much time. In this study, six trained individuals contributed to manual counts and reported their time to count a unit video hour, as shown in Figure 5.

It can be observed from Figure 5 that the average counting time is 21 minutes. The individuals reported that conducting counts continuously for a long time is challenging. They suggested taking a break of 5 minutes every hour. If this break is considered, the average counting time is more than 21 minutes. Traffic counting using automated methods, for example, computer programs and *in-situ* technologies can be a good option to eliminate the manual counting time. The quality of a video also controls the time of manual counting. If the quality of the video is high, an individual can easily recognize vehicles and increase the speed of the video.

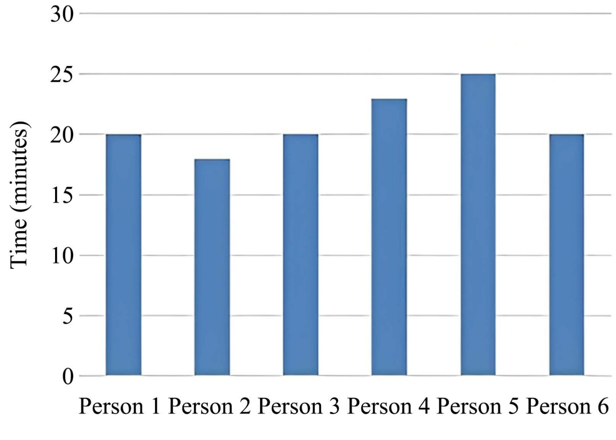

Figure 5. Estimated hourly manual counting time.

4.2. Error Estimation

There is no true ground to estimate errors in manual counts. This study proposes to estimate the error in counts by conducting a repeated count. It is assumed that repeated counts are more accurate than the first counts. If the repeated counts and first counts are the same, it is assumed that there is no error in the first counts. If the repeated counts are not the same as the first count, it is assumed that there is an error in the first count. In this case, conducting a second repeated count is recommended to investigate the error and increase the confidence of counts.

Repeated counts cost double time and money. Therefore, in this study, the repeated counts were limited to several sites, where the sites were selected through random sampling. The total, classification, and interval errors were estimated by comparing the first and repeated counts. In this project, manual counting was conducted for 40 different sites, and repeated counts were conducted for five randomly selected sites. The selected sites for repeated counting are shown in **Table 4**. Different individuals conducted the first and repeated counts.

4.2.1. Total Count Error

Original and repeated counts of daily entry, exit, and total vehicle counts at individual sites are shown in **Table 5** and **Table 6** for day-1 and day-2, respectively. The deviation of first counts from repeated counts was used to estimate total error. For each site, errors were estimated individually for entry, exit, and total counts of day-1 and day-2. The estimations of errors are shown in **Table 5** and **Table 6** for day-1 and day-2, respectively. Using Equation (1), the total count error for day-1 and day-2, were found to be 26 (no's) and 24 (no's), respectively. The average percent total count error for each site for day-1 and day-2 were found to be 1.15 percent and 0.94 percent, respectively. Besides, the average percent error for all sites is 1.05 percent.

Table 5 and **Table 6** show that counts are often underestimated because individuals generally fail to report counts rather than overcount them. Overestimation of counts occurred in three cases, which are exit counts of site 1 for day 1, exit counts of site 21 for day 1, and entry counts of site 31 for day 1, as shown in **Table 5**. The reported reasons for the overestimation of counts are poor visibility, high vehicle speed, and vehicle overlapping at the point of observation.

Table 4. Selected sites for repeated counting.

Site No	Site Name
1	6031 Siegen Ln, 70809
12	702 N Lobdell Hwy Suite 9, Port Allen, LA 70767
21	12,240 Coursey Blvd, 70816
31	4404 Moss St, Lafayette, LA 70507
39	13,091 Airline Hwy, Gonzales, LA 70737

Table 5. Total count error for day 1.

Site No	Entry				Exit				Total			
	First	Repeated	Error (no's)	Error (%)	First	Repeated	Error (no's)	Error (%)	First	Repeated	Error (no's)	Error (%)
1	306	309	3	0.97	289	287	−2	−0.70	595	596	1	0.17
12	405	410	5	1.22	384	387	3	0.78	789	797	8	1.00
21	221	224	3	1.34	184	181	−3	−1.66	405	405	0	0.00
31	76	75	−1	−1.33	67	68	1	1.47	143	143	0	0.00
39	251	254	3	1.18	230	232	2	0.86	481	486	5	1.03

Table 6. Total count error for day 2.

