Investigating Temporal Patterns in Traffic Volumes Obtained using Video Imagery from Buses Operating in Regular Service

Thesis

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By

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Abstract

Roadway traffic volumes are used as inputs for a variety of planning, operations, and monitoring purposes. Among other dimensions, traffic volumes vary by time of day and by day of week. Understanding these time of day and day of week patterns can be important, for example, in understanding whether a traffic count taken at one time of day or on one day of week is representative of a more general time period. Therefore, it is important to detect systematic time of day and day of week patterns.

Although traffic volumes are typically estimated from traffic counts taken at a fixed location over an extended time, they can conceivably be estimated from vehicle observations appearing in video imagery obtained from cameras on public transit vehicles that have been installed for other purposes. Since fleets of transit buses cover most important roadways in an urban network on an ongoing basis, this approach would provide extensive geographic coverage. Contrary to traditional volume data collection at a fixed location, however, vehicles appearing in imagery obtained by transit buses would be identified at different locations at different times. A method to estimate traditional traffic volumes from this very different data acquisition approach has been proposed elsewhere and empirically evaluated to quantify the magnitude of errors in estimating volumes for a typical time of day period on a given day. However, no studies have been conducted to investigate the ability of this new method to determine time of day or day of week patterns in traffic volumes.

This thesis empirically investigates the ability of traffic volumes estimated from transit bus video imagery to identify differences in volumes by time of day and by day of week. To allow for this investigation, empirical data sets are collected over many months during specified hours and on specified days in one traffic direction on one roadway segment of the campus of The Ohio State University (OSU). Manually collected traffic counts are used to determine "manual volumes" in 60-, 30-, and 15-minute intervals for recurring time of day and day of week periods during which the data were collected. Distributions of the manual volumes, which serve as ground truth, are visually inspected to determine the existence of time of day and day of week differences for the 60-, 30-, and 15-minute intervals. In parallel, distributions of "video volumes," determined from processed imagery obtained from OSU buses in regular service, are visually inspected in the same 60-, 30-, and 15-minute time intervals and seen to reveal most, but not all time of day and day of week patterns seen in the ground truth manual volume distributions.

Quantitative analyses are also conducted to investigate whether the video volumes are representative of the time of day and day of week differences found in the manual (true) volumes. Specifically, the quantitative analyses are based on the differences between the mean volume of the distribution for one time of day or day of week period and the mean volume of the distribution for another time of day or day of week period obtained with the same data source (manual or video). Linear regression shows that the differences in the manual volumes are strongly and positively related to the differences in the video volumes taken for the same time of day or day of week comparison. The relationship between the orderings (whether the mean of the volume distribution for one time of day or day of week period is greater than or less than the mean of the volume distribution for another time of day or day of week period) determined with the manual or video volumes is also investigated. The orderings obtained with the video volumes are seen to be strongly and positively related to the orderings obtained with the manual volumes.

In addition, indicator values are assigned to depict whether the difference between the mean volumes in a pair of different time of day or day of week periods in the true (manual) data is large, slight or small. Independent indicator values are assigned for the differences obtained using the video data. The indicator values from the video and true (manual) data for the same time of day or day of week comparisons are again seen to be strongly and positively related.

Based upon the qualitative and quantitative investigations it is found that, although the limited number of video volumes available cannot depict exactly the time of day and day of week effects found in the true (manual) volumes, the video volumes appear to be strongly representative of most time of day and day of week patterns found in the true (manual) volumes.

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Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction and Overview

Traffic volumes are important inputs for a variety of transportation planning, operations, and monitoring purposes. A traffic volume value is used as the primary dynamic variable of a roadway segment to determine facility level of service (e.g., Mannering & Washburn, 2011). Traffic volumes are also important inputs to setting traffic signal cycle and green times (e.g., Mannering & Washburn, 2011). In addition, traffic volumes are used as inputs to calculate vehicle distance traveled (FHWA, 2016), the fundamental metric of motorized travel across roadway networks. Traffic volumes are also used in travel demand model calibration (e.g., Wegmann & Everett, 2012). Travel demand models are used to predict volumes on roadway segments under assumptions of growth or policy decisions and consist of multiple related submodules, each with multiple input parameters. By running the models using inputs obtained from past conditions, traffic volumes corresponding to these past conditions are determined from the models and compared to empirical volumes at the time. Model parameters are then adjusted to improve the match between predicted and empirical volumes.

By definition, traffic volume is the number of vehicles that pass a point over time during a specified time period. Therefore, empirical volumes are determined by taking traffic counts at a fixed location on a specific roadway segment over an extended period of time. Whether the counts are obtained using human observers or automatic sensors, such as road tubes or loop detectors, this approach results in very good traffic data for extended periods of time at specific segments. However, because of resource limitations, the counts can only be collected on a limited number of roadway segments.

Traffic volumes vary by time of day (TOD), day of week (DOW), and other time dimensions. Understanding TOD and DOW effects can be important for analysis. For example, if a traffic count is collected on a specific Tuesday from 9:00-10:00 am, before applying the volume determined from this count to a larger period – for example, a “typical weekday daily volume” – it is important to understand if the volume is representative of the entire day on Tuesday or of all 9:00-10:00 am periods throughout the week. Traffic monitoring sections (e.g., those in state Departments of Transportation) establish TOD and DOW factors for roadways in their jurisdictions from empirical data obtained on a regular basis. For example, Table 1.1 displays the Ohio Department of Transportation (ODOT) 2022 hourly percent by vehicle type for urban minor arterial roadways (ODOT, 2022). In Table 1.1 the 0.4% found in the last column for the 12:00-1:00 am period, for example, indicates that on average 0.4% of an average 24-hour volume is carried on a typical urban minor arterial between 12:00 am and 1:00 am. Similarly, Table 1.2 displays the ODOT 2022 seasonal adjustment factors for urban minor arterial, collectors, and local roadways (ODOT, 2022). In Table 1.2, the 1.733 factor found in the Sunday and January cell, for example, indicates that the average annual daily traffic (FHWA, 2016) is 1.733 times the average 24-hour traffic volume on an urban minor arterial, collector or local roadway on an average Sunday in January.

Table 1.1 ODOT 2022 Hourly Percent by Vehicle Type for Urban Minor Arterial Roadways; *from https://www.transportation.ohio.gov/programs/technical-services/traffic-monitoring/hourly-percent-by-vehicle*

Hour	Hour of Day	P&A (Cars)	**% P&A (Cars)**	B&C (Trucks)	**% B&C (Trucks)**	Total	**% Total**
0	12-1am	139,725	**0.4%**	7,363	**0.7%**	147,088	**0.4%**
1	1-2am	66,558	**0.2%**	6,114	**0.6%**	72,672	**0.2%**
2	2-3am	54,789	**0.1%**	6,913	**0.6%**	61,702	**0.2%**
3	3-4am	69,897	**0.2%**	10,595	**1.0%**	80,492	**0.2%**
4	4-5am	162,041	**0.4%**	17,599	**1.7%**	179,640	**0.5%**
5	5-6am	552,109	**1.5%**	26,578	**2.5%**	578,687	**1.5%**
6	6-7am	1,528,696	**4.0%**	46,527	**4.4%**	1,575,223	**4.1%**
7	7-8am	2,631,818	**7.0%**	68,918	**6.5%**	2,700,736	**6.9%**
8	8-9am	2,529,626	**6.7%**	81,754	**7.7%**	2,611,380	**6.7%**
9	9-10am	2,075,956	**5.5%**	84,164	**7.9%**	2,160,120	**5.6%**
10	10-11am	2,069,568	**5.5%**	84,604	**7.9%**	2,154,172	**5.5%**
11	11-12am	2,348,870	**6.2%**	86,351	**8.1%**	2,435,221	**6.3%**
12	12-1pm	2,604,460	**6.9%**	84,582	**7.9%**	2,689,042	**6.9%**
13	1-2pm	2,540,796	**6.7%**	82,638	**7.8%**	2,623,434	**6.7%**
14	2-3pm	2,875,895	**7.6%**	78,734	**7.4%**	2,954,629	**7.6%**
15	3-4pm	3,119,435	**8.2%**	70,501	**6.6%**	3,189,936	**8.2%**
16	4-5pm	3,155,255	**8.3%**	59,425	**5.6%**	3,214,680	**8.3%**
17	5-6pm	2,919,569	**7.7%**	45,820	**4.3%**	2,965,389	**7.6%**
18	6-7pm	2,081,567	**5.5%**	34,077	**3.2%**	2,115,644	**5.4%**
19	7-8pm	1,493,035	**3.9%**	25,525	**2.4%**	1,518,560	**3.9%**
20	8-9pm	1,110,902	**2.9%**	19,808	**1.9%**	1,130,710	**2.9%**
21	9-10pm	788,436	**2.1%**	15,512	**1.5%**	803,948	**2.1%**
22	10-11pm	548,819	**1.5%**	12,332	**1.2%**	561,151	**1.4%**
23	11-12pm	354,156	**0.9%**	9,644	**0.9%**	363,800	**0.9%**
	Total	37,821,978	**100%**	1,066,078	**100%**	38,888,056	**100%**

Sample of 843 permanent ATR's and portable counts taken in 2022, Monday to Friday counts only.

Table 1.2 ODOT 2022 Seasonal Adjustment Factors for Urban Minor Arterial Roadways; from *https://www.transportation.ohio.gov/wps/wcm/connect/gov/769a78d9-6fa9-48ff-9fc8-d0f4bfe8de05/Seasonal+Adjustment+Factors+2022.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=ROOTWORKSPACE.Z18_K9I401S01H7F40QBNJU3SO1F56-769a78d9-6fa9-48ff-9fc8-d0f4bfe8de05-oyd5D1B*
Group: UBARN MINOR ARTERIAL, COLLECTORS, LOCAL (U04,05,06,07)

From Year:		2022	To Year:		2022		
	Sun	Mon	Tue	Wed	Thu	Fri	Sat
Jan	1.733	1.043	1.067	0.995	1.021	1.054	1.311
Feb	1.470	0.982	0.928	0.927	0.943	0.925	1.265
Mar	1.453	0.955	0.918	0.905	0.898	0.884	1.256
Apr	1.324	0.964	0.910	0.889	0.874	0.857	1.115
May	1.243	0.890	0.872	0.865	0.854	0.853	1.065
Jun	1.319	0.955	0.932	0.920	0.902	0.863	1.091
Jul	1.388	0.979	0.959	0.949	0.921	0.904	1.180
Aug	1.304	0.921	0.900	0.874	0.868	0.839	1.082
Sep	1.343	0.896	0.878	0.867	0.851	0.819	1.112
Oct	1.325	0.927	0.889	0.891	0.864	0.832	1.105
Nov	1.431	0.938	0.899	0.916	0.874	0.867	1.223
Dec	1.461	0.951	0.915	0.906	0.899	0.868	1.181

It has been proposed that imagery obtained from cameras on transit buses while the buses are in general operation could be used to determine traffic volumes (McCord et al., 2020). Bus based cameras are installed on transit buses for other purposes, such as safety, liability, and security. However, vehicles can be seen in the imagery obtained from the outward looking cameras on transit buses. Since the cameras are already installed for other purposes, the marginal cost of obtaining the data would be minimal. In addition, unlike traditional traffic counts, which can only observe a limited number of segments, transit buses cover most major segments in urban areas on a repeated basis. This availability and repeated coverage make buses an attractive data source for volume estimation and ongoing monitoring. However, buses are moving observers where, unlike traditional traffic counts taken at fixed locations, vehicles are observed at different locations on roadway segments as buses proceed along their routes.

Researchers have developed a method to estimate traffic volumes from bus based imagery and conducted empirical studies to document the accuracy of volumes obtained with this method using imagery from buses operating in regular service (McCord et al., 2020, Toosi, 2021). For example, Table 1.3, excerpted from (Toosi, 2021), displays summary statistics of various metrics related to the "error," under various estimation and data aggregation approaches on multiple segments and days, obtained when estimating hourly volumes from bus based imagery relative to determining the volumes from road tubes, which served as the ground truth in the study. In the last column, for example, the median ARE indicates that the median over many comparisons of hourly volume estimates in the study ranged from approximately 15% to 20%, depending on the approach and data set used. In another study (McCord et al., 2020), the error is seen to decrease greatly when estimating volumes over longer periods of time.

Table 1.3 Summary Statistics of Metrics Obtained with the Arithmetic Average of Volume Estimated from Bus Passes by Case and Data set, for 60-minute Periods; Table 4.2 from Toosi (2021)

Case Number	Data set	Number of Segment Direction	Difference			ABS Difference			ARE		
			Mean	Standard Deviation	Median	Mean	Standard Deviation	Median	Mean	Standard Deviation	Median
1	2018 Pooled	110 Segment-60-minute periods	19.755	74.731	11.937	51.49	57.472	32.733	0.226	0.238	0.154
	2019 Pooled	88 Segment-60-minute periods	36.084	108.969	16.503	70.922	90.020	46.463	0.301	0.308	0.232
	2018 and 2019 Pooled	198 Segment-60-minute periods	27.013	91.653	13.638	60.126	74.162	36.240	0.259	0.273	0.188
2	2018 Pooled	110 Segment-60-minute periods	9.853	55.965	9.093	39.665	40.522	27.727	0.204	0.266	0.136
	2019 Pooled	88 Segment-60-minute periods	18.849	71.195	13.089	54.452	49.281	40.460	0.242	0.190	0.211
	2018 and 2019 Pooled	198 Segment-60-minute periods	13.867	63.202	11.6/16	46.262	45.128	33.418	0.221	0.235	0.154
3	2018 Pooled	110 Segment-60-minute periods	11.793	57.423	11.937	42.518	40.166	32.239	0.205	0.228	0.149
	2019 Pooled	88 Segment-60-minute periods	28.061	83.039	13.638	62.047	61.627	42.959	0.270	0.222	0.214
	2018 and 2019 Pooled	198 Segment-60-minute periods	19.023	70.252	12.683	51.198	51.619	35.174	0.234	0.227	0.170

The studies that document errors when estimating volumes from bus based video imagery are limited to comparing estimated volumes to ground truth volumes and have not investigated the ability to detect changes in the estimated volumes by time of day or day of week using bus based video imagery. Therefore, the objective of this thesis is to investigate the ability of traffic volumes estimated from video imagery to validly detect time of day and day of week patterns in traffic volumes.

This thesis is organized into five chapters. Chapter 1 presents the background, motivation, and objective of this thesis. Chapter 2 discusses the collection and processing of the data used for the empirical study developed to investigate the ability of traffic volumes estimated from bus based video imagery to detect time of day and day of week patterns. In Section 2.1, the design and implementation of the large-scale data collection study is presented, where manual traffic counts were obtained on a roadway segment on multiple days and for different hours across two academic semesters on the campus of The Ohio State University (OSU). Two methods are proposed and compared to determine 5-minute traffic volumes from the traffic counts. One method is then selected for use when aggregating the 5-minute volumes into 15-, 30-, and 60-minute volumes at various times of days and on different days of the week. These "manual volumes" serve as the true volumes in this investigation. In Section 2.2, an overview of the method used to convert vehicle observations in imagery into traffic volumes is presented. Aggregated 15-, 30-, and 60-minute video volumes were provided by researchers in the OSU Campus Transit Lab for the same time of day and day of week periods in which manual data were collected.

In Chapter 3, the traffic volumes determined from the manually collected data are investigated as a function of time of day and day of week. In Section 3.1, empirical cumulative distribution functions (ecdfs) of the sets of manual volumes during different time of day periods are visually inspected to determine time of day patterns. In Section 3.2, the same approach is used to investigate day of week patterns. In Section 3.3, time of day and day of week patterns seen in the manual data are investigated more quantitively using various metrics related to the differences in the means of the time of day or day of week distributions. The correspondence of the observed time of day and day of week patterns to expectations of traffic patterns on campus are presented.

In Chapter 4, the traffic volumes determined for the video data are investigated as a function of time of day and day of week. In Section 4.1, empirical cumulative distribution functions (ecdfs) of the sets of video volumes during different time of day periods are visually inspected to determine time of day patterns. In Section 4.2, the same approach is used to investigate day of week patterns. In Section 4.3, time of day and day of week patterns seen in the video data are investigated more quantitively using the same metrics from Section 3.3 related to the differences in the means of the time of day or day of week. The ability of the differences in the video volumes by time of day and day of week are investigated to see if they are able to represent the differences in the true (manual) volumes.

In Chapter 5, the findings, and conclusions of this study are presented. Recommendations for further work are discussed based upon the results and limitations of this study.

Chapter 2: Data Collection and Processing

This chapter discusses the collection and processing of the data used in this thesis. Traffic volume counts were obtained on multiple days across Spring and Autumn semesters on the campus of The Ohio State University (OSU). Traffic volumes were obtained for one segment-direction during specified time periods. Manual data were collected using a short break method where counting occurred for 4 minutes followed by a one minute break. Two approaches are used to estimate the volume in the "missing" one minute of data. After a comparison of results obtained by the two methods, one of the methods is chosen to aggregate these "manual" volumes into 15-, 30-, and 60-minute increments. Video imagery was obtained from the OSU campus buses for the same segment, days of week, and time periods that manual data were collected. A state-of-the-art method was used to convert the imagery to "video volumes" for the same 15-, 30-, and 60-minute periods for which the manual volumes were obtained.

2.1 Manual Data Collection and Processing

This section discusses the collection and processing of the data obtained from manual traffic counts. The manual counts were collected using a short break method (Roess et al., 2004) where counting occurred for 4 minutes followed by a one minute break. Therefore, a method is required to compute the "missing" one minute of data. Two different methods are proposed and compared to determine the "missing" one minute of data. The selected method is then used to aggregate 5-minute volumes from the human traffic counts. Lastly, the 5-minute volumes are then used to aggregate the human traffic counts into 15-, 30-, and 60-minute intervals.

2.1.1 Manual Data Collection

To obtain hourly volume estimates, manual traffic counts were obtained on one segment-direction on the north campus of The Ohio State University. Specifically counts were taken for eastbound traffic on Woody Hayes Drive between Coffey Road and Cannon Drive. Data collection was performed by students who were instructed to only count motorized vehicles during data collection. Manual data collection followed an hour of day and day of week schedule. Students situated themselves approximately in the middle and on the sidewalk on the north side of this segment. Figure 2.1 highlights this segment, and the red X mark in the figure indicates the approximate location where the students collected manual counts.

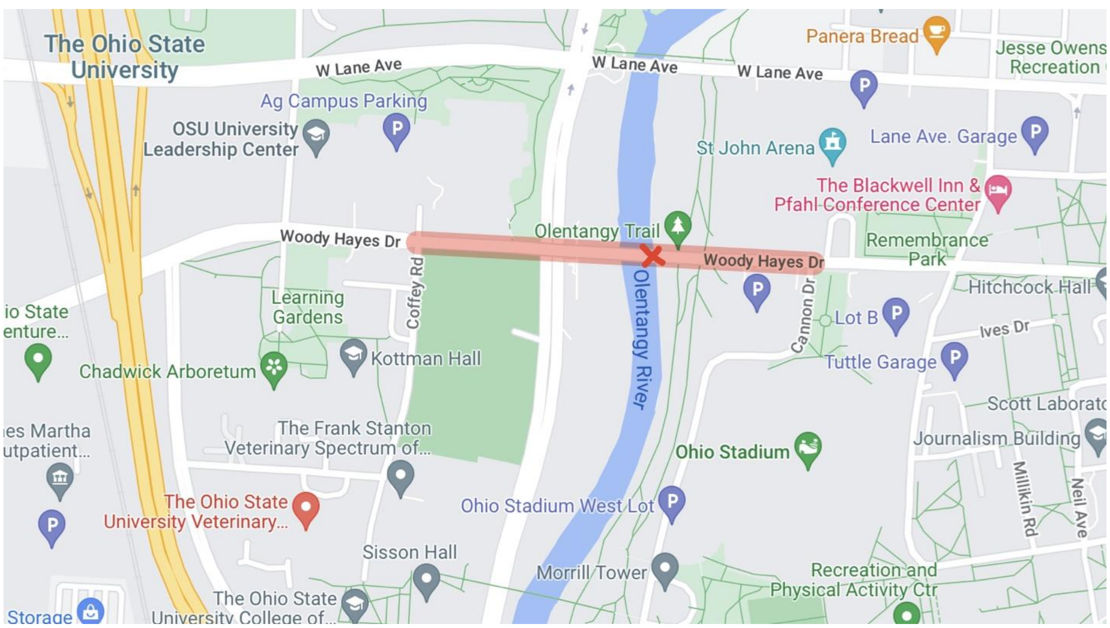

Figure 2.1 Manual Count Segment Location; (Highlighting indicates the segment; Counts were taken in eastbound direction; North is up in this map; X indicates the approximate location of the manual data collectors)

Volume counts were taken near the center of the segment in order to reduce the effect of vehicle queues on the counts. Counting began either on the hour or half hour, and students counted using a "short break" method (Roess et al., 2004). Specifically, they counted for four minutes, took a one minute break, and repeated until the end of their counting period. The short break method is used to reduce human error associated with manual traffic counts. The break is intended to allow human counters to remain focused during the counting interval and to ensure that data are being recorded appropriately. A sample of the data collection sheet used can be found as Figure A.1 in Appendix A. The 4-minute counts by date and start time are presented in Appendix B.

Manual count data were collected during three different hours of the day across Spring and Autumn semesters from January 31st, 2022 to December 8th, 2022. Table 2.1 displays the hour of day and day of week manual data collection schedule. The counting periods were scheduled for one hour, but counting periods were reduced or eliminated in the event of harsh weather conditions. Table A.1 in Appendix A summarizes the specification of weather conditions that the manual data collectors used to determine if they should count for a shorter time period or skip counting entirely for the scheduled hour.

Table 2.1 Hour-of-day and Dav-of-Week Manual Data Collection Schedule and Number of Times Traffic Counts were Taken in each Hour-Day Combination[1]

	Spring Semester 2022 (1/31/22 – 5/12/22)			Autumn Semester 2022 (9/12/22 – 12/8/22)		
Hour	Monday	Wednesday	Thursday	Monday	Wednesday	Thursday
9:30-10:30		8	8		10	9
11:30-12:30	11		8			
13:00-14:00				12		10

[1]On some days the counts during the period were truncated due to weather interruptions. The numbers indicate when any counts were taken during the period.

2.1.2 Short-Break Expansion

The 4-minute volume beginning at hh:mm collected manually on day d is represented by $V_{hh:mm,d}^{man,4}$. To estimate volumes over periods including the 1-minute break, the 4-minute volumes $V_{hh:mm,d}^{man,4}$ are expanded to 5-minute volumes $V_{hh:mm,d}^{man,5}$, which are then aggregated into longer time periods, namely 15-minute, 30-minute, and 60-minute (hourly) volumes. Two methods were considered to expand the observed counts from 4- to 5-minute volumes. The first method is referred to as the “4-minute expansion,” and is the method generally presented for expansion of a traffic count taken with a short break method (Roess et al., 2004). The 5-minute volume beginning at the same time as the 4-minute count determined with this first method is denoted $V_{hh:mm,d}^{man,5,1}$ and calculated as:

$$V_{hh:mm,d}^{man,5,1} = V_{hh:mm,d}^{man,4} + \frac{1}{4} V_{hh:mm,d}^{man,4} = \frac{5}{4} \times V_{hh:mm,d}^{man,4} \tag{2.1}$$

Note that the superscript 1 indicates the estimate obtained from this first method (4-minute expansion).

The 4-minute expansion approach assumes that the flow rate (vehicles per minute) in the "missing" 1-minute interval is the same as the flow rate over the preceding 4-minute interval, the interval during which traffic counts were taken. However, it could be assumed that the flow rate in the missing interval is equally similar to the flow rate over the preceding or over the following 4-minute interval. Therefore, a second method, referred to as the "8-minute interpolation," was considered to determine $V_{hh:mm,d}^{man,5,2}$. In this method the missing 1-minute volume is computed as the average of the flow rate over the previous and following 4-minute intervals. The 5-minute volume for this method is calculated as:

$$V_{hh:mm,d}^{man,5,2} = V_{hh:mm,d}^{man,4} + \frac{1}{2}[\frac{1}{4}\left(V_{hh:mm,d}^{man,4}\right) + \frac{1}{4}\left(V_{hh:mm+00:05,d}^{man,4}\right)]$$

$$= V_{hh:mm,d}^{man,4} + \frac{1}{8} \times (V_{hh:mm,d}^{man,4} + V_{hh:mm+00:05,d}^{man,4}) \qquad (2.2)$$

where, $V_{hh:mm,d}^{man,4}$ is again the 4-minute volume beginning at hh:mm collected manually on day d. Note that the superscript 2 indicates the estimate obtained from the second method (8-minute interpolation).

In practice it is common to be interested in 2-way traffic volumes. Therefore, when performing manual counts, it is common to alternate which traffic direction is being counted on a regular basis (Roess et al., 2004), e.g., every 5 minutes. As a result, no data are available for consecutive 5-minute increments in the same direction. In this case same direction data would only be available for the four minutes preceding the missing one minute, making the 4-minute expansion method more common in practice.

Manual count data were only collected in one direction. Therefore, both methods are feasible in this thesis. No ground truth volumes are available for the 1-minute intervals where manual data were not collected. As a result, the two estimated 5-minute volume values were compared to each other, rather than to any true value, to identify if the choice of method would tend to greatly influence subsequent empirical analysis. To compare the two methods, the difference,

$$D = V_{hh:mm,d}^{man,5,1} - V_{hh:mm,d}^{man,5,2} \tag{2.3}$$

absolute difference,

$$AD = |D| \tag{2.4}$$

relative difference (RD),

$$RD = \frac{V_{hh:mm,d}^{man,x,1} - V_{hh:mm,d}^{man,x,2}}{V_{hh:mm,d}^{man,x,2}} \tag{2.5}$$

and absolute relative difference (ARD),

$$ARD = |RD| \tag{2.6}$$

were taken between each $V_{hh:mm,d}^{man,5,1}$ and $V_{hh:mm,d}^{man,5,2}$ with the same start time hh:mm and day *d*.

The difference *D* represents the difference in volumes estimated with the two methods in terms of vehicles per 5-minute interval. A positive *D* value indicates that the first method provides a higher volume value. When taking averages of *D* values, the sign of the average *D* indicates if the first method produced smaller or larger values than the second method "on average." However, when averaging, positive and negative differences could cancel each other out, possibly leading to an average value close to zero despite the individual volumes obtained when using the two approaches being very different. The absolute difference *AD* indicates the magnitude of the differences in the 5-minute volumes obtained with the two approaches, without considering which method had the larger value. By not considering the sign, the average *AD* is the average magnitude of the difference without positive and negatives cancelling out. It therefore provides a better indication of the average "size" of error than does the average *D*.

The *RD* measure is used to compare the difference on a relative scale. For example, consider a case in which method 1 produces a 5-min volume of 11 vehicles and method 2 produces a 5-min volume of 10 vehicles, and a second case where method 1 produces a 5-min volume of 101 vehicles and method 2 produces a 5-min volume of 100 vehicles. Both would have D =1. However, a difference of 1 would appear to be of less importance when estimating a volume on the order of 100 vehicles than when estimating a volume on the order of 10 vehicles. The first case would have a RD = 0.10 and the second case would have a RD = 0.01, indicating that the relative size of the difference in the first case is much larger than that of the second case. In this thesis the 8-minute interpolation method was chosen as the denominator for the *RD* because it considers two 4-minute increments rather than just one. This is more reasonable as it can be assumed that the volume in the 4-minute increment following the missing 1-minute interval is equally similar to the unobserved volume in this 1-minute interval as is the 4-minute volume in the increment preceding the missing 1-minute interval. A positive *RD* value indicates that the first interpolation method produced a larger volume value than the second interpolation method. In addition, the sign of the average *RD* indicates whether the mean of the first method is larger or smaller than the mean of the second method. Similar to when considering differences *D*, when taking the average of *RD* values, positive and negative changes could cancel each other and lead to an average value close to zero despite the individual volumes obtained when using the two approaches being very different. The absolute relative difference *ARD* indicates the magnitude of the relative change between the two 5-minute volumes. By not allowing positives and negatives to cancel out, the average *ARD* provides a better indication of the average “size” of relative difference than does the *RD*.

As explained above, manual count data used in this thesis were collected between 01/31/2022 and 12/08/2022. A subset of these data, specifically, the manual count data collected between 01/31/2022 and 05/12/2022, were used to compare method 1, the "4-minute expansion", and method 2, the "8-minute interpolation." There are 427 usable observations collected during this time period. The individual data values are available in Appendix B. The mean, median, and standard deviation of the *D*, *AD*, *RD*, and *ARD* values of this data set are presented in Table 2.2. Figure 2.2 presents the empirical cumulative distribution functions (ecdfs) of the difference and absolute difference values. Figure 2.3 presents the ecdfs of the relative difference and absolute relative difference values. The ecdfs were computed manually. The y-axis represents the cumulative probability of the value indicated on the x-axis. The cumulative probability of x is computed as $k(x)/n$, where n is the number of observations in the data set, and $k(x)$ is the number of observations in the data set that are less than or equal to x.

Table 2.2: Summary Statistics of the Comparison between Expansion, Method 1, and Interpolation, Method 2

	Difference (*D*) (veh/5-min)	Absolute Difference (*AD*) (veh/5-min)	Relative Difference (*RD*) (dimensionless)	Absolute Relative Difference (*ARD*) (dimensionless)
Median	-0.1250	0.6250	-0.0033	0.0215
Mean	-0.0340	0.6956	-0.0057	0.0270
Standard Deviation	0.8996	0.5706	0.0350	0.0229
Number of Observation (N)				427

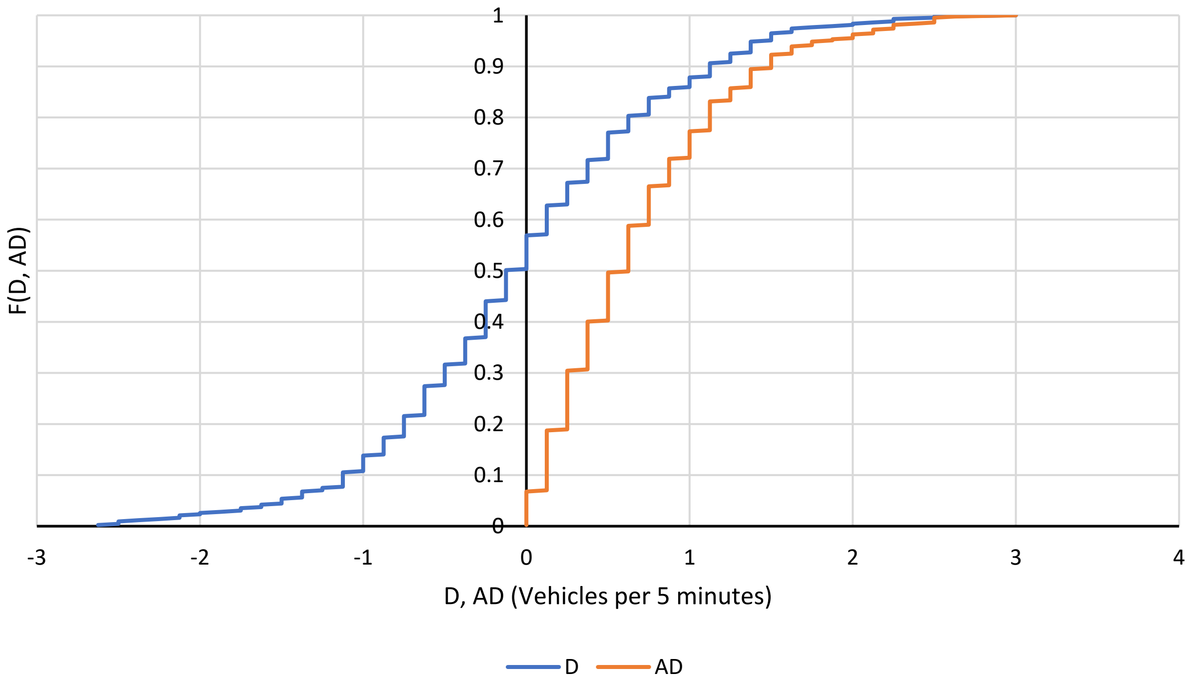

Figure 2.2: Ecdfs of Difference and Absolute Difference between Expansion (Method 1) and Interpolation (Method 2). $F(x)$ is the proportion of values less than or equal to x.

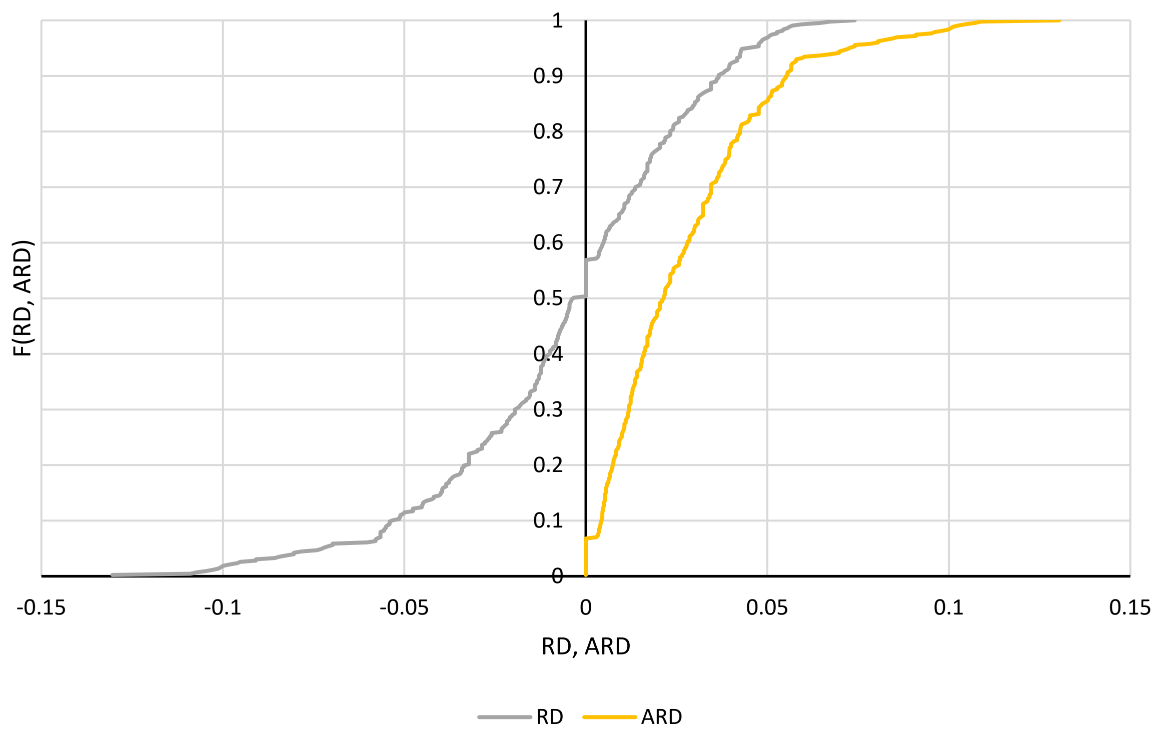

Figure 2.3: Ecdfs of Relative Difference and Absolute Relative Difference between Expansion (Method 1) and Interpolation (Method 2). $F(x)$ is the proportion of values less than or equal to x.

From Table 2.2, the mean and median *D* and *RD* are close to zero when considering the size of the standard deviation, indicating no strong tendency for one method to lead to a larger or smaller estimate compared to the other method. The average difference (*D*) between the two methods is -0.0340, and the average absolute difference (*AD*) is about 0.7 vehicles per 5-minute period. The set of *AD* values translate to an average absolute relative difference (*ARD*) between 2% and 3% with a standard deviation of 2.15%. From Figure 2.2, one sees that the proportion of observations in which the absolute difference is less than one vehicle per 5 minutes is over 0.75. In addition, Figure 2.3 shows that the proportion of observations in which the absolute relative difference is less than 0.05 is over 0.85. These results further indicate that the two methods produce very similar values.

As stated above, no ground truth data are available, and therefore there is no means to determine if one method is more accurate than the other. However, since the differences and relative differences are distributed around zero and the average and median difference and absolute difference are small, it appears that the results of subsequent analysis in this thesis would not be affected by which method is used. Since the logic of method 2 (8-minute interpolation) is more appealing, as it considers the previous and following 4-minute volumes, method 2 is used to determine 5-minute volumes for subsequent analysis.

2.1.3. Aggregation of Data

The $V_{hh:mm,d}^{man,5,2}$ volumes were used to determine nonoverlapping 15-, 30-, and 60-minute volumes beginning on either the hour or half hour by summing the 5-minute volumes in the applicable interval. The 15-minute volume is denoted as $V_{hh:mm,d}^{man,15}$ and calculated as:

$$V_{hh:mm,d}^{man,15} = V_{hh:mm,d}^{man,5,2} + V_{hh:mm+00:05,d}^{man,5,2} + V_{hh:mm+00:10,d}^{man,5,2} \tag{2.7}$$

with mm being 00, 15, 30, or 45.

The 30-minute volume is denoted as $V_{hh:mm,d}^{man,30}$ and calculated as:

$$V_{hh:mm,d}^{man,30} = V_{hh:mm,d}^{man,15} + V_{hh:mm+00:15,d}^{man,15} \tag{2.8}$$

with mm being 00, or 30.

The 60-minute volume is denoted as $V_{hh:mm,d}^{man,60}$ and calculated as:

$$V_{hh:mm,d}^{man,60} = V_{hh:mm,d}^{man,30} + V_{hh:mm+00:30,d}^{man,30} \tag{2.9}$$

with mm being 00 or 30. Each collection period lasted a maximum of 60 minutes. Some counts were truncated due to inclement weather. The 60-minute volumes considered are only those that correspond to periods in which manual data collection occurred for the entire hour. If the manual counts were truncated due to weather, the counts are still used to estimate shorter interval volumes if possible. For example, on 03/09/2023, manual counts were only taken between 9:30 and 10:00. No 60-minute volume was considered for the 9:30-10:30 period from the traffic counts, but a 30-minute volume was considered for the 9:30-10:00 period and 15-minute volumes were considered for the 9:30-9:45 and 9:45-10:00 periods. The $V_{hh:mm,d}^{man,15}$, $V_{hh:mm,d}^{man,30}$, and $V_{hh:mm,d}^{man,60}$ values are listed in Appendix C.

