Applicability of an automatic pneumatic–tube–based traffic counting device for collecting data under mixed traffic

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Abstract. Traffic volume and composition data can be collected using several techniques such as manual, camera video recordings and automatic traffic count devices installed across the road pavement. An automatic traffic count device is often used for long hours of traffic data collection exercises. In view that the accuracy of the data is an important aspect of data analysis, this paper discusses the applicability of an automatic traffic count device to be used for traffic volume and composition data collections based on Malaysian vehicle classification system, i.e. where traffic is characterised by various types of vehicles or mixed traffic. The automatic traffic count (ATC) used in the study was the pneumatic tube-based equipment known as Metrocount@5600. The data used for validating the ATC was obtained using a video recording technique. The data was collected at four different sites to ensure the result of the analysis is reliable. A video camera and ATC were installed at each of the sites considered in the study. Traffic volumes and compositions from video recordings were extracted manually based on five classes of vehicles, i.e. cars and small vans, medium trucks and lorries with two axles, large trucks and lorries with three and more axles, buses and motorcycles. The ATC was set to classify vehicle types using one of the equipment’s default setting, i.e. 13 classes (Scheme F). The data retrieved from the ATC was reorganised based on the vehicle classifications used in the data collected using the video recording technique. Twenty datasets of vehicles composition from four sites were used in the analysis. The result of the statistical analysis showed that there is no significant different in traffic volumes and compositions obtained using both techniques. The finding implies that an automatic pneumatic-tube-based traffic counting device such as MetroCount@5600 with scheme F can be used as an alternative technique to collect traffic volumes and compositions data based on five standard classes of vehicles classification system.

1. Introduction
Traffic data is an important input in traffic analysis for planning and design of a transportation system, forecasting and impact assessment of urbanisation development projects. The accuracy of the results of the analysis depends on the accuracy of traffic data collected which subsequently will influence the design of the required transportation system or types of improvement to be made to the road facilities in the development area. One of many aspects considered in traffic data collection exercises is the method for collecting traffic volumes and compositions. Several studies have been carried out to evaluate the advantages and disadvantages of various traffic data collection methods [1]-[3].

Traffic volume and composition data can be collected using several techniques such as manual, camera video recordings and automatic traffic count devices installed across the road pavement [1].
An automatic traffic count device is often used for long hours of traffic data collection exercises. Gates et al. [2] recommended the selection of on-pavement devices if the data collection need to be collected daily due to little effort for sample size more than 150 vehicles with other traffic characteristic data such as axles, speed, headway or spacing. The accuracy of data is very important to ensure the validity of the analysis and result obtained. Toth et al. [3] reported that pneumatic tube has lesser human error as compared to manual. This study was carried out to evaluate the potential use of a pneumatic tube-based vehicle classified counting device (also known as an automatic traffic counter (ATC)) for traffic volume and speed studies. In this study, the ATC brand MetroCount®5600, as shown in Fig. 1, was used. The selection of such a type of traffic counting device was made on the basis that the cost of data collection using this device is the lowest if compare with other on-pavement devices such as piezoelectric sensor system or tape switch sensor system [2], especially for long period of traffic monitoring exercises.

The current practice in Malaysia is to classify vehicles into five classes, i.e. (a) cars/small vans/utilities; (b) large vans/lorries (with two axles); (c) large lorry, trailers and heavy vehicles (with three and more axles); (d) buses; and (e) motorcycles [4]. Basically, the classification is made based on the types of vehicles. However, MetroCount®5600’s, or ATC, classify vehicles based on number of axles.

The ATC provides a selection of 22 schemes of vehicles classification criteria [5] and none of them is directly applicable for Malaysian vehicle classification system. To date, there is no reported study on the validation of the ATC for collecting the data based on Malaysian vehicle classification system. Brosnan [6] conducted a study to validate two different brand of pneumatic tubes, MetroCount and Timemark, in the bicycle speed data collection. The study compares ARX and BOCO scheme in MetroCount and standard Timemark axle base classification scheme. The study found that there is
some significant differences in error for both of pneumatic tube and need to be calibrated. The equipment calibration process must be conducted to verify the equipment used before proceed to the analysis.

In view that the accuracy of the data is an important aspect of data analysis, this paper discusses the applicability of an automatic traffic count device to be used for traffic volume and composition data collections based on Malaysian vehicle classification system.

2. Methodology
The main data required in this study is the vehicle classification counts. Therefore, the methodology adopted to collect such a data and to achieve the main objective of the study is summarised in Fig. 2.