Site No	Entry				Exit				Total			
	First	Repeated	Error (no's)	Error (%)	First	Repeated	Error (no's)	Error (%)	First	Repeated	Error (no's)	Error (%)
1	284	288	4	1.39	256	259	3	1.16	540	547	7	1.28
12	481	487	6	1.23	452	454	2	0.44	933	941	8	0.85
21	246	247	1	0.40	207	209	2	0.96	453	456	3	0.66
31	59	59	0	0.00	52	53	1	1.89	111	112	1	0.89
39	261	264	3	1.14	237	239	2	0.84	498	503	5	0.99

The percent root means square error (% RMSE) was estimated to get an overall estimate of error. The percent RMSE was calculated using Equation (2), as shown in Table 5 and Table 6. The percent RMSE for day-1 and day-2 for all the sites were found to be 1.19 percent and 1.07 percent, respectively. The estimated RMSE of total counts for day-1 and day-2 was found to be 1.13 percent.

4.2.2. Classification Error

The classified first counts were compared with the classified repeated counts to estimate classification error. Classification errors of first, repeated, and total counts were estimated for day-1 and day-2 individually for each site. The classification error in vehicle number and error in percent for day-1 and day-2 are shown in Table 7 and Table 8, respectively. Using Equation (3), total classification error for day-1 and day-2 were found to be 26 (no's) and 31 (no's), respectively. The average percent classification error for each site for day-1 and day-2 were found to be 0.99 percent and 1.18 percent, respectively. In addition, the average percent classification error for all sites for all days is 1.08 percent.

The percent RMSE of classification counts was calculated using Formula (4) discussed in the methodology section. The estimated RMSE of day-1 and day-2 were found to be 1.09 percent and 1.31 percent, respectively. Classification RMSE for all sites and days was found to be 1.21 percent.

Table 7. Classification error for day 1.

Site No	Entry			Exit			Total		
	Error (No's)	Repeated	Error (%)	Error (No's)	Repeated	Error (%)	Error (No's)	Repeated	Error (%)
1	3	309	0.97	4	287	1.39	7	596	1.17
12	3	410	0.73	6	387	1.55	9	797	1.13
21	2	224	0.89	1	181	0.55	3	405	0.74
31	1	75	1.33	0	68	0.00	1	143	0.70
39	4	254	1.57	2	232	0.86	6	486	1.23

Table 8. Classification error for day 2.

Site No	Entry			Exit			Total		
	Error (No's)	Repeated	Error (%)	Error (No's)	Repeated	Error (%)	Error (No's)	Repeated	Error (%)
1	2	288	0.69	4	259	1.54	6	547	1.10
12	9	487	1.85	3	454	0.66	12	941	1.28
21	3	247	1.21	4	209	1.91	7	456	1.54
31	0	59	0.00	1	53	1.89	1	112	0.89
39	2	264	0.76	3	239	1.26	5	503	0.99

4.2.3. Interval Error

Interval error occurs when a vehicle count is recorded in an incorrect time interval. The probability of an interval error increases as the interval time decreases; for example, the probability of an interval error when using 5-minute intervals is higher than 15-minute intervals. In this research, a 5-minute interval was considered for manual counting, which is a low time interval, and the chance of error is higher.

Interval error was calculated by comparing the first counts with the repeated counts. Table 9 and Table 10 show interval errors in vehicle number and errors for day-1 and day-2, respectively. As per Equation (5) total interval error for day-1 and day-2 were found to be 28 (no's) and 37 (no's), respectively. The average percent interval error for each site for day-1 and day-2 were found to be 1.22 percent and 1.37 percent, respectively. Besides, the average percent interval error for all sites for all days is 1.29 percent.

The percent RMSE of interval counts was calculated using Formula (6) discussed in the methodology section. The estimated RMSE of day-1 and day-2 were found to be 1.43 percent and 1.53 percent, respectively. Total classification RMSE was found to be 1.48 percent.

4.3. Analyzing Error

The underestimation of counts was observed as the most frequent scenario for total count error because individuals generally fail to record counts. Overestimation of counts happens when a queue or a group of vehicles arrives or departs at

Table 9. Interval error for day 1.

Site No	Entry			Exit			Total		
	Error (No's)	Repeated	Error (%)	Error (No's)	Repeated	Error (%)	Error (No's)	Repeated	Error (%)
1	3	309	0.97	4	287	1.39	7	596	1.17
12	3	410	0.73	5	387	1.29	8	797	1.00
21	2	224	0.89	4	181	2.21	6	405	1.48
31	2	75	2.67	0	68	0.00	2	143	1.40
39	4	254	1.57	1	232	0.43	5	486	1.03

Table 10. Interval error for day 2.