2.2 Video Data Collection and Processing

This section discusses how the bus based video traffic volumes (video volumes) were obtained. The video imagery obtained from the transit buses was processed by OSU's Campus Transit Lab (CTL). A single direction moving observer method was used to compute the volume for a single bus pass. Next, a description of how the imagery is converted to volumes for 15-, 30-, and 60-minute intervals is presented.

2.2.1 Traffic Volumes from Bus-Based Video

As described previously, traffic volumes can be estimated from observations of vehicles appearing imagery obtained from cameras carried on transit buses in regular service. A method has been proposed (Toosi, 2021, McCord et al., 2020) to estimate traffic volumes for a specified time period from this bus based video imagery. There are two parts to the method used to produce these estimated volumes. The first involves computing a traffic volume for a single bus pass. The second part is the aggregation of the single pass traffic volumes across all bus passes that occur during the specified time period.

As the bus travels along an identified segment *S* it "observes" a number of vehicles *n* traveling in the opposite direction. The bus "observes" these vehicles at different points along the segment. The traditional definition of traffic volume (Roess et al., 2004) is the number of vehicles passing a fixed point over time. Therefore, a method is required to transform the observations obtained at different points on the roadway segment at different times to the equivalent of a number of vehicles past a fixed point over a specified time period. The "one-direction" moving observer method (Toosi, 2021) was developed to allow this transformation. To compute the traditional concept of volume – namely, vehicles passing a fixed location during a specified time interval – a virtual observer at the downstream traffic end (where the bus entered the segment) and a virtual vehicle at the upstream traffic end (where the bus left the segment) are considered.

The bus traverses the segment *S* in time t_1. During this time the bus "observes" *n* vehicles traveling in the opposite direction on the segment. The bus also observes no vehicles on the segment travelling in this opposite direction between the time the n^{th} vehicle was observed and the time the bus exits the segment. One can consider that the "bus" makes a final observation – either a vehicle or no vehicle at the instant it leaves the segment, which occurs t_1 time units after it entered the segment. The time it would take for this "final observation" (either a vehicle or no vehicle) to reach the downstream traffic end of the segment *S* is denoted as t_2. This time t_2 is called the "virtual vehicle" time. This is the time it would take an imaginary (virtual) vehicle entering the segment at the upstream traffic end at the instant the bus leaves the segment to traverse the segment S and arrive downstream at the virtual observer. There are multiple ways to compute the virtual vehicle time t_2. In this thesis the CTL video volumes were derived assuming the virtual vehicle time t_2 is equal to the length of segment S divided by the speed limit of segment S.

To compute a fixed location observation based upon a moving observer observation, the “equivalent observation time” must be determined. Assuming the fixed location observer is located at the downstream traffic end of the segment, the equivalent observation time is the time it takes for the bus to traverse the segment t_1 plus the virtual vehicle time t_2. Therefore, the volume n observed by the moving observer in time t_1 would be the same volume n observed by the fixed location virtual observer in time $t_1 + t_2$. The equivalent fixed location volume that would be recorded by the virtual observer corresponding to the moving observer’s observations from a single bus pass is then a volume of n vehicles in time $t_1 + t_2$.

A MATLAB-based Graphical User Interface (GUI) was previously developed to allow the digitization of vehicle observations from the bus-based video. Data processors view the bus based video played within the GUI and “click” when a vehicle is seen. Each “click” represents an observed vehicle on segment S. The GUI-recorded clicks are coupled with the bus’s Automatic Vehicle Location (AVL) system to determine the mapping of the clicks to a specified segment and the time t_1 for the bus to traverse a specified segment. As discussed above, t_2 is then added to t_1 to produce an equivalent observation time for the virtual observer.

2.2.2 Aggregation of Data

With this data collection approach, each individual bus pass over a segment leads to a volume n in equivalent observation time $t_1 + t_2$, where $t_1 + t_2$ will be on the order of a minute or so. The goal is to determine the volume for a longer time period, e.g., 15 minutes or an hour (60 minutes). Multiple bus passes will likely be available in this time period. Therefore, the flow rate from each individual bus passes must be aggregated to get a volume for the desired time period. There are multiple ways to aggregate the volume for an individual bus pass. In this thesis a method described in (Toosi, 2021) is used. In this method a volume over a time period between T and $T + \Delta T$ in determined by integrating a flow rate function $q(t)$ over the interval:

$$V(T, T + \Delta T) = \int_{T}^{T+\Delta T} q(t)dt \qquad (2.10)$$

Each individual bus pass volume of n vehicles in equivalent time $t_1 + t_2$ can be converted to an approximation of flow rate $q(t)$ at time t (presently considered to be when the bus enters the segment):

$$q(t) = \frac{n}{t_1+t_2} \qquad (2.11)$$

The multiple bus passes during the interval (T, $T + \Delta T$) lead to multiple flow rates q at different times t during the interval. The $q(t)$ values are used to approximate a continuous flow rate function for the interval. CTL investigators aggregated the video volumes obtained from single bus passes into longer period volumes using linear interpolation between adjacent flow rates to derive the continuous flow rate function $q(t)$. The approximated continuous flow rate function is then integrated according to Equation (2.10) to produce the video based volumes for specified time periods.

The bus based video traffic volumes used in this thesis were provided by CTL investigators using the methods described above. Sets of video volumes provided for specified time increments will be compared to sets of manual volumes for the same time increments to identify similarities and differences in patterns obtained when using manual or video data. The manual volumes were only collected for a maximum of 60 minutes and aggregated in 15-, 30-, and 60-minute increments. Therefore, nonoverlapping 15-, 30-, and 60-minute volumes beginning on either the hour or half hour were provided for the time periods in which manual data were collected. The k-minute volume beginning at hh:mm collected on day *d* is represented by $V_{hh:mm,d}^{bus,k}$. The 15-minute volume is denoted as $V_{hh:mm,d}^{bus,15}$ with mm being 00, 15, 30, or 45. The 30-minute volume is denoted as $V_{hh:mm,d}^{bus,30}$ with mm being 00 or 30. The 60-minute volume is denoted as $V_{hh:mm,d}^{bus,60}$ with mm being 00 or 30. The $V_{hh:mm,d}^{bus,15}$, $V_{hh:mm,d}^{bus,30}$, and $V_{hh:mm,d}^{bus,60}$ values are listed in Appendix D.

Chapter 3: Temporal Effects in Volumes Determined from Manually Collected Data

This chapter investigates the vehicle volumes determined from manually collected data, which will be called “manual volumes.” In Sections 3.1 and 3.2, respectively, the manual volumes will be investigated as a function of time of day and day of week using empirical cumulative distribution functions (ecdfs). In Section 3.3, differences in the manual volumes by time of day and day of week will be investigated more quantitively using differences in the means of the distributions. Behavioral patterns for time of day and day of week effects will be analyzed. Lastly, distinct time of day and day of week patterns will be noted to be looked for within the video based volumes.

3.1 Time of Day Effects in Manual Volumes

This section will investigate the manual vehicle volumes as a function of the time of day. As discussed in Section 2.1.1, manual data were collected for hour-long intervals on Mondays, Wednesdays, and Thursdays. Of the three days, Thursday was the day of the week with most hours of manual volumes collected. On Thursdays manual data were collected from 9:30 to 10:30 during both Spring 2022 and Autumn 2022 semesters, 11:30 to 12:30 during Spring 2022, and 13:00 to 14:00 during Autumn 2022. In this thesis it is assumed that the volumes in the same time of day and on the same day of week in different semesters – specifically, the Wednesday and Thursday 9:30 to 10:30 volumes in Spring 2022 and Autumn 2002 – can be grouped together for analysis. That is, it is assumed that there is no “semester” effect. Investigating such an effect could be a topic for further research. The manual vehicle volumes for 60-, 30-, and 15-minute intervals – i.e., $V_{hh:mm,d}^{man,60}$, $V_{hh:mm,d}^{man,30}$, and $V_{hh:mm,d}^{man,15}$ – can be found in Appendix C. These manual vehicle volumes used in the analysis were aggregated using the 8-minute interpolation method described in Section 2.1.

Figure 3.1 presents the empirical cumulative distribution functions (ecdfs) of 60-minute volumes estimated from manually collected data for the three 60-minute Thursday intervals, that is, for $V_{9:300,4}^{man,60}$, $V_{11:30,4}^{man,60}$, and $V_{13:00,4}^{man,60}$ with 4 representing the fourth day of the week (Thursday). The y-axis represents the cumulative probability of the volume indicated on the x-axis. The ecdfs were calculated manually. The cumulative probability of x is computed as $k(x)/n$ where n is the number of observations in the data set, and $k(x)$ is the number of observations in the data set that are less than or equal to x.

As discussed in Section 2.1, if there were weather conditions that limited the ability to conduct manual counts, the manual counts were either truncated after 15 or 30 minutes or not conducted at all for that hour. If the manual counts were truncated, volumes were estimated for the shorter (e.g., 15- or 30-minute) periods in which the counts were taken but not expanded to the longer periods that were not completely counted. Furthermore, manual data were only collected 11:30-12:30 for Spring semester and 13:00-14:00 for Autumn semester, while manual data were collected 9:30-10:30 for both Spring and Autumn semesters. As a result, the number of observations in each $V_{hh:mm,d}^{man,60}$, $V_{hh:mm,d}^{man,30}$, and $V_{hh:mm,d}^{man,15}$ data set varies. Summary statistics of the distributions shown in Figure 3.1 are presented in Table 3.1.

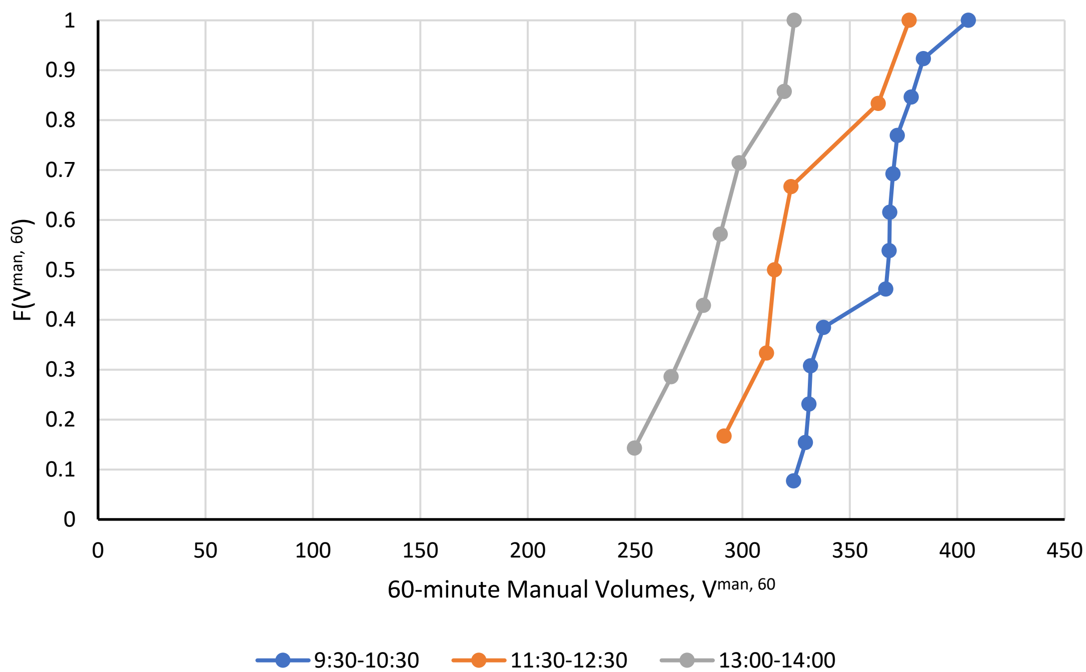

Figure 3.1: Ecdfs of 60-minute Thursday Volumes Determined from Manual Data for Time Intervals beginning at 9:30, 11:30, and 13:00

Table 3.1: Summary Statistics of the Thursday 60-minute Distributions, Manual Volumes

Hour	Number of Volumes	Median[1]	Mean	Standard Deviation
9:30-10:30	13	368.38	359.07	25.48
11:30-12:30	6	318.81	330.21	33.13
13:00-14:00	7	289.75	290.05	26.86

[1]Medians calculated with Excel function, which takes midpoint between middle numbers when the number of volumes is even. This may differ from $F^{-1}(0.5)$ from the ECDF.

In Figure 3.1 there is a clear distinction between each of the three hourly ecdfs. The volumes from largest (ecdf is farthest to the right) to smallest (ecdf is farthest to the left) are as follows: 9:30-10:30, 11:30-12:30, and lastly 13:00-14:00. This ordering is also evident in the means and medians shown in Table 3.1.

It would be interesting to investigate if clear distinctions among the manual traffic volumes, such as those observed in Figure 3.1, occur during subperiods within the hours. Therefore, 30-minute ecdfs were created for each of the hourly ecdfs presented in Figure 3.1. Figures 3.2, 3.3, and 3.4 present the empirical cumulative distribution functions (ecdfs) of 30-minute manual volumes for the six 30-minute Thursday intervals, that is, for the six $V_{hh:mm,4}^{man,30}$ with mm being 00 or 30 in each of the three hourly periods, and 4 representing the fourth day of the week (Thursday). Figure 3.2 presents the volumes in the 30-minute intervals during the 9:30-10:30 hour ($V_{09:30,4}^{man,30}, V_{10:00,4}^{man,30}$). Figure 3.3 presents the volumes in the 30-minute intervals during the 11:30-12:30 hour ($V_{11:30,4}^{man,30}, V_{12:00,4}^{man,30}$). Figure 3.4 presents the volumes in the 30-minute intervals during the 13:00-14:00 hour ($V_{13:00,4}^{man,30}, V_{13:30,4}^{man,30}$). Summary statistics of the distributions shown in Figure 3.2 through 3.4 are presented in Table 3.2.

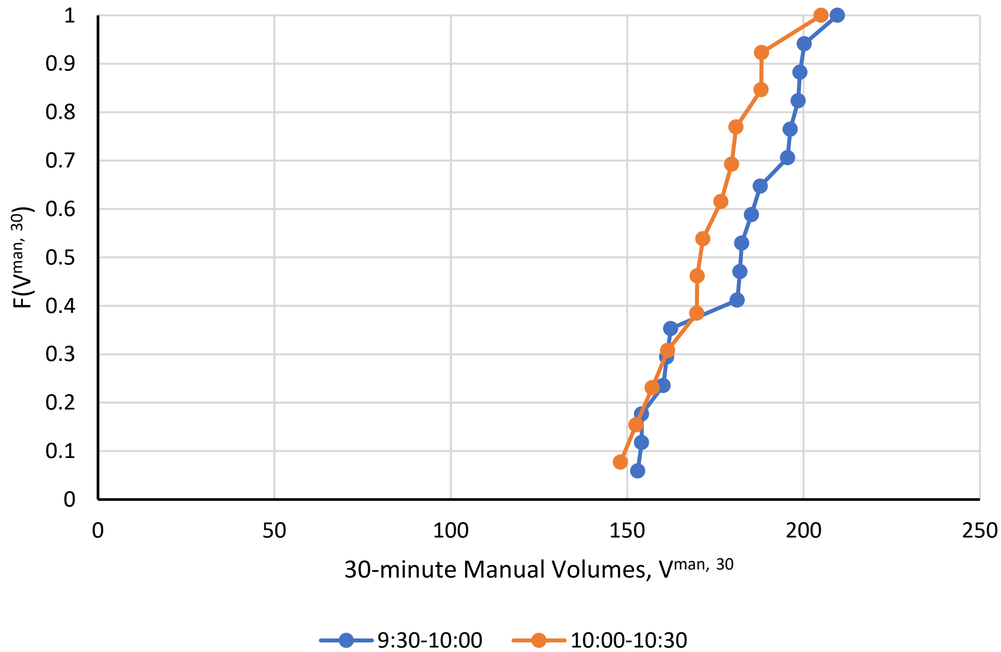

Figure 3.2: Ecdfs of 30-minute Thursday Volumes Determined from Manual Data for Time Intervals beginning at 9:30 and 10:00

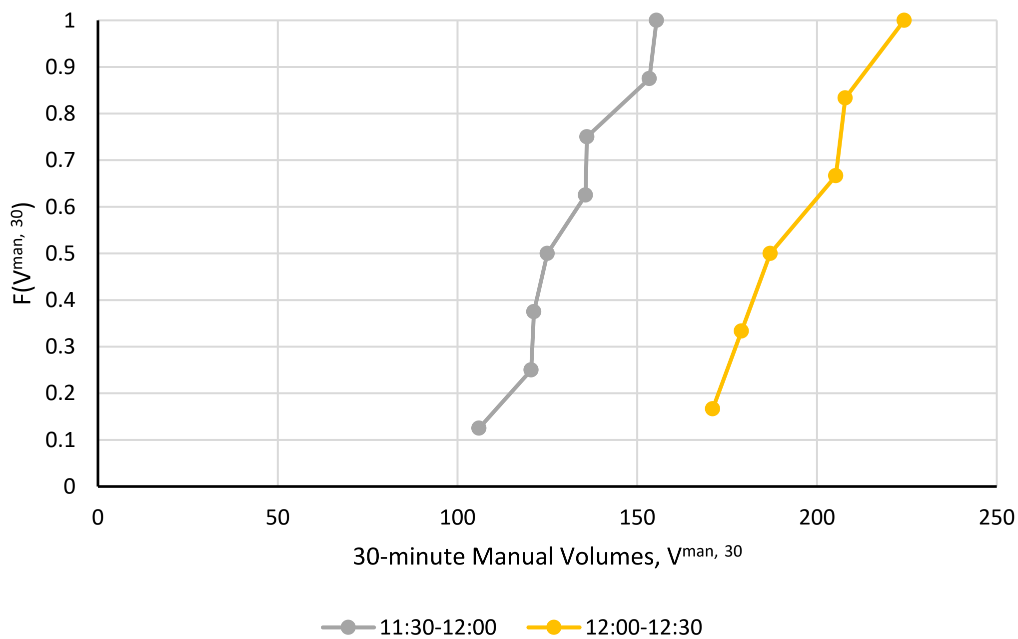

Figure 3.3: Ecdfs of 30-minute Thursday Volumes Determined from Manual Data for Time Intervals beginning at 11:30 and 12:00

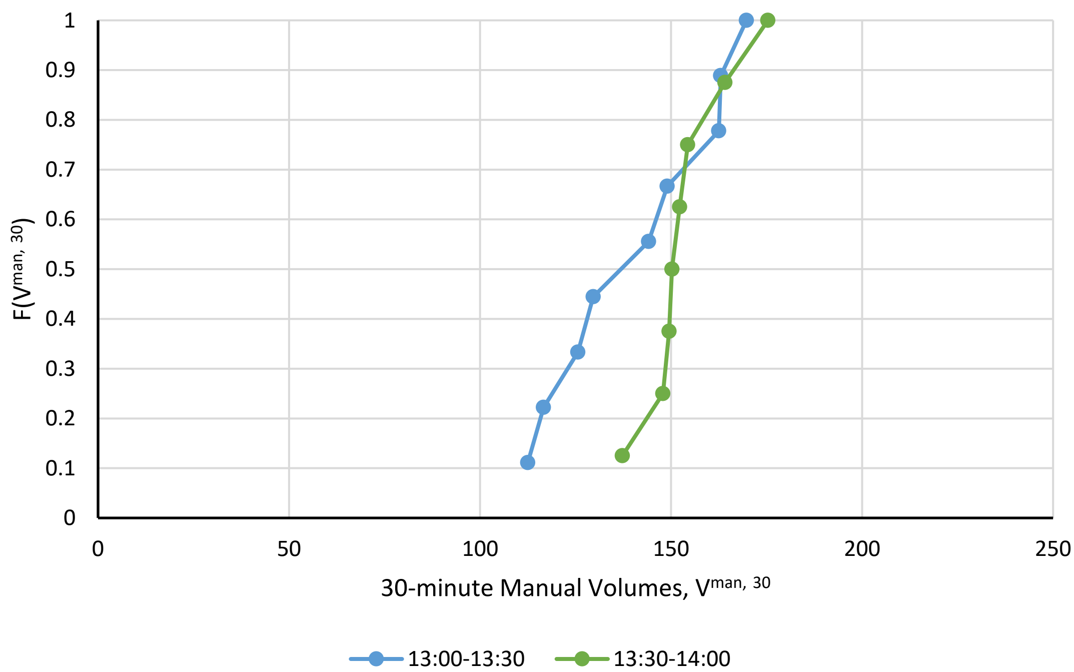

Figure 3.4: Ecdfs of 30-minute Thursday Volumes Determined from Manual Data for Time Intervals beginning at 13:00 and 13:30

Table 3.2: Summary Statistics of the Thursday 30-minute Distributions, Manual Volumes

Hour	Number of Volumes	Interval	Median[1]	Mean	Standard Deviation
9:30-10:30	17	9:30-10:00	182.50	180.18	18.90
	13	10:00-10:30	171.50	172.97	15.92
11:30-12:30	8	11:30-12:00	130.31	131.64	16.92
	6	12:00-12:30	196.13	195.73	20.10
13:00-14:00	9	13:00-13:30	144.13	141.42	21.26
	8	13:30-14:00	151.25	153.88	11.43

[1]Medians calculated with Excel function which takes midpoint between middle numbers when the number of volumes is even. This may differ from $F^{-1}(0.5)$ from the ECDF.

In Figure 3.2 there is a small amount of separation in the ecdfs for the higher volume values (e.g., volumes with ecdf value greater than 0.5) for the 9:30-10:30 hour. However, generally the two ecdfs are very similar. These findings are consistent with what is found in the summary statistics shown in Table 3.2, as the means and medians are close between the half-hour divisions of the 9:30-10:30 hour. In Figure 3.3 there is a clear distinction between the two 30-minute periods during the 11:30-12:30 hour. The 12:00-12:30 volumes are much larger than the 11:30-12:00 volumes. This ordering is also evident in the means and medians Table 3.2. In Figure 3.4 the two ecdfs for the 13:00-14:00 hour overlap at the larger volume values (e.g., volumes with ecdf value greater than 0.5). There is more separation in the ecdfs for the lower volume values (e.g., volumes with ecdf value greater than 0.5), where the 13:00-13:30 volumes are smaller than the 13:30-14:00 volumes. These findings are also evident in the means and medians Table 3.2, as the mean and median of the 13:30-14:00 period are slightly larger than the mean and median of the 13:00-13:30 period, while the medians between the 13:30-14:00 and 13:00-13:30 periods are closer together than the means.

To investigate time of day patterns further, ecdfs for 15-minute subperiods are plotted in Figures 3.5, 3.6, and 3.7 for each of the four 15-minute intervals within the respective hour, that is, for the twelve $V_{hh:mm,4}^{man,15}$ with mm being 00, 15, 30, or 45 in each of the three hourly periods, and 4 representing the fourth day of the week (Thursday). Figure 3.5 presents the 15-minute intervals during the 9:30-10:30 hour ($V_{09:30,4}^{man,15}$, $V_{09:45,4}^{man,15}$, $V_{10:00,4}^{man,15}$, $V_{10:15,4}^{man,15}$). Figure 3.6 presents the 15-minute interavls during the 11:30-12:30 hour ($V_{11:30,4}^{man,15}$, $V_{11:45,4}^{man,15}$, $V_{12:00,4}^{man,15}$, $V_{12:15,4}^{man,15}$). Figure 3.7 presents the 15-minute interavls during the 13:00-14:00 hour ($V_{13:00,4}^{man,15}$, $V_{13:15,4}^{man,15}$,

$V_{13:30,4}^{man,15}, V_{13:45,4}^{man,15}$). Summary statistics of the distributions shown in Figure 3.5 through 3.7 are presented in Table 3.3.

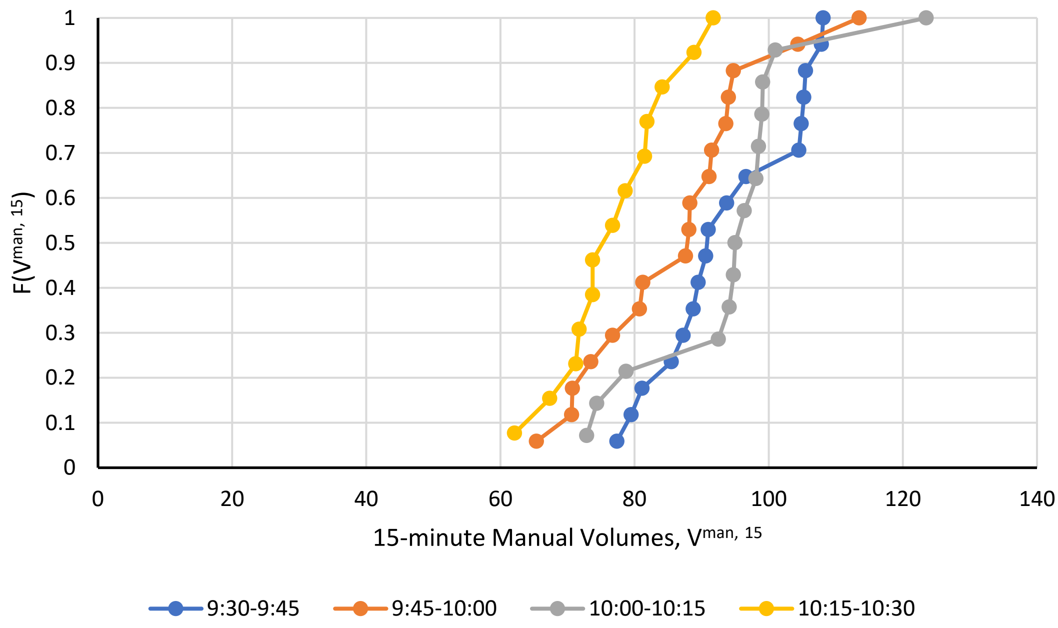

Figure 3.5: Ecdfs of 15-minute Thursday Volumes Determined from Manual Data for Time Intervals beginning at 9:30, 9:45, 10:00 and 10:15

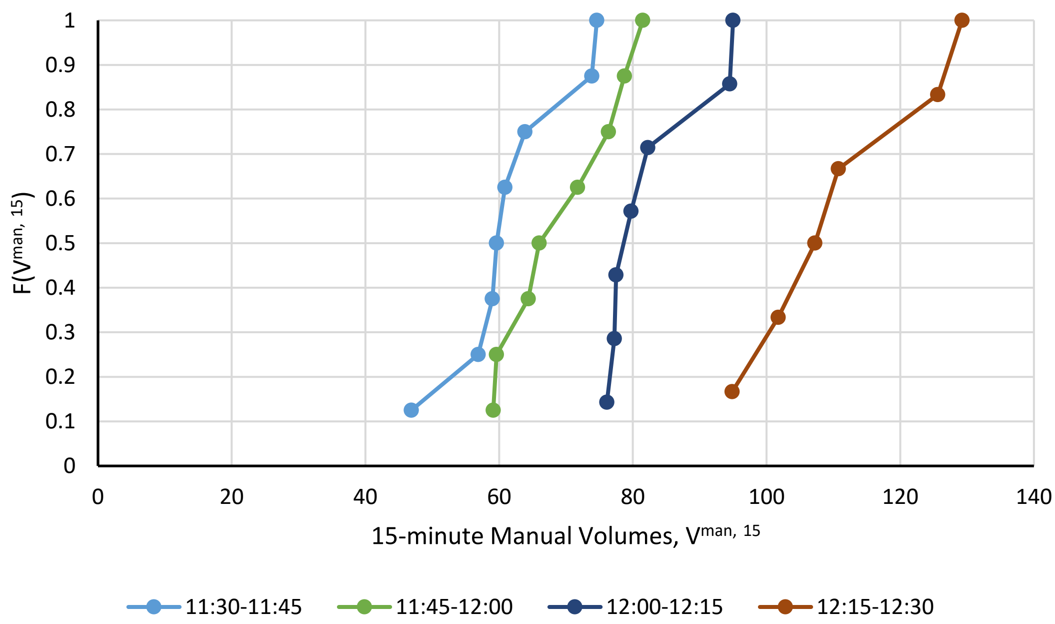

Figure 3.6: Ecdfs of 15-minute Thursday Volumes Determined from Manual Data for Time Intervals beginning at 11:30, 11:45, 12:00 and 12:15

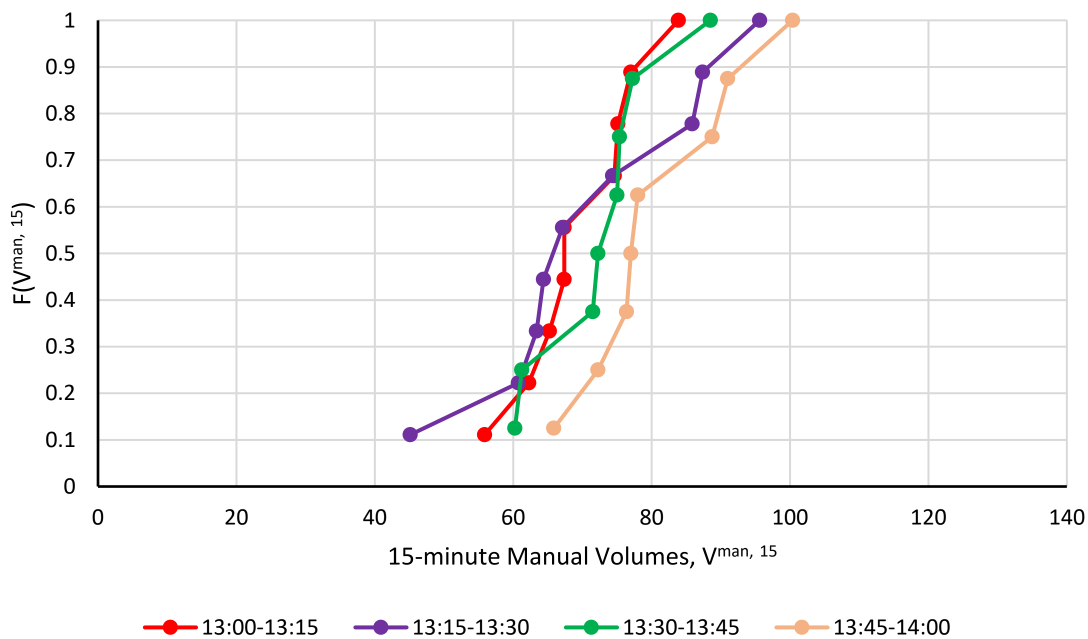

Figure 3.7: Ecdfs of 15-minute Thursday Volumes Determined from Manual Data for Time Intervals beginning at 13:00, 13:15, 13:30, and 13:45

Table 3.3: Summary Statistics of the Thursday 15-minute Distributions, Manual Volumes

Hour	Number of Volumes	Interval	Median[1]	Mean	Standard Deviation
9:30-10:30	17	9:30-9:45	91.00	93.95	10.38
	17	9:45-10:00	88.13	86.23	12.62
	14	10:00-10:15	95.69	94.14	12.65
	13	10:15-10:30	76.75	77.19	8.42
11:30-12:30	8	11:30-11:45	60.25	61.95	9.06
	8	11:45-12:00	71.75	65.44	20.46
	9	12:00-12:15	79.75	83.20	8.14
	6	12:15-12:30	109.00	111.58	13.45
13:00-14:00	9	13:00-13:15	67.38	69.86	8.55
	9	13:15-13:30	67.13	71.56	15.80
	8	13:30-13:45	73.63	72.67	9.03
	8	13:45-14:00	77.50	81.20	11.26

[1]Medians calculated with Excel function which takes midpoint between middle numbers when the number of volumes is even. This may differ from $F^{-1}(0.5)$ from the ECDF.

The ecdfs of the 15-minute intervals mostly overlap for more for the the 9:30-10:30 (Figure 3.5) and 13:00-14:00 (Figure 3.7) hours than for the 11:30-12:30 hour (Figure 3.6), where there is a distinct ordering of the intervals. In Figure 3.5 the volumes collected 10:15-10:30 are the smallest. For the other three 15-minute periods the ecdfs are similar. This is evident in the means and medians Table 3.3 as the mean and median of the 10:15-10:30 period are much smaller than the mean and meadian of other 3 periods, which are somewhat similar. In Figure 3.6 there is a clear distinction among the ecdfs of the four 15-minute periods. This distinction is also found in the 30-minute periods of the same hour (Figure 3.3). The volumes from largest to smallest values are as follows: 12:15-12:30, 12:00-12:15, 11:45-12:00, and lastly 11:30-11:45. This ordering is also evident in the means and medians Table 3.3. In Figure 3.7 the volumes collected 13:45-14:00 appear to be the largest. For the other three 15-minute periods the ecdfs are very similar. This patterns is evident in the means and medians Table 3.3, as the mean and median of the 13:45-14:00 period is larger than the mean and median of the other 3 periods, which all have very similar mean values.

The analysis above considers the data collected on Thursdays, the day of the week with the highest number of different hours for which manaul data were collected. The manual vehicle volumes are also investigated as a function of time of day for Mondays and Wednesdays. Monday is the day of week with the second most hours for which manual data were collected. On Mondays manual data were collected from 11:30 to 12:30 during Spring semester, and 13:00 to 14:00 during Autumn semester. Wednesday only had one hour for which manual volumes were collected. On Wednesdays manual data were collected from 9:30 to 10:30 during both Spring and Autumn semester. Therefore, patterns cannot be investigated within different hours on Wednesdays but can still be investigated for sub-periods within the hour.

Figure 3.8 presents the empirical cumulative distribution functions (ecdfs) of the two 60-minute Monday intervals, that is, for the two $V_{hh:mm,1}^{man,60}$ with hh:mm being 11:30 or 13:00, and 1 representing the first day of the week (Monday). Figures 3.9 and 3.10 present the empirical cumulative distribution functions (ecdfs) of 30-minute manual volumes for the four 30-minute Monday intervals, that is, for the four $V_{hh:mm,1}^{man,30}$ with mm being 00 or 30 in each of the two hours and 1 representing the first day of the week (Monday). Figure 3.9 presents the 30-minute intervals during the 11:30-12:30 hour ($V_{11:30,1}^{man,30}, V_{12:00,1}^{man,30}$). Figure 3.10 presents the 30-minute intervals during the 13:00-14:00 hour ($V_{13:00,1}^{man,30}, V_{13:30,1}^{man,30}$). Figures 3.11 and 3.12 present the empirical cumulative distribution functions (ecdfs) of 15-minute manual volumes for the eight

15-minute Monday intervals, that is, for the eight $V_{hh:mm,1}^{man,15}$ with mm being 00, 15, 30, or 45 in each of the two hours, and 1 representing the first day of the week (Monday). Figure 3.11 presents the 15-minute intervals during the 11:30-12:30 hour ($V_{11:30,1}^{man,15}$, $V_{11:45,1}^{man,15}$, $V_{12:00,1}^{man,15}$, $V_{12:15,1}^{man,15}$). Figure 3.12 presents the 15-minute intervals during the 13:00-14:00 hour ($V_{13:00,1}^{man,15}$, $V_{13:15,1}^{man,15}$, $V_{13:30,1}^{man,15}$, $V_{13:45,1}^{man,15}$). Summary statistics of the distributions shown in Figure 3.8 through 3.12 are presented in Table 3.4.