![Figure 2. Simplified methodology of the study](image)

As shown in Fig. 2, in this study, traffic data was collected using two different approaches, i.e. the ATC, i.e. MetroCount@5600 automatic traffic counter and video recording technique. Four segments of roadways were selected for traffic data collection purposes. Both ATC and video camera were set to record traffic flow movements at each site for a duration of one hour. The following sub-sections describe the application of these approaches.

2.1. Data Collection using ATC Equipment
The ATCs were installed at four sites along the selected segment, namely Point A, Point B, Point C and Point D. Each ATC was connected with a pair of pneumatic tubes laid across the pavement. Fig. 3 shows the schematic diagram of the layout of the ATC. Fig. 4 shows installation process of the ATC at the studied sites and the typical view of the road segments selected for the study.

The locations of laying the pneumatic tubes were selected in such a way that the road segments are straight with a flat and good pavement surface condition. The pneumatic tubes were carefully fixed on the pavement surface perpendicular to the directional lane to reduce detection errors [6], [7]. The two pneumatic tubes were fixed at a distance of one (1) meter apart as required by the ATC configuration.
Figure 3. Layout of on-pavement equipment and video camera

(a) Laying the tubes at 1 meter apart  
(b) Connecting the tubes to the ATC  
(c) Checking the integrity of ATC’s tubes  
(d) The ATC is locked to a permanent pole  
(e) Data recording in progress

Figure 4. ATC installation activities at site
2.2. Data Collection using Video Recording Technique

Traffic scene at each of the sites at which the traffic data is recorded using the ATC was recorded using a video camera recording technique. The application of video recording techniques for traffic data collection and analysis has been described by numerous researchers. For example, an earlier study by Ashworth [8] explained the benefits of utilizing video recording technique for traffic data collection. The said technique was also used Ashalatha and Chandra [9] in their gap acceptance study.

In practice, information from video recordings can be extracted using computer image processing techniques, a computer event recorder tool, or manually processed. In the post-processing of this study, traffic volume and vehicle classification (MCC) were extracted manually from the playbacks of the video recordings. Vehicles were classified based on the following five main types of vehicles:

i. cars/small vans/utilities;
ii. large vans/lorries (with two axles);
iii. large lorries, trailers, heavy vehicles (with three and more axles);
iv. buses; and
v. motorcycles

The manual counts from the video were used as the control or best estimate of the actual number and classification of vehicles.

3. Results and Discussion

The vehicles classification data from ATC was extracted based on scheme F, i.e. one of the default classification schemes set in the MetroCount@5600 equipment. Scheme F is a visual classification scheme as an axle-based classification scheme implemented by the Federal Highway Administration (FHWA)’s [5]. Scheme F was selected based on the visual inspection of the data which that the scheme’s classification is almost similar to the types of vehicles classified using Malaysian Highway Capacity Manual (MHCM) 2011 [10]. Table 1 and Table 2 summarise the vehicles classification for both references [4], [10].

Table 1. Type of vehicles based on Malaysia Highway Capacity Manual 2011 classification [4]

| Vehicle Class | Description                                           |
|---------------|-------------------------------------------------------|
| 1             | Cars, small vans, utilities                           |
| 2             | Large vans, small lorries or trucks with 2 axles      |
| 3             | Large lorries or trucks with 3 axles or more          |
| 4             | Buses                                                 |
| 5             | Motorcycles                                           |

Table 2. Type of vehicles based on ATC Scheme F classification system (USA) [5]

| Class | Description                     | Axles |
|-------|---------------------------------|-------|
| F1    | Motorcycles                     | 1 axles|
| F2    | Passenger car or light pickup 2 axles | 2 axles|
| F3    | Heavy pickup 2 axles            | 2 axles|
| F4    | Bus                             | 2 axles|
| F5    | 2 axles truck                   | 2 axles|
| F6    | 3 axles truck                   | 3 axles|
| F7    | 4 axles truck                   | 4 axles|
The data retrieved from the ATC was reorganised based on the vehicle classifications used in the data collected using the video recording technique which is MHCM classification. The matching style according classes is as per Table 3. The same category of vehicles in scheme F were combined and categorised under the same class in MHCM 2011’s vehicle classification.

Table 3. Matching vehicle classification from Scheme F, United States with Malaysia classification scheme

| MHCM 2011 [4] | Scheme F | Description |
|---------------|-----------|-------------|
| Class 1 | F2 | Cars/Small Vans/ Utilities |
| Class 2 | F3+F5 | Lorries (with 2 axles)/ Large Vans |
| Class 3 | F6+F7+F8+F9+F10 +F11+F12+F13 | Large lorry, trailers, heavy vehicles with 3 axles and more |
| Class 4 | F4 | Buses |
| Class 5 | F1 | Motorcycles |

It is a common approach to use a sample size of hundred (100) vehicles in a validation study as adopted by Gates et al. [2] who conducted a study to calibrate the pneumatic tube devices. The current study, however, considered all vehicles recorded during the one-hour recording period. Table 4 tabulates the classified traffic count data collected using both methods.