Site No	Entry			Exit			Total		
	Error (No's)	Repeated	Error (%)	Error (No's)	Repeated	Error (%)	Error (No's)	Repeated	Error (%)
1	4	288	1.39	3	259	1.16	7	547	1.28
12	4	487	0.82	9	454	1.98	13	941	1.38
21	5	247	2.02	2	209	0.96	7	456	1.54
31	1	59	1.69	0	53	0.00	1	112	0.89
39	3	264	1.14	6	239	2.51	9	503	1.79

high speed. Classification and interval errors do not have any effect on total counts. Interval error happens between the end and start of two adjacent intervals, so one interval error affects only the previous interval or the next interval. Like classification counts, one interval error causes two count errors. The total counts remain the same if there is still an interval error. Therefore, the interval error is not highly significant. Total and classification counts are generally used in practice. Total counts are usually used to calculate daily trips. Interval counts are used to estimate peak hour volume or expanded traffic counts. The individuals who conducted manual counts reported several reasons for the error in manual counts, which are as follows.

1) Due to a manual increase in frames per second in a media player, the chance of failure to recognize vehicles increases, which is the main reason for total, classification, and interval errors.

2) It is hard to recognize vehicles when the video quality is poor, especially recorded during evening, fog, and heavy rain.

3) Raindrops obscure the camera lens, which makes a dark video frame, and individuals fail to report vehicles.

4) Sometimes a queue of vehicles arrives and departs simultaneously, and the probability of error increases.

4.4. General Guidelines

4.4.1. Site Selection

The selection of sites is crucial because selected sites must represent the trips of an entire survey area. Generally, random sampling is used to identify sample sites. A sampling frame can be selected from the survey area, and then sites can be randomly selected from the sampling frame.

4.4.2. Timeframe Selection

A few factors should be considered for selecting the timeframe of a traffic survey, such as the category of a survey area, season, and characteristics of sites.

1) There are mainly three categories of sites: residential, industrial, or recreational. Typically, if an area is residential, a survey can be conducted on any weekday because trip distribution is almost uniform on weekdays. At weekends, residential areas generate primarily shopping and recreational trips. Thus, weekday and weekend surveys in residential areas are appropriate if peak-period trips are needed. However, if the area is industrial, most trips are generated in the morning and afternoon unless the industry is open at night. Recreational areas generate peak demand over weekends and public holidays.

2) A site's purpose and business hours should be considered while selecting the survey time. The weekend is appropriate for commercial sites. Both weekends and weekdays are suitable for residential areas. Lastly, the business hours of a site determine the survey time ends.

3) Spring or fall is typically suitable for traffic surveys because traffic conditions remain normal during this period. Traffic conditions are abnormal in summer because schools remain closed, and people travel. During winter, the weather may affect the regular traffic, especially in the cold regions. Late spring and early fall might be the appropriate time for a traffic survey. Considering the site category, spring and fall are suitable for surveys for residential and industrial areas. Recreational areas are suitable for survey during weekends and holidays.

4.4.3. Instrument Selection

The main instrument of a traffic video data collection survey is cameras, which typically come with default poles. Resolution, battery life, weight, and weather protection should be considered for the camera selection. The following guidelines can be followed for the selection of instruments.

1) High-resolution cameras result in good-quality video, and individuals can increase the speed of media players without failing to recognize vehicles, which saves money and time. The most common camera resolutions are 360 p, 480 p, 720 p, and 1080 p. It is recommended to use cameras no lower than 480 p resolution camera.

2) The battery life and the charging time are important factors for long-duration video recording and repeated camera use. Selecting cameras with a minimum of 5 hours more battery life than the duration of a single site recording is recommended because sometimes it is needed to survey multiple sites on the same day, and some cameras have to install a couple of hours ahead for successful camera installment in all sites. The batteries' charging time should be no more than 6 hours to survey on consecutive days.

3) Some cameras available in the market are too heavy to handle. The research recommends using lightweight cameras to ensure successful installation and retrieval.

4) The ability of a camera to operate in bad weather is an essential factor to consider. The survey area may have extreme weather, for example, too cold, too warm, heavy rain, or dense fog. The performance of the cameras should, ideally, continue during these weather conditions. Moreover, the cameras must be waterproof and weather resistant. In addition, before every installation, it must be verified that the camera lens is clear.

5) The other instruments such as camera poles, metal angel and metal straps should be selected carefully so that those can support cameras.