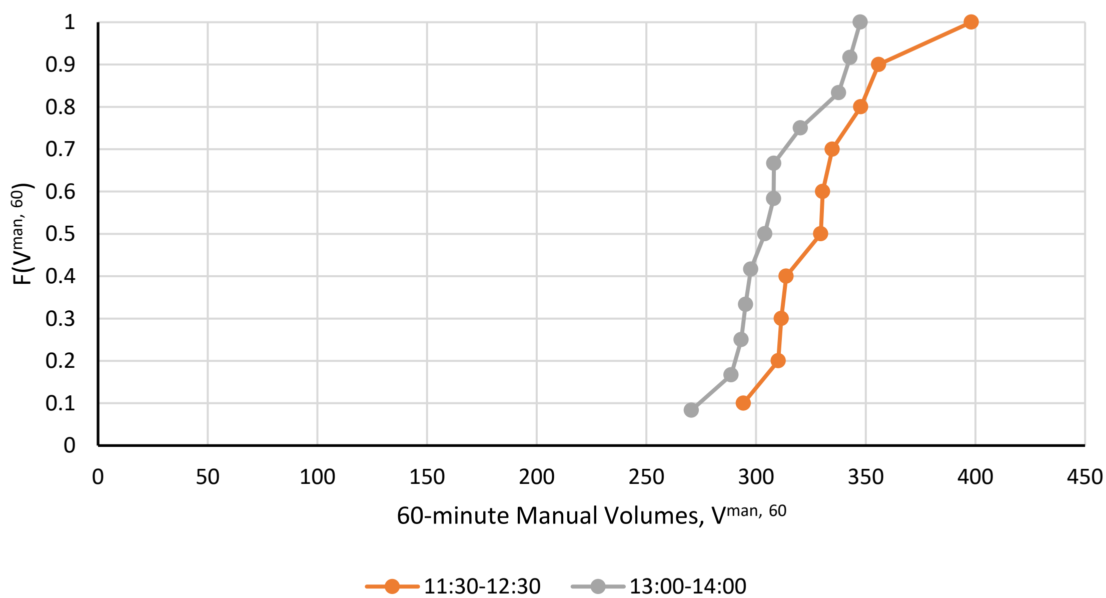

Figure 3.8: Ecdfs of 60-minute Monday Volumes Determined from Manual Data for Time Intervals beginning at 11:30, and 13:00

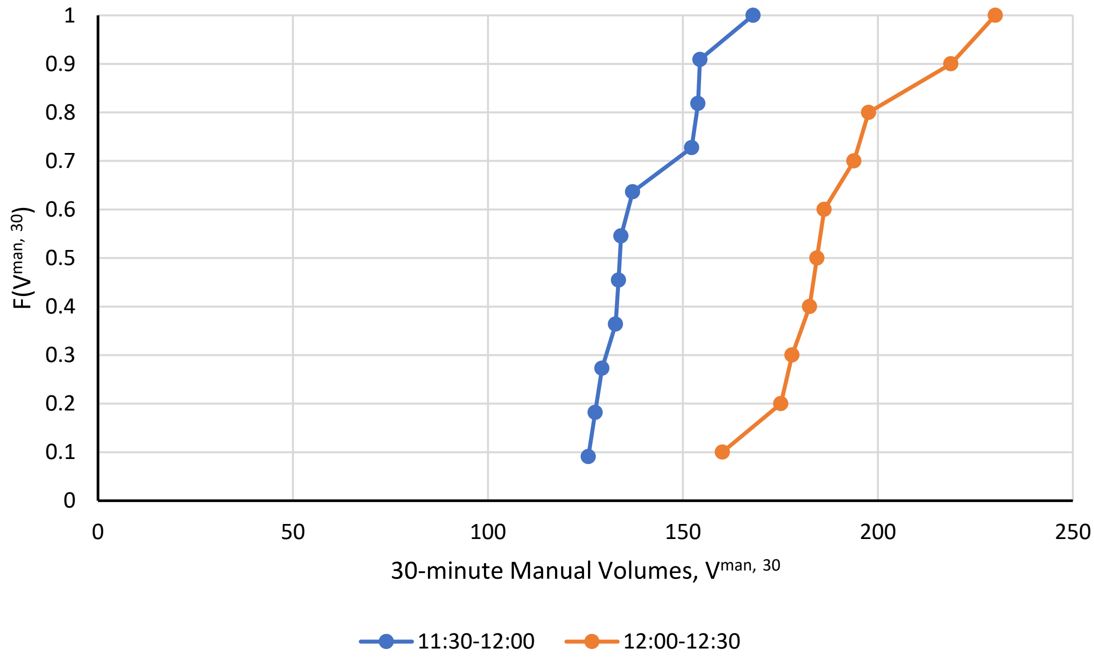

Figure 3.9: Ecdfs of 30-minute Monday Volumes Determined from Manual Data for Time Intervals beginning at 11:30 and 12:00

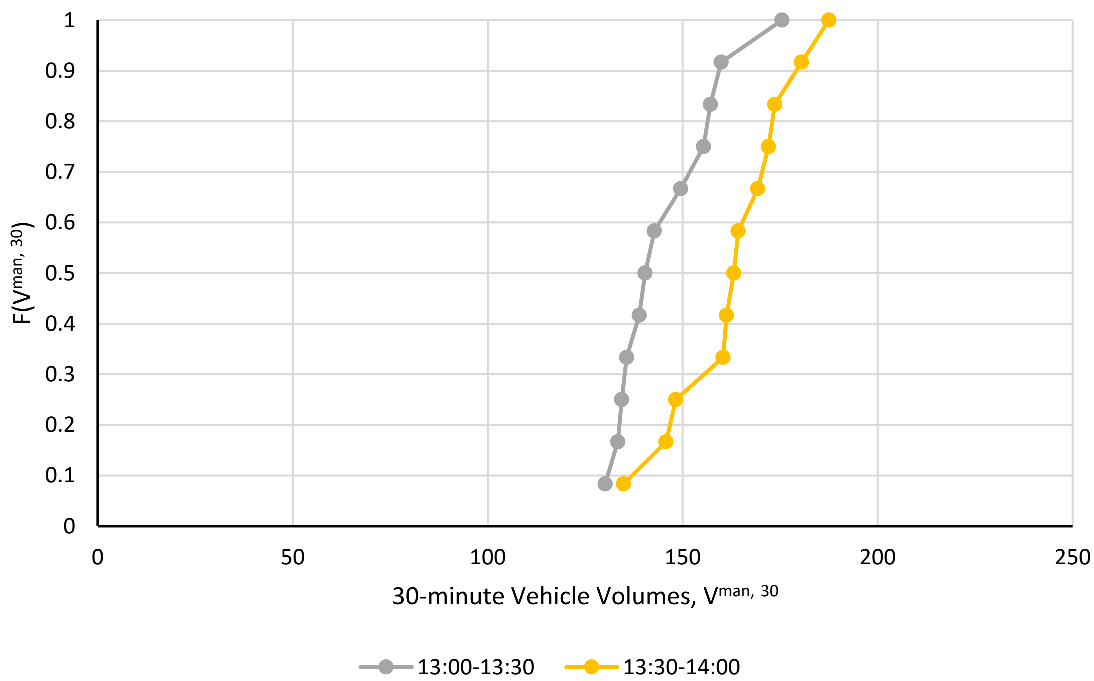

Figure 3.10: Ecdfs of 30-minute Monday Volumes Determined from Manual Data for Time Intervals beginning at 13:00 and 13:30

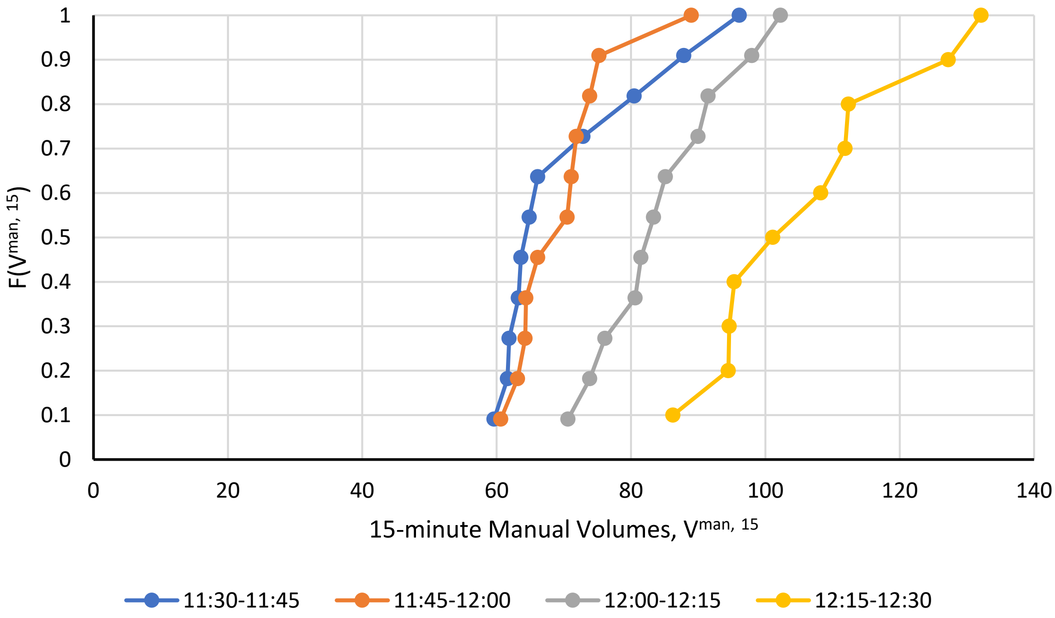

Figure 3.11: Ecdfs of 15-minute Monday Volumes Determined from Manual Data for Time Intervals beginning at 11:30, 11:45, 12:00 and 12:15

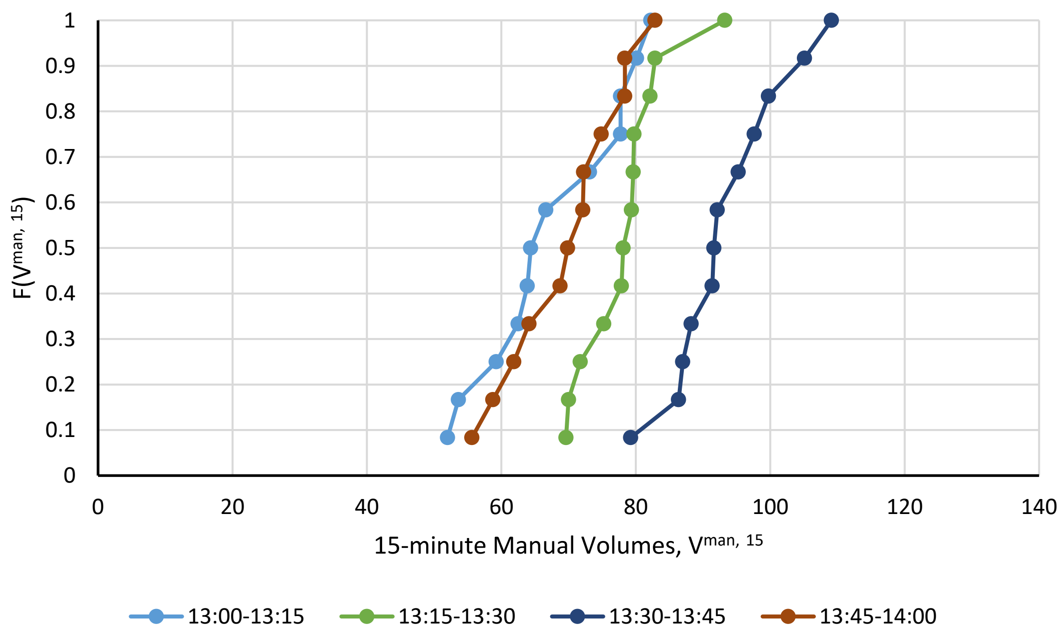

Figure 3.12: Ecdfs of 15-minute Monday Volumes Determined from Manual Data for Time Intervals beginning at 13:00, 13:15, 13:30, and 13:45

Table 3.4: Summary Statistics of the Monday Distributions, Manual Volumes

Length	Number of Volumes	Interval	Median[1]	Mean	Standard Deviation
60 minutes	10	11:30-12:30	329.94	332.60	29.55
	12	13:00-14:00	306.00	309.47	23.48
30 minutes	11	11:30-12:00	134.13	140.77	13.93
	10	12:00-12:30	185.31	190.68	20.72
	12	13:00-13:30	141.56	146.07	13.60
	12	13:30-14:00	163.69	163.40	14.94
15 minutes	11	11:30-11:45	64.88	70.76	12.19
	11	11:45-12:00	70.50	70.01	7.90
	11	12:00-12:15	83.38	84.82	9.88
	10	12:15-12:30	104.69	106.38	14.91
	12	13:00-13:15	65.50	67.77	10.30
	12	13:15-13:30	78.75	78.30	6.47
	12	13:30-13:45	91.88	93.57	8.38
	12	13:45-14:00	71.00	69.82	8.39

[1]Medians calculated with Excel function which takes midpoint between middle numbers when the number of volumes is even. This may differ from $F^{-1}(0.5)$ from the ECDF.

Figure 3.8 shows distinction between the two distributions of hourly volumes. The 11:30-12:30 volumes are larger than the 13:00-14:00 volumes. This ordering is evident in the means and medians shown in Table 3.4. This ordering between the 11:30-12:30 volumes and the 13:00-14:00 volumes is also consistent with what was found above in Figure 3.1 for the Thursday hourly volume distributions. However, the magnitude of the difference between the 11:30-12:30 volumes and the 13:00-14:00 volumes is larger on Thursday than Monday.

Figures 3.9 and 3.10 also show distinction within the 30-minute periods. In Figure 3.9 the 12:00-12:30 volumes are seen to be larger than the 11:30-12:00 volumes. In Figure 3.10 the 13:30-14:00 volumes are seen to be larger than the 13:00-13:30 volumes. The ordering found in both Figures 3.9 and 3.10 are also evident in the summary statistics Table 3.4. These findings are also consistent with what was found in Figures 3.3 and 3.4 when considering Thursday volumes. However, in the 13:00 hour on Thursdays (Figure 3.4) there is some overlap between the two periods, whereas the Monday ecdfs do not overlap.

The two largest 15-minute ecdfs for both Monday hours have clear distinctions relative to the other ecdfs. In Figure 3.11 the 12:15-12:30 volumes are the largest, followed by the 12:00-12:15 volumes. The 11:30-11:45 and 11:45-12:00 volumes are smaller and have similar ecdfs that overlap. In Figure 3.12 the 13:30-13:45 volumes are the largest, followed by the 13:15-13:30 volumes. The 13:00-13:15 and 13:45-14:00 volumes are smaller and have similar ecdfs that overlap. The ordering for the 15-minute periods within the 11:30-12:30 and 13:00-14:00 hours are also evident in the summary statistics Table 3.4.

On Wednesdays manual data were only collected for one hour. Therefore, comparisons cannot be made among different hourly volume distributions on Wednesdays. However, comparisons can be made among the distributions of the 30-, and 15-minute periods within the hour. Figure 3.13 presents the empirical cumulative distribution functions (ecdfs) of the 60-minute Wednesday interval, that is, for $V_{hh:mm,3}^{man,60}$ with hh:mm being 9:30, and 3 representing the third day of the week (Wednesday). Figure 3.14 presents the empirical cumulative distribution functions (ecdfs) of 30-minute manual volumes for the two 30-minute Wednesday intervals, that is, for the two $V_{hh:mm,3}^{man,30}$ with hh:mm being 9:30, or 10:00, and 3 representing the third day of the week (Wednesday). Figure 3.15 presents the empirical cumulative distribution functions (ecdfs) of 15-minute manual volumes for the four 15-minute Wednesday intervals, that is, for the four $V_{hh:mm,3}^{man,15}$ with hh:mm being 9:30, 9:45, 10:00, or 10:15, and 3 representing the third day of the week (Wednesday). Summary statistics of the distributions shown in Figure 3.13 through 3.15 are presented in Table 3.5.

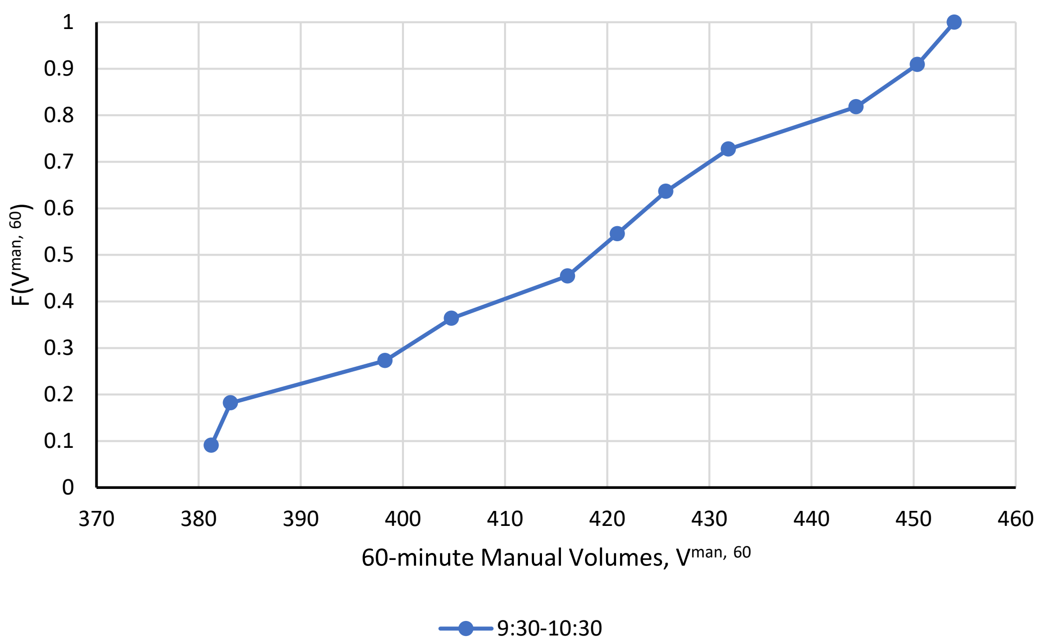

Figure 3.13: Ecdfs of 60-minute Wednesday Volumes for Manual Data for Hours beginning at 9:30

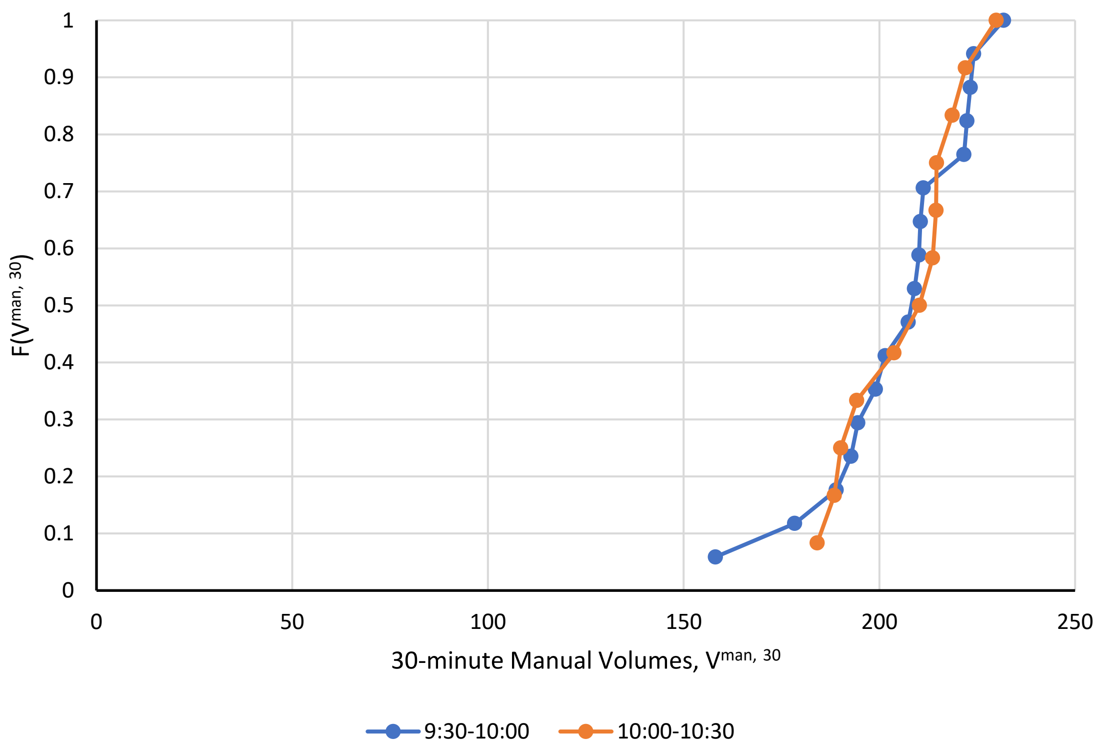

Figure 3.14: Ecdfs of 30-minute Wednesday Volumes from 9:30 to 10:30 for Manual Data beginning at 9:30 and 10:00

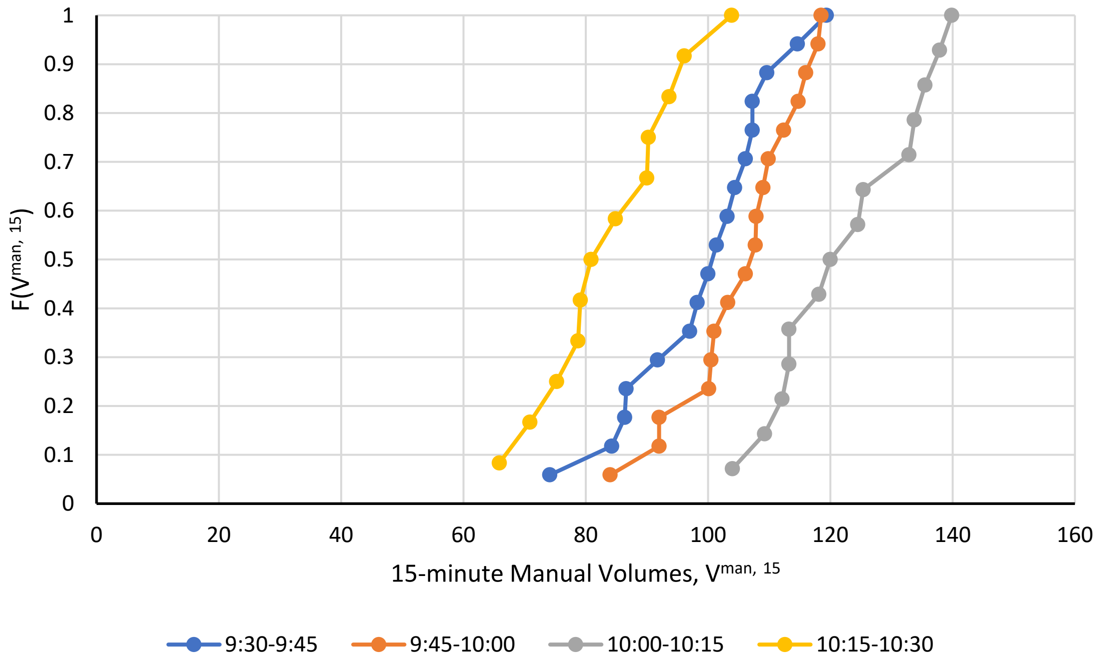

Figure 3.15: Ecdfs of 15-minute Wednesday Volumes from 9:30 to 10:30 for Manual Data beginning at 9:30, 9:45, 10:00 and 10:15

Table 3.5: Summary Statistics of the Wednesday Distributions, Manual Volumes

Length	Number of Volumes	Interval	Median[1]	Mean	Standard Deviation
60 minutes	12	9:30-10:30	421.00	419.17	25.34
30 minutes	17	9:30-10:00	209.00	204.98	18.68
	12	10:00-10:30	211.94	207.02	14.70
15 minutes	17	9:30-9:45	101.38	99.50	11.76
	17	9:45-10:00	107.75	105.48	9.74
	14	10:00-10:15	122.25	122.84	11.68
	12	10:15-10:30	82.88	84.13	11.07

[1]Medians calculated with Excel function which takes midpoint between middle numbers when the number of volumes is even. This may differ from $F^{-1}(0.5)$ from the ECDF.

Figure 3.14 shows no distinction between the two 30-minute periods, as the 9:30-10:00 and 10:00-10:30 ecdfs overlap. This is consitent with the means and medians shown in Table 3.5, as both periods have very similar values. Figure 3.15 shows distinction for the four 15-minute periods. The volumes from largest to smallest values are as follows 10:00-10:15, 9:45-10:00, 9:30-9:45, 10:15-10:30. This ordering is also evident in the means and medians shown in Table 3.5. These findings can explain why there was no distinction found between the two 30-minute periods. The largest and smallest 15-minute periods, 10:00-10:15 and 10:15-10:30, fall within the 10:00-10:30 30-minute period. While the second largest and second smallest 15-minute periods, 9:45-10:00 and 9:30-9:45, fall within the 9:30-10:00 30-minute period.

The correspondence of these numerically based observations with prior expectations or after the fact interpretations are presented in Section 3.3.

3.2 Day of Week Effects in Manual Volumes

This section investigates the manual vehicles volumes as a function of day of week using the data previously introduced in Section 2.1 and found in Appendix C. On Mondays and Thursdays manual data were collected from 11:30 to 12:30 during Spring semester and 13:00 to 14:00 during Autumn semester. On Wednesdays and Thursdays manual data were collected from 9:30 to 10:30 during both Spring and Autumn semester. Therefore, Monday and Thursday will be compared first in this investigation. The manual vehicle volumes for 60-, 30-, and 15-minute intervals – i.e., $V_{hh:mm,d}^{man,60}$, $V_{hh:mm,d}^{man,30}$, and $V_{hh:mm,d}^{man,15}$ – will again be used, where the volumes were aggregated using the 8-minute interpolation method described in Section 2.1.

Figure 3.16 presents the empirical cumulative distribution functions (ecdfs) of the two 60-minute intervals for the 11:30-12:30 hour on Mondays ($V_{11:30,1}^{man,60}$) and Thursdays ($V_{11:30,4}^{man,60}$). Figure 3.16 additionally presents the ecdfs of the two 60-minute intervals for the 13:00-14:00 hour on Mondays ($V_{13:00,1}^{man,60}$) and Thursdays ($V_{13:00,4}^{man,60}$). Summary statistics of the distributions shown in Figure 3.16 are presented in Table 3.6.

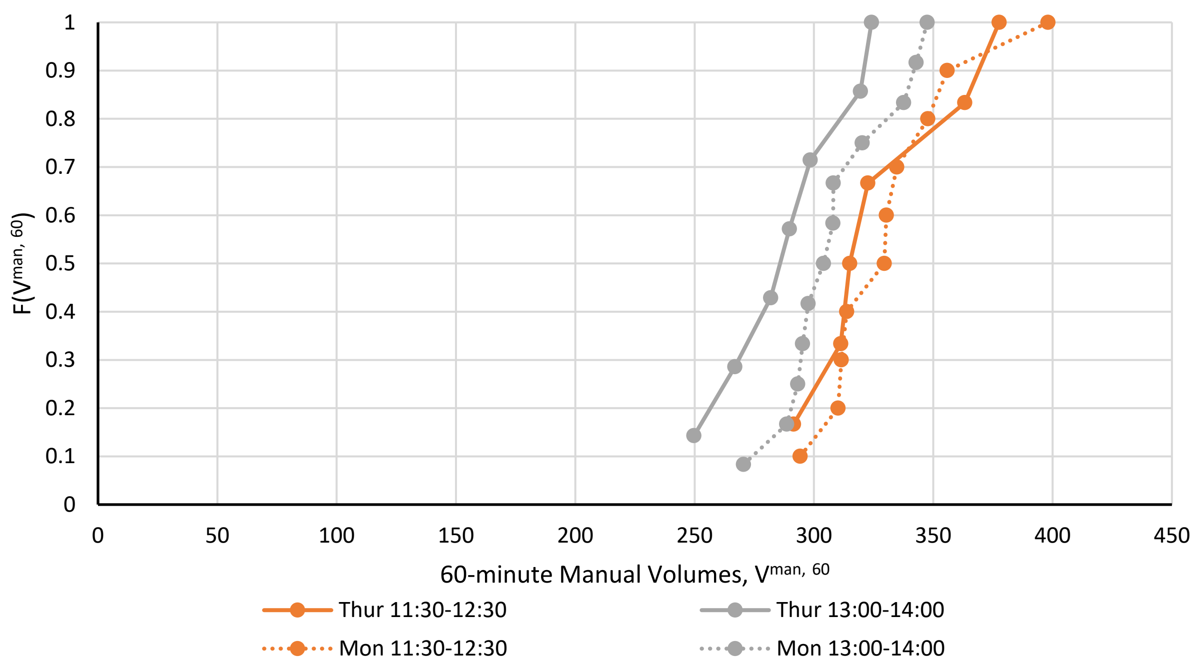

Figure 3.16: Ecdfs of 60-minute Monday and Thursday Volumes from Manual Data for Hours beginning at 11:30 and 13:00

Table 3.6: Summary Statistics of Monday and Thursday 60-minute Distributions, Manual Volumes

Period	Number of Volumes	Day of Week	Median[1]	Mean	Standard Deviation
11:30-12:30	10	Monday	329.94	332.60	29.55
	6	Thursday	318.81	330.21	33.13
13:00-14:00	12	Monday	306.00	309.47	23.48
	7	Thursday	289.75	290.05	26.86

[1]Medians calculated with Excel function which takes midpoint between middle numbers when the number of volumes is even. This may differ from $F^{-1}(0.5)$ from the ECDF.

From Figure 3.16, it appears that there is no day of week effect for the 11:30-12:30 hour. However, there appears to be a slight day of week effect for the 13:00-14:00 hour. For the 13:00-14:00 hour the Monday volumes are found to be larger than the Thursday volumes. These finding are evident in the means and median Table 3.6, as for the 11:30-12:30 hour the means and medians are more similar for each day, than they are for the for the 13:00-14:00 hour.

As with the time of day analysis, the shorter 30- and 15-minute intervals are also investigated for different days. Figures 3.17 and 3.18 present the empirical cumulative distribution functions (ecdfs) of the two 30-minute Monday and Thursday intervals, for each respective hour. Figure 3.17 presents the 30-minute increments during the 11:30-12:30 hour on Mondays ($V_{11:30,1}^{man,30}$, $V_{12:00,1}^{man,30}$) and Thursdays ($V_{11:30,4}^{man,30}$, $V_{12:00,4}^{man,30}$). Figure 3.18 presents the 30-minute increments during the 13:00-14:00 hour on Mondays ($V_{13:00,1}^{man,30}$, $V_{13:30,1}^{man,30}$) and Thursdays ($V_{13:00,4}^{man,30}$, $V_{13:30,4}^{man,30}$). Summary statistics of the distributions shown in Figures 3.17 and 3.18 are presented in Table 3.7.

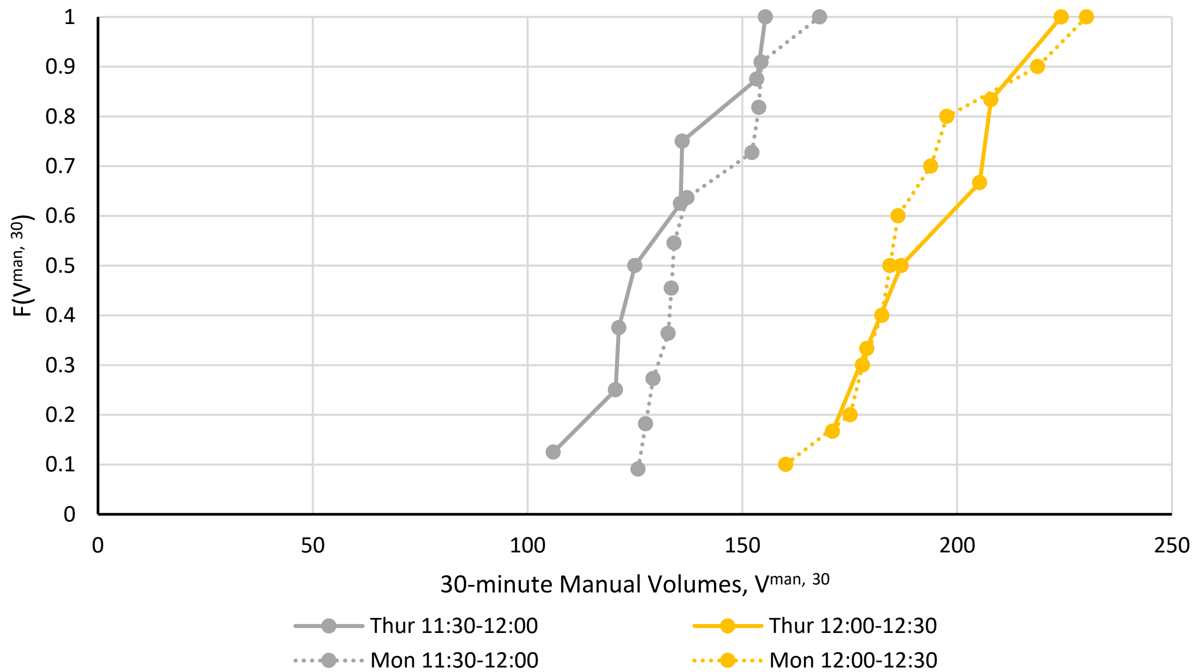

Figure 3.17: Ecdfs of 30-minute Monday and Thursday Volumes from 11:30 to 12:30 for Manual Data beginning at 11:30 and 12:00

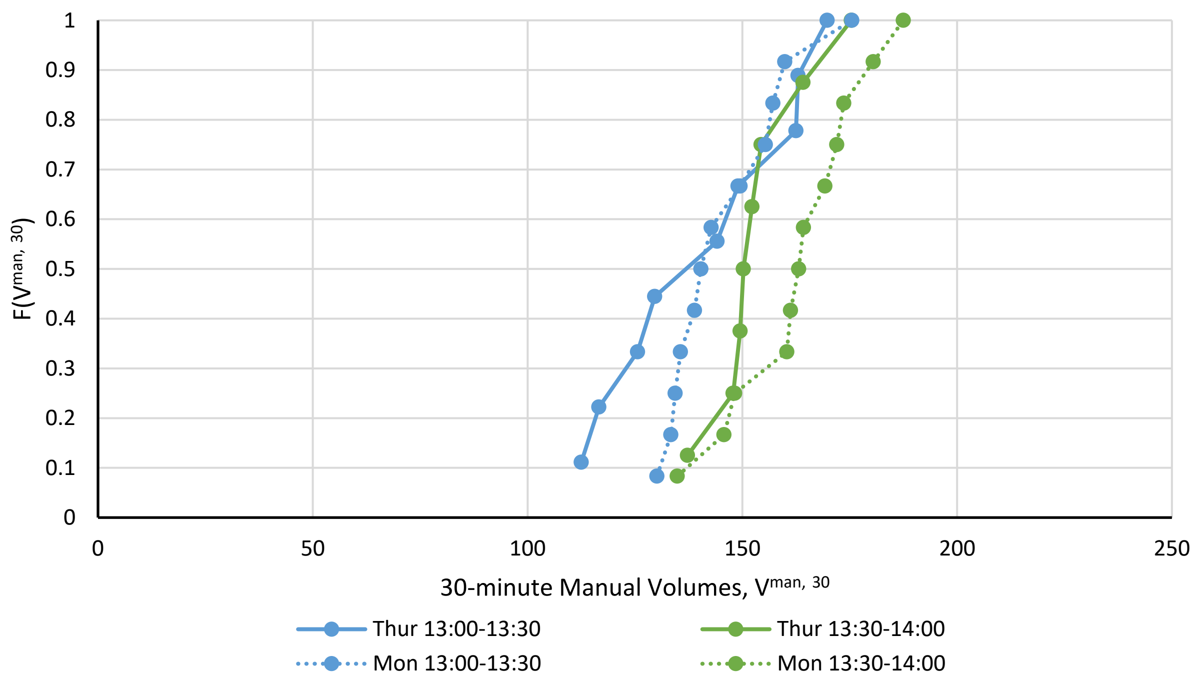

Figure 3.18: Ecdfs of 30-minute Monday and Thursday Volumes from 13:00 to 14:00 for Manual Data beginning at 13:00 and 13:30

Table 3.7: Summary Statistics of Monday and Thursday 30-minute Distributions, Manual Volumes

Period	Number of Volumes	Day of Week	Median[1]	Mean	Standard Deviation
11:30-12:00	11	Monday	134.13	140.77	13.93
	8	Thursday	130.31	131.64	16.92
12:00-12:30	10	Monday	185.31	190.68	20.72
	6	Thursday	196.13	195.73	20.10
13:00-13:30	12	Monday	141.56	146.07	13.60
	9	Thursday	144.13	141.42	21.26
13:30-14:00	12	Monday	163.69	163.40	14.94
	8	Thursday	151.25	153.88	11.43

[1]Medians calculated with Excel function which takes midpoint between middle numbers when the number of volumes is even. This may differ from $F^{-1}(0.5)$ from the ECDF.

In Figure 3.17 there appears to be a small day of week effect for the 11:30-12:00 period. For the 11:30-12:00 period the Monday volumes are slightly larger than the Thursday volumes. For the 12:00-12:30 period there appears to be no day of week effect. These findings are also evident in the means and medians Table 3.7 as for the 11:30-12:00 period Monday has slightly higher mean and median values than Thursday while for the 12:00-12:30 period both Monday and Thursday have very similar mean and median values.

From Figure 3.18 it appears that there is a slight day of week effect for the 13:30-14:00 period. For the 13:30-14:00 period the Monday volumes appear to be slightly larger than the Thursday volumes. For the 13:00-13:30 period there appears to be no day of week effect. These findings are also evident in the means and medians Table 3.7, as for the 13:30-14:00 period Monday has slightly higher mean and median values than Thursday. While for the 13:00-13:30 period both Monday and Thursday have very similar mean and median values.

Figures 3.19 and 3.20 present the empirical cumulative distribution functions (ecdfs) of the four 15-minute Monday and Thursday intervals, for each respective hour. Figure 3.19 presents the 15-minute increments during the 11:30-12:30 hour on Mondays ($V_{11:30,1}^{man,15}$, $V_{11:45,1}^{man,15}$, $V_{12:00,1}^{man,15}$, $V_{12:15,1}^{man,15}$) and Thursdays ($V_{11:30,4}^{man,15}$, $V_{11:45,4}^{man,15}$, $V_{12:00,4}^{man,15}$, $V_{12:15,4}^{man,15}$). Figure 3.20 presents the 15-minute increments during the 13:00-14:00 hour on Mondays ($V_{13:00,1}^{man,15}$, $V_{13:15,1}^{man,15}$, $V_{13:30,1}^{man,15}$, $V_{13:45,1}^{man,15}$) and Thursdays ($V_{13:00,1}^{man,15}$, $V_{13:15,1}^{man,15}$, $V_{13:30,1}^{man,15}$, $V_{13:45,1}^{man,15}$). Summary statistics of the distributions shown in Figures 3.19 and 3.20 are presented in Table 3.8.