Table 4. Traffic volume data collected using video recording technique and ATC

| No. | Measurement Point | Vehicle Class | Traffic count, veh/h |
|-----|-------------------|---------------|----------------------|
|     |                   |               | Video recording | Automatic Traffic Counter (ATC) |
| 1   | A                 | Class 1       | 406               | 379 |
| 2   |                   | Class 2       | 50                | 36  |
| 3   |                   | Class 3       | 20                | 30  |
| 4   |                   | Class 4       | 4                 | 2   |
| 5   |                   | Class 5       | 88                | 62  |
|     |                   | **Total volumes**, veh/h | **568** | **509** |
| 6   | B                 | Class 1       | 340               | 358 |
| 7   |                   | Class 2       | 62                | 46  |
| 8   |                   | Class 3       | 22                | 23  |
| 9   |                   | Class 4       | 7                 | 3   |
| 10  |                   | Class 5       | 62                | 44  |
|     |                   | **Total volumes**, veh/h | **493** | **474** |
| 11  | C                 | Class 1       | 395               | 370 |
| 12  |                   | Class 2       | 51                | 35  |
| 13  |                   | Class 3       | 22                | 28  |
| 14  |                   | Class 4       | 3                 | 2   |
As can be seen from Table 4, the total number of vehicle recorded by the ATC at all observation points was about 7.6% lower than the total count obtained from video recording playbacks. Both video recording playbacks and ATC records were inspected visually using the individual vehicle’s detection time to identify the possible factors that caused counting errors in the ATC equipment. From the video recording playbacks, it was found that the ATC failed to register the present of overtaking vehicle when both overtaking and overtaken vehicles were exactly at the detection point. Such a situation will cause the ATC equipment to produce a traffic count lower than the actual number of vehicles that passed the detection point. In a situation where an overtaking vehicle initiated an overtaking manoeuvre at the detection point, both overtaking and overtaken vehicles were recorded as one large vehicle, i.e. a Class 3 vehicle. As a result, the number of Class 3 vehicles was counted slightly more than actual number of vehicles observed from the video recording playbacks. To validate the counts, procedures applied in other research were used i.e. graphical observation, percentage difference and statistical test (i.e. the Geoffrey E. Havers (GEH) value and Paired T-test) [2], [3], [5], [11]-[16].

For the graphical validation method, the vehicle classified counts using both techniques at each observation point were plotted on a 45° line plot to evaluate visually the variations of the data as shown in Fig. 5. It can be seen from Fig. 5 that the data collected using both techniques are scattered along the 45° diagonal line. The result indicates that the relationship between these two approaches is reasonably well fitted. This analysis suggests that the data collected using ATC is similar with the data collected using the video recording technique.

![Figure 5. Comparison of vehicle counts between ATC equipment and video recording technique](image)

The data is further reorganised in Table 5 to facilitate the comparisons of the traffic count by vehicle classes between the video recording and ATC data collection techniques.
In general, the data based on classified counts shows that the data collected using ATC is consistently lower than the classified counts extracted from the video recording playbacks except for Class 3 vehicles, i.e. large lorry or trucks with 3 or more axles. However, the statistical analysis needs to be performed to verify the differences. To assess the relative accuracy of the ATC data, the percentage difference between each pair of the vehicle classified count data was computed using Equation (1) and the Geoffrey E. Havers formula as shown in Equation (2) was used to compute the GEH value.

\[
d = \frac{a - v}{v} \tag{1}
\]

where,
- \(d\) = percentage difference,
- \(a\) = automated count,
- \(v\) = video confirmed count, and
- \(i\) = site.

\[
GEH = \sqrt{\frac{(M-C)^2}{(M+C)/2}} \tag{2}
\]

where,
- \(GEH\) = GEH value for each pair of the counts,
- \(M\) = traffic count using ATC, and
- \(C\) = traffic count extracted from video recordings.