4.4.4. Guidelines for Fieldwork

The Traffic video data survey guidelines are comprised of two parts: planning and execution. Planning is performed at the survey office and is a precursor to a successful survey. Execution is conducted based on planning and includes the installation and retrieval of cameras.

Planning: The planning guidelines include preparing a checklist, scheduling, and field-worker management. A checklist includes the list and status of all necessary instruments for a survey. This research recommends preparing a checklist to avoid instruments being unavailable when needed at the site, as shown in Table 11. A team member must be assigned to ensure that all the required instruments are loaded on the survey vehicle according to the checklist.

Scheduling is the assignment of survey dates, departing times, and retrieval times of instruments for a site or a group of sites. Scheduling depends on the inter and intra distance of sites and the availability of instruments. Inter-distance refers to the distance between the office and the site, and intra-distance is the distance between sites. If the inter-distances of sites are long and intra-distances are short, then a pair or a group of sites can be selected for a single survey day to save travel time and cost. In this case, adequate instruments must be available for conducting the survey.

The departing time refers to when the survey team departs from the office for the fieldwork, which is selected depending on the distances of the sites from the office and the number of survey sites. This study's survey team reported that finding the correct survey location was sometimes challenging. They recommended starting from the survey office early to keep sufficient time for finding suitable spots in the field, and it is better to pre-define the exact spot using GIS software. The retrieval of instruments should be conducted immediately after the survey time to avoid missing data.

The fieldwork should be distributed among the survey team to conduct an efficient and smooth survey. For example, handling checklists, loading instruments into the vehicle, installing, and retrieving cameras, and downloading data, should be assigned to individual team members before the survey date. A few recommendations are provided below from successfully planning for a traffic data collection survey.

Table 11. A typical checklist for fieldwork.

Instrument Name	Number required (no's)	Status	Check yes	Check no	Remark
Site name: Site address:					
Number of individuals: Date of survey: Office reporting time:					
Number of entrances: Number of exits:					
Camera					
Fully charged battery					
Traffic boxes					
Plastic pole					
Steel pole					
Steel angle					
Metal straps					
Wheel measurer					
Hammer					
Drill					
Safety vast					
Steel tape measure					
Site map					
Survey plan					
Survey vehicle checking					
Permission from authority (if the survey site is private property)					
Raincoat					
Others (if any)					

1) The ownership of the survey spots must be determined before the survey day. If the ownership is private, permission must be obtained from the property owner.

2) Since recording video in a public place or a commercial space is sensitive, it is recommended that team members must keep a personal identity card and a letter authorizing the survey in the event of an inquiry.

3) Each team member must have detailed information about the survey sites to avoid unnecessary errors. For example, each member should be provided with a printed copy of the pre-selected camera installation spots, the departing time from the office, the location of the sites, and the required instruments.

Execution: The experience of this study recommends that the survey team should arrive at the survey office at least 30 minutes prior to departing time to load all the instruments in the survey vehicle successfully. It should ensure that the camera batteries are fully charged, and all the instruments are loaded into the vehicle according to the checklist before departing from the survey office. The first task on the site is to find suitable spots for camera installation. Then the team members should work according to their responsibility. While installing cameras, the following factors should be addressed:

1) Ensure the charge of batteries is sufficient to record through the survey day(s).

2) Ensure the camera covers a full view of entrances or exits. While adjusting the focusing angle, adjacent roads should preferably not enter the camera's field of view because vehicles on those roads may confuse individuals while conducting counts.

3) It is recommended to use a 10 feet height for mounting cameras because it was tested in this study that this height ensures a broad view of entrances.

The cameras must be retrieved at the planned time, and the instruments should not be allowed to stay on the site unnecessarily. On the retrieving time, it should ensure that the camera saved all the recordings successfully. When the team reaches the office, the video data should be downloaded and uploaded to the server. Lastly, all the batteries should be left to charge for the following survey.

4.4.5. Data Storage

The first factor for selecting storage is security. Since camera recordings contain sensitive data and business owners demand the confidentiality of the data, the storage must not be accessible to other people. The second factor is accessibility. As multiple individuals may be involved in counting, the stored data should always be accessible to them simultaneously. The third factor is the capacity of the storage. This research recommends using a computer server for storing data because it is enormous and accessible to multiple people simultaneously. Online storage, for example, Dropbox and Clouds, are also convenient data storage methods.