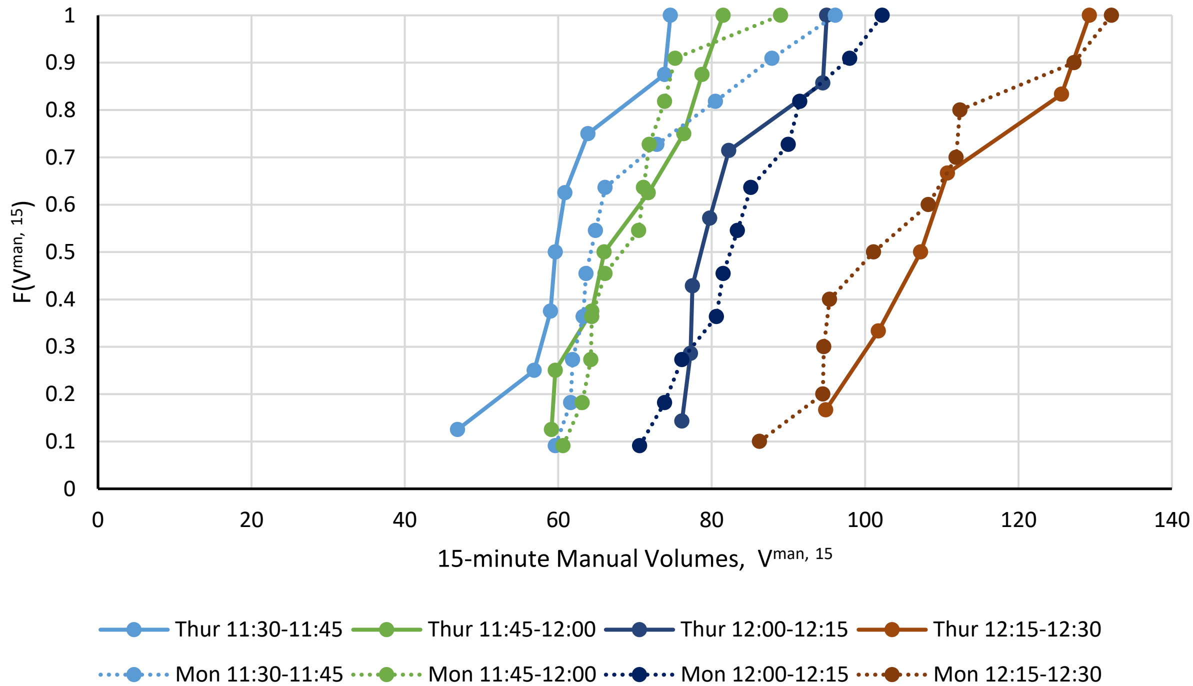

Figure 3.19: Ecdfs of 15-minute Monday and Thursday Volumes from 11:30 to 12:30 for Manual Data beginning at 11:30, 11:45, 12:00 and 12:15

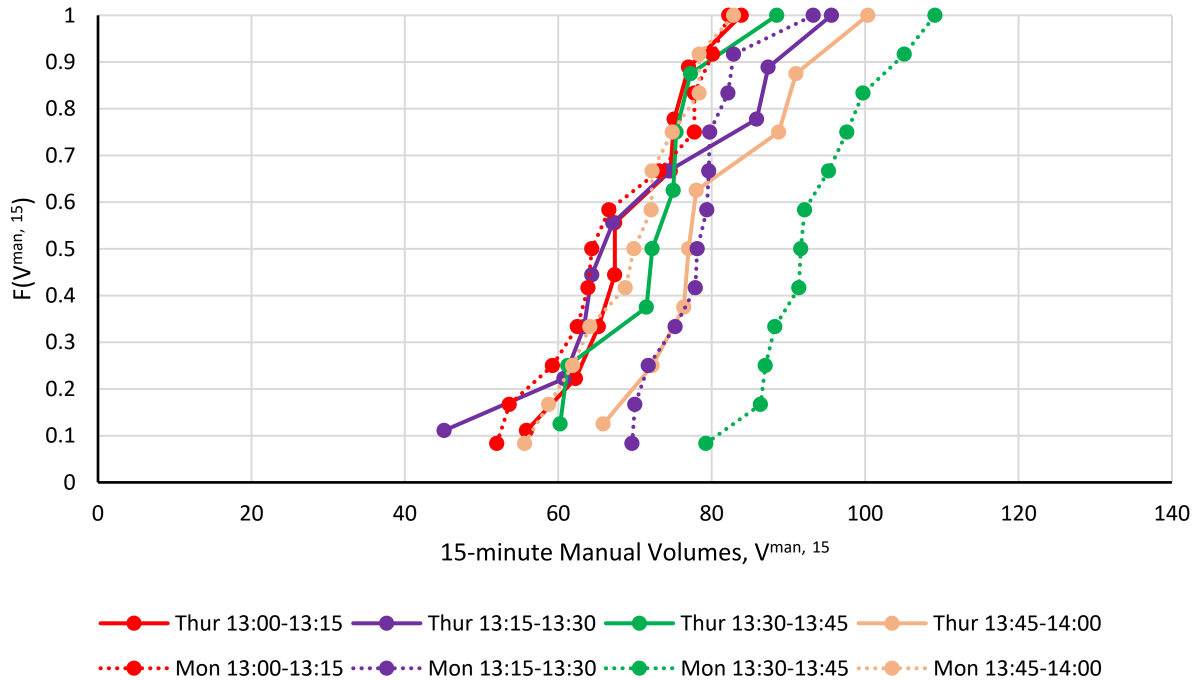

Figure 3.20: Ecdfs of 15-minute Monday and Thursday Volumes from 13:00 to 14:00 for Manual Data beginning at 13:00, 13:15, 13:30, and 13:45

Table 3.8: Summary Statistics of Monday and Thursday 15-minute Distributions, Manual Volumes

Period	Number of Volumes	Day of Week	Median[1]	Mean	Standard Deviation
11:30-11:45	11	Monday	64.88	70.76	12.19
	8	Thursday	60.25	61.95	9.06
11:45-12:00	11	Monday	70.50	70.01	7.90
	8	Thursday	71.75	65.44	20.46
12:00-12:15	11	Monday	83.38	84.82	9.88
	9	Thursday	79.75	83.20	8.14
12:15-12:30	10	Monday	104.69	106.38	14.91
	6	Thursday	109.00	111.58	13.45
13:00-13:15	12	Monday	65.50	67.77	10.30
	9	Thursday	67.38	69.86	8.55
13:15-13:30	12	Monday	78.75	78.30	6.47
	9	Thursday	67.13	71.56	15.80
13:30-13:45	12	Monday	91.88	93.57	8.38
	8	Thursday	73.63	72.67	9.03
13:45-14:00	12	Monday	71.00	69.82	8.39
	8	Thursday	77.50	81.20	11.26

[1]Medians calculated with Excel function which takes midpoint between middle numbers when the number of volumes is even. This may differ from $F^{-1}(0.5)$ from the ECDF.

Figure 3.19 shows no noticeable day of week effect for the 11:45-12:00, 12:00-12:15, and 12:15-12:30 periods. However, there appears to be a small day of week effect for the 11:30-11:45 period. For the 11:30-11:45 period the Monday volumes are larger than the Thursday volumes. These finding are also evident in the means and medians Table 3.8, as 11:30-11:45 is the only period within the 11:30-12:30 hour where the Monday mean and median values are slightly larger than the Thursday mean and median values.

Figure 3.20 shows no noticeable day of week effect for the 13:00-13:15 period. For the 13:15-13:30 period there appears to be a small day of week effect. The Monday volumes for the 13:15-13:30 period are slightly larger than the Thursday volumes. There is a very noticeable day of week effect for the 13:30-13:45 period. On Monday the 13:30-13:45 volumes are much larger than the Thursday volumes. There also appears to be a day of week effect for the 13:45-14:00 volumes. The Thursday volumes for the 13:45-14:00 period are larger than the Monday volumes. These findings are also evident in the means and medians Table 3.8.

Wednesdays and Thursday had one hour for which manual data were collected on both days. Therefore, Wednesday and Thursday will be compared next in this investigation. Figure 3.21 presents the empirical cumulative distribution functions (ecdfs) of the 60-minute intervals for the 9:30-10:30 hour on Wednesdays ($V_{9:30,3}^{man,60}$) and Thursdays ($V_{9:30,4}^{man,60}$). Summary statistics of the distributions shown in Figure 3.21 are presented in Table 3.9.

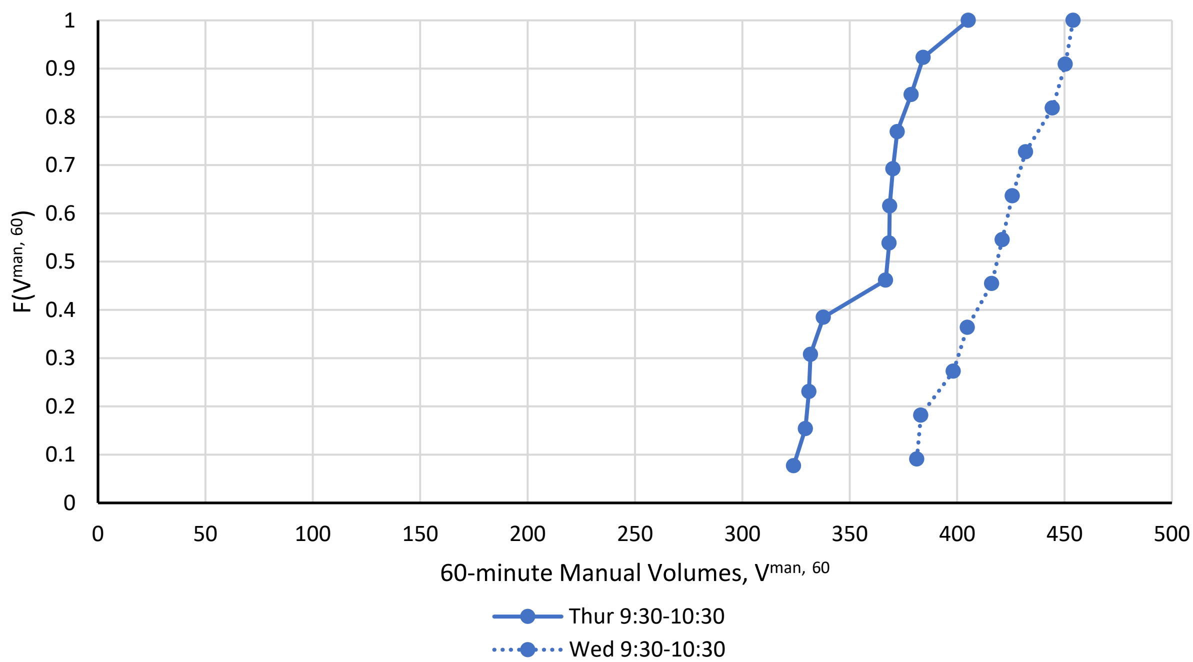

Figure 3.21: Ecdfs of 60-minute Wednesday and Thursday Volumes for Manual Data for Hours beginning at 9:30

Table 3.9: Summary Statistics of Wednesday and Thursday 60-minute Distribution, Manual Volumes

Period	Number of Volumes	Day of Week	Median[1]	Mean	Standard Deviation
9:30-10:30	12	Wednesday	421.00	419.17	25.34
	13	Thursday	368.38	359.07	25.48

[1]Medians calculated with Excel function which takes midpoint between middle numbers when the number of volumes is even. This may differ from $F^{-1}(0.5)$ from the ECDF.

Figure 3.21 shows a noticeable day of week effect for the 9:30-10:30 hour. The Wednesday hourly volumes are found to be larger than the Thursday hourly volumes (ecdf furthest to the right). This ordering is consistent with what is found in the means and medians in Table 3.9.

Figure 3.22 presents the empirical cumulative distribution functions (ecdfs) of the two 30-minute intervals for the 9:30-10:30 hour on Wednesdays ($V_{9:30,3}^{man,30}$, $V_{10:00,3}^{man,30}$) and Thursdays ($V_{9:30,4}^{man,30}$, $V_{10:00,4}^{man,30}$). Summary statistics of the distributions shown in Figure 3.22 are presented in Table 3.10.

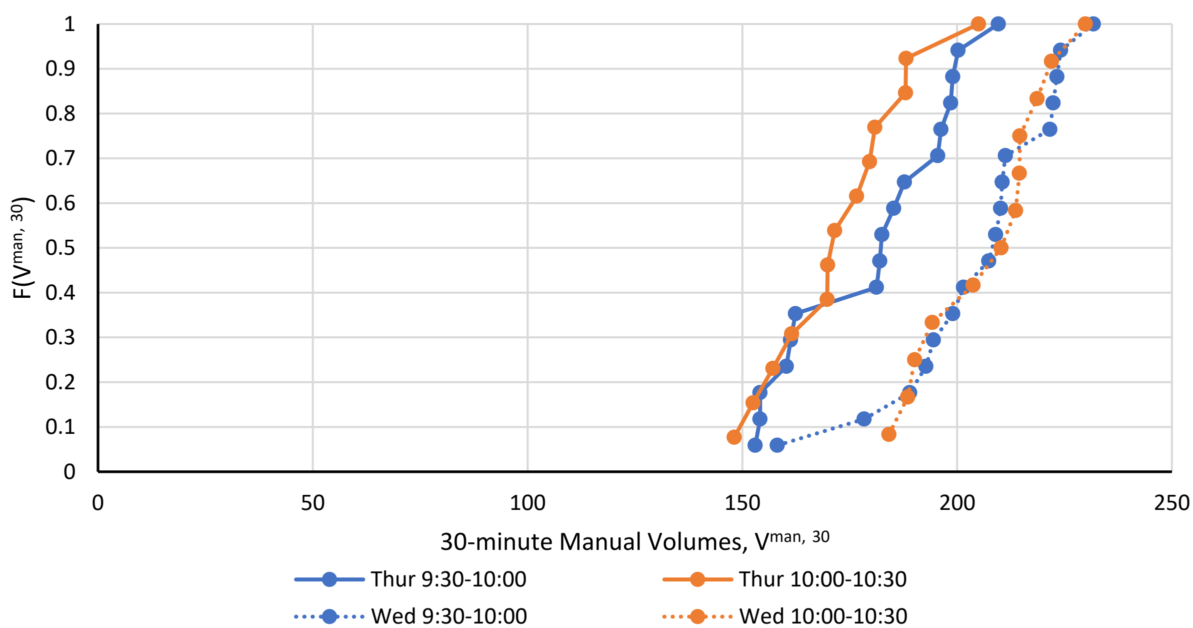

Figure 3.22: Ecdfs of 30-minute Wednesday and Thursday Volumes from 9:30 to 10:30 for Manual Data beginning at 9:30 and 10:00

Table 3.10: Summary Statistics of Wednesday and Thursday 30-minute Distributions, Manual Volumes

Period	Number of Volumes	Day of Week	Median[1]	Mean	Standard Deviation
9:30-10:00	17	Wednesday	209.00	204.98	18.68
	17	Thursday	182.50	180.18	18.90
10:00-10:30	12	Wednesday	211.94	207.02	14.70
	13	Thursday	171.50	172.97	15.92

[1]Medians calculated with Excel function which takes midpoint between middle numbers when the number of volumes is even. This may differ from $F^{-1}(0.5)$ from the ECDF.

Figure 3.22 shows a noticeable day of week effect for two 30-minute periods within the 9:30-10:30 hour. For both the 9:30-10:00 and 10:00-10:30 periods the Wednesday volumes are larger than the Thursday volumes. This ordering is also evident in the means and medians of Table 3.10.

Figure 3.23 presents the empirical cumulative distribution functions (ecdfs) of the four 15-minute intervals for the 9:30-10:30 hour on Wednesdays ($V_{9:30,3}^{man,15}$, $V_{9:45,3}^{man,15}$, $V_{10:00,3}^{man,15}$, $V_{10:15,3}^{man,15}$) and Thursdays ($V_{9:30,4}^{man,15}$, $V_{9:45,4}^{man,15}$, $V_{10:00,4}^{man,15}$, $V_{10:15,4}^{man,15}$). Summary statistics of the distributions shown in Figure 3.23 are presented in Table 3.11.

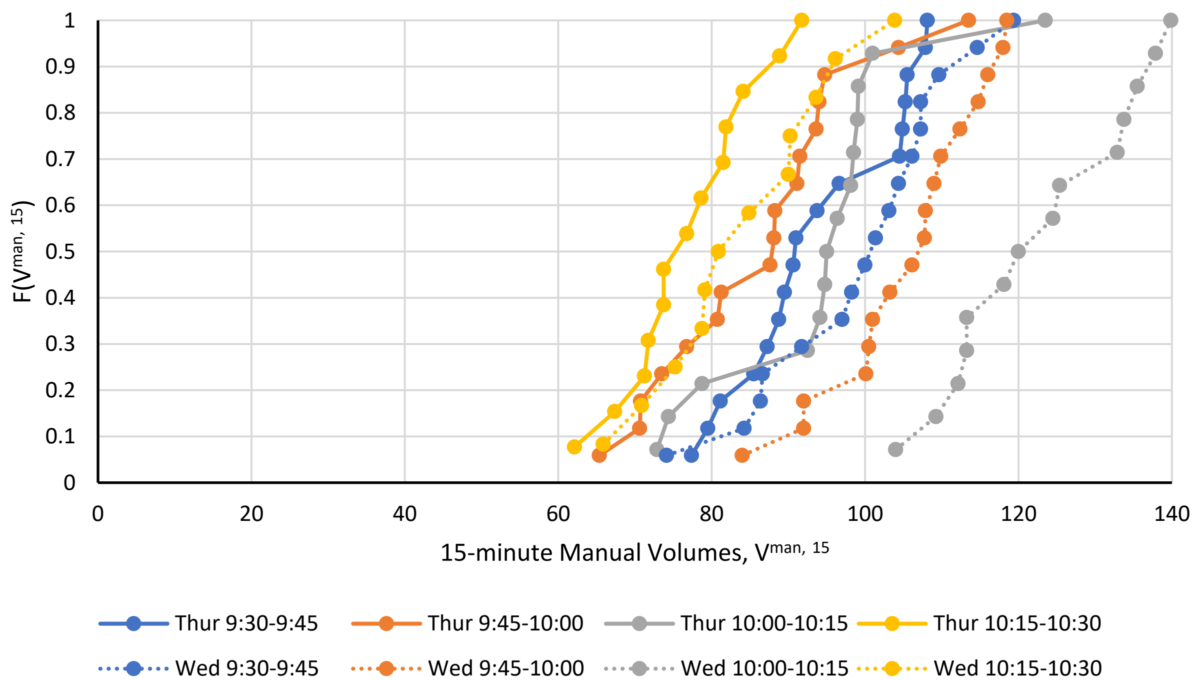

Figure 3.23: Ecdfs of 15-minute Wednesday and Thursday Volumes from 9:30 to 10:30 for Manual Data beginning at 9:30, 9:45, 10:00 and 10:15

Table 3.11: Summary Statistics of Wednesday and Thursday 15-minute Distributions, Manual Volumes

Period	Number of Volumes	Day of Week	Median[1]	Mean	Standard Deviation
9:30-9:45	17	Wednesday	101.38	99.50	11.76
	17	Thursday	91.00	93.95	10.38
9:45-10:00	17	Wednesday	107.75	105.48	9.74
	17	Thursday	88.13	86.23	12.62
10:00-10:15	14	Wednesday	122.25	122.84	11.68
	14	Thursday	95.69	94.14	12.65
10:15-10:30	12	Wednesday	82.88	84.13	11.07
	13	Thursday	76.75	77.19	8.42

[1]Medians calculated with Excel function which takes midpoint between middle numbers when the number of volumes is even. This may differ from $F^{-1}(0.5)$ from the ECDF.

Figure 3.23 shows a noticeable day of week effect for the four 15-minute periods within the 9:30-10:30 hour. The volumes for all of the four 15-minute periods are higher on Wednesdays than on Thursdays. This ordering is also evident in the means and medians of Table 3.11.

The correspondence of these numerically based observations with prior expectations or after the fact interpretations are presented in Section 3.3.

3.3 Summary of Manual Findings

Sections 3.1 and 3.2 investigated time of day and by day of week differences in manual volumes by looking at ecdfs qualitatively. In this section differences in the means of the distributions will be quantified to investigate differences in manual volumes by time of day and by day of week more quantitatively. Both means and medians of the distributions of volumes for the specified time periods are presented in the summary statistics tables in Section 3.1 and 3.2. Differences in mean are chosen for the analysis of this this section, as the mean more explicitly considers the magnitudes of all volumes in the distribution than does the median. To compare the volume distribution in two periods, the difference in means (D^{mean}),

$$D^{mean}{}_{i,j} = Mean_i - Mean_j \tag{3.1}$$

is calculated for each pair of distributions *i* and *j* considered, where $Mean_i$, and $Mean_j$ are, respectively, the mean (average) volume of distributions *i* and *j*.

When determining D^{mean} for distributions corresponding to 15- minute intervals, D^{mean} is in units of vehicles per 15 minutes, whereas D^{mean} values for 30- and 60-minute intervals are in units of vehicles per 30 minutes and vehicles per hour (60 minutes), respectively. In order to compare the differences of means across the 60-, 30, and 15-minute intervals, the differences are converted to a metric $D^{mean(60)}_{i,j}$ where the units are all in terms of vehicles per hour (60 minutes),

$$D^{mean(60)}{}_{i,j} = \frac{60\ min}{interval\ length\ (\text{min})} \times D_{i,j} \tag{3.2}$$

To focus on the magnitude of differences, the absolute value of the $D^{mean(60)}_{i,j}$ is taken to determine the 60-minute equivalent absolute difference ($AD^{mean(60)}_{i,j}$),

$$AD^{mean(60)}{}_{i,j} = |D^{mean(60)}{}_{i,j}| \tag{3.3}$$

Values of $AD^{mean(60)}$ are first used to investigate differences in volumes by time of day. The differences are taken between pairs of distributions for intervals of the same length on the same day of week. For the 60-minute intervals, the difference metrics are calculated for every possible pair of 60-minute periods. Table 3.12 presents the D^{mean}, $D^{mean(60)}$, and $AD^{mean(60)}$ values obtained when comparing the different 60-minute intervals on the same days.

Metrics are also computed for 30- and 15-minute subperiods within each hourly interval on the same day. The 30-minute intervals metrics are computed between the pair of 30-minute intervals in the hour. Table 3.13 presents the D^{mean}, $D^{mean(60)}$, and $AD^{mean(60)}$ values for the 30-minute intervals. For the 15-minute intervals, the metrics are computed considering pairs of consecutive 15-minute intervals. Table 3.14 presents the D^{mean}, $D^{mean(60)}$, and $AD^{mean(60)}$ values for the 15-minute intervals.

Table 3.12 Metrics for Manual Volumes Differences in 60-minute Periods for Time of Day Investigation; n is number of volumes (data points) in corresponding distribution

Day	Period	$Mean_i$ (n_i)	Period	$Mean_j$ (n_j)	$D^{mean}_{i,j}$	$D^{mean(60)}_{i,j}$	$AD^{mean(60)}_{i,j}$	$Ind_{i,j}$
Thursday	9:30-10:30	359.07 (13)	11:30-12:30	330.21 (6)	28.86	28.86	28.86	1
Thursday	9:30-10:30	359.07 (13)	13:00-14:00	290.05 (7)	69.02	69.02	69.02	2
Thursday	11:30-12:30	330.21 (6)	13:00-14:00	290.05 (7)	40.16	40.16	40.16	1
Monday	11:30-12:30	332.6 (10)	13:00-14:00	309.47 (12)	23.13	23.13	23.13	1

Table 3.13 Metrics for Manual Volumes Differences in 30-minute Periods for Time of Day Investigation; n is number of volumes (data points) in corresponding distribution

Day	$Period_1$	$Mean_i$ (n_i)	Period	$Mean_j$ (n_j)	$D^{mean}_{i,j}$	$D^{mean(60)}_{i,j}$	$AD^{mean(60)}_{i,j}$	$Ind_{i,j}$
Thursday	9:30-10:00	180.18 (17)	10:00-10:30	172.97 (13)	7.21	14.42	14.42	0
Thursday	11:30-12:00	131.64 (8)	12:00-12:30	195.73 (6)	-64.09	-128.18	128.18	2
Thursday	13:00-13:30	141.42 (9)	13:30-14:00	153.88 (8)	-12.46	-24.92	24.92	1
Monday	11:30-12:00	140.77 (11)	12:00-12:30	190.68 (10)	-49.91	-99.82	99.82	2
Monday	13:00-13:30	146.07 (12)	13:30-14:00	163.4 (12)	-17.33	-34.66	34.66	1
Wednesday	9:30-10:00	204.98 (17)	10:00-10:30	207.02 (12)	-2.04	-4.08	4.08	0

Table 3.14 Metrics for Manual Volumes Differences in 15-minute Periods for Time of Day Investigation; n is number of volumes (data points) in corresponding distribution

Day	Period	$Mean_i$ (n_i)	Period	$Mean_j$ (n_j)	$D^{mean}_{i,j}$	$D^{mean(60)}_{i,j}$	$AD^{mean(60)}_{i,j}$	$Ind_{i,j}$
Thursday	9:30-9:45	93.95 (17)	9:45-10:00	86.23 (17)	7.72	30.88	30.88	1
Thursday	9:45-10:00	86.23 (17)	10:00-10:15	94.14 (14)	-7.91	-31.64	31.64	1
Thursday	10:00-10:15	94.14 (14)	10:15-10:30	77.19 (13)	16.95	67.8	67.8	2
Thursday	11:30-11:45	61.95 (8)	11:45-12:00	65.44 (8)	-3.49	-13.96	13.96	0
Thursday	11:45-12:00	65.44 (8)	12:00-12:15	83.2 (9)	-17.76	-71.04	71.04	2
Thursday	12:00-12:15	83.2 (9)	12:15-12:30	111.58 (6)	-28.38	-113.52	113.52	2
Thursday	13:00-13:15	69.86 (9)	13:15-13:30	71.56 (9)	-1.7	-6.8	6.8	0
Thursday	13:15-13:30	71.56 (9)	13:30-13:45	72.67 (8)	-1.11	-4.44	4.44	0
Thursday	13:30-13:45	72.67 (8)	13:45-14:00	81.2 (8)	-8.53	-34.12	34.12	1
Monday	11:30-11:45	70.76 (11)	11:45-12:00	70.01 (11)	0.75	3	3	0
Monday	11:45-12:00	70.01 (11)	12:00-12:15	84.82 (11)	-14.81	-59.24	59.24	2
Monday	12:00-12:15	84.82 (11)	12:15-12:30	106.38 (10)	-21.56	-86.24	86.24	2
Monday	13:00-13:15	67.77 (12)	13:15-13:30	78.3 (12)	-10.53	-42.12	42.12	1
Monday	13:15-13:30	78.3 (12)	13:30-13:45	93.57 (12)	-15.27	-61.08	61.08	2

Continued

Table 3.14 Continued Metrics for Manual Volumes Differences in 15-minute Periods for Time of Day Investigation; n is number of volumes (data points) in corresponding distribution

Day	Period	$Mean_i$ (n_i)	Period	$Mean_j$ (n_j)	$D^{mean}_{i,j}$	$D^{mean(60)}_{i,j}$	$AD^{mean(60)}_{i,j}$	$Ind_{i,j}$
Monday	13:30-13:45	93.57 (12)	13:45-14:00	69.82 (12)	23.75	95	95	2
Wednesday	9:30-9:45	99.5 (17)	9:45-10:00	105.48 (17)	-5.98	-23.92	23.92	1
Wednesday	9:45-10:00	105.48 (17)	10:00-10:15	122.84 (14)	-17.36	-69.44	69.44	2
Wednesday	10:00-10:15	122.84 (14)	10:15-10:30	84.13 (12)	38.71	154.84	154.84	2

Figure 3.24 presents the ecdf of all the $AD^{mean(60)}$ values found in Table 3.12 through 3.14. The ecdfs were calculated manually where the y-axis represents the cumulative probability of the absolute difference indicated on the x-axis. The cumulative probability of x is computed as $k(x)/n$ where n is the number of observations in the data set, and $k(x)$ is the number of observations in the data set that are less than or equal to x. The ecdf in Figure 3.24 is used to designate which time of day differences are considered, large, slight and small, as indicated by indicator values of 2, 1, and 0, respectively. Looking at Figure 3.24, there appear to be three clusters of points, leading to three ranges of volume values. The first range is from 0-20 vehicles per hour, the second range is from 20-50 vehicles per hour, and the third ranges is greater than 50 vehicles per hour. Specifically, for the time of day investigation the indicator, $Ind_{i,j}$, value is specified as:

$$Ind_{i,j} = \begin{cases} 0, \text{ if } 0 \leq AD^{mean(60)}_{i,j} < 20 \\ 1, \text{ if } 20 \leq AD^{mean(60)}_{i,j} < 50 \\ 2, \text{ if } 50 \leq AD^{mean(60)}_{i,j} \end{cases} \tag{3.4}$$

The indicator values from each comparison of distributions are provided in the last column of Tables 3.12, 3.13, and. 3.14.

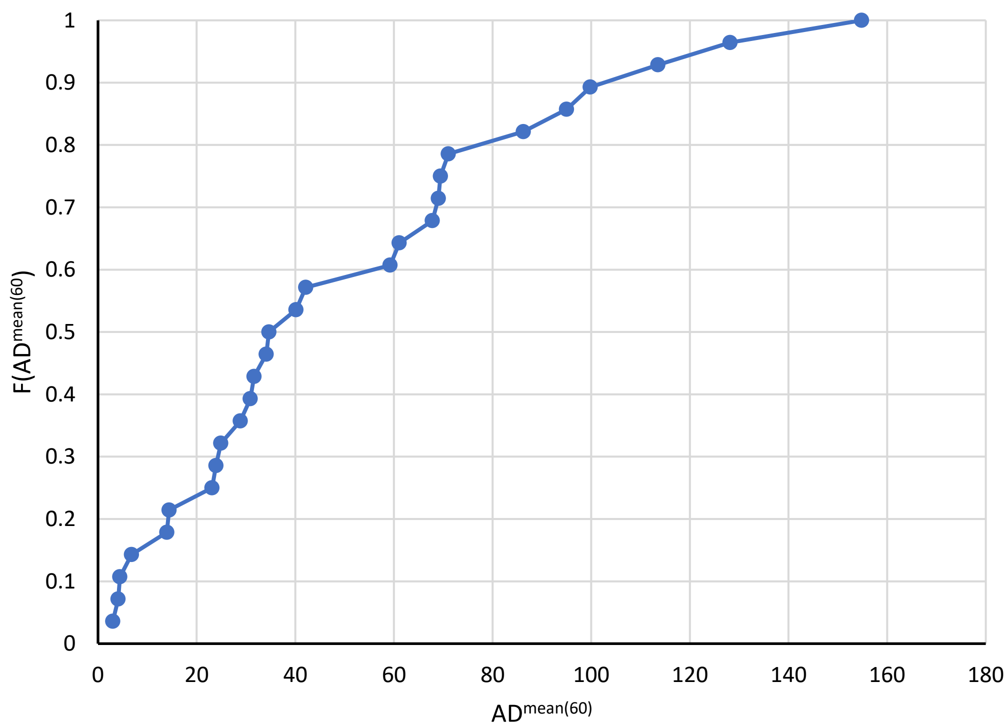

Figure 3.24: Ecdf of 60-minute Equivalent Absolute Difference $AD^{mean(60)}$ Values for Time of Day Investigation, Manual Volumes

For the 60-minute periods shown in Table 3.12, the difference between the 9:30-10:30 and 13:00-14:00 hour volumes on Thursdays is indicated to be large, as the indicator value for this comparison is equal to 2. The distributions of these intervals shown in Figure 3.1 were previously seen to be very different when discussing the ecdfs. The other pairs of 60-minute periods are indicated to have slight differences in volumes, as the indicator values for the comparisons are equal to 1. Looking at Figure 3.1 it is seen that the 9:30-10:30 and 13:00-14:00 distributions do indeed appear to be more different than either of the other two comparisons. These findings appear to be expected based upon the time of day. The 9:30-10:30 hour likely includes the end of morning commute traffic, and therefore would be expected to have relatively large traffic volumes. The 11:30-12:30 hour would include lunch hour traffic, and therefore it would also be expected to have relatively large traffic volumes, but volumes still smaller than those in the morning commute periods. The 13:00-14:00 hour is after lunch hour and before evening commute traffic begins. Therefore, it would be expected for the 13:00-14:00 hour to have smaller traffic volumes compared to the morning commute and lunch hour volumes. As such, the 11:30-12:30 traffic volumes would be expected to be "in between" the 9:30-10:30 volumes and 13:00-14:00 volumes, and it is not surprising that the differences in volumes between the 9:30-10:30 and 13:00-14:00 volumes would be large (Ind = 2) while the other hourly comparisons are smaller, but still notable (Ind = 1).

Comparisons of the 30-minute periods in the 11:30-12:30 hour on both Monday and Thursday (Table 3.13) are indicated to have a large difference in volumes, as their indicator value is equal to 2. These findings are consistent with what was found in Figures 3.3 and 3.9 in Section 3.1. From Table 3.13 it is seen that the 12:00-12:30 mean volume is greater than the 11:30-12:00 mean volume for both Thursday and Monday. Recall that the volumes were collected in the eastbound direction on this segment which is towards the main part of OSU's campus. Therefore, the higher mean volume found in the 12:00-12:30 period could be returning traffic from lunch or people coming to campus for the afternoon after not having been on campus in the morning. Furthermore, the $AD^{mean(60)}$ value between the 11:30-12:00 and 12:00-12:30 period is the second highest of all $AD^{mean(60)}$ values obtained in all three tables on Thursday and the fourth highest on Monday. When using the $AD^{mean(60)}$ metric, which allows comparisons in terms of volumes per the same duration of time, the 12:00-12:30 interval is seen to be an important time of day distinction.

Comparisons of the 30-minute periods of the 13:00-14:00 hour on Monday and Thursday (Table 3.13), are indicated to have a slight difference in volumes, as their indicator values are equal to 1. The distributions of these intervals shown in Figures 3.4 and 3.10 were previously noted to be slightly different. From Table 3.13 it is seen that the 13:30-14:00 mean volume is greater than then 13:00-13:30 mean volume for both Monday and Thursday. This could be related to 13:00-13:30 being outside of the lunch hour and 13:30-14:00 being associated with class start times. Whatever the reason, the data show that this could be an important time of day distinction.

Lastly, for the 9:30-10:30 hour on Wednesday and Thursday, both sets of 30-minute pairs are indicated to have little difference, as their indicator values are equal to 0. These findings are consistent with the distributions shown in Figures 3.2 and 3.14 as it was previously noted there is little difference between the 30-minute periods for the 9:30-10:30 hour. This is likely the results of 15-minute peaks within the 30-minute periods, where relatively higher volumes in the first 15 minutes of the 30-minute period are followed by relatively lower volumes in the second 15 minutes of the 30-minute period, both during the first and second 30-minutes periods. The relatively high and low 15-minute volumes balance each other out when considering the 30-minute periods, resulting in little difference in the mean volumes in these periods (Ind = 0).

For the 15-minute periods shown in Table 3.14, nine pairs are indicated to have a large difference in volumes, as their indicator values are equal to 2.

- Wednesday 9:45-10:00 and 10:00-10:15: The $AD^{mean(60)}$ value between the 9:45-10:00 and 10:00-10:15 period on Wednesday has the largest $AD^{mean(60)}$ value of all comparisons. Note that the Thursday comparison for this time of day pair has only a slight difference, as its indicator value is equal to 1, but from Table 3.14 it is seen that the 10:00-10:15 mean volume is greater than the 9:45-10:00 mean volume for both Wednesday and Thursday.
- Wednesday and Thursday 10:00-10:15 and 10:15-10:30: From Table 3.14 it is seen that the 10:00-10:15 mean volume is greater than the 10:15-10:30 mean volume for both Wednesday and Thursday. This could be related to 10:15-10:30 being outside of the morning peak traffic and 10:00-10:15 being associated with class start times. When coupled with the previous bullet indicating larger volumes in 10:00-10:15 than in 9:45-10:00 with relatively large indicator values on both days, it appears that there is a time of day effect for the 10:00-10:15 period.
- Monday and Thursday 11:45-12:00 and 12:00-12:15: From Table 3.14 it is seen that 12:00-12:15 mean volume is larger than the 11:45-12:00 mean volume for both Monday and Thursday. These findings could be the result of returning traffic from lunch, or people coming to campus for the first time in the afternoon as noted for the 30-minute periods. Traffic counts were collected in the direction of vehicles arriving to campus. The 12:00-12:15 period would likely be more associated with this afternoon arriving traffic than would the 11:45-12:00 period.
- Monday and Thursday 12:00-12:15 and 12:15-12:30: From Table 3.14 it is seen that the 12:15-12:30 mean volume is larger than the 12:00-12:15 mean volume for

both Monday and Thursday. Therefore, similar to the previous comparison these findings could be the result of be returning traffic from lunch, or people coming to campus after lunch as noted for the 30-minute periods. The 12:15-12:30 period would likely be more associated with this afternoon arriving traffic than would the 12:00-12:15 period. In addition, the $AD^{mean(60)}$ value between the 12:00-12:15 and 12:15-12:30 period on Thursday is the third highest $AD^{mean(60)}$ value of all time of day comparisons. This is consistent with what was found for the 30-minute periods, as the $AD^{mean(60)}$ value between the 11:30-12:00 and 12:00-12:30 period on Thursday is the second highest $AD^{mean(60)}$ value of all time of day comparisons. It can again be noted that the 12:00-12:30 interval is an important time of day period.

- Monday 13:15-13:30 and 13:30-13:45: Note that the Thursday comparison for this time of day pair has little difference as its indicator value is equal to 0. These findings indicate that there is likely not a consistent time of day pattern for this interval.
- Monday 13:30-13:45 and 13:45-14:00. Note that the Thursday comparison for this time of day pair has a slight difference as its indicator value is equal to 1. However, the mean volume of the 13:30-13:45 period is larger on Monday and smaller on Thursday than the mean volume of the 13:45-14:00 period. These findings indicate that there is likely not a consistent time of day pattern for this interval.

These differences in volumes are consistent with what was noted when comparing ecdfs in Section 3.1

In summary, by looking at the above findings there is a consistent time of day effect for all of the 60-minute periods. The 60-minute periods from largest to smallest mean volume are as follows: 9:30-10:30, 11:30-12:30, and lastly 13:00-14:00. For the 30-minute periods there is a consistent time of day effect for the 11:30-12:00 and 12:00-12:30 periods, with 12:00-12:30 having higher volumes. Lastly, for the 15-minute periods there is a consistent time of day effect for the 10:00-10:15 period, with 10:00-10:15 having the largest mean volume in the 9:30-10:30 hour. In addition, for the 11:30-12:30 hour there is a consistent time of day effect, with the 12:15-12:30 period having the largest mean volume and the 12:00-12:15 period having the second largest mean volume.

Values of the $AD^{mean(60)}$ are additionally used to investigate differences in volumes by day of week. The differences are taken between pairs of distributions for intervals that begin at the same time of day and have the same time duration but occur on different days of the week. The difference metrics are calculated for every possible day of week pair of 60-, 30-, and 15-minute periods. Table 3.15 presents the D^{mean}, $D^{mean(60)}$, and $AD^{mean(60)}$ for pairs of distributions of volumes on Mondays and Thursdays. Table 3.16 presents the D^{mean}, $D^{mean(60)}$, and $AD^{mean(60)}$ for pairs of distributions of volumes on Wednesdays and Thursdays. Note that, unlike Tables 3.12 – 3.14 for the time of day effects, these day of week effect tables have one (time of day) Period column but two Day (of week) columns, rather than one Day (of week) column and two (time of day) Period columns.