| Vehicle Class | Point | Traffic Count, veh/h | Difference, % | GEH value |
|---------------|------|----------------------|---------------|-----------|
|               |      | Video Recording | Automatic Traffic Counter (ATC) |               |
| 1             | A    | 406               | 379           | -6.65     | 1.36      |
|               | B    | 340               | 358           | 5.29      | 0.96      |
|               | C    | 395               | 370           | -6.33     | 1.28      |
|               | D    | 340               | 349           | 2.65      | 0.48      |
| 2             | A    | 50                | 36            | -28.00    | 2.13      |
|               | B    | 62                | 46            | -25.81    | 2.18      |
|               | C    | 51                | 35            | -31.37    | 2.44      |
|               | D    | 69                | 44            | -36.23    | 3.33      |
| 3             | A    | 20                | 30            | 50.00     | 2.00      |
|               | B    | 22                | 23            | 4.55      | 0.21      |
|               | C    | 22                | 28            | 27.27     | 1.20      |
|               | D    | 25                | 26            | 4.00      | 0.20      |
| 4             | A    | 4                 | 2             | -50.00    | 1.15      |
|               | B    | 7                 | 3             | -57.14    | 1.79      |
|               | C    | 3                 | 2             | -33.33    | 0.63      |
|               | D    | 5                 | 4             | -20.00    | 0.47      |
| 5             | A    | 88                | 62            | -29.55    | 3.00      |
|               | B    | 62                | 44            | -29.03    | 2.47      |
|               | C    | 91                | 74            | -18.68    | 1.87      |
|               | D    | 58                | 44            | -24.14    | 1.96      |
The percentage difference is a normal indicator to observe the different between both devices but it is not represented the significant of the different in the total volume value as it only the percentage. However, the GEH value is more reliable in indicating the error or the different [11]. Equation (2) is similar to the chi-squared statistic concept that incorporates both relative and absolute error as The British Highways Agency, Department of Transportation reported in the Design Manual for Roads and Bridges [13]-[14]. It is accepted as a standard measure of the ‘goodness of fit’ between two traffic flows datasets. Low GEH values show similarity between the values, whereas a high GEH indicates a greater difference. The report accepts the GEH value up to 5 (GEH < 5) for individual traffic flow. Unlike comparing the traffic volumes using percentage difference, the GEH statistic value is more emphasis on larger volumes than on smaller volumes [11].

The percentage differences and GEH values for each pair of the total traffic classified counts collected using both techniques are tabulated in the earlier Table 5. The highest percentage different is 57.14% meanwhile the lowest is 2.65%. The average different is 15.13%. The result shows that the lesser the vehicles count in the class, the higher the percentage error found. If a bigger sample size is used the percentage error is expected to reduce. However, as Chitturi et al. [11] reported that the percentage difference is not a good indicator for traffic volume or traffic modelling. It does not represent the real error due to different range of number for traffic volume count in every segment or in every class. The statistical test, i.e. the GEH value test, was applied to verify the differences between the two methods of data collection exercises. GEH value calculated for each of the classes is less than 5 (i.e. GEH < 5) which implies that each pair of the data are similar [11], [13]-[14].

A paired t-test was also used to compare the differences between the data obtained using both techniques since both datasets passed the normality test (i.e. normally distributed with p-value > 0.05 at 95% confident level). The result of the paired T-test is as tabulated in Table 6. The p-value is 0.08, which greater than 0.05, with a t-critical value is 4.3026. The result shows that the datasets from both methods has no significant different at 95% confident level.

It can be inferred from the result of this study that the automatic traffic counter brand MetroCount@5600 series can be used for data traffic volume collection in Malaysia. Selection on scheme F with matching procedure as in Table 3 able to represent vehicles classification for Malaysia vehicles classification. The finding implies that an automatic pneumatic-tube-based traffic counting device such as MetroCount@5600 with scheme F can be used as an alternative technique to collect traffic volumes and compositions data based on five standard classes of vehicles classification system.

| Table 6. Summary of paired t–test result |
|----------------------------------------|
| Parameter | Method | Video recording | ATC |
| Mean | | 517.33 | 483.33 |
| Variance | | 1500.33 | 506.33 |
| P(T<=t) two-tail | | 0.08 | |
| t Critical two-tail | | 4.3026 | |

4. Concluding Remarks
This paper evaluated the accuracy of the MetroCount@5600, i.e. an automatic pneumatic–tube–based traffic count device, to record traffic data based on Malaysian vehicle classification scheme. The results of the study can be summarised as follows:

i. The vehicle classified count data collected using automatic traffic count device, i.e. the MetroCount@5600, is considered accurate when compared with the data collected using the video recording technique.
ii. The used of soft pneumatic tube tends to produce high error due to bumping issue that can produce many pulse per hit axle.

iii. Installing the ATC at a location where number of overtaking manoeuvres is high can reduce the accuracy of the traffic counts and vehicles classification data produced.

An automatic pneumatic-tube-based traffic count device can be considered as a preferred method for traffic data collection especially for long period of traffic monitoring exercises. Manual classified count method can be tedious and expensive if the data has to be collected for long period of times.

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