4.4.6. Manual Counts

The format of manual counts depends on the requirements of a project. The first parameter of formatting is the time interval. This study recommends using a 5-minutes time interval so that the counts can be used to estimate peak-period count in any multiple of 5 minutes. The second parameter is the starting and ending time of counting. Generally, most of the businesses open at 8 AM and close at 6 PM. So, for a whole-day survey, the starting time should not be after 8 AM, and the ending time should not be before 6 PM. For peak hour counting, the starting time and ending time can vary depending on the characteristics of a site, such as land-use type, land-use diversity, road density, etc. Typically, peak hours at individual land uses occur from 4 PM to 6 PM. The third parameter is the vehicle classification. The number of vehicle classes depends on the requirements of a project. The counting time increases with an increase in vehicle classes, and it also increases the classification error. This investigation recommends classifying vehicles into as many classes as possible because it provides detailed data that can be aggregated later in various ways. The fourth parameter is the number of lanes on the road. Counts may be reported according to the lanes to separate the number of through, left-turning, and right-turning vehicles. In addition, a modern media player can be used while counting to save time, and a 5-minute break is recommended every hour of count to reduce human error.

4.5. Benefit-Cost Analysis

The benefit-cost (B/C) analysis was conducted using the Equation (7) as provided in the methodology section.

Working hours to collect videos = 640 hours

Hours for conducting manual counts = 553 hours

Pay rate = $10 per hour

$$\text{B/C} = \frac{\text{Benefit}}{\text{Cost}} = \frac{\geq (640\text{ hours} + 553\text{ hours})}{(640\text{ hours} + 553\text{ hours})} = \frac{\geq (\$6400 + \$5530)}{(\$6400 + \$5530)} = (\geq 1.00)$$

Form the B/C analysis it was found that the ratio is greater than or equal to 1, which implies that the survey would at least return the investment.

5. Discussion

This research investigates the errors in vehicle counting from pre-recorded videos; and fills the gap in general guidelines for collecting video data and conducting manual counts. The total error, classification error, and interval error in manual counts were invested in this research. The percentage of total error, classification error, and interval error for all sites and days were found to be 1.05 percent, 1.08 percent, and 1.29 percent, respectively. Additionally, the percent root means square errors (RMSE) of total counts, classification counts, and interval counts for all sites and days were found to be 1.13 percent, 1.21 percent, and 1.48 percent, respectively. From the observation of errors, it was found that the total error is the lowest compared to other errors, and the interval error is the highest. Although classification and interval errors are higher, they do not affect the total count. Total and classification error is significant because they highly use in practice, unlikely interval error. It is recommended to follow the proposed guidelines of this study to conduct an economical and efficient survey. The survey sites can be randomly selected, and the selected sites must represent the total survey area. The category of a survey area, season, and characteristics of sites should be considered for the selection of the timeframe. The cameras should be selected based on resolution, battery life, weight, and weather protection. A checklist is highly recommended for the planning and execution of fieldwork. The study found that 10 feet mounting height of the camera provides a wide video of traffic movement. It was found that it takes about 21 minutes to conduct manual counts for an hour of videos. From the observation of errors, it was found that individuals usually underestimate the counts because individuals generally fail to report counts rather than over-count them. To reduce the number of errors, the study suggests taking a 5-minute break for every hour of manual counts from pre-recorded video. From the benefit-cost (B/C) analysis, the B/C was found to be greater than or equal to 1. Thus, the assessment of errors and general guidelines of this study can help engineers and planners to get more accurate traffic counts. However, the presented research has some limitations, such as, the research sample is small due to the time and cost, the guidelines were provided based on the randomly selected sites, the might be a potential individuals bias, the time-frame of survey is limited, bad weather can reduce the accuracy of counts, there might be error in repeated counts and the research is time consuming.

6. Conclusion

Repeated counts were considered the true count for evaluating manual counting errors. The percentage of total error, classification error, and interval error were found to be 1.05 percent, 1.08 percent, and 1.29 percent, respectively. Moreover, the percent root means square errors (RMSE) were found to be 1.13 percent, 1.21 percent, and 1.48 percent for total counts, classification counts and interval counts, respectively. The results indicate that interval and classification counts are more prone to error than total count error, though they do not affect total counts. The guidelines were provided on selecting survey sites, instruments, and timeframe, planning, and executing fieldwork, and conducting manual counts. It is recommended to follow the guidelines for an economical and efficient traffic survey.

Author Contributions

Conceptualization, C.W. and M.M.; methodology, M.M.; validation, C.W. and M.M.; formal analysis, M.M.; investigation, M.M.; resources, C.W.; data curation, M.M.; writing—original draft preparation, M.M.; writing—review and editing, C.W.; visualization, M.M.; supervision, C.W.; project administration, C.W. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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