Table 3.15 Metrics for Manual Volumes Differences in Monday and Thursday Periods for Day of Week Investigation; n is number of volumes (data points) in corresponding distribution

Period	Day_1	$Mean_i$ (n_i)	Day_2	$Mean_j$ (n_j)	$D^{mean}_{i,j}$	$D^{mean(60)}_{i,j}$	$AD^{mean(60)}_{i,j}$	$Ind_{i,j}$
11:30-12:30	Monday	332.6 (10)	Thursday	330.21 (6)	2.39	2.39	2.39	0
13:00-14:00	Monday	309.47 (12)	Thursday	290.05 (7)	19.42	19.42	19.42	1
11:30-12:00	Monday	140.77 (11)	Thursday	131.64 (8)	9.13	18.26	18.26	1
12:00-12:30	Monday	190.68 (10)	Thursday	195.73 (6)	-5.05	-10.1	10.1	0
13:00-13:30	Monday	146.07 (12)	Thursday	141.42 (9)	4.65	9.3	9.3	0
13:30-14:00	Monday	163.4 (12)	Thursday	153.88 (8)	9.52	19.04	19.04	1
11:30-11:45	Monday	70.76 (11)	Thursday	61.95 (8)	8.81	35.24	35.24	2
11:45-12:00	Monday	70.01 (11)	Thursday	65.44 (8)	4.57	18.28	18.28	1
12:00-12:15	Monday	84.82 (11)	Thursday	83.2 (9)	1.62	6.48	6.48	0
12:15-12:30	Monday	106.38 (10)	Thursday	111.58 (6)	-5.2	-20.8	20.8	1
13:00-13:15	Monday	67.77 (12)	Thursday	69.86 (9)	-2.09	-8.36	8.36	0
13:15-13:30	Monday	78.3 (12)	Thursday	71.56 (9)	6.74	26.96	26.96	1
13:30-13:45	Monday	93.57 (12)	Thursday	72.67 (8)	20.9	83.6	83.6	2
13:45-14:00	Monday	69.82 (12)	Thursday	81.2 (8)	-11.38	-45.52	45.52	2

Table 3.16 Metrics for Manual Volumes Differences in Wednesday and Thursday Periods for Day of Week Investigation; n is number of volumes (data points) in corresponding distribution

Period	Day_1	$Mean_i$ (n_i)	Day_2	$Mean_j$ (n_j)	$D^{mean}_{i,j}$	$D^{mean(60)}_{I,j}$	$AD^{mean(60)}_{i,j}$	$Ind_{i,j}$
9:30-10:30	Wednesday	419.17 (12)	Thursday	359.07 (13)	60.1	60.1	60.1	2
9:30-10:00	Wednesday	204.98 (17)	Thursday	180.18 (17)	24.8	49.6	49.6	2
10:00-10:30	Wednesday	207.02 (12)	Thursday	172.97 (13)	34.05	68.1	68.1	2
9:30-9:45	Wednesday	99.5 (17)	Thursday	93.95 (17)	5.55	22.2	22.2	1
9:45-10:00	Wednesday	105.48 (17)	Thursday	86.23 (17)	19.25	77	77	2
10:00-10:15	Wednesday	122.84 (14)	Thursday	94.14 (14)	28.7	114.8	114.8	2
10:15-10:30	Wednesday	84.13 (12)	Thursday	77.19 (13)	6.94	27.76	27.76	1

Figure 3.25 presents the ecdf of all the $AD^{mean(60)}$ values found in Tables 3.15 and 3.16. This ecdf was again calculated manually as described previously. It is noted that the range of $AD^{mean(60)}$ values for the day of week comparisons (Figure 3.25) is smaller than the range of $AD^{mean(60)}$ values for the time of day comparisons (Figure 3.24), indicating smaller day of week effects than time of day effects for the manual (true) volumes.

As was done for the time of day effects, the ecdf in Figure 3.25 is used to indicate which day of week differences are considered large, slight, and small, as indicated by indicator values of 2, 1, and 0, respectively. Looking at the ecdf in Figure 3.25, there again appear to be three clusters of points, leading to three ranges of volume values. The first range is from 0-15 vehicles per hour, the second range is from 15-30 vehicles per hour, and the third range is greater than 30 vehicles per hour. Specifically, for the day of week investigation the indicator, $Ind_{i,j}$, is specified as:

$$Ind_{i,j} = \begin{cases} 0, \text{ if } 0 \leq AD^{mean(60)}_{i,j} < 15 \\ 1, \text{ if } 15 \leq AD^{mean(60)}_{i,j} < 30 \\ 2, \text{ if } 30 \leq AD^{mean(60)}_{i,j} \end{cases} \quad (3.5)$$

The indicator values are provided in the last column of Tables 3.15, and 3.16.

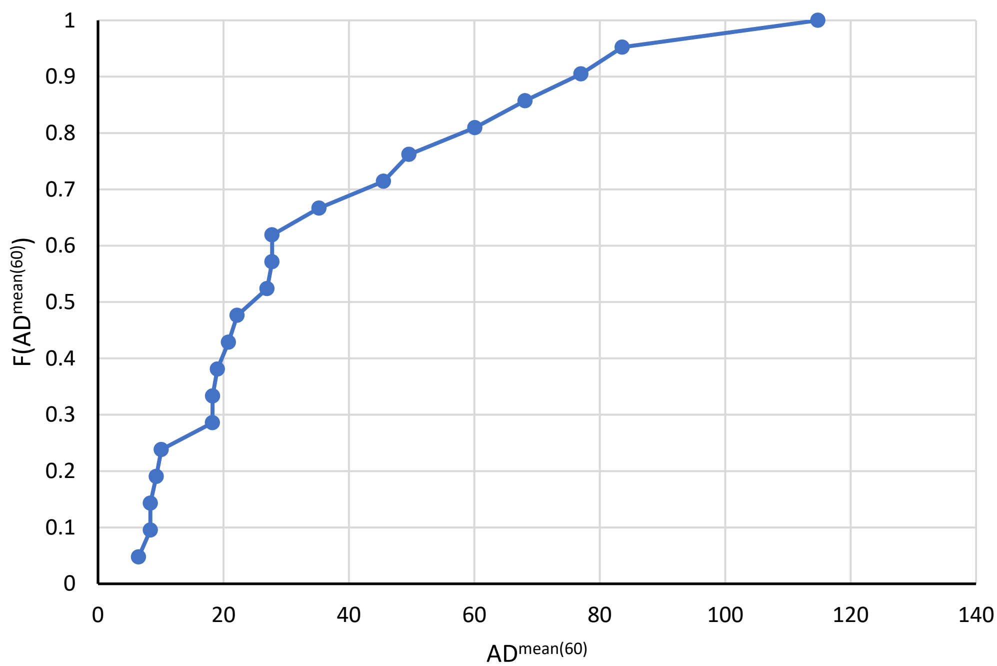

Figure 3.25: Ecdf of 60-minute Equivalent Absolute Difference $AD^{mean(60)}$ Values for Day of Week Investigation, Manual Volumes

For the Monday and Thursday comparisons shown in Table 3.15, none of the 60-, and 30-minute comparisons are indicated to have a large difference in volumes, as their indicator value are equal to 0 or 1. There are three 15-minute periods that show a large difference between Monday and Thursday, as they have indicator values equal to 2. The first is for 11:30-11:45 period. The second comparisons that show large differences in means of volumes between Monday and Thursday are for the 13:30-13:45 and 13:45-14:00 periods. However, note that, as indicated by $D^{mean(60)}$, two of the differences indicate greater volumes on Monday (positive $D^{mean(60)}$) and one shows greater volumes on Thursday (negative $D^{mean(60)}$). That is, there does not appear to be a systematic day of week effect for the 15-minute periods that are indicated as having large differences in means for the Monday and Thursday periods. Rather, the effect of the day of week depends on the time of day in this comparison. The rest of the 15-minute periods appear to have a little or slight difference as their indicator values are equal to 0 or 1 and have a mix of positive and negative $D^{mean(60)}$ values. In conclusion, there does not seem to be a systematic day of week effect between Monday and Thursday.

Unlike the Monday and Thursday comparisons in Table 3.15, comparisons between volume means on Wednesday and Thursday for the same time period shown in Table 3.16 all show positive $D^{mean(60)}$ values, indicting larger mean volumes on Wednesday than Thursday. Furthermore, all the 60-, and 30-minute comparisons show a large difference between Wednesday and Thursday, as they have indicator values equal to 2. Moreover, all of the 15-minute comparisons have indicator values of either 2 or 1, indicating large or slight differences in volumes. No explanation is presently available as to why the mean volumes on Wednesday are greater than the mean volumes on Thursdays, but the values in Table 3.16 support this empirical systematic finding for the subintervals in the 9:30-10:30 hour. When comparing the ecdfs in Section 3.2, it was previously noted that the Wednesday volumes are larger than the Thursday volumes when considering same intervals. Note that because of the data collection schedule, day of week comparisons between Wednesday and Thursday could only be made during the 9:30-10:30 hour.

In summary, it appears that these is a systematic day of week effect between Wednesday and Thursday (during the 9:30-10:30 hour) with Wednesday having larger volume, but that there is no systematic day of week effect between Monday and Thursday. Presently there is no interpretation for the Wednesday-Thursday pattern and the lack of Monday-Thursday pattern.

However, it is possible these empirical results could be attributed to the hours on which data were sampled on the various days and the correspondence of these hours to different class schedules that occur on different days of the week throughout the semester.

Chapter 4: Temporal Effects in Volumes Determined from Video Based Data

This chapter investigates the vehicle volumes determined from the bus based video imagery. In Sections 4.1 and 4.2, respectively, the video volumes will be investigated as a function of time and day and day of week using empirical cumulative distribution functions (ecdfs) to see if the video volume ecdfs represent the same time of day and day of week effects seen in the true (manual) volumes in Chapter 3. In Section 4.3, the ability of the differences in the video volumes by time of day and day of week to represent the differences in the true (manual) volumes will be investigated more quantitively.

4.1 Time of Day Effects

This section will investigate the ability of the bus based video vehicle estimates to detect the time of day patterns seen in the empirical volumes determined from manually collected data. As discussed in Section 2.2.1, traffic volumes from bus based videos were estimated on the same days and for the same time periods for which volumes from the manually collected data were determined. Therefore, as discussed in Section 3.1, video volumes were estimated for 60-, 30-, and 15-minute intervals on Mondays, Wednesdays, and Thursdays. The video vehicle volumes for 60-, 30-, and 15-minute intervals – i.e., $V_{hh:mm,d}^{bus,60}$, $V_{hh:mm,d}^{bus,30}$, and $V_{hh:mm,d}^{bus,15}$ – can be found in Appendix D. These video volumes were estimated and aggregated using the methods described in Section 2.2.

Of the three days, Thursday was the day of week with the most hours in which video volumes were estimated for. As with the volumes estimated from the manually collected data (manual volumes), on Thursdays video volumes were estimated from 9:30 to 10:30 during both

Spring 2022 and Autumn 2022 semesters, 11:30 to 12:30 during Spring 2022 semester, and 13:00 to 14:00 during Autumn 2022 semester. Figure 4.1 presents the empirical cumulative distribution functions (ecdfs) of the 60-minute video volumes for the three 60-minute Thursday intervals, that is, for the three $V_{9:30,4}^{bus,60}$, $V_{11:30,4}^{bus,60}$, and $V_{13:00,4}^{bus,60}$, with 4 representing the fourth day of the week (Thursday). The y-axis represents the cumulative probability of the volume indicated on the x-axis. The ecdfs were calculated manually. The cumulative probability of x is computed as $k(x)/n$ where n is the number of observations in the data set, and $k(x)$ is the number of observations in the data set that are less than or equal to x. Summary statistics of the distributions shown in Figure 4.1 are presented in Table 4.1. As with the manual volume the number of observations in each $V_{hh:mm,d}^{man,60}$, $V_{hh:mm,d}^{man,30}$, and $V_{hh:mm,d}^{man,15}$ data set varies.

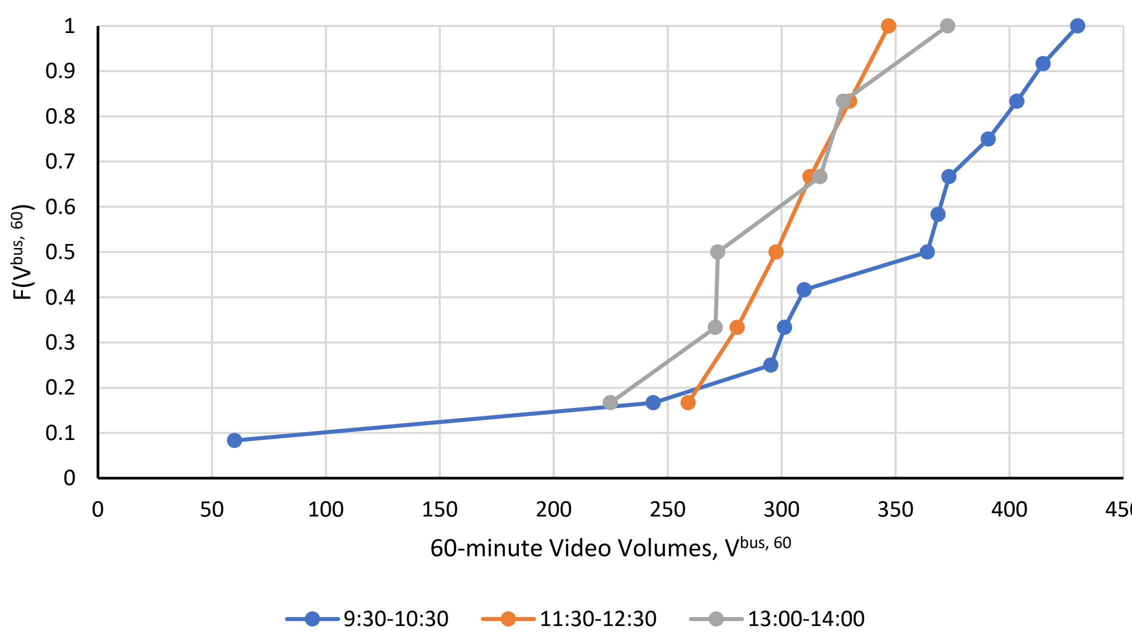

Figure 4.1: Ecdfs of 60-minute Thursday Volumes from Video Data for Hours beginning at 9:30, 11:30, and 13:00

Table 4.1: Summary Statistics of the Distributions of the 60-minute Thursday, Video Volumes

Hour	Number of Volumes	Median	Mean[1]	Standard Deviation
9:30-10:30	12	366.35	329.62	101.61
11:30-12:30	6	305.09	304.44	32.27
13:00-14:00	6	294.48	297.49	52.10

[1]Medians calculated with Excel function which takes midpoint between middle numbers when the number of volumes is even. This may differ from $F^{-1}(0.5)$ from the ECDF.

In Figure 4.1 there is a clear distinction of the 9:30-10:30 volume distributions from the other two hourly volume distributions. The 9:30-10:30 volumes are the largest (ecdf is farthest to the right). The 11:30-12:30 and 13:00-14:00 hours have smaller volumes and are similar as their ecdfs overlap. These finding are also evident in the means and medians of Table 4.1, as the mean and median of the 9:30-10:30 hour are larger than the means and medians of the 11:30-12:30 and 13:00-14:00 hour which have very similar mean and median values.

As in Chapter 3 the hourly volumes are investigated in subintervals within the hours. Therefore, 30-minute ecdfs were created for each of the hourly ecdfs presented in Figure 4.1. Figures 4.2, 4.3, and 4.4 present the empirical cumulative distribution functions (ecdfs) of 30-minute video volumes for the six 30-minute Thursday intervals, that is, for the six $V_{hh:mm,4}^{bus,30}$ with mm being 00 or 30 in each of the three hourly periods, and 4 representing the fourth day of the week (Thursday). Figure 4.2 presents the volumes in the 30-minute increments during the 9:30-10:30 hour ($V_{09:30,4}^{bus,30}, V_{10:00,4}^{bus,30}$). Figure 4.3 presents the volumes in the 30-minute increments during the 11:30-12:30 hour ($V_{11:30,4}^{bus,30}, V_{12:00,4}^{bus,30}$). Figure 4.4 presents the volumes in the 30-minute increments during the 13:00-14:00 hour ($V_{13:00,4}^{bus,30}$, $V_{13:30,4}^{bus,30}$). Summary statistics of the distrubutions shown in Figures 4.2 through 4.4 are presented in Table 4.2.

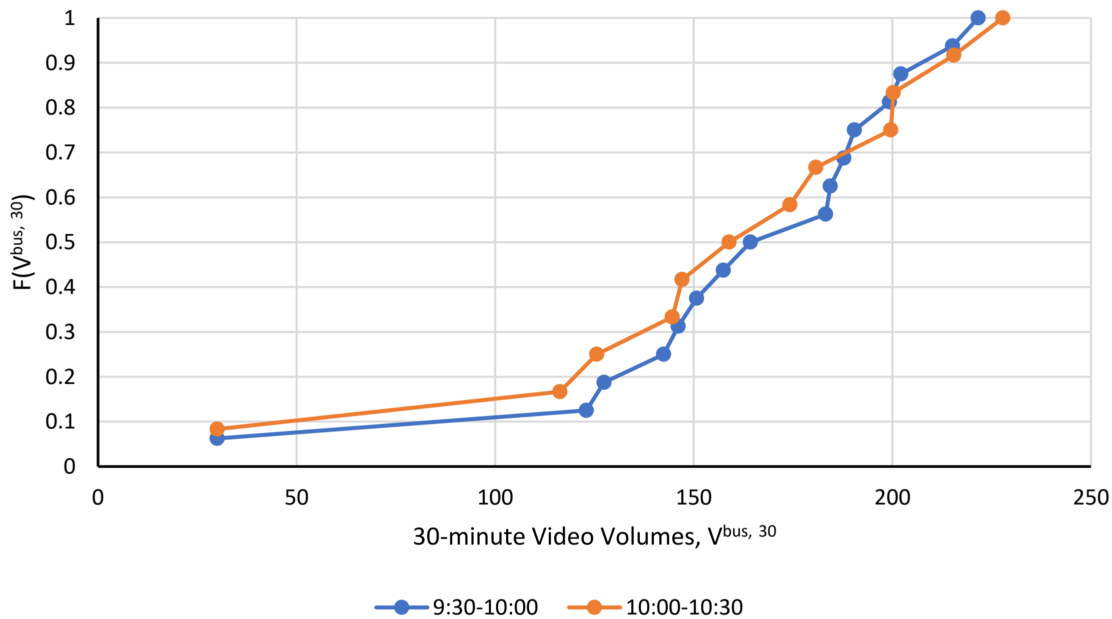

Figure 4.2: Ecdfs of 30-minute Thursday Volumes from 9:30 to 10:30 for Video Data beginning at 9:30 and 10:00

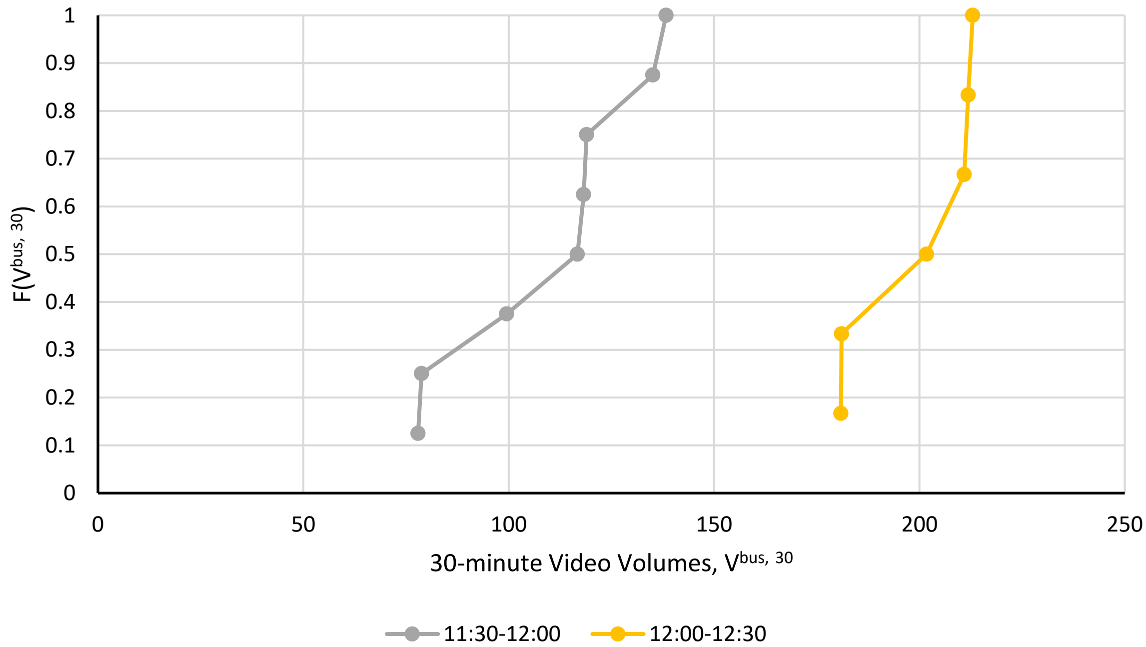

Figure 4.3: Ecdfs of 30-minute Thursday Volumes from 11:30 to 12:30 for Video Data beginning at 11:30 and 12:00

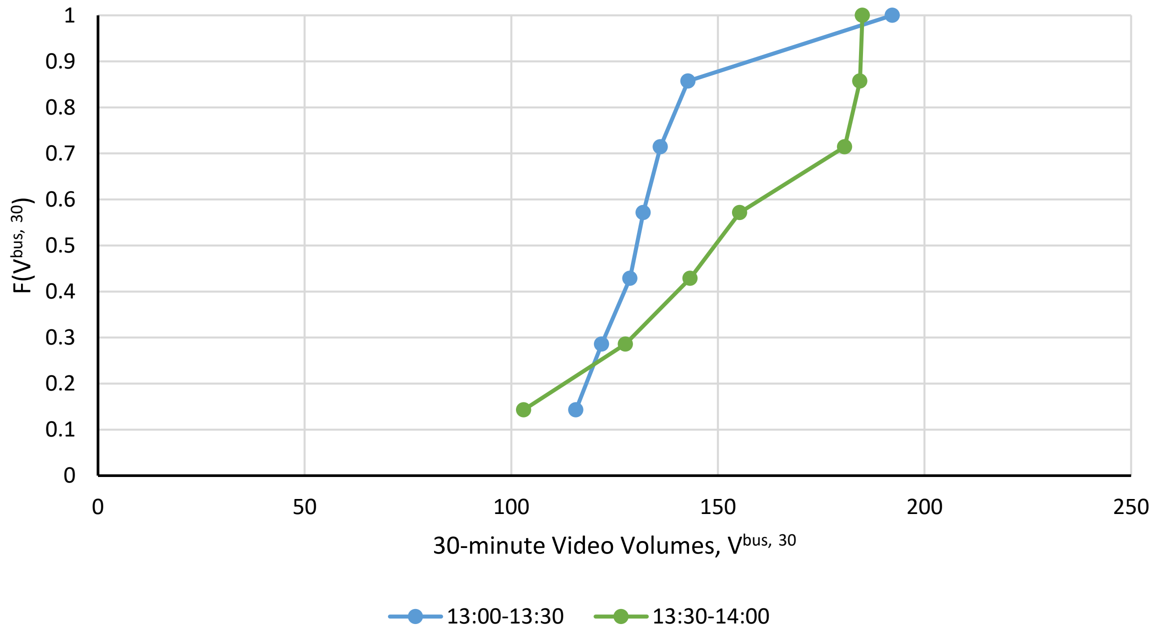

Figure 4.4: Ecdfs of 30-minute Thursday Volumes from 13:00 to 14:00 for Video Data beginning at 13:00 and 13:30

Table 4.2: Summary Statistics of the Distributions of the 30-minute Thursday, Video Volumes

Hour	Number of Volumes	Interval	Median[1]	Mean	Standard Deviation
9:30-10:30	16	9:30-10:00	173.76	164.09	46.68
	12	10:00-10:30	166.57	160.05	53.86
11:30-12:30	8	11:30-12:00	117.50	110.46	23.11
	6	12:00-12:30	206.34	199.92	15.21
13:00-14:00	7	13:00-13:30	131.95	138.47	25.32
	7	13:30-14:00	155.30	154.18	31.64

[1]Medians calculated with Excel function which takes midpoint between middle numbers when the number of volumes is even. This may differ from $F^{-1}(0.5)$ from the ECDF.

In Figure 4.2 the ecdfs of the 30-minute periods for the 9:30-10:30 hour are very similar and overlap. This is also evident in the means and medians Table 4.2, as the two periods have very similar mean and median values. In Figure 4.3 there is a clear distinction between the two 30-minute periods for the 11:30-12:30 hour. The 12:00-12:30 volumes are much larger than the 11:30-12:00 volumes. This ordering is also evident in the means and medians Table 4.2. In Figure 4.4 there is some distinction between the two 30-minute periods for the 13:00-14:00 hour. The 13:30-14:00 volumes are slightly larger than the 13:00-13:30 volumes. This finding is also evident in the means and medians Table 4.2 as the mean and median of the 13:30-14:00 period are slightly larger than the mean and median of the 13:00-13:30 period.

As was done in Chapter 3, the time of day patterns can be investigated further by looking at the 15-minute subperiods. Figure 4.5, 4.6, and 4.7, plot the ecdfs of each of the four 15-minute intervals within the respective hour, that is, for the twelve $V_{hh:mm,4}^{bus,15}$ with mm being 00, 15, 30, or 45 in each of the three hourly periods, and 4 representing the fourth day of the week (Thursday). Figure 4.5 presents the 15-minute increments during the 9:30-10:30 hour ($V_{09:30,4}^{bus,15}$, $V_{09:45,4}^{bus,15}$, $V_{10:00,4}^{bus,15}$, $V_{10:15,4}^{bus,15}$). Figure 4.6 presents the 15-minute increments during the 11:30-12:30 hour ($V_{11:30,4}^{bus,15}$, $V_{11:45,4}^{bus,15}$, $V_{12:00,4}^{bus,15}$, $V_{12:15,4}^{bus,15}$). Figure 4.7 presents the 15-minute increments during the 13:00-14:00 hour ($V_{13:00,4}^{bus,15}$, $V_{13:15,4}^{bus,15}$, $V_{13:30,4}^{bus,15}$, $V_{13:45,4}^{bus,15}$). Summary statistics of the distrubutions shown in Figures 4.5 through 4.7 are presented in Table 4.3.

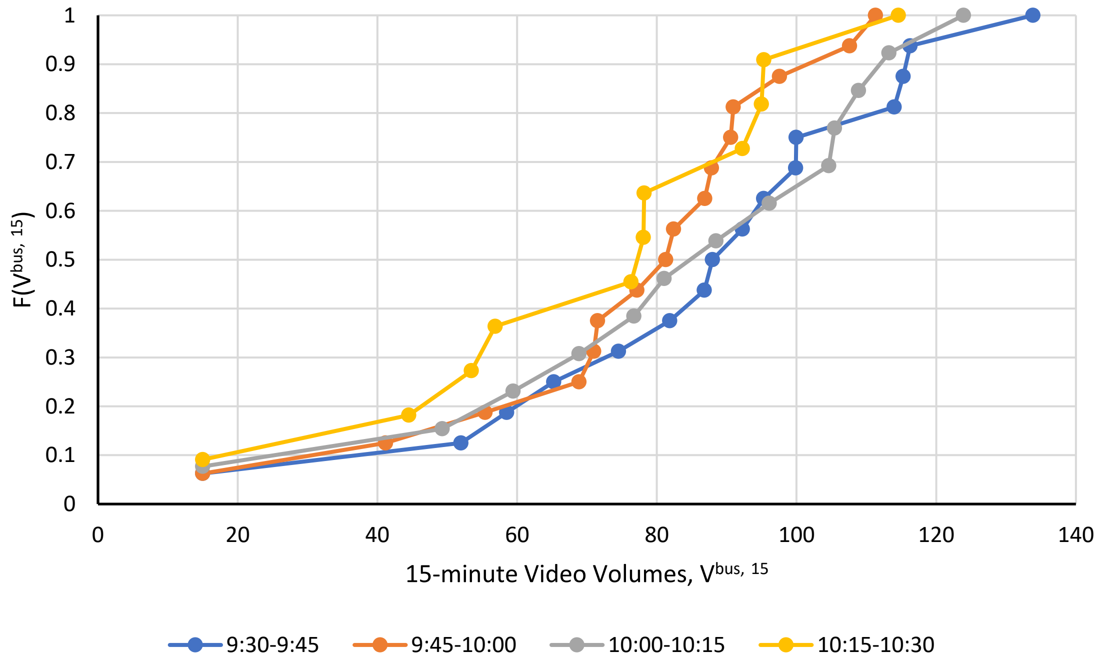

Figure 4.5: Ecdfs of 15-minute Thursday Volumes from 9:30 to 10:30 for Video Data beginning at 9:30, 9:45, 10:00 and 10:15

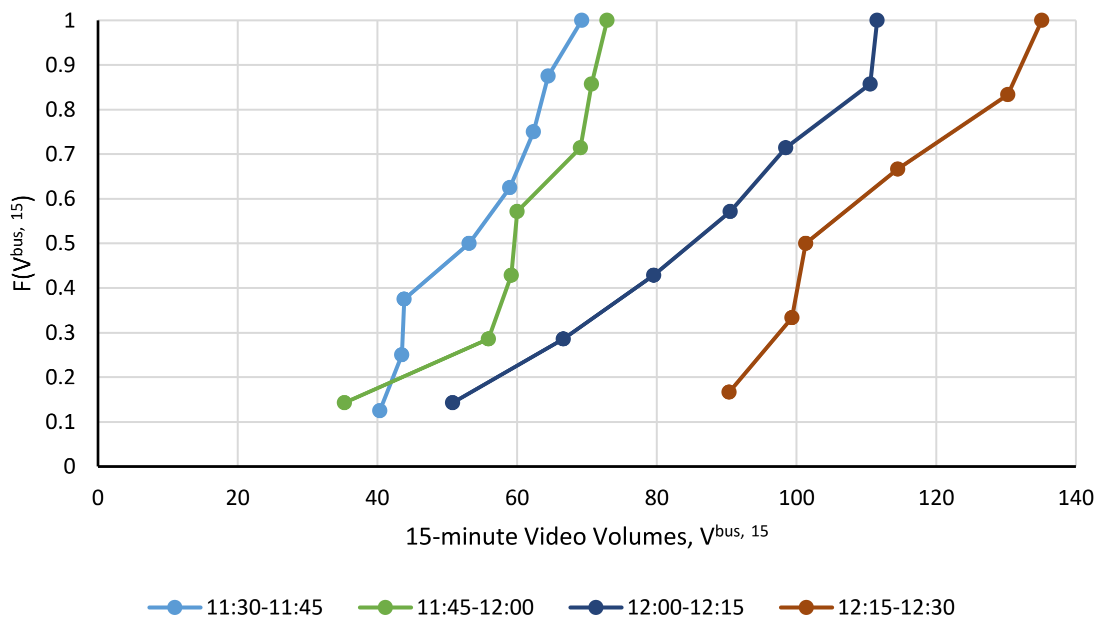

Figure 4.6: Ecdfs of 15-minute Thursday Volumes from 11:30 to 12:30 for Video Data beginning at 11:30, 11:45, 12:00 and 12:15

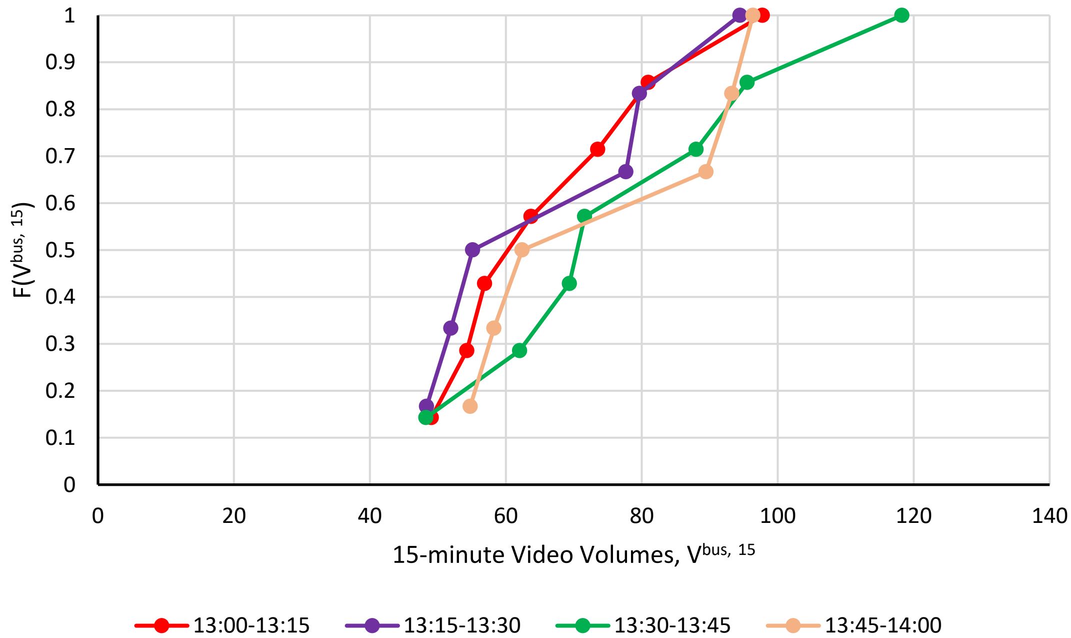

Figure 4.7: Ecdfs of 15-minute Thursday Volumes from 13:00 to 14:00 for Video Data beginning at 13:00, 13:15, 13:30, and 13:45

Table 4.3: Summary Statistics of the Distributions of the 15-minute Thursday, Video Volumes

Hour	Number of Volumes	Interval	Median[1]	Mean	Standard Deviation
9:30-10:30	16	9:30-9:45	90.11	86.80	29.32
	16	9:45-10:00	81.85	77.29	24.36
	13	10:00-10:15	88.47	83.93	30.25
	11	10:15-10:30	78.09	72.69	28.22
11:30-12:30	8	11:30-11:45	56.06	54.48	10.92
	7	11:45-12:00	60.02	60.43	12.84
	7	12:00-12:15	90.53	86.87	22.67
	6	12:15-12:30	107.91	111.82	17.98
13:00-14:00	7	13:00-13:15	63.72	68.02	17.19
	6	13:15-13:30	66.40	67.87	18.65
	7	13:30-13:45	71.61	79.01	23.37
	6	13:45-14:00	75.93	75.75	19.20

[1]Medians calculated with Excel function which takes midpoint between middle numbers when the number of volumes is even. This may differ from $F^{-1}(0.5)$ from the ECDF.

In Figure 4.5 there is little distinction among the ecdfs of the 15-minute periods for the 9:30-10:30 hour. The 9:30-9:45 and 10:00-10:15 volumes appear to be slightly larger than the 9:45-10:00 and 10:15-10:30 volumes. This pattern is also evident in the means and median Table 4.3. In Figure 4.6 there is clear distinction among the four 15-minute increments for the 11:30-12:30 hour. The volumes from largest to smallest values are 12:15-12:30, 12:00-12:15, 11:45-12:00, and lastly 11:30-11:45. This ordering is also evident in the means and medians Table 4.3. In Figure 4.7 the ecdfs of the four 15-minute periods for the 13:00-14:00 hour are very similar, as they overlap each other. This finding is also evident in the means and medians Table 4.3 as all four periods have very similar mean and median values.

As in Chapter 3, the video volumes are also investigated as a function of time of day for Mondays and Wednesdays. Monday is the day of week with the second most hours for which video volumes were estimated. On Mondays, video volumes were estimated from 11:30 to 12:30 during Spring semester, and 13:00 to 14:00 during Autumn semester. Wednesday only had one hour for which video volumes were estimated. On Wednesdays video volumes were estimated from 9:30-10:30 during both Spring and Autumn semester. Therefore, patterns cannot be investigated among different hours on Wednesdays. However, patterns can still be investigated in sub-intervals within the hour.

Figure 4.8 presents the empirical cumulative distribution functions (ecdfs) of the two 60-minute Monday intervals, that is, for the two $V_{hh:mm,1}^{bus,60}$ with hh:mm being 11:30 or 13:00, and 1 representing the first day of the week (Monday). Figures 4.9 and 4.10 present the empirical cumulative distribution functions (ecdfs) of 30-minute manual volumes for the two 30-minute Monday intervals within the respective hour, that is, for the four $V_{hh:mm,1}^{bus,30}$ with being 00, or 30 in each of the two hourly periods, and 1 representing the first day of the week (Monday). Figure 4.9 presents the 30-minute increments during the 11:30-12:30 hour ($V_{11:30,1}^{bus,30}, V_{12:00,1}^{bus,30}$). Figure 4.10 presents the 30-minute increments during the 13:00-14:00 hour ($V_{13:00,1}^{bus,30}, V_{13:30,1}^{bus,30}$). Figures 4.11 and 4.12 present the empirical cumulative distribution functions (ecdfs) of 15-minute manual volumes for the four 15-minute Monday intervals within the respective hour, that is, for the eight $V_{hh:mm,1}^{bus,15}$ with mm being 00, 15, 30, or 45 in each of the two hourly periods, and 1 representing the first day of the week (Monday). Figure 4.11 presents the 15-minute increments during the 11:30-12:30 hour ($V_{11:30,1}^{bus,15}, V_{11:45,1}^{bus,15}, V_{12:00,1}^{bus,15}, V_{12:15,1}^{bus,15}$). Figure 4.12 presents the 15-minute increments during the 13:00-14:00 hour ($V_{13:00,1}^{bus,15}, V_{13:15,1}^{bus,15}, V_{13:30,1}^{bus,15}, V_{13:45,1}^{bus,15}$). Summary statistics of the distrubutions shown in Figures 4.8 through 4.12 are presented in Table 4.4.

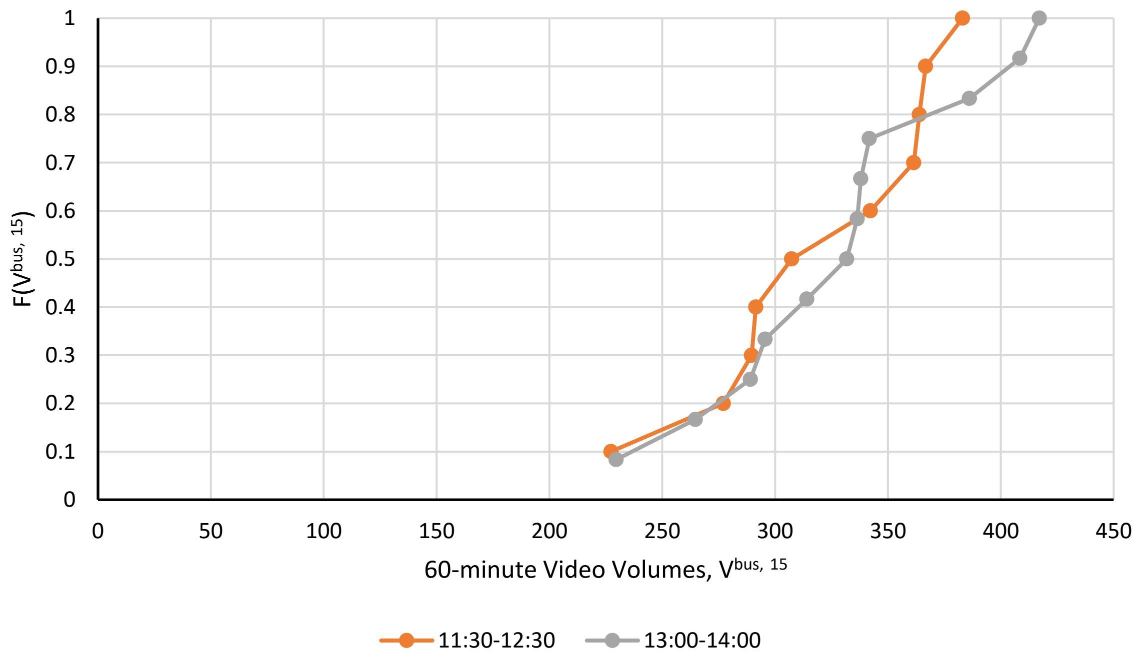

Figure 4.8: Ecdfs of 60-minute Monday Volumes from Video Data for Hours beginning at 11:30 and 13:00

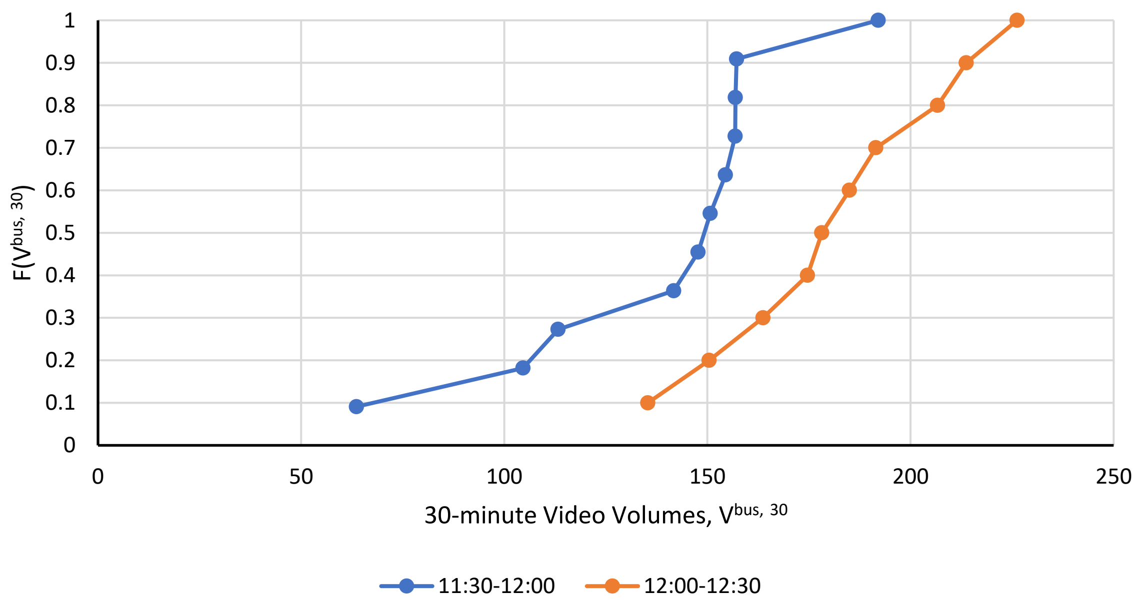

Figure 4.9: Ecdfs of 30-minute Monday Volumes from 11:30 to 12:30 for Video Data beginning at 11:30 and 12:00

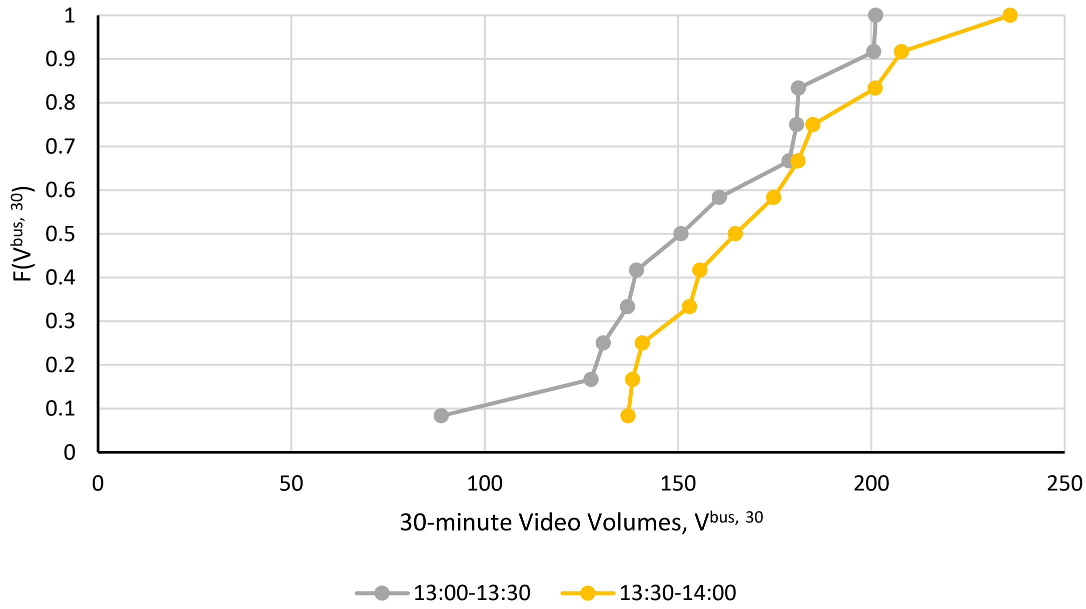

Figure 4.10: Ecdfs of 30-minute Monday Volumes from 13:00 to 14:00 for Video Data beginning at 13:00 and 13:30

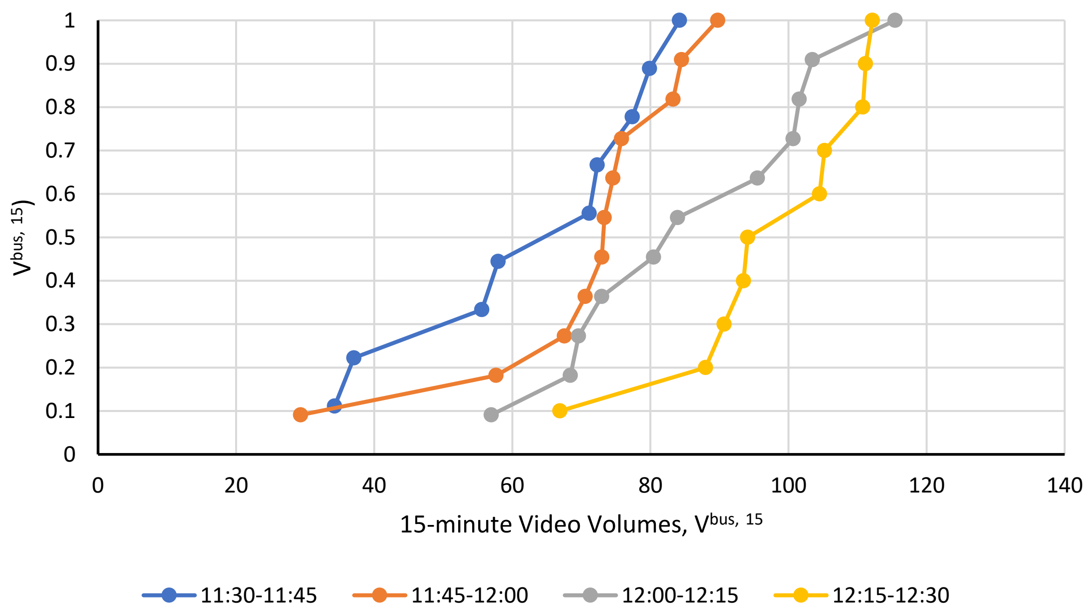

Figure 4.11: Ecdfs of 15-minute Monday Volumes from 11:30 to 12:30 for Video Data beginning at 11:30, 11:45, 12:00 and 12:15

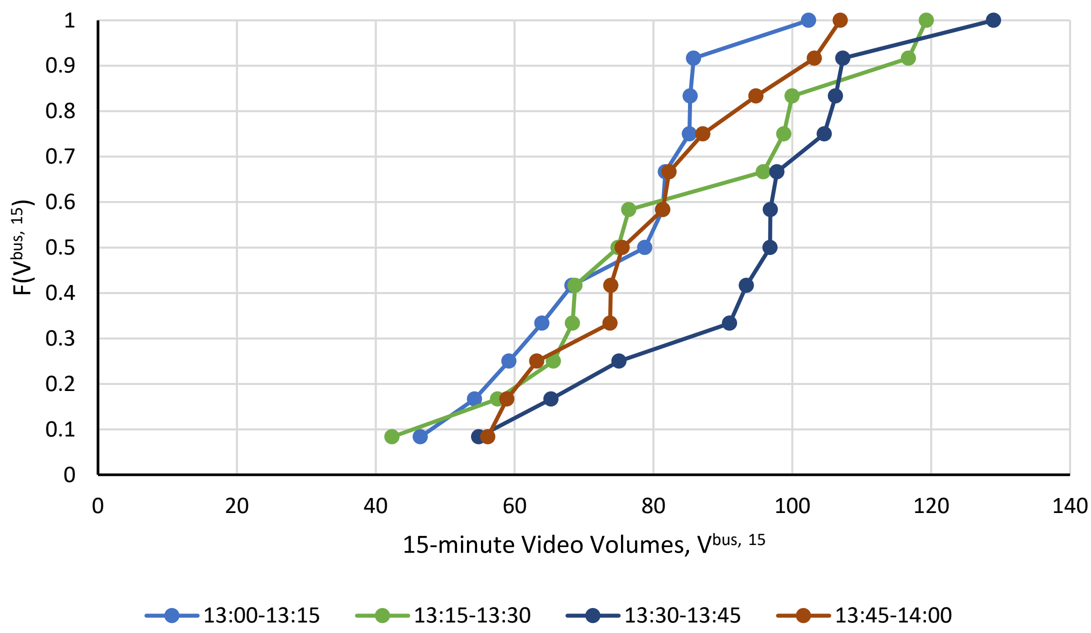

Figure 4.12: Ecdfs of 15-minute Monday Volumes from 13:00 to 14:00 for Video Data beginning at 13:00, 13:15, 13:30, and 13:45

Table 4.4: Summary Statistics of the Distributions of the Monday Video Volumes

Length	Number of Volumes	Interval	Median[1]	Mean	Standard Deviation
60 minutes	10	11:30-12:30	324.79	321.02	50.14
	12	13:00-14:00	334.09	329.38	56.09
30 minutes	11	11:30-12:00	150.73	139.92	34.30
	10	12:00-12:30	181.58	182.54	28.37
	12	13:00-13:30	155.75	156.43	33.64
	12	13:30-14:00	169.82	172.94	30.85
15 minutes	9	11:30-11:45	71.15	63.31	18.28
	11	11:45-12:00	73.33	70.86	16.30
	11	12:00-12:15	83.95	86.27	18.29
	10	12:15-12:30	99.30	97.70	14.09
	12	13:00-13:15	78.77	74.38	16.05
	12	13:15-13:30	74.91	82.05	23.89
	12	13:30-13:45	96.80	93.17	20.03
	12	13:45-14:00	75.52	79.76	16.32

[1]Medians calculated with Excel function which takes midpoint between middle numbers when the number of volumes is even. This may differ from $F^{-1}(0.5)$ from the ECDF.

In Figure 4.8 the ecdfs of the 11:30-12:30 and 13:00-14:00 hours are very similar and overlap. This finding is also evident in the means and medians Table 4.4, as the two hours have very similar mean and median values.

Figures 4.9 and 4.10 show distinction within the two 30-minute periods for each hour. In Figure 4.9 the 12:00-12:30 volumes are found to be larger than the 11:30-12:00 volumes. In Figure 4.10 the 13:30-14:00 volumes are found to be larger than the 13:00-13:30 volumes. The ordering found in both Figures 4.9 and 4.10 is also evident in the means and medians of Table 4.4.

In Figure 4.11 there are distinctions among the four 15-minute periods for the 11:30-12:30 hour. The volumes from largest to smallest values are 12:15-12:30, 12:00-12:15, 11:45-12:00, and lastly 11:30-11:45. This ordering is also evident in means and medians of Table 4.4. In Figure 4.12 the ecdfs show that the 13:30-13:45 period volumes are the largest. The ecdfs for the other 3 periods in the 13:00-14:00 hour are similar and overlap. These patterns are also evident in the means and medians of Table 4.4, as the 13:30-13:45 period has the largest mean and median values while the other three periods have smaller and similar mean and median values.

On Wednesdays video data were only estimated for one hour. Therefore, no comparisons can be made among the Wednesday hourly volume distributions. However, comparisons can be made among the distributions of the 30-, and 15-minute periods within the hour. Figure 4.13 presents the empirical cumulative distribution functions (ecdfs) of the 60-minute Wednesday interval, that is, for $V_{hh:mm,3}^{bus,60}$ with hh:mm being 9:30, and 3 representing the third day of the week (Wednesday). Figure 4.14 present the empirical cumulative distribution functions (ecdfs) of 30-minute manual volumes for the two 30-minute Wednesday intervals, that is, for the two $V_{hh:mm,3}^{bus,30}$ with hh:mm being 9:30, or 10:00, and 3 representing the third day of the week (Wednesday). Figure 4.15 presents the empirical cumulative distribution functions (ecdfs) of 15-minute manual volumes for the four 15-minute Wednesday intervals, that is, for the four $V_{hh:mm,3}^{bus,15}$ with hh:mm being 9:30, 9:45, 10:00, or 10:15, and 3 representing the third day of the week (Wednesday). Summary statistics of the distributions shown in Figures 4.13 through 4.15 are presented in Table 4.4.

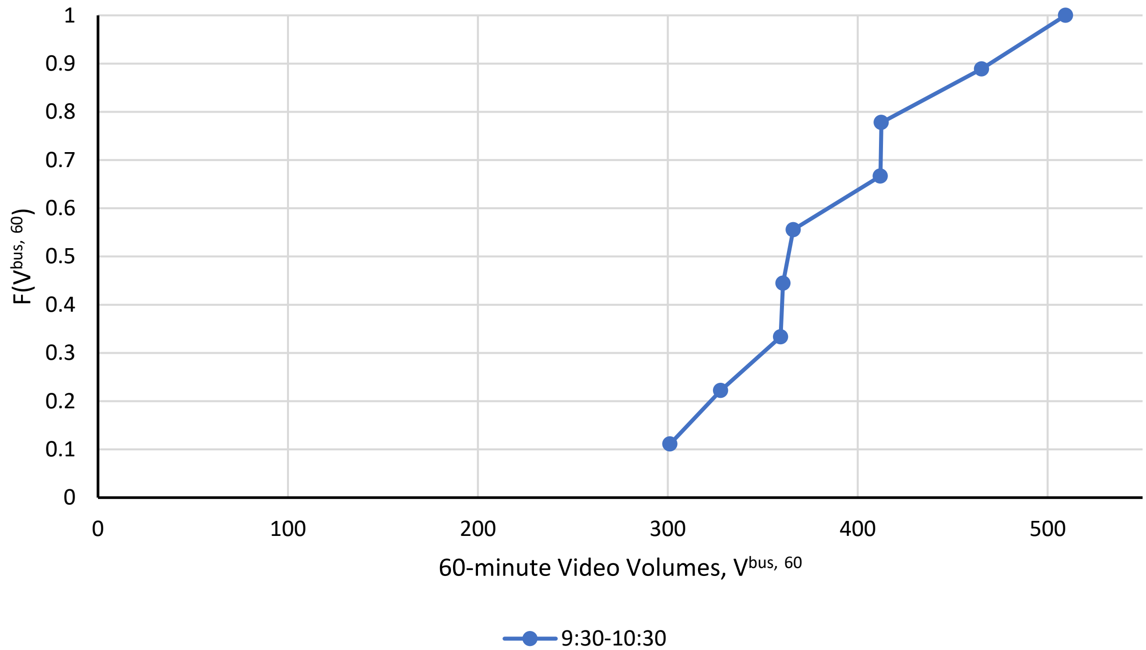

Figure 4.13: Ecdfs of 60-minute Wednesday Volumes for Video Data for Hours beginning at 9:30

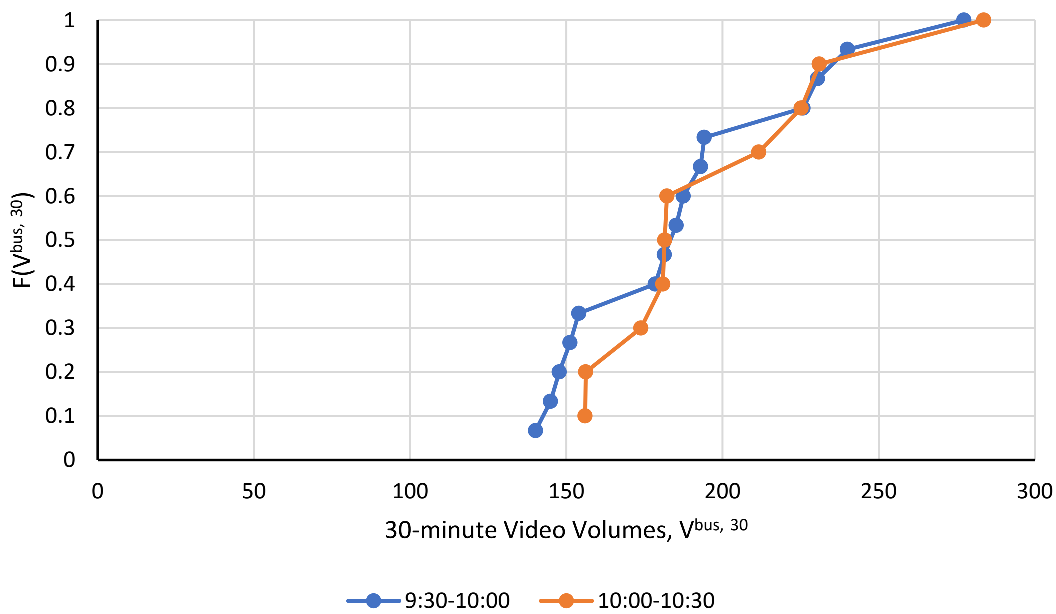

Figure 4.14: Ecdfs of 30-minute Wednesday Volumes from 9:30 to 10:30 for Video Data beginning at 9:30 and 10:00

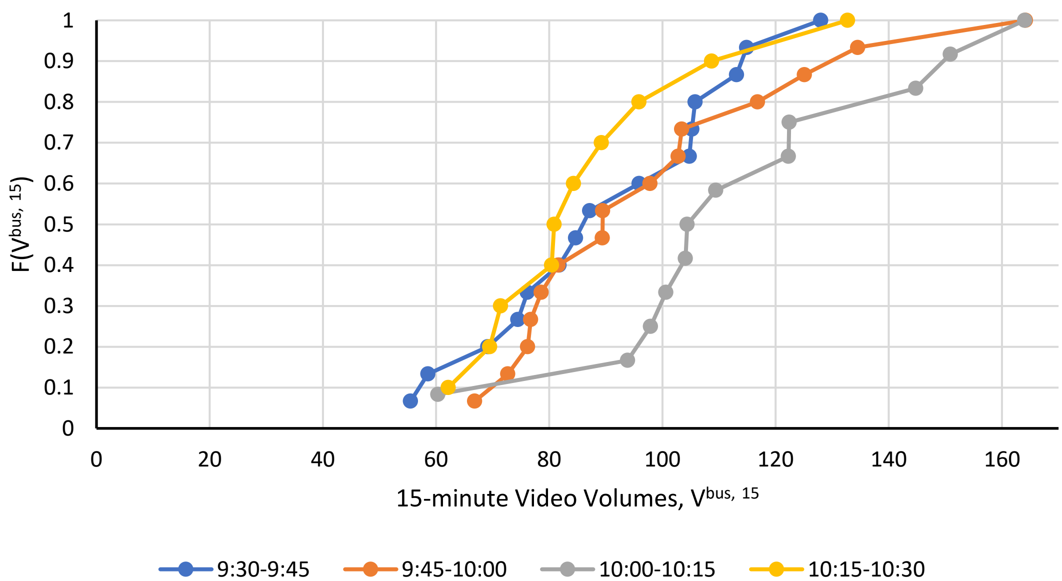

Figure 4.15: Ecdfs of 15-minute Wednesday Volumes from 9:30 to 10:30 for Video Data beginning at 9:30, 9:45, 10:00 and 10:15

Table 4.5: Summary Statistics of the Distributions of the Wednesday Video Volumes

Length	Number of Volumes	Interval	Median[1]	Mean	Standard Deviation
60 minutes	9	9:30-10:30	366.09	390.49	66.17
30 minutes	15	9:30-10:00	185.19	188.76	39.98
	10	10:00-10:30	181.86	198.23	39.79
15 minutes	15	9:30-9:45	87.15	90.34	21.51
	15	9:45-10:00	89.45	98.41	26.97
	12	10:00-10:15	106.92	114.58	28.41
	10	10:15-10:30	82.58	87.52	20.81

[1]Medians calculated with Excel function which takes midpoint between middle numbers when the number of volumes is even. This may differ from $F^{-1}(0.5)$ from the ECDF.

Figure 4.14 shows no distinction between the two 30-minute periods for the 9:30-10:30 hour, as the ecdfs overlap. This is consistent with the means and medians Table 4.5, as both periods have very similar values.

In Figure 4.15 the ecdfs indicate that the 10:00-10:15 volumes are largest. The ecdfs for the other 3 periods in the 9:30-10:30 hour are similar, as they overlap. This pattern is also evident in the means and medians Table 4.5, as the 10:00-10:15 period has the largest mean and median values while the other three periods have smaller mean and median values that are similar.

The correspondence of these numerically based observations to the patterns seen in the manual volumes are presented in Section 4.3.

4.2 Day of Week Effects in Video Volumes

This section investigates the volume estimated from the bus based video imagery ("video volumes") as a function of day of week using the data previously introduced in Section 2.2. As discussed in Section 2.2.1, traffic volumes from bus based videos were estimated on the same days and for the same time periods for which volumes from the manually collected data were determined. Therefore, on Mondays and Thursdays video volumes were estimated from 11:30 to 12:30 during Spring semester and 13:00 to 14:00 during Autumn semester. On Wednesdays and Thursday video volumes were estimated from 9:30 to 10:30 during both Spring and Autumn semester. As in Section 3.2 Monday and Thursday will be compared first in this investigation. The video vehicle volumes for 60-, 30-, and 15-minute intervals – i.e., $V_{hh:mm,d}^{bus,60}$, $V_{hh:mm,d}^{bus,30}$, and

$V_{hh:mm,d}^{bus,15}$ – can be found in Appendix D. These video volumes were estimated and aggregated using the methods described in Section 2.2.

Figure 4.16 presents the empirical cumulative distribution functions (ecdfs) of the two 60-minute intervals for the 11:30-12:30 hour on Mondays ($V_{11:30,1}^{bus,60}$) and Thursdays ($V_{11:30,4}^{bus,60}$) and, additionally, of the two 60-minute intervals for the 13:00-14:00 hour on Mondays ($V_{13:00,1}^{bus,60}$) and Thursdays ($V_{13:00,4}^{bus,60}$). Summary statistics of the distributions shown in Figure 4.16 are presented in Table 4.6.

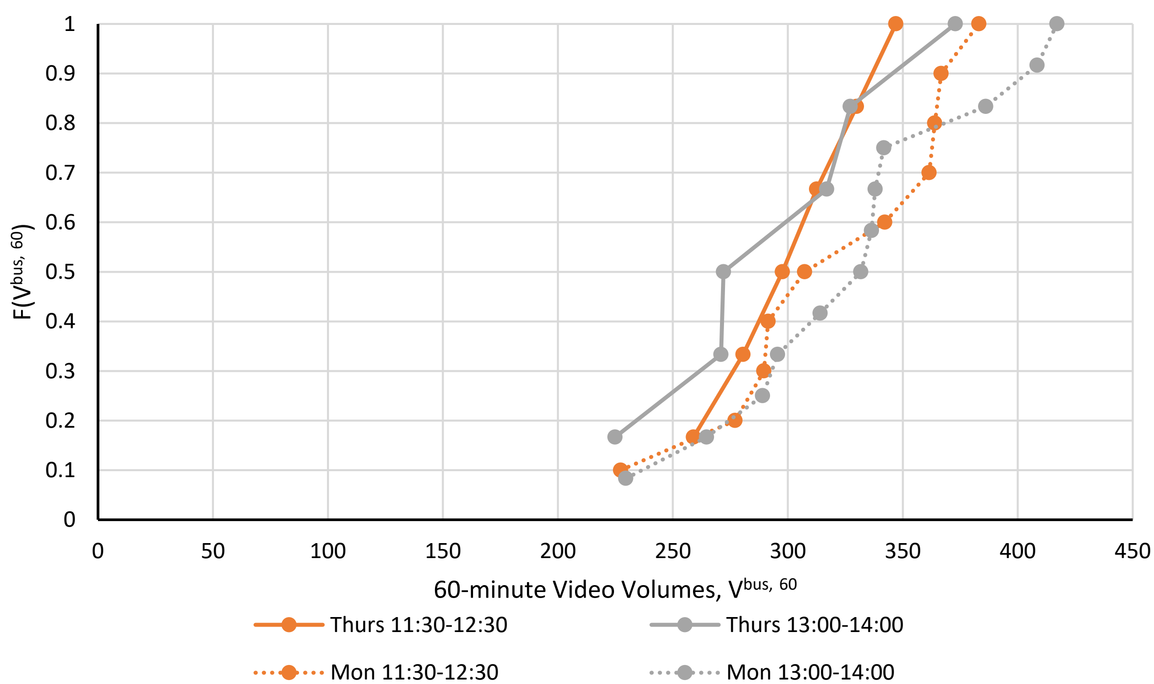

Figure 4.16: Ecdfs of 60-minute Monday and Thursday Volumes from Video Data for Hours beginning at 11:30, and 13:00

Table 4.6: Summary Statistics of Monday and Thursday 60-minute Distributions, Video Volumes

Period	Number of Volumes	Day of Week	Median[1]	Mean	Standard Deviation
11:30-12:30	10	Monday	324.79	321.02	50.14
	6	Thursday	305.09	304.44	32.27
13:00-14:00	12	Monday	334.09	329.38	56.09
	6	Thursday	294.48	297.49	52.10

[1]Medians calculated with Excel function which takes midpoint between middle numbers when the number of volumes is even. This may differ from $F^{-1}(0.5)$ from the ECDF.

From Figure 4.16 there appears to be a day of week effect for both the 11:30-12:30 and 13:00-14:00 hours. For the both the 11:30-12:30 and 13:00-14:00 hours, the Monday volumes are found to be larger than the Thursday volumes. These findings are also evident in the means and medians of Table 4.6, as Monday has higher mean and median values than Thursday for both hours.

As with the time of day analysis of Section 4.1, the shorter 30-, and 15-minute intervals are also investigated for different days. Figures 4.17 and 4.18 present the empirical cumulative distribution functions (ecdfs) of the two 30-minute Monday and Thursday intervals, for each respective hour. Figure 4.17 presents the 30-minute increments during the 11:30-12:30 hour on Mondays ($V_{11:30,1}^{bus,30}$, $V_{12:00,1}^{bus,30}$) and Thursdays ($V_{11:30,4}^{bus,30}$, $V_{12:00,4}^{bus,30}$). Figure 4.18 presents the 30-minute increments during the 13:00-14:00 hour on Mondays ($V_{13:00,1}^{bus,30}$, $V_{13:30,1}^{bus,30}$) and Thursdays ($V_{13:00,4}^{bus,30}$, $V_{13:30,4}^{bus,30}$). Summary statistics of the distributions shown in Figures 4.17 and 4.18 are presented in Table 4.7.

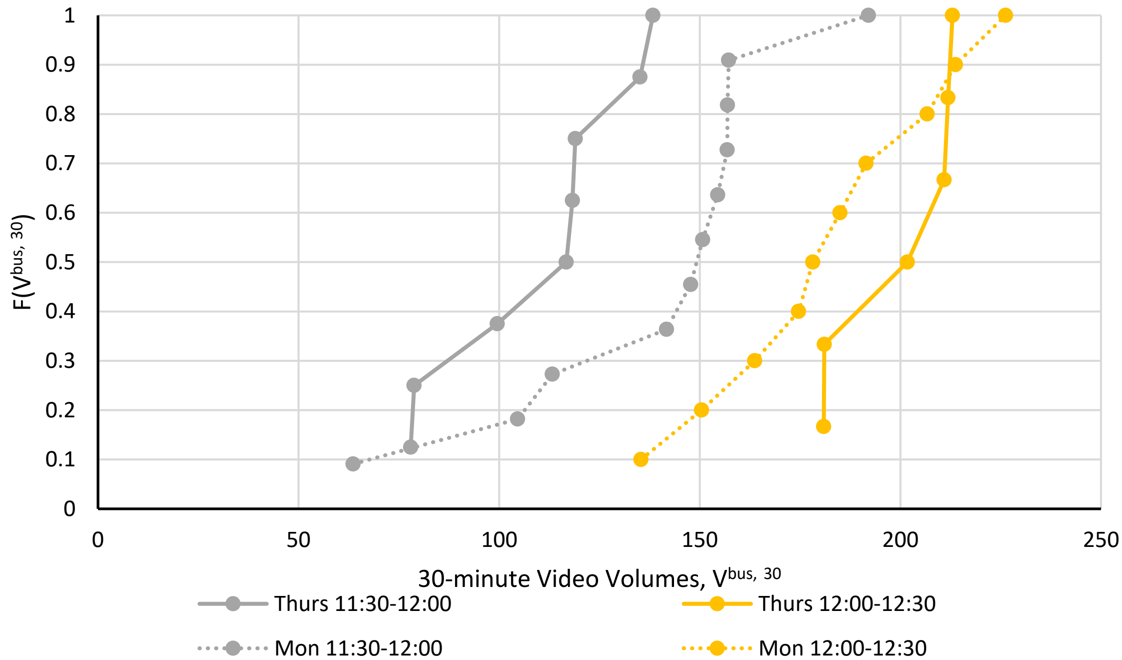

Figure 4.17: Ecdfs of 30-minute Monday and Thursday Volumes from 11:30 to 12:30 for Video Data beginning at 11:30 and 12:00

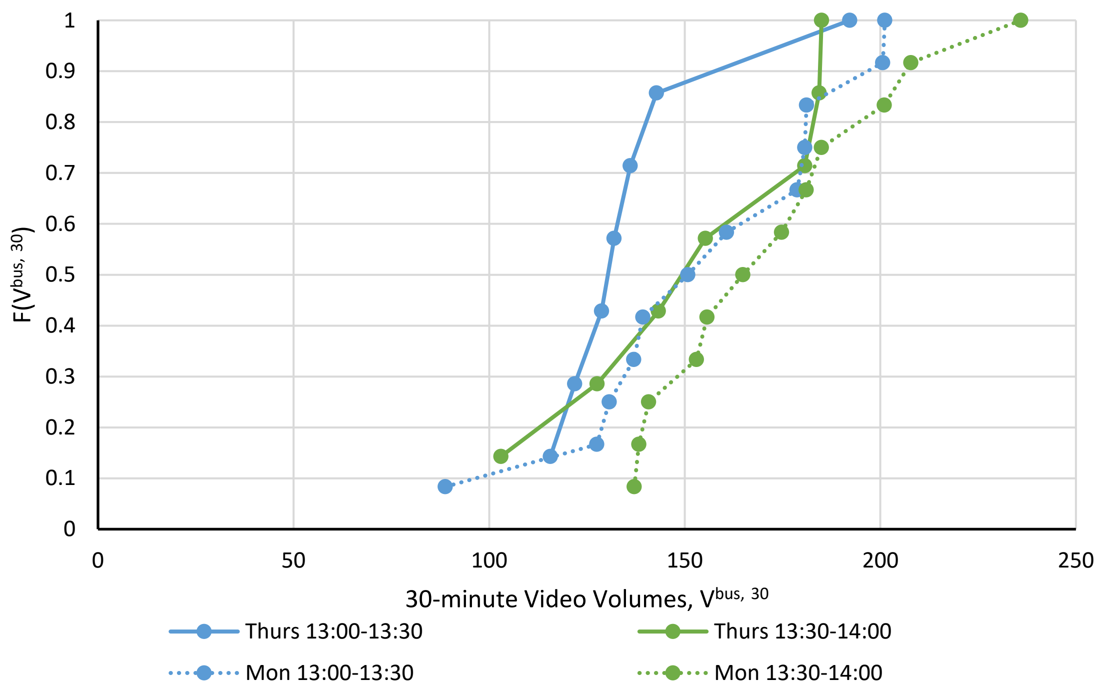

Figure 4.18: Ecdfs of 30-minute Monday and Thursday Volumes from 13:00 to 14:00 for Video Data beginning at 13:00 and 13:30

Table 4.7: Summary Statistics of Monday and Thursday 30-minute Distributions, Video Volumes

Period	Number of Volumes	Day of Week	Median[1]	Mean	Standard Deviation
11:30-12:00	11	Monday	150.73	139.92	34.30
	8	Thursday	117.50	110.46	23.11
12:00-12:30	10	Monday	181.58	182.54	28.37
	6	Thursday	206.34	199.92	15.21
13:00-13:30	12	Monday	155.75	156.43	33.64
	7	Thursday	131.95	138.47	25.32
13:30-14:00	12	Monday	169.82	172.94	30.85
	7	Thursday	155.30	154.18	31.64

[1]Medians calculated with Excel function which takes midpoint between middle numbers when the number of volumes is even. This may differ from $F^{-1}(0.5)$ from the ECDF.

In Figure 4.17 there appears to be a day of week effect for both the 11:30-12:00 and 12:00-12:30 periods. For the 11:30-12:00 period the Monday volumes are much larger than the Thursday volumes. For the 12:00-12:30 period the Thursday volumes are larger than the Monday volumes. The ordering found for each period is also evident in the means and medians Table 4.7.

From Figure 4.18 there appears to be a day of week effect for both the 13:00-13:30 and 13:30-14:00 periods. For both the 13:00-13:30 and 13:30-14:00 periods the Monday volumes are larger than the Thursday volumes. These findings are evident in the means and medians Table 4.7 as Monday has higher mean and median values than Thursday for both periods.

Figures 4.19 and 4.20 present the empirical cumulative distribution functions (ecdfs) of the four 15-minute Monday and Thursday intervals, for each respective hour. Figure 4.19 presents the 15-minute increments during the 11:30-12:30 hour on Mondays ($V_{11:30,1}^{bus,15}$, $V_{11:45,1}^{bus,15}$, $V_{12:00,1}^{bus,15}$, $V_{12:15,1}^{bus,15}$) and Thursdays ($V_{11:30,4}^{bus,15}$, $V_{11:45,4}^{bus,15}$, $V_{12:00,4}^{bus,15}$, $V_{12:15,4}^{bus,15}$). Figure 4.20 presents the 15-minute increments during the 13:00-14:00 hour on Mondays ($V_{13:00,1}^{bus,15}$, $V_{13:15,1}^{bus,15}$, $V_{13:30,1}^{bus,15}$, $V_{13:45,1}^{bus,15}$) and Thursdays ($V_{13:00,1}^{bus,15}$, $V_{13:15,1}^{bus,15}$, $V_{13:30,1}^{bus,15}$, $V_{13:45,1}^{bus,15}$). Summary statistics of the distributions shown in Figures 4.19 and 4.20 are presented in Table 4.8.

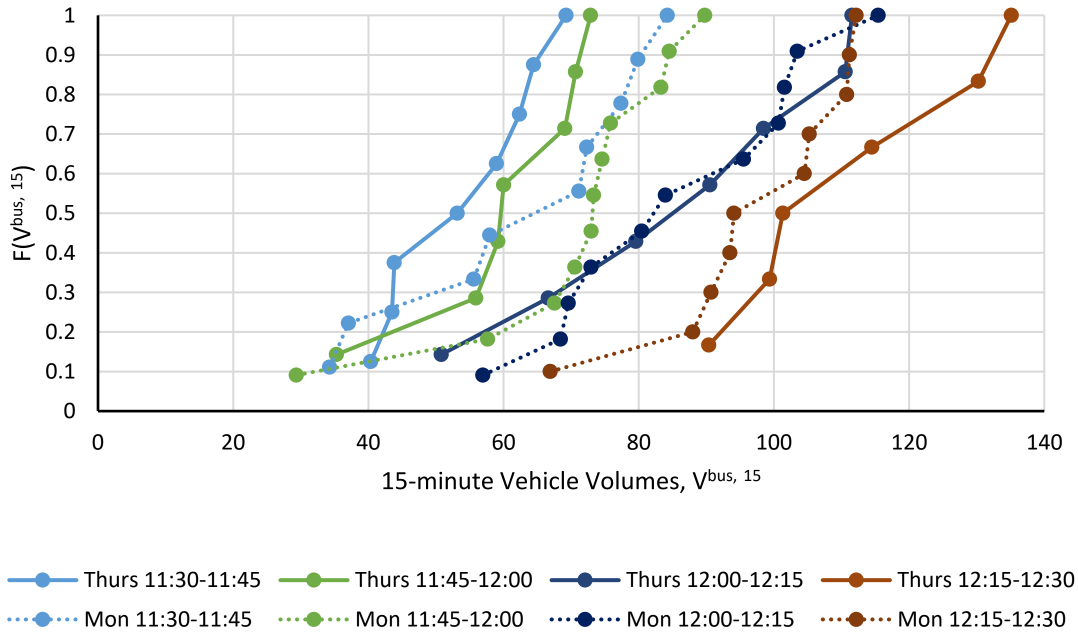

Figure 4.19: Ecdfs of 15-minute Monday and Thursday Volumes from 11:30 to 12:30 for Video Data beginning at 11:30, 11:45, 12:00 and 12:15

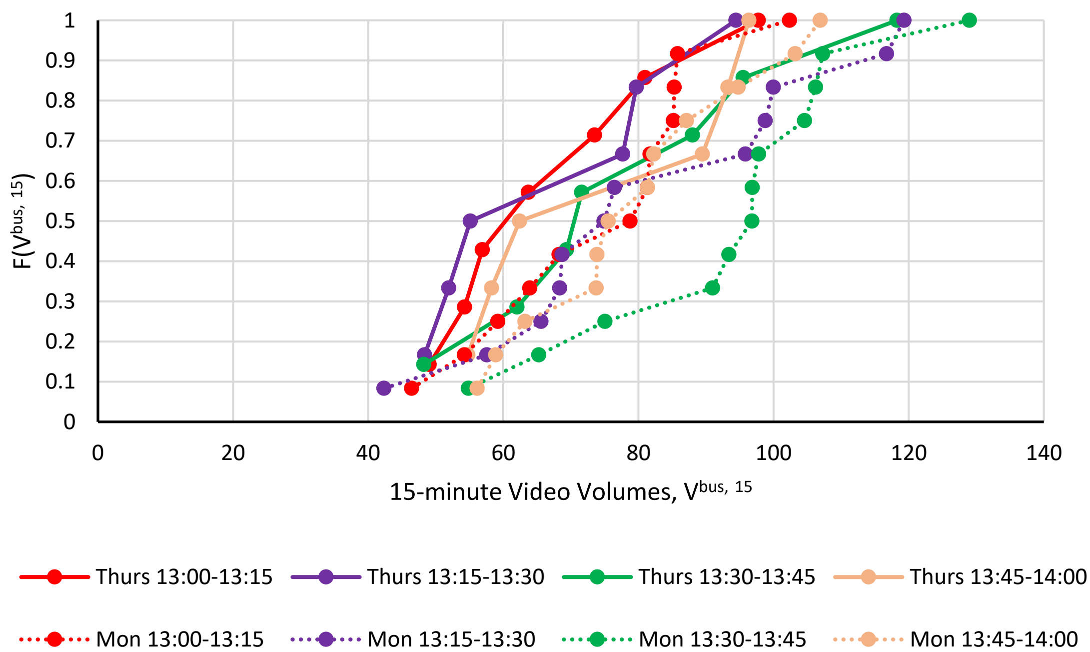

Figure 4.20: Ecdfs of 15-minute Monday and Thursday Volumes from 13:00 to 14:00 for Video Data beginning at 13:00, 13:15, 13:30, and 13:45

Table 4.8: Summary Statistics of Monday and Thursday 15-minute Distributions, Video Volumes

Period	Number of Volumes	Day of Week	Median[1]	Mean	Standard Deviation
11:30-11:45	9	Monday	71.15	63.31	18.28
	8	Thursday	56.06	54.48	10.92
11:45-12:00	11	Monday	73.33	70.86	16.30
	7	Thursday	60.02	60.43	12.84
12:00-12:15	11	Monday	83.95	86.27	18.29
	7	Thursday	90.53	86.87	22.67
12:15-12:30	10	Monday	99.30	97.70	14.09
	6	Thursday	107.91	111.82	17.98
13:00-13:15	12	Monday	78.77	74.38	16.05
	7	Thursday	63.72	68.02	17.19
13:15-13:30	12	Monday	74.91	82.05	23.89
	6	Thursday	66.40	67.87	18.65
13:30-13:45	12	Monday	96.80	93.17	20.03
	7	Thursday	71.61	79.01	23.37
13:45-14:00	12	Monday	75.52	79.76	16.32
	6	Thursday	75.93	75.75	19.20

[1]Medians calculated with Excel function which takes midpoint between middle numbers when the number of volumes is even. This may differ from $F^{-1}(0.5)$ from the ECDF.

From Figure 4.19 there appears to be a day of week effect for the 11:30-11:45, 11:45-12:00, and 12:15-12:30 periods. For the 11:30-11:45 and 11:45-12:00 periods the Monday volumes are larger than the Thursday volumes. For the 12:15-12:30 period the Thursday volumes are larger than the Monday volumes. Figure 4.19 shows no noticeable day of week effect for the 12:00-12:15 period. These findings are consistent with the means and medians Table 4.8.

In Figure 4.20 there appears to be a day of week effect for all four 15-minute periods within the 13:00-14:00 hour. For all four periods –13:00-13:15, 13:15-13:30, 13:30-13:45, and 13:45-14:00– the Monday volumes are found to be larger than the Thursday volumes. These findings are evident in the means and medians of Table 4.8, as Monday has higher mean values than Thursday for all four periods.

As with the manual volumes in Section 3.2, Wednesday and Thursday are compared next in this day of week effect investigation. Figure 4.21 presents the empirical cumulative distribution functions (ecdfs) of the 60-minute intervals for the 9:30-10:30 hour on Wednesdays ($V_{9:30,3}^{bus,60}$) and Thursdays ($V_{9:30,4}^{bus,60}$). Summary statistics of the distributions shown in Figure 4.21 are presented in Table 4.9.

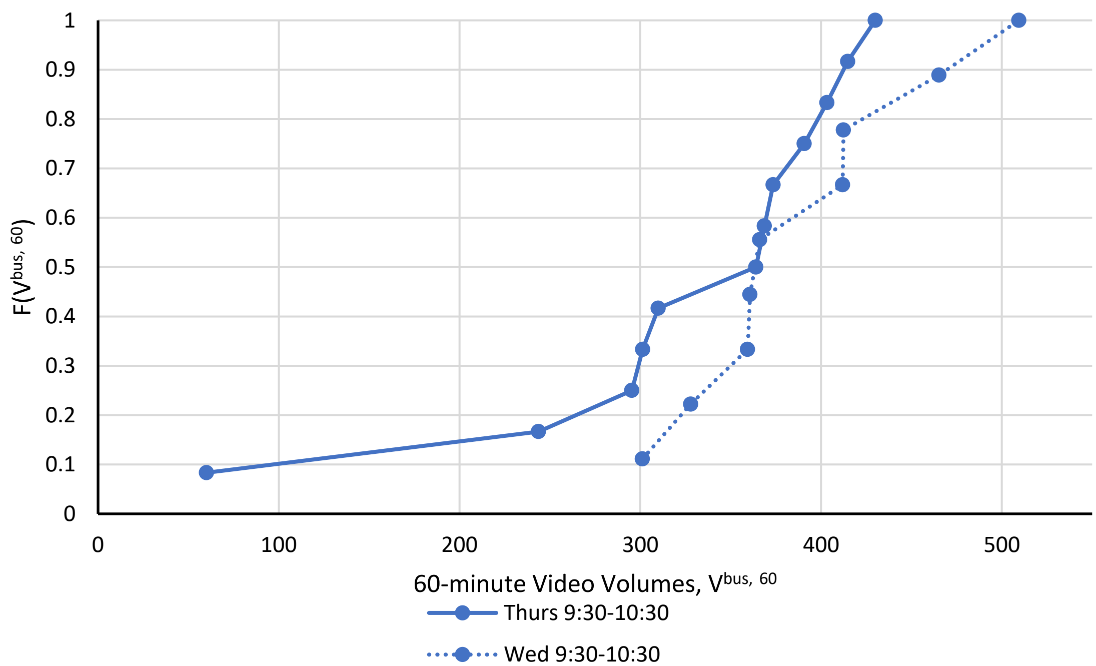

Figure 4.21: Ecdfs of 60-minute Wednesday and Thursday Volumes for Video Data for Hours beginning at 9:30

Table 4.9: Summary Statistics of Wednesday and Thursday 60-minute Distribution, Video Volumes

Period	Number of Volumes	Day of Week	Median[1]	Mean	Standard Deviation
9:30-10:30	9	Wednesday	366.09	390.49	66.17
	12	Thursday	366.35	329.62	101.61

[1]Medians calculated with Excel function which takes midpoint between middle numbers when the number of volumes is even. This may differ from $F^{-1}(0.5)$ from the ECDF.

In Figure 4.21 there appears to be a day of week effect for the 9:30-10:30 hour. The Wednesday hourly volumes are found to be larger than the Thursday hourly volumes. This ordering is also evident in the means of Table 4.9.

Figure 4.22 presents the empirical cumulative distribution functions (ecdfs) of the two 30-minute intervals for the 9:30-10:30 hour on Wednesdays ($V_{9:30,3}^{bus,30}$, $V_{10:00,3}^{bus,30}$) and Thursdays ($V_{9:30,4}^{bus,30}$, $V_{10:00,4}^{bus,30}$). Summary statistics of the distributions shown in Figure 4.22 are presented in Table 4.10.

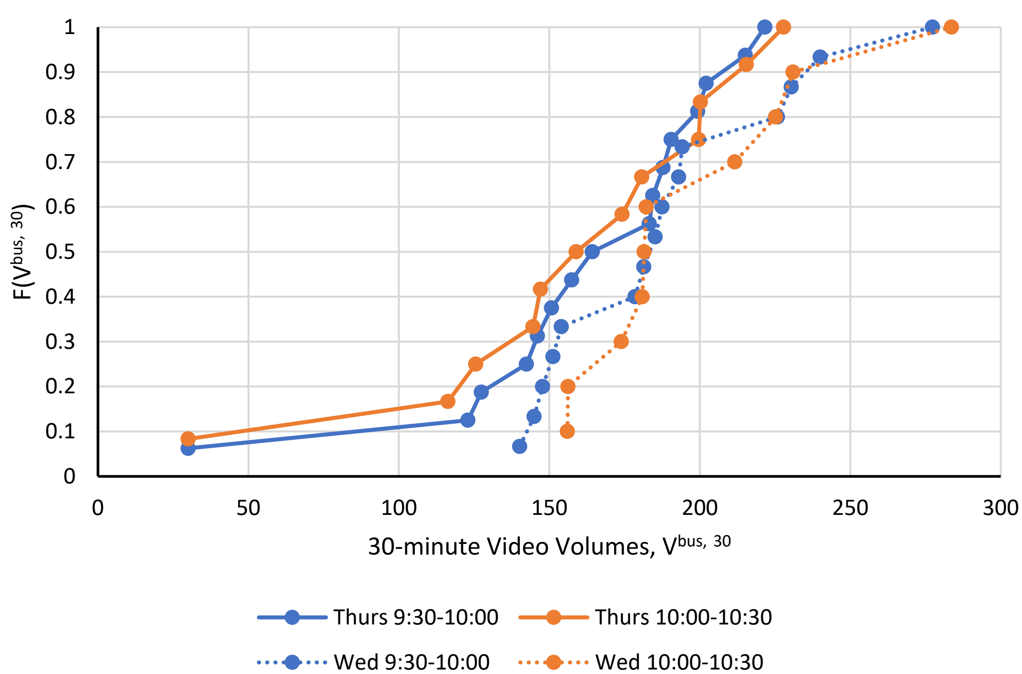

Figure 4.22: Ecdfs of 30-minute Wednesday and Thursday Volumes from 9:30 to 10:30 for Video Data beginning at 9:30 and 10:00

Table 4.10: Summary Statistics of Wednesday and Thursday 30-minute Distributions, Video Volumes

Period	Number of Volumes	Day of Week	Median[1]	Mean	Standard Deviation
9:30-10:00	15	Wednesday	185.19	188.76	39.98
	16	Thursday	173.76	164.09	46.68
10:00-10:30	10	Wednesday	181.86	198.23	39.79
	12	Thursday	166.57	160.05	53.86

[1]Medians calculated with Excel function which takes midpoint between middle numbers when the number of volumes is even. This may differ from $F^{-1}(0.5)$ from the ECDF.

Figure 4.22 shows a slight day of week effect for both 30-minute periods within the 9:30-10:30 hour. For both the 9:30-10:00 and 10:00-10:30 periods the Wednesday volumes are larger than the Thursday volumes. This ordering is also evident in the means and medians of Table 4.10.

Figure 4.23 presents the empirical cumulative distribution functions (ecdfs) of the four 15-minute intervals for the 9:30-10:30 hour on Wednesdays ($V_{9:30,3}^{bus,15}$, $V_{9:45,3}^{bus,15}$, $V_{10:00,3}^{bus,15}$, $V_{10:15,3}^{bus,15}$) and Thursdays ($V_{9:30,4}^{bus,15}$, $V_{9:45,4}^{bus,15}$, $V_{10:00,4}^{bus,15}$, $V_{10:15,4}^{bus,15}$). Summary statistics of the distributions shown in Figure 4.23 are presented in Table 4.11.

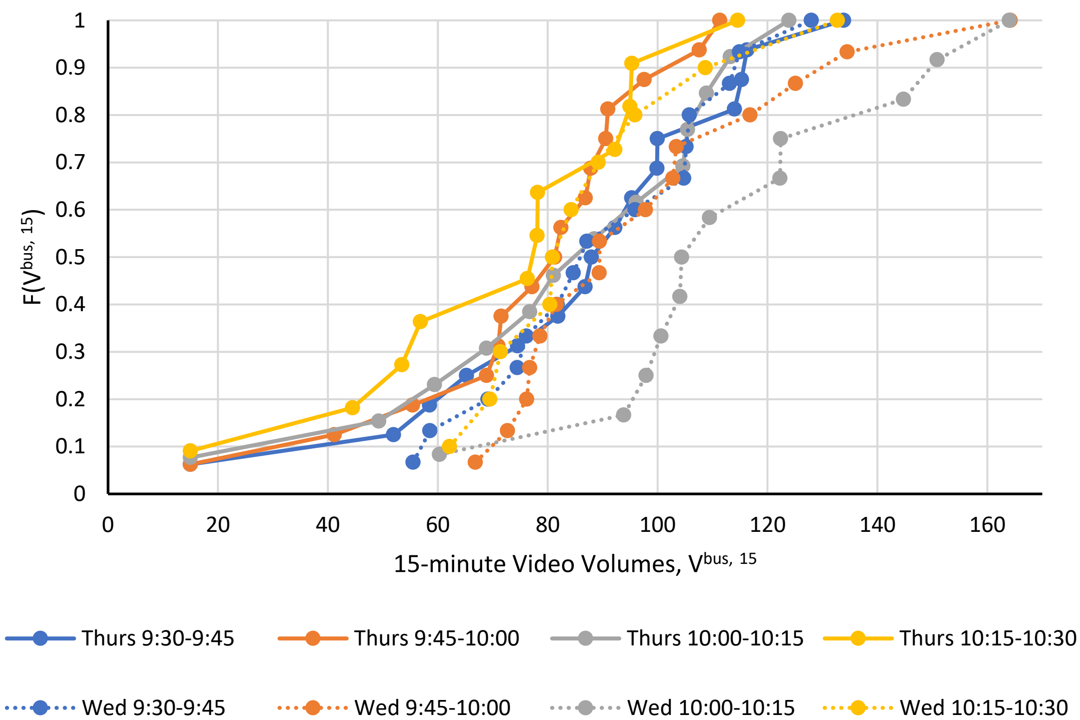

Figure 4.23: Ecdfs of 15-minute Wednesday and Thursday Volumes from 9:30 to 10:30 for Video Data beginning at 9:30, 9:45, 10:00 and 10:15

Table 4.11: Summary Statistics of Wednesday and Thursday 15-minute Distributions, Video Volumes

Period	Number of Volumes	Day of Week	Median[1]	Mean	Standard Deviation
9:30-9:45	15	Wednesday	87.15	90.34	21.51
	16	Thursday	90.11	86.80	29.32
9:45-10:00	15	Wednesday	89.45	98.41	26.97
	16	Thursday	81.85	77.29	24.36
10:00-10:15	12	Wednesday	106.92	114.58	28.41
	13	Thursday	88.47	83.93	30.25
10:15-10:30	10	Wednesday	82.58	87.52	20.81
	11	Thursday	78.09	72.69	28.22

[1]Medians calculated with Excel function which takes midpoint between middle numbers when the number of volumes is even. This may differ from $F^{-1}(0.5)$ from the ECDF.

In Figure 4.23 there appears to be a day of week effect for the 9:45-10:00, 10:00-10:15, and 10:15-10:30 periods. For all three of these periods the Wednesday volumes are found to be larger than the Thursday volumes. There appears to be no noticeable day of week effect for the 9:30-9:45 period. These finding are also evident in the means and medians of Table 4.11.

The correspondence of these numerically based observations to the patterns seen in the manual volumes are presented in Section 4.3.

4.3 Quantitative Comparisons Between Video and Manual Findings

Sections 4.1 and 4.2 investigated time of day and day of week differences in video volumes by looking at ecdfs qualitatively. This section will quantify differences in the means of the video volumes distributions to investigate whether these quantified differences are indicative of the time of day and day of week differences found in the manual volumes, which serve as the true volumes.

The distributions of video volumes in the time of day and day of week periods are compared using the same metrics as those used to compare distributions of manual volumes. Equations 3.1, 3.2, and 3.3, respectively, are repeated here as Equations 4.1, 4.2, and 4.3 for convenience. To compare the volume distributions in two periods the difference in means (D^{mean}),

$$D^{mean}{}_{i,j} = Mean_i - Mean_j \tag{4.1}$$

is calculated for the pair of distributions *i* and *j* considered, where $Mean_i$, and $Mean_j$ are respectively the mean (average) volume of distributions *i* and *j*.

As was done in Section 3.3, in order to compare the differences of means across the 60-, 30-, and 15-minute intervals, the differences are converted to a metric $D^{mean(60)}{}_{i,j}$ where the units are all in terms of vehicles per hour (60 minutes),

$$D^{mean(60)}{}_{i,j} = \frac{60\ min}{interval\ length\ (\text{min})} \times D_{i,j} \tag{4.2}$$

As was also done in Section 3.3, to focus on magnitude of differences, the absolute value of the $D^{mean(60)}{}_{i,j}$ is taken to determine the 60-minute equivalent absolute difference ($AD^{mean(60)}{}_{i,j}$),

$$AD^{mean(60)}{}_{i,j} = |D^{mean(60)}{}_{i,j}| \tag{4.3}$$

To investigate time of day effects, values of these metrics are determined between the same pairs of distributions considered when investigating pairs of manual volume distributions. Table 4.12 presents the D^{mean}, $D^{mean(60)}$, and $AD^{mean(60)}$ values obtained when comparing the different 60-minute intervals on the same days. In the table, $D^{mean(60),vid}$ is used to indicate the $D^{mean(60)}$ value obtained from the video volumes and to distinguish it from the $D^{mean(60)}$ value obtained from the metric value obtained from manual volumes, which were found in Section 3.3. The $D^{mean(60)}$ value obtained from the manual volumes is added to the table for convenience and indicated by $D^{mean(60),man}$. Table 4.13 presents the D^{mean}, $D^{mean(60),vid}$, $AD^{mean(60)}$, and $D^{mean(60), man}$ values for the 30-minute intervals. Table 4.14 presents the D^{mean}, $D^{mean(60),vid}$, $AD^{mean(60)}$, and $D^{mean(60), man}$ values for the 15-minute intervals.

In addition to these metrics, Tables 4.12, 4.13, and 4.14 present a "Same $Sign_{i,j}$" indicator value. This indicator takes on a value 1 when the manual and video $D^{mean(60)}_{i,j}$ values have the same sign for the comparisons, which indicates that the mean of the volume distribution *i* as determined by the video and manual data are either both greater than or less than the means of the volume distributions *j*. The indicator takes on a value of 0 when the ordering (greater than or less than) of the means of volume distributions *i* and *j* are different when using video and manual volumes.

Table 4.12 Metrics for Video Volumes Differences in 60-minute Periods for Time of Day Investigation; n is number of volumes (data points) in corresponding distribution

Day	Period	$Mean_i$ (n_i)	Period	$Mean_j$ (n_j)	$D^{mean}_{i,j}$	$D^{mean(60),vid}_{i,j}$	$AD^{mean(60)}_{i,j}$	$D^{mean(60),man}_{i,j}$	Same $Sign_{i,j}$
Thursday	9:30-10:30	329.62 (12)	11:30-12:30	304.44 (6)	25.18	25.18	25.18	28.86	1
Thursday	9:30-10:30	329.62 (12)	13:00-14:00	297.49 (6)	32.13	32.13	32.13	69.02	1
Thursday	11:30-12:30	304.44 (6)	13:00-14:00	297.49 (6)	6.95	6.95	6.95	40.16	1
Monday	11:30-12:30	321.02 (10)	13:00-14:00	329.38 (12)	-8.36	-8.36	8.36	23.13	0

Table 4.13 Metrics for Video Volumes Differences in 30-minute Periods for Time of Day Investigation; n is number of volumes (data points) in corresponding distribution

Day	$Period_1$	$Mean_i$ (n_i)	Period	$Mean_j$ (n_j)	$D^{mean}_{i,j}$	$D^{mean(60),vid}_{i,j}$	$AD^{mean(60)}_{i,j}$	$D^{mean(60),man}_{i,j}$	Same $Sign_{i,j}$
Thursday	9:30-10:00	164.09 (16)	10:00-10:30	160.05 (12)	4.04	8.08	8.08	14.42	1
Thursday	11:30-12:00	110.46 (8)	12:00-12:30	199.92 (6)	-89.46	-178.92	178.92	-128.18	1
Thursday	13:00-13:30	138.47 (7)	13:30-14:00	154.18 (7)	-15.71	-31.42	31.42	-24.92	1
Monday	11:30-12:00	139.92 (11)	12:00-12:30	182.54 (10)	-42.62	-85.24	85.24	-99.82	1
Monday	13:00-13:30	156.43 (12)	13:30-14:00	172.94 (12)	-16.51	-33.02	33.02	-34.66	1
Wednesday	9:30-10:00	188.76 (15)	10:00-10:30	198.23 (10)	-9.47	-18.94	18.94	-4.08	1

Table 4.14 Metrics for Video Volumes Differences in 15-minute Periods for Time of Day Investigation; n is number of volumes (data points) in corresponding distribution

Day	Period	$Mean_i$ (n_i)	Period	$Mean_j$ (n_j)	$D^{mean}_{i,j}$	$D^{mean(60),vid}_{i,j}$	$AD^{mean(60)}_{i,j}$	$D^{mean(60),man}_{i,j}$	Same $Sign_{i,j}$
Thursday	9:30-9:45	86.8 (16)	9:45-10:00	77.29 (16)	9.51	38.04	38.04	30.88	1
Thursday	9:45-10:00	77.29 (16)	10:00-10:15	83.93 (13)	-6.64	-26.56	26.56	-31.64	1
Thursday	10:00-10:15	83.93 (13)	10:15-10:30	72.69 (11)	11.24	44.96	44.96	67.8	1
Thursday	11:30-11:45	54.48 (8)	11:45-12:00	60.43 (7)	-5.95	-23.8	23.8	-13.96	1
Thursday	11:45-12:00	60.43 (7)	12:00-12:15	86.87 (7)	-26.44	-105.76	105.76	-71.04	1
Thursday	12:00-12:15	86.87 (7)	12:15-12:30	111.82 (6)	-24.95	-99.8	99.8	-113.52	1
Thursday	13:00-13:15	68.02 (7)	13:15-13:30	67.87 (6)	0.15	0.6	0.6	-6.8	0
Thursday	13:15-13:30	67.87 (6)	13:30-13:45	79.01 (7)	-11.14	-44.56	44.56	-4.44	1
Thursday	13:30-13:45	79.01 (7)	13:45-14:00	75.75 (6)	3.26	13.04	13.04	-34.12	0
Monday	11:30-11:45	63.31 (9)	11:45-12:00	70.86 (11)	-7.55	-30.2	30.2	3	0
Monday	11:45-12:00	70.86 (11)	12:00-12:15	86.27 (11)	-15.41	-61.64	61.64	-59.24	1
Monday	12:00-12:15	86.27 (11)	12:15-12:30	97.7 (10)	-11.43	-45.72	45.72	-86.24	1
Monday	13:00-13:15	74.38 (12)	13:15-13:30	82.05 (12)	-7.67	-30.68	30.68	-42.12	1
Monday	13:15-13:30	82.05 (12)	13:30-13:45	93.17 (12)	-11.12	-44.48	44.48	-61.08	1

Continued

Table 4.14 Continued Metrics for Video Volumes Differences in 15-minute Periods for Time of Day Investigation; n is number of volumes (data points) in corresponding distribution

Day	Period	$Mean_i$ (n_i)	Period	$Mean_j$ (n_j)	$D^{mean}_{i,j}$	$D^{mean(60),vid}_{i,j}$	$AD^{mean(60)}_{i,j}$	$D^{mean(60),man}_{i,j}$	Same $Sign_{i,j}$
Monday	13:30-13:45	93.17 (12)	13:45-14:00	79.76 (12)	13.41	53.64	53.64	95	1
Wednesday	9:30-9:45	90.34 (15)	9:45-10:00	98.41 (15)	-8.07	-32.28	32.28	-23.92	1
Wednesday	9:45-10:00	98.41 (15)	10:00-10:15	114.58 (12)	-16.17	-64.68	64.68	-69.44	1
Wednesday	10:00-10:15	114.58 (12)	10:15-10:30	87.52 (10)	27.06	108.24	108.24	154.84	1

There are 28 pairs of time of day periods presented in Tables 4.12, 4.13, and 4.14. Of the 28 pairs, 24 of them have the same sign for their manual and video $D^{mean(60)}$ values (Same Sign = 1). The probability of achieving 24 or more same signs (successes) out of 28 comparisons (trials) is calculated under the null hypothesis that the probability of obtaining the same sign (probability of success) is 0.5 (i.e., no relation between the means of the video and manual volume distributions) using the binomial distribution. This probability (p-value) is found to be 8.9996×10^{-5}. Therefore, the null hypothesis that the probability of obtaining the same sign is equal to 0.5 is rejected at any reasonable significance level in favor of the probability being greater than 0.5. This indicates that if the mean of time of day volume distribution *i* is greater (less) than the mean of time of day volume distribution *j* when the distributions are obtained using the video volumes, it is very likely (much more likely than random chance) that the mean of time of day volume distribution *i* will be greater (less) than the mean of time of day volume distribution *j* in the true (manual) volume distributions. That is, the orderings (greater than or less than) of the means of the video volumes are strongly related to the orderings obtained when using the manual volumes.

To investigate the day of week differences the difference metrics of Equations 4.1, 4.2, and 4.3 are taken between the same pairs of distributions considered in Section 3.3. As when tabulating metrics related to time of day differences above, in Tables 4.15 and 4.16 $D^{mean(60), vid}$ is used to indicate the $D^{mean(60)}$ value obtained from the video volumes and to distinguish it from the $D^{mean(60)}$ value obtained from the manual volumes found in Section 3.3. The $D^{mean(60)}$ values obtained from the manual volumes are added to the table for convenience and indicated by $D^{mean(60),man}$. Table 4.15 presents the D^{mean}, $D^{mean(60),vid}$, $AD^{mean(60)}$, and $D^{mean(60), man}$ values for intervals that occur on Mondays and Thursdays. Table 4.16 presents the D^{mean}, $D^{mean(60),vid}$, $AD^{mean(60)}$, and $D^{mean(60), man}$ values for intervals that occur on Wednesdays and Thursdays.

As in Tables 4.12-4.14, in addition to the difference metrics Tables 4.15, and 4.16 present a "Same $Sign_{i,j}$" indicator value. This indicator takes on a value 1 when the manual and video $D^{mean(60)}_{i,j}$ values have the same sign, which indicates that the means of the volume distributions *i* as determined by the video and manual data are either both greater than or less than the means of the volume distributions *j*. The indicator takes on a value of 0 when the ordering (greater than or less than) of the means of volume distributions *i* and *j* are different when using video and manual volumes.

Table 4.15 Metrics for Video Volumes Differences in Monday and Thursday Periods for Day of Week Investigation; n is number of volumes (data points) in corresponding distribution

Period	Day_1	$Mean_i$ (n_i)	Day_2	$Mean_j$ (n_j)	$D^{mean}_{i,j}$	$D^{mean(60),vid}_{i,j}$	$AD^{mean(60)}_{i,j}$	$D^{mean(60),man}_{i,j}$	Same $Sign_{i,j}$
11:30-12:30	Monday	321.02 (10)	Thursday	304.44 (6)	16.58	16.58	16.58	2.39	1
13:00-14:00	Monday	329.38 (12)	Thursday	297.49 (6)	31.89	31.89	31.89	19.42	1
11:30-12:00	Monday	139.92 (11)	Thursday	110.46 (8)	29.46	29.46	29.46	18.26	1
12:00-12:30	Monday	182.54 (10)	Thursday	199.92 (6)	-17.38	-34.76	34.76	-10.1	1
13:00-13:30	Monday	156.43 (12)	Thursday	138.47 (7)	17.96	35.92	35.92	9.3	1
13:30-14:00	Monday	172.94 (12)	Thursday	154.18 (7)	18.76	37.52	37.52	19.04	1
11:30-11:45	Monday	63.31 (9)	Thursday	54.48 (8)	8.83	35.32	35.32	35.24	1
11:45-12:00	Monday	70.86 (11)	Thursday	60.43 (7)	10.43	41.72	41.72	18.28	1
12:00-12:15	Monday	86.27 (11)	Thursday	86.87 (7)	-0.6	-2.4	2.4	6.48	0
12:15-12:30	Monday	97.7 (10)	Thursday	111.82 (6)	-14.12	-56.48	56.48	-20.8	1
13:00-13:15	Monday	74.38 (12)	Thursday	68.02 (7)	6.36	25.44	25.44	-8.36	0
13:15-13:30	Monday	82.05 (12)	Thursday	67.87 (6)	14.18	56.72	56.72	26.96	1
13:30-13:45	Monday	93.17 (12)	Thursday	79.01 (7)	14.16	56.64	56.64	83.6	1
13:45-14:00	Monday	79.76 (12)	Thursday	75.75 (6)	4.01	16.04	16.04	-45.52	0

Table 4.16 Metrics for Video Volumes Differences in Wednesday and Thursday Periods for Day of Week Investigation; n is number of volumes (data points) in corresponding distribution

Period	Day_1	$Mean_i$ (n_i)	Day_2	$Mean_j$ (n_j)	$D^{mean}_{i,j}$	$D^{mean(60),vid}_{i,j}$	$AD^{mean(60)}_{i,j}$	$D^{mean(60),man}_{i,j}$	Same $Sign_{i,j}$
9:30-10:30	Wednesday	390.49 (9)	Thursday	329.62 (12)	60.87	60.87	60.87	60.1	1
9:30-10:00	Wednesday	188.76 (15)	Thursday	164.09 (16)	24.67	49.34	49.34	49.6	1
10:00-10:30	Wednesday	198.23 (10)	Thursday	160.05 (12)	38.18	76.36	76.36	68.1	1
9:30-9:45	Wednesday	90.34 (15)	Thursday	86.8 (16)	3.54	14.16	14.16	22.2	1
9:45-10:00	Wednesday	98.41 (15)	Thursday	77.29 (16)	21.12	84.48	84.48	77	1
10:00-10:15	Wednesday	114.58 (12)	Thursday	83.93 (13)	30.65	122.6	122.6	114.8	1
10:15-10:30	Wednesday	87.52 (10)	Thursday	72.69 (11)	14.83	59.32	59.32	27.76	1

There are 21 pairs of day of week periods presented in Tables 4.15, and 4.16. Of the 21 pairs, 18 of them have the same sign for their manual and video $D^{mean(60)}$ values (Same Sign = 1). Similar to what was done for the time of day investigation, the probability of achieving 18 or more same signs (successes) out of 21 comparisons (trials) is calculated under the null hypothesis that the probability of obtaining the same sign (probability of success) is 0.5 (i.e., no relation between the means of the video and manual volume distributions) using the binomial distribution. This probability (p-value) is found to be 0.00074482. Therefore, the null hypothesis that the probability of obtaining the same sign is equal to 0.5 is rejected at any reasonable significance level in favor of the probability being greater than 0.5. This indicates that if the mean of day of week volume distribution *i* is greater (less) than the mean of day of week volume distribution *j* when the distributions are obtained using the video volumes, it is very likely (much more likely than random chance) that the mean of day of week volume distribution *i* will be greater (less) than the mean of day of week volume distribution *j* in the true (manual) volume distributions. That is, the orderings (greater than or less than) of the means of the video volumes are strongly related to the orderings obtained when using the manual volumes.

Above, it is found that the ordering of the means of two time of day or day of week volume distribution obtained when using the video volumes is very indicative of the ordering of the means of the same time of day or day of week distributions obtained when considering the true (manual) volumes. To further investigate whether the differences in means of time of day and day of week volume distributions obtained when using the video volumes are representative of the differences in mean volumes obtained when using the true volume distributions, the

$D^{mean(60), man}_{i,j}$ values from Tables 4.12 through 4.16 are pooled and regressed against the corresponding $D^{mean(60), vid}_{i,j}$ values. Specifically, the following specification is considered:

$$D_{i,j}^{mean(60),man} = \beta_0 + \beta_1 D_{i,j}^{mean(60),vid} \tag{4.4}$$

The results of the regression using the specification in Equation (4.4) are presented in Table 4.17. A specification with $D^{mean(60), man}_{i,j}$ as the independent variable and $D^{mean(60), vid}_{i,j}$ as the dependent variable could have also been used. The estimated magnitudes of the β_0 and β_1 would be different, but the sign and significance level of β_1 would be the same. The goal of this regression is to investigate if the differences $D^{mean(60), man}_{i,j}$ and $D^{mean(60), vid}_{i,j}$ are positively related (positive β_1) which can be investigated with the specification in Equation (4.4).

Table 4.17 Estimated regression model results for specification from Equation (4.4)

Explanatory Variable	Estimated Coefficient	Std. err.	*t*-stat	*p*-value
Constant	1.659617	3.615917	0.458976	0.648367
$D^{mean(60),vid}$	0.907674	0.063561	14.280455	1.0265E-18
	# of observations = 49; R-squared = 0.808717			

From Table 4.17, the positive (β_1= 0.907674) and highly significant (p-value = 1.0265×10^{-18}) estimated coefficient of $D^{mean(60), vid}_{i,j}$ indicates that the differences obtained when using the video and manual volumes are positively and highly significantly related. That is, as the difference in means of the video volume distribution increases, the differences in means of the corresponding true (manual) volume distributions also increases. If the $D^{mean(60), man}_{i,j}$ and $D^{mean(60), vid}_{i,j}$ were exactly equal to each other, the values of β_0 and β_1 should be 0 and 1, respectively. As seen in Table 4.17 the high p-value (0.648367) of the estimated value of the constant (β_0) would not allow rejecting the null hypothesis that the true value is equal to zero at reasonable significance levels. Moreover, the estimated magnitude of the constant (1.659617) implies that a difference in the means of video volumes of 0 would be associated with a difference in the means of the true volumes of 1.659617 vehicles per hour, which is a very small discrepancy. The estimated coefficient of β_1 is 0.907674, which may be considered to be close to 1. One could conduct a hypothesis test on whether this value is significantly different from 1, but the object of this regression is to show that $D^{mean(60), man}_{i,j}$ and $D^{mean(60), vid}_{i,j}$ values are strongly and positively related and not that one value can predict the other exactly.

The absolute value of the difference in means in units of vehicles per hour represents the magnitude of the error between the differences in means of the distribution obtained when using the video volumes and the differences in means of the distributions when using the true (manual) volumes. To investigate if this error depends on the magnitude of difference in video volumes, on whether the $D^{mean(60)}$ values were obtained for a time of day or day of week comparison, and on whether $D^{mean(60)}$ values were obtained using a 15-, 30-, or 60-minute period, a regression model using the specification in Equation (4.5) is estimated:

$$ABS({D_{i,j}}^{mean(60),man} - {D_{i,j}}^{mean(60),vid}) = \beta_0 + \beta_1 ABS({D_{i,j}}^{mean(60),vid}) + \beta_2 {i_{i,j}}^{DOW} + \beta_3 {i_{i,j}}^{15\,min} + \beta_4 {i_{i,j}}^{30\,min} \quad (4.5)$$

where ABS() represents the absolute value of the difference, the $D^{mean(60)}_{i,j}$ variables are defined as above, i^{DOW} is a binary variable equal 1 one if the difference in means is a day of week comparison and 0 if it is a time of day comparison; $i^{15\ min}$ is a binary variable equal 1 one if the difference in means is for a 15-minute period and 0 if not; and $i^{30\ min}$ is a binary variable equal 1 one if the difference in means is for a 30-minute period and 0 if not. Comparisons made between 60-min periods are represented when $i^{15\ min} = i^{30\ min} = 0$. The results of the regression using the specification in Equation (4.5) are presented in Table 4.18.

Table 4.18 Estimated regression model results for specification from Equation (4.5)

Explanatory Variable	Estimated Coefficient	Std. err.	*t*-stat	*p*-value
Constant	17.565428	6.506502	2.699673	0.009812
$ABS(D^{mean(60),vid})$	0.084907	0.068337	1.242468	0.220645
i^{DOW}	-1.902568	4.549495	-0.418193	0.677840
$i^{15\ min}$	1.397388	6.759536	0.206728	0.837176
$i^{30\ min}$	-5.648797	7.676990	-0.735809	0.465752
	# of observations = 49; R-squared = 0.072908			

The coefficients of all the variables presented in Table 4.18 have very high p-values, indicating that they are not significantly different from zero at any significance level less than 0.2. Therefore, the absolute difference between the manual and video $D^{mean(60)}$ values does not appear to depend on the magnitude of the $D^{mean(60),vid}$, whether the comparison is made for the day of week or time of day, or whether the interval for which the comparison was made is a 15-, 30-, or 60-minute interval.

In summary, these regressions indicate that the difference in means of two distributions used for a time of day or day of week comparison obtained when using video volumes is strongly and positively related to the differences for the same time of day or day of week comparison obtained when using the true (manual) volumes. In addition, the magnitude of the difference between the differences in means obtained with the video and true (manual) volume do not appear to depend on the value of the difference, whether the $D^{mean(60)}$ values were obtained for a time of day or day of week comparison, or whether $D^{mean(60)}$ values were obtained using a 15-, 30-, or 60-minute period.

Similar to what was done in Section 3.3, indicator values of 2, 1, 0, representing, large, slight, and small difference in means of the distribution are determined for each comparison based on the $AD^{mean(60)}$ values. Figure 4.24 presents the ecdf of all the $AD^{mean(60)}$ values found in Tables 4.12 through 4.14. The ecdf was calculated manually where the y-axis represents the cumulative probability of the absolute difference indicated on the x-axis. The cumulative probability of x is computed as $k(x)/n$ where n is the number of observations in the data set, and $k(x)$ is the number of observations in the data set that are less than or equal to x. Looking at Figure 4.24, there again appears to be three sets of points, leading to three ranges of volume values. The first range is from 0-20 vehicles per hour, the second range is from 20-40 vehicles per hour, and the third range is greater than 40 vehicles per hour. Specifically, for the time of day investigation the indicator, $Ind_{i,j}^{vid}$, value is specified as:

$$Ind_{i,j}^{vid} = \begin{cases} 0, & \text{if } 0 \leq AD^{mean(60)}_{i,j} < 20 \\ 1, & \text{if } 20 \leq AD^{mean(60)}_{i,j} < 40 \\ 2, & \text{if } 40 \leq AD^{mean(60)}_{i,j} \end{cases} \qquad (4.7)$$

where the superscript vid is added to differentiate from the indicator value determined previously in Section 3.3 when using the manual volumes. Table 4.19 presents the indicator, $Ind_{i,j}^{vid}$, values for all of the time of day comparisons in the second to last column. For convenience Table 4.19 also presents the "Same $Sign_{i,j}$" indicator, and $D^{mean(60)}{}_{i,j}^{vid}$ that were previously introduced above in Tables 4.12, 4.13, and 4.14. In addition, for convenience as done above, Table 4.19 presents the $D^{mean(60)}$ and $Ind_{i,j}$ values obtained from the manual volumes in Section 3.3 as indicated by $D^{mean(60)}{}_{i,j}^{man}$, and the $Ind_{i,j}^{man}$ respectively.

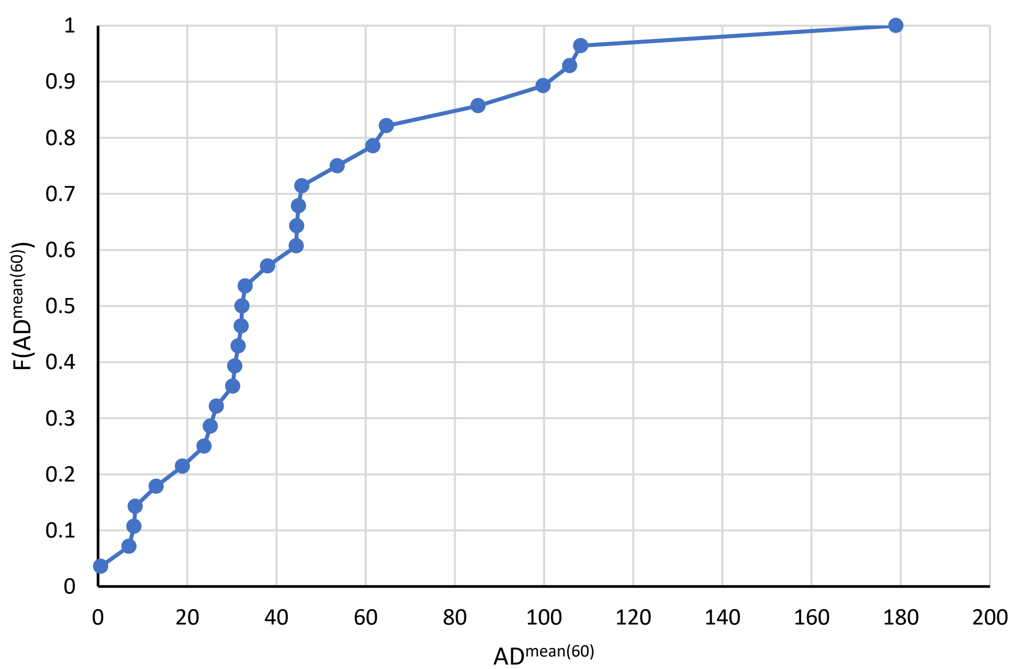

Figure 4.24: Ecdf of 60-minute Equivalent Absolute Difference, $AD^{mean(60)}$, Values for Time of Day Investigation, Video Volumes

Table 4.19 Indicator Values for Manual and Video Time of Day Differences

Day	Period	Period	$D^{mean(60),vid}_{i,j}$	$D^{mean(60),man}_{i,j}$	Same $Sign_{i,j}$	$Ind^{vid}_{i,j}$	$Ind^{man}_{i,j}$
Thursday	9:30-10:30	11:30-12:30	25.18	28.86	1	1	1
Thursday	9:30-10:30	13:00-14:00	32.13	69.02	1	1	2
Thursday	11:30-12:30	13:00-14:00	6.95	40.16	1	0	1
Monday	11:30-12:30	13:00-14:00	-8.36	23.13	0	0	1
Thursday	9:30-10:00	10:00-10:30	8.08	14.42	1	0	0
Thursday	11:30-12:00	12:00-12:30	-178.92	-128.18	1	2	2
Thursday	13:00-13:30	13:30-14:00	-31.42	-24.92	1	1	1
Monday	11:30-12:00	12:00-12:30	-85.24	-99.82	1	2	2
Monday	13:00-13:30	13:30-14:00	-33.02	-34.66	1	1	1
Wednesday	9:30-10:00	10:00-10:30	-18.94	-4.08	1	0	0
Thursday	9:30-9:45	9:45-10:00	38.04	30.88	1	1	1
Thursday	9:45-10:00	10:00-10:15	-26.56	-31.64	1	1	1
Thursday	10:00-10:15	10:15-10:30	44.96	67.8	1	2	2
Thursday	11:30-11:45	11:45-12:00	-23.8	-13.96	1	1	0
Thursday	11:45-12:00	12:00-12:15	-105.76	-71.04	1	2	2
Thursday	12:00-12:15	12:15-12:30	-99.8	-113.52	1	2	2
Thursday	13:00-13:15	13:15-13:30	0.6	-6.8	0	0	0
Thursday	13:15-13:30	13:30-13:45	-44.56	-4.44	1	2	0
Thursday	13:30-13:45	13:45-14:00	13.04	-34.12	0	0	1
Monday	11:30-11:45	11:45-12:00	-30.2	3	0	1	0
Monday	11:45-12:00	12:00-12:15	-61.64	-59.24	1	2	2
Monday	12:00-12:15	12:15-12:30	-45.72	-86.24	1	2	2
Monday	13:00-13:15	13:15-13:30	-30.68	-42.12	1	1	1
Monday	13:15-13:30	13:30-13:45	-44.48	-61.08	1	2	2
Monday	13:30-13:45	13:45-14:00	53.64	95	1	2	2
Wednesday	9:30-9:45	9:45-10:00	-32.28	-23.92	1	1	1
Wednesday	9:45-10:00	10:00-10:15	-64.68	-69.44	1	2	2
Wednesday	10:00-10:15	10:15-10:30	108.24	154.84	1	2	2

Table 4.20 presents the number of times each combination of manual and video indicator values results during the time of day investigation. For example, the value of 3 in cell (0,0) indicates that indicator values for three time of day comparisons were 0 when determined from the manual volumes and 0 when determined from the video volumes. Similarly, the 2 in cell (0,1) indicates that the indicator values for two time of day comparisons were 0 when determined from the manual volumes and 1 when determined from the video volumes. In addition, in parentheses, Table 4.20 presents the number of times each combination of manual and video $D^{mean(60)}$ values have the same sign (the means of the volume distributions i as determined by the video and manual data are either both greater than or less than the means of the volume distributions j). For example, the entry 3(2) in cell (0,0) indicates that of the three time of day comparisons that have a manual indicator of 0 and video indicator of 0, two of them have the same sign for their manual and video $D^{mean(60)}$ value. (This implies that one of the comparisons resulting in indicator pair (0,0) had different signs). Similarly, the entry 2(1) in cell (0,1) indicates that of the two time of day comparisons that have a manual indicator of 0 and video indicator of 1, one of them has the same sign for their manual and video $D^{mean(60)}$ value.

Table 4.20: Video versus Manual Indicator Results for Time of Day Investigation; Numbers in parentheses represent the number of times each combination of manual and video $D^{mean(60)}$ values have the same sign

Manual Indicator	Video Indicator			Total
	0	1	2	
0	3 (2)	2 (1)	1 (1)	6
1	3 (1)	7 (7)	0 (0)	10
2	0 (0)	1 (1)	11 (11)	12
Total	6	10	12	28

Entries on the diagonal of Table 4.20 represent when there was a large, slight, or little time of day effect that was the same when determined by both the video and manual volumes. Entries off the diagonal represent that the strength of the indicated effect was different, depending on whether the means of the volume distributions were determined using the video or manual (true) volumes. Of the 28 combinations represented in Table 4.20, 21 have the same indicator value for both manual and video volumes. However, one of the 21 combinations represented on the diagonal has a different sign in the difference of means depending on whether the means were determined using video or manual (true) volumes. Specifically, comparison between 13:00-13:15 and 13:15-13:30 on Thursday (see Table 4.19) indicated that the mean of 13:15-13:30 was greater than the mean of 13:00-13:15 when using manual volumes and less than the means of 13:00-13:15 when using video volumes. Even though the indicator values of 0 indicate no time of day effect whether determined by video or manual volumes, it is conservatively considered that 20 of the 28 combinations were "successful" in having the same indicator whether based on video or manual volumes.

If combinations were assigned randomly to cells in the table, there would be a probability of 3 cells/9 cells = 1/3 that a combination would be entered into a diagonal cell. The probability of achieving 20 or more paired indicator values entered on a diagonal (successes) out of 28 pairs of indicators (trials) is calculated under the null hypothesis that the probability of obtaining paired indicator values entered on a diagonal (probability of success) is 1/3 (i.e., no relation between the true (manual) and video volume distribution indicators) using the binomial distribution. This probability (p-value) is found to be 7.8319×10^{-6}. Therefore, the null hypothesis that the probability of obtaining paired indicator values entered into a diagonal cell is equal to 1/3 is rejected at any reasonable significance level in favor that the probability should be greater than 1/3. This indicates that the indicator values of the video volume distributions for the time of day comparisons are much more consistent with the indicator values of the true volume distributions then would be expected by chance.

A similar analysis is applied to investigate day of week comparisons. As was done in Section 3.3, indicator values of 2, 1, 0, representing, large, slight, and small difference in means of the distributions are determined for each comparison based on the $AD^{mean(60)}$ values. Figure 4.25 presents the ecdf of all the $AD^{mean(60)}$ values found in Tables 4.15 and 4.16. This ecdf was calculated manually using the previously described method. Looking at the ecdf in Figure 4.25 there again appears to be three sets of points, leading to three ranges of volume values. The first range is from 0-20 vehicles per hour, the second range is from 20-50 vehicles per hour, and the third range is greater than 50 vehicles per hour. Specifically, for the day of week investigation the indicator, $Ind_{i,j}^{vid}$, is specified as:

$$Ind_{i,j}^{vid} = \begin{cases} 0, \text{ if } 0 \le AD^{mean(60)}_{i,j} \le 20 \\ 1, \text{ if } 20 \le AD^{mean(60)}_{i,j} < 50 \\ 2, \text{ if } 50 \le AD^{mean(60)}_{i,j} \end{cases} \qquad (4.8)$$

where the superscript vid is added to differentiate from the indicator value determined previously in Section 3.3 when using the manual volumes. Table 4.21 presents the indicator, $Ind_{i,j}^{vid}$, values for all of the day of week comparisons in the second to last column. For convenience Table 4.21 also presents the "Same $Sign_{i,j}$" indicator and $D^{mean(60)}{}_{i,j}^{vid}$ values that were previously introduced above in Tables 4.15 and 4.16. In addition, for convenience as done above, Table 4.21 presents the $D^{mean(60)}$ and $Ind_{i,j}$ values obtained from the manual volumes in Section 3.3 as indicated by $D^{mean(60)}{}_{i,j}{}^{man}$, and the $Ind_{i,j}{}^{man}$ respectively.

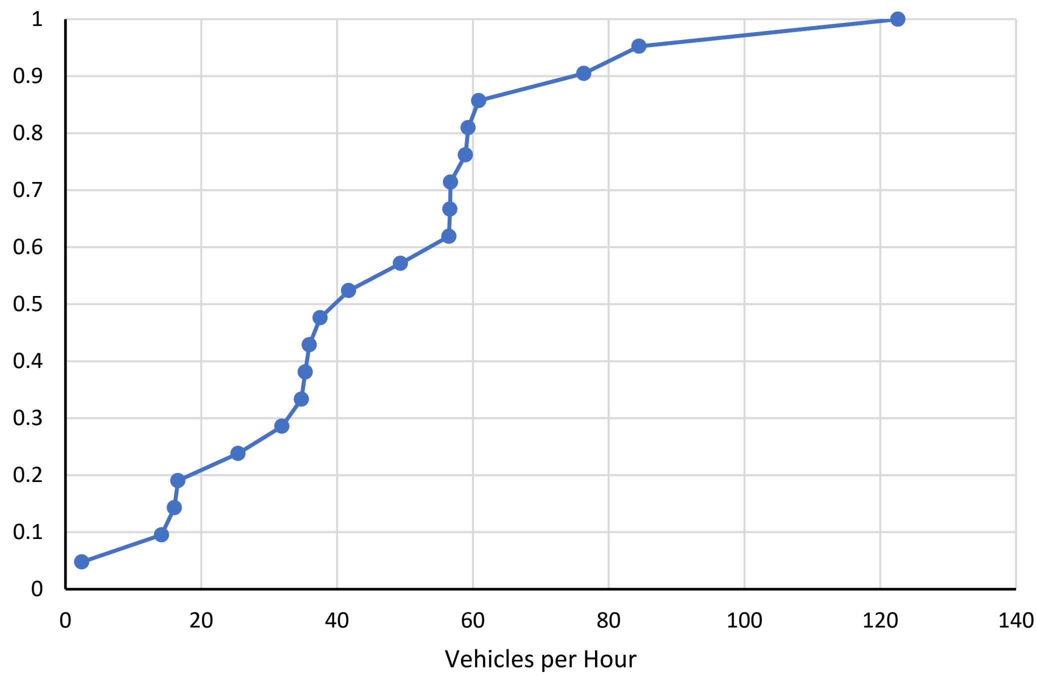

Figure 4.25: Ecdf of 60-minute Equivalent Absolute Difference, $AD^{mean(60)}$, for Day of Week Investigation, Video Volumes

Table 4.21 Indicator Values for Manual and Video Day of Week Differences

Period	Day_1	Day_2	$D^{mean(60),vid}_{i,j}$	$D^{mean(60),man}_{i,j}$	Same $Sign_{i,j}$	$Ind^{vid}_{i,j}$	$Ind^{man}_{i,j}$
11:30-12:30	Monday	Thursday	16.58	2.39	1	0	0
13:00-14:00	Monday	Thursday	31.89	19.42	1	1	1
11:30-12:00	Monday	Thursday	29.46	18.26	1	1	1
12:00-12:30	Monday	Thursday	-34.76	-10.1	1	1	0
13:00-13:30	Monday	Thursday	35.92	9.3	1	1	0
13:30-14:00	Monday	Thursday	37.52	19.04	1	1	1
11:30-11:45	Monday	Thursday	35.32	35.24	1	1	2
11:45-12:00	Monday	Thursday	41.72	18.28	1	1	1
12:00-12:15	Monday	Thursday	-2.4	6.48	0	0	0
12:15-12:30	Monday	Thursday	-56.48	-20.8	1	2	1
13:00-13:15	Monday	Thursday	25.44	-8.36	0	1	0
13:15-13:30	Monday	Thursday	56.72	26.96	1	2	1
13:30-13:45	Monday	Thursday	56.64	83.6	1	2	2
13:45-14:00	Monday	Thursday	16.04	-45.52	0	0	2
9:30-10:30	Wednesday	Thursday	60.87	60.1	1	2	2
9:30-10:00	Wednesday	Thursday	49.34	49.6	1	1	2
10:00-10:30	Wednesday	Thursday	76.36	68.1	1	2	2
9:30-9:45	Wednesday	Thursday	14.16	22.2	1	0	1
9:45-10:00	Wednesday	Thursday	84.48	77	1	2	2
10:00-10:15	Wednesday	Thursday	122.6	114.8	1	2	2
10:15-10:30	Wednesday	Thursday	59.32	27.76	1	2	1

Table 4.22 presents the number of times each combination of manual and video indicator values results during the day of week investigation. For example, the value of 2 in cell (0,0) indicates that indicator values for two time of day comparisons were 0 when determined from the manual volumes and 0 when determined from the video volumes. Similarly, the 3 in cell (0,1)

indicates that the indicator values for three day of week comparisons were 0 when determined from the manual volumes and 1 when determined from the video volumes. In addition, in parentheses, Table 4.22 presents the number of times each combination of manual and video $D^{mean(60)}$ values have the same sign (the means of the volume distributions *i* as determined by the video and manual data are either both greater than or less than the means of the volume distributions *j*). For example, the entry 2(1) in cell (0,0) indicates that of the two day of week comparisons that have a manual indicator of 0 and video indicator of 0, one of them has the same sign for their manual and video $D^{mean(60)}$ value. (This implies that one of the comparisons resulting in indicator pair (0,0) had different signs). Similarly, the entry 3(2) in cell (0,1) indicates that of the three day of week comparisons that have a manual indicator of 0 and video indicator of 1, two of them have the same sign for their manual and video $D^{mean(60)}$ value.

Table 4.22: Video versus Manual Indicator Results for Day of Week Investigation; Numbers in parentheses represent the number of times each combination of manual and video $D^{mean(60)}$ values have the same sign

Manual Indicator	Video Indicator			Total
	0	1	2	
0	2 (1)	3 (2)	0 (0)	5
1	1 (1)	4 (4)	3 (3)	8
2	1 (0)	2 (2)	5 (5)	8
Total	4	9	8	21

Similar to the time of day results, entries on the diagonal of Table 4.22 represent when there was a large, slight, or little day of week effect that was the same when determined by both the video and manual volumes. Entries off the diagonal represent that the strength of the indicated effect was different, depending on whether the means of the volume distributions were determined using the video or manual (true) volumes. Of the 21 combinations represented in Table 4.22, 11 have the same indicator value for both manual and video volumes. However, one of the 11 combinations represented on the diagonal has a different sign in the difference of means depending on whether the means were determined using video or manual (true) volumes. Specifically, comparison between Monday and Thursday from 12:00-12:15 (see Table 4.19) indicated that the mean on Monday was greater than the mean on Thursday when using manual volumes and less than the means on Thursday when using video volumes. Even though the indicator values of 0 indicate no day of week effect whether determined by video or manual volumes, it is conservatively considered that 10 of the 21 combinations were "successful" in having the same indicator whether based on video or manual volumes.

As mentioned previously if combinations were assigned randomly to cells in the table, there would be a probability of 3 cells/9 cells = 1/3 that a combination would be entered into a diagonal cell. The probability of achieving 10 or more paired indicator values entered on a diagonal (successes) out of 21 pairs of indictors (trials) is calculated under the null hypothesis that the probability of obtaining the same sign (probability of success) is 1/3 (i.e., no relation between the true (manual) and video volume distribution indicators) using the binomial distribution. This probability (p-value) is found to be 0.055722972. Therefore, the null hypothesis that the probability of obtaining paired indicator values entered into a diagonal cell is equal to 1/3 is small and would be rejected at an $\alpha = 0.10$ level in favor that the probability should be greater than 1/3. This indicates that the indicator values of the video volume distributions for the day of week comparisons are much more consistent with the indicator values of the true volume distributions then would be expected by chance.

In summary, based upon the same sign indicator (assigned value of 1 indicates that the mean of the volume distribution *i* as determined by the video and manual data are either both greater than or less than the means of the volume distributions *j*, and 0 when the ordering (greater than or less than) of the means of volume distributions *i* and *j* is different when using video and manual volumes) the ordering obtained with the video volumes are seen to be strongly and positively related to the orderings obtained with the manual volumes. In addition, regression results show that the differences in the manual volumes are strongly and positively related to the differences in the video volumes taken for the same time of day or day of week comparison. Lastly, indicator values were assigned to depict whether the difference between the mean volumes in different time of day or day of week periods in the video data is large, slight or small. These video indicator values were compared to the independently assigned manual indicator values for the same time of day or day of week comparison. The indicator values from the video and true (manual) data for the same time of day or day of week comparisons are again seen to be strongly and positively related. In conclusion, it appears that the video volumes are capturing the time of day and day of week effects found in the true (manual) volumes to a large extent.

Chapter 5: Summary, Further Studies, and Conclusions

Traffic volumes, which are defined as the number of vehicles that pass a fixed location during a specified time interval, are used as inputs for a variety of transportation planning, operations, and monitoring purposes. Traffic volumes vary by time of day, day of week, and other time dimensions. Understanding time of day and day of week effects can be important for analysis, explaining why traffic monitoring sections frequently establish time of day and day of week factors.

Multiple types of stationary sensors are able to collect very good traffic data that are used to estimate volumes for extended periods of time at specific segments. However, the data can only be collected at a limited number of locations with these stationary sensors. Transit buses travel over most major roadway segments in urban areas on a repeated basis and are usually equipped with cameras that are installed for other purposes. Vehicles on the surrounding roadways can be seen in the imagery obtained from these cameras. The availability of this imagery and the extensive geographic coverage offered by transit buses make them an attractive source of data that could be used to estimate traffic volumes at low cost. A method has previously been proposed for estimating traffic volumes from this bus based imagery, and empirical studies have documented errors associated with the resulting bus based video volume estimates. However, no studies have been performed on whether the accuracy of the volume estimates is sufficient to determine time of day and day of week patterns. Therefore, in this thesis an empirical study was conducted to investigate if the video volumes can validly detect time of day and day of week patterns.

To conduct this investigation, a large, ongoing manual data collection effort was designed and implemented. Manual traffic counts were taken over the course of the Spring 2022 and Autumn 2022 semesters for one roadway segment-direction on the campus of The Ohio State University (OSU) during specified time periods on different days of the week. The “manual volumes” resulting from these traffic counts were aggregated into 15-, 30-, and 60-minute periods for various times of the day and on different days of the week and served as the ground truth in the analysis. Video volumes aggregated for the same 15-, 30-, and 60-minute periods, derived from the video imagery recorded by OSU buses in regular operation, were provided for use in this thesis.

The manual (true) and video volumes were compared to analyze time of day and day of week patterns. Empirical cumulative distribution functions (ecdfs) were formed by grouping the resulting volumes from the various data collection days at the same time of day and day of week period. The ecdfs for different time of day periods on the same day of week or on different days of week for the same time of day period were visually inspected to detect time of day or day of week patterns in the true (manual) data and to see if the estimated, video volumes resulted in similar patterns. It was found that the video volumes reveal most, but not all time of day and day of week patterns seen in the ground truth manual volume distributions.

To analyze correspondence between the video and true (manual) volumes more quantitatively, various metrics related to the differences in the means of the time of day or day of week distributions were developed. A regression was performed between the differences of the means of the distributions obtained from the manual and video volumes. The regression results indicate that the differences in the true (manual) volumes are strongly and positively related to the differences in the video volumes taken for the same time of day or day of week comparison.

In addition, a same sign indicator was assigned for all time of day and day of week comparisons. This indicator takes on a value 1 when the manual and video differences in means ($D^{mean(60),man}_{i,j}$ and $D^{mean(60),vid}_{i,j}$) have the same sign for the comparisons, which indicates that the mean of a volume distribution *i* as determined by the video and manual data are either both greater than or less than the means of a volume distributions *j*. Hypothesis test results showed that the ordering (same signs) obtained with the video volumes are much more related to the orderings obtained with the true (manual) volumes than would be expected by chance.

Furthermore, indicator values were assigned to depict the strength of the differences (large, slight, or small) between the mean volumes in different time of day and day of week periods. Hypothesis test results showed that indicator values obtained from the video and true (manual) volumes for the same time of day or day of week comparison are much more related then would be expected by chance.

Despite the large data collection effort, there was still only a limited number of time periods in which both manual (true) and video observations could be compared. Therefore, definite conclusions are difficult to draw. It was found that the limited number of video volumes available cannot depict exactly the time of day and day of week effects found in the true (manual) volumes. However, the video volumes appear to be strongly representative of most time of day and day of week patterns found in the true (manual) volumes. As a result, it appears that bus based video volumes could likely be used to detect time of day and day of week patterns with larger video data collection. It is noted that buses operate continuously on a frequent basis, day after day and week after week. Therefore, this larger video data collection would be possible.

Although the results of this thesis support the promise of using video imagery obtained from buses operating in regular service to detect time of day and day of week patterns, there is still a need for further work to solidify findings. Some time of day and day of week patterns were not represented well by the video volumes. For example, from Table 4.20, one sees that when comparing strength of difference indicator values obtained from video and manual data for the Thursday 13:30-13:45 and 13:45-14:00 periods, the video data indicated a large difference (indicator value of 2) in the time of day periods considered, while the manual data indicated little difference (indicator value of 0). It would be useful to investigate further the individual volume estimates that led to different strength of indicator values for the means of the distribution between the video and true (manual) volumes for this comparison and others as well. It is also noted that the video volumes were provided by the Campus Transit Lab using their best methodology at the time. Research is ongoing to improve volume estimation from bus based video imagery and it is expected that video volumes would be even closer to true (manual) volumes in the future.

As discussed in Chapter 1, traffic volumes are important inputs for traffic monitoring groups to obtain quantitative time of day and day of week factors. Although the metrics used may vary slightly, the factors represent how a volume in one period compares to that in another period. It would be interesting to compare such time of day or day of week factors resulting from the video estimates to those determined from the true (manual) volumes. For example, one could calculate a video-based time of day factor for the 9:30-10:30 hour by dividing the video 9:30-

10:30 volume on one data collection day by the sum of the video volumes over all of the hours for which data were collected on that day. This could then be repeated for all the days on which the same hourly video volumes were obtained, and the factors calculated for the various days could be averaged. The entire process could then be repeated using the manual (true) volumes, and the average factors could be compared. The same process could be used to determine average time of day factors for the other hours or sub hourly periods in which data were collected. In a similar way, average day of week factors could be determined and compared using video and manual volumes that were collected for the same period across different days.

The focus in this thesis was on determining if traffic volumes from bus based video imagery can detect time of day and day of week patterns. Other temporal dimensions or interactions of these dimensions may be important in determining homogeneous volume periods. It would be interesting to investigate if video volumes could be used to detect differences among these other dimension that occur in the true volumes. For example, in this thesis the volumes for the 9:30-10:30 hour on Wednesday and Thursday were collected in both the Spring 2022 and Autumn 2022 semesters. It is possible that there could be differences in volume for same time of day and day of week period depending on the semester. Similarly, there could be an interaction between of time of day and day of week. For example, as a result of differing class schedules by day of week, the volume in one time of day period may be different from the volumes in another time of day period on Wednesday, but not on Thursday. In this thesis, these results would represent no consistent time of day pattern, although the pattern may be indicative of interaction between time of day and day of week, and it would be interesting to investigate if the video volumes could be used to detect such interactions that appear in the true (manual) volumes.

However, investigating these interactions would likely require substantially more data then was collected in this thesis.

The empirical study in this thesis was limited to one segment-direction. It would be interesting to see if similar results would be obtained on different segment-directions and on other times of day and days of week. However, expanding to other segment-directions and time periods would require other large data collection efforts. Empirical data collection for this thesis was limited by the ability to collect manual, ground truth volume data. The ability to do so was limited by student schedules, i.e., by the ability of the student data collectors to get to and from the segment and collect data for an hour between classes. It is noted that although it presently takes time to process video imagery into volume estimates using the procedures described in Section 2.2, video imagery would be readily available on many segment-directions and on many more days that were considered in this thesis because of the extensive and repeated overage offered by transit buses.

Regardless of the need for future work, the empirical results in this thesis indicate for the first time that traffic volumes produced from bus based video imagery can likely be used to identify time of day and day of week patterns.

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Appendix A: Manual Data Collection

All tables and figures related to the manual data collection process.

Table A.1 Counting Weather Requirements

Weather	Duration of Count
Temp < 25 degree	Skip
Temp [25, 35]	30 minutes
Temp [35, 40]	45 minutes
Temp > 40 degrees	1 hour
Rain or Heavy Snow	Skip
Light Snow	1 hour

Name	
Date_of_Count	
Day_of_Week	
Start_Segment_Hour	
Segment_Number	4
Segment_Name	Woody/Coffey to Woody/Cannon
Weather	
Duration_of_Count	

Time Interval		Direction	Time Interval		Direction
From	To	EB	From	To	EB
9:30 AM	9:34 AM		10:00 AM	10:04 AM	
9:35 AM	9:39 AM		10:05 AM	10:09 AM	
9:40 AM	9:44 AM		10:10 AM	10:14 AM	
9:45 AM	9:49 AM		10:15 AM	10:19 AM	
9:50 AM	9:54 AM		10:20 AM	10:24 AM	
9:55 AM	9:59 AM		10:25 AM	10:29 AM	

Figure A.1 Data Collection Sheet

Appendix B: 5-minute Volume Estimation

Table B.1 presents the 4-minute volumes collected 1/31/22 - 5/12/22, 5-minute volumes estimated using the 4-minute expansion and 8-minute interpolation methods, and resulting difference measures between the two methods. "5 min Method 1" is referring to the 4-minute expansion method while "5 min Method 2" is referring to the 8-minute interpolation method. If no data is available for the 4-minutes proceeding the "missing" one minute the 4-minute expansion method must be used. Therefore, no difference measure were calculated for those time periods.

Table B1: Empirical 4-minute volumes collected 1/31/22 - 5/12/22, 5-minute volumes estimated using the 4-minute expansion and 8-minute interpolation methods, and resulting difference measures between the two methods.

Date	Day of Week	Start Time	Duration	Count	5 min Method 1	5 min Method 2	D	AD	RD	ARD
2022-01-31	1	11:30 AM	4 min	19	23.75	23.375	0.375	0.375	0.016043	0.016043
2022-01-31	1	11:35 AM	4 min	16	20	20.25	-0.25	0.25	-0.01235	0.012346
2022-01-31	1	11:40 AM	4 min	18	22.5	22.5	0	0	0	0
2022-01-31	1	11:45 AM	4 min	18	22.5	22.125	0.375	0.375	0.016949	0.016949
2022-01-31	1	11:50 AM	4 min	15	18.75	19	-0.25	0.25	-0.01316	0.013158
2022-01-31	1	11:55 AM	4 min	17	21.25	22	-0.75	0.75	-0.03409	0.034091
2022-01-31	1	12:00 PM	4 min	23	28.75	29.125	-0.375	0.375	-0.01288	0.012876
2022-01-31	1	12:05 PM	4 min	26	32.5	32.125	0.375	0.375	0.011673	0.011673
2022-01-31	1	12:10 PM	4 min	23	28.75	28.75				
2022-02-07	1	11:30 AM	4 min	17	21.25	20.75	0.5	0.5	0.024096	0.024096
2022-02-07	1	11:35 AM	4 min	13	16.25	17.25	-1	1	-0.05797	0.057971
2022-02-07	1	11:40 AM	4 min	21	26.25	25.25	1	1	0.039604	0.039604
2022-02-07	1	11:45 AM	4 min	13	16.25	16.875	-0.625	0.625	-0.03704	0.037037
2022-02-07	1	11:50 AM	4 min	18	22.5	22.75	-0.25	0.25	-0.01099	0.010989
2022-02-07	1	11:55 AM	4 min	20	25	24.625	0.375	0.375	0.015228	0.015228
2022-02-07	1	12:00 PM	4 min	17	21.25	22.125	-0.875	0.875	-0.03955	0.039548
2022-02-07	1	12:05 PM	4 min	24	30	30.375	-0.375	0.375	-0.01235	0.012346
2022-02-07	1	12:10 PM	4 min	27	33.75	32.625	1.125	1.125	0.034483	0.034483
2022-02-07	1	12:15 PM	4 min	18	22.5	23.25	-0.75	0.75	-0.03226	0.032258
2022-02-07	1	12:20 PM	4 min	24	30	31.625	-1.625	1.625	-0.05138	0.051383
2022-02-07	1	12:25 PM	4 min	37	46.25	46.25				
2022-02-09	3	9:30 AM	4 min	22	27.5	27.25	0.25	0.25	0.009174	0.009174
2022-02-09	3	9:35 AM	4 min	20	25	24.75	0.25	0.25	0.010101	0.010101
2022-02-09	3	9:40 AM	4 min	18	22.5	22.125	0.375	0.375	0.016949	0.016949
2022-02-09	3	9:45 AM	4 min	15	18.75	19.875	-1.125	1.125	-0.0566	0.056604

2022-02-09	3	9:50 AM	4 min	24	30	30.375	-0.375	0.375	-0.01235	0.012346
2022-02-09	3	9:55 AM	4 min	27	33.75	32.375	1.375	1.375	0.042471	0.042471
2022-02-10	4	9:30 AM	4 min	16	20	21.125	-1.125	1.125	-0.05325	0.053254
2022-02-10	4	9:35 AM	4 min	25	31.25	30.75	0.5	0.5	0.01626	0.01626
2022-02-10	4	9:40 AM	4 min	21	26.25	25.5	0.75	0.75	0.029412	0.029412
2022-02-10	4	9:45 AM	4 min	15	18.75	19.25	-0.5	0.5	-0.02597	0.025974
2022-02-10	4	9:50 AM	4 min	19	23.75	24.75	-1	1	-0.0404	0.040404
2022-02-10	4	9:55 AM	4 min	27	33.75	32.75	1	1	0.030534	0.030534
2022-02-10	4	10:00 AM	4 min	19	23.75	23.5	0.25	0.25	0.010638	0.010638
2022-02-10	4	10:05 AM	4 min	17	21.25	21.875	-0.625	0.625	-0.02857	0.028571
2022-02-10	4	10:10 AM	4 min	22	27.5	27.5				
2022-02-10	4	11:30 AM	4 min	17	21.25	20.25	1	1	0.049383	0.049383
2022-02-10	4	11:35 AM	4 min	9	11.25	11.625	-0.375	0.375	-0.03226	0.032258
2022-02-10	4	11:40 AM	4 min	12	15	15	0	0	0	0
2022-02-10	4	11:45 AM	4 min	12	15	15.5	-0.5	0.5	-0.03226	0.032258
2022-02-10	4	11:50 AM	4 min	16	20	20.25	-0.25	0.25	-0.01235	0.012346
2022-02-10	4	11:55 AM	4 min	18	22.5	23.375	-0.875	0.875	-0.03743	0.037433
2022-02-10	4	12:00 PM	4 min	25	31.25	31.5	-0.25	0.25	-0.00794	0.007937
2022-02-10	4	12:05 PM	4 min	27	33.75	33.25	0.5	0.5	0.015038	0.015038
2022-02-10	4	12:10 PM	4 min	23	28.75	29.75	-1	1	-0.03361	0.033613
2022-02-10	4	12:15 PM	4 min	31	38.75	38.75	0	0	0	0
2022-02-10	4	12:20 PM	4 min	31	38.75	38.25	0.5	0.5	0.013072	0.013072
2022-02-10	4	12:25 PM	4 min	27	33.75	33.75				
2022-02-14	1	11:30 AM	4 min	20	25	24.375	0.625	0.625	0.025641	0.025641
2022-02-14	1	11:35 AM	4 min	15	18.75	18.875	-0.125	0.125	-0.00662	0.006623
2022-02-14	1	11:40 AM	4 min	16	20	20.375	-0.375	0.375	-0.0184	0.018405
2022-02-14	1	11:45 AM	4 min	19	23.75	24	-0.25	0.25	-0.01042	0.010417
2022-02-14	1	11:50 AM	4 min	21	26.25	25.625	0.625	0.625	0.02439	0.02439
2022-02-14	1	11:55 AM	4 min	16	20	20.875	-0.875	0.875	-0.04192	0.041916

2022-02-14	1	12:00 PM	4 min	23	28.75	27.75	1	1	0.036036	0.036036
2022-02-14	1	12:05 PM	4 min	15	18.75	19.5	-0.75	0.75	-0.03846	0.038462
2022-02-14	1	12:10 PM	4 min	21	26.25	26.625	-0.375	0.375	-0.01408	0.014085
2022-02-14	1	12:15 PM	4 min	24	30	29.625	0.375	0.375	0.012658	0.012658
2022-02-14	1	12:20 PM	4 min	21	26.25	26.625	-0.375	0.375	-0.01408	0.014085
2022-02-14	1	12:25 PM	4 min	24	30	30				
2022-02-16	3	9:30 AM	4 min	21	26.25	26.25	0	0	0	0
2022-02-16	3	9:35 AM	4 min	21	26.25	26.625	-0.375	0.375	-0.01408	0.014085
2022-02-16	3	9:40 AM	4 min	24	30	31.375	-1.375	1.375	-0.04382	0.043825
2022-02-16	3	9:45 AM	4 min	35	43.75	42.5	1.25	1.25	0.029412	0.029412
2022-02-16	3	9:50 AM	4 min	25	31.25	32.25	-1	1	-0.03101	0.031008
2022-02-16	3	9:55 AM	4 min	33	41.25	40	1.25	1.25	0.03125	0.03125
2022-02-16	3	10:00 AM	4 min	23	28.75	29.75	-1	1	-0.03361	0.033613
2022-02-16	3	10:05 AM	4 min	31	38.75	39.5	-0.75	0.75	-0.01899	0.018987
2022-02-16	3	10:10 AM	4 min	37	46.25	44	2.25	2.25	0.051136	0.051136
2022-02-16	3	10:15 AM	4 min	19	23.75	24.125	-0.375	0.375	-0.01554	0.015544
2022-02-16	3	10:20 AM	4 min	22	27.5	26.75	0.75	0.75	0.028037	0.028037
2022-02-16	3	10:25 AM	4 min	16	20	20				
2022-02-21	1	11:30 AM	4 min	14	17.5	18.5	-1	1	-0.05405	0.054054
2022-02-21	1	11:35 AM	4 min	22	27.5	26.375	1.125	1.125	0.042654	0.042654
2022-02-21	1	11:40 AM	4 min	13	16.25	16.75	-0.5	0.5	-0.02985	0.029851
2022-02-21	1	11:45 AM	4 min	17	21.25	21.375	-0.125	0.125	-0.00585	0.005848
2022-02-21	1	11:50 AM	4 min	18	22.5	22.875	-0.375	0.375	-0.01639	0.016393
2022-02-21	1	11:55 AM	4 min	21	26.25	26.875	-0.625	0.625	-0.02326	0.023256
2022-02-21	1	12:00 PM	4 min	26	32.5	32.625	-0.125	0.125	-0.00383	0.003831
2022-02-21	1	12:05 PM	4 min	27	33.75	34	-0.25	0.25	-0.00735	0.007353
2022-02-21	1	12:10 PM	4 min	29	36.25	35.625	0.625	0.625	0.017544	0.017544
2022-02-21	1	12:15 PM	4 min	24	30	30.125	-0.125	0.125	-0.00415	0.004149
2022-02-21	1	12:20 PM	4 min	25	31.25	31.5	-0.25	0.25	-0.00794	0.007937

2022-02-21	1	12:25 PM	4 min	27	33.75	33.75				
2022-02-23	3	10:00 AM	4 min	18	22.5	25	-2.5	2.5	-0.1	0.1
2022-02-23	3	10:05 AM	4 min	38	47.5	46.75	0.75	0.75	0.016043	0.016043
2022-02-23	3	10:10 AM	4 min	32	40	40	0	0	0	0
2022-02-23	3	10:15 AM	4 min	32	40	37.875	2.125	2.125	0.056106	0.056106
2022-02-23	3	10:20 AM	4 min	15	18.75	19.25	-0.5	0.5	-0.02597	0.025974
2022-02-23	3	10:25 AM	4 min	19	23.75	23.75				
2022-02-24	4	9:30 AM	4 min	30	37.5	36.125	1.375	1.375	0.038062	0.038062
2022-02-24	4	9:35 AM	4 min	19	23.75	23.375	0.375	0.375	0.016043	0.016043
2022-02-24	4	9:40 AM	4 min	16	20	20	0	0	0	0
2022-02-24	4	9:45 AM	4 min	16	20	20.25	-0.25	0.25	-0.01235	0.012346
2022-02-24	4	9:50 AM	4 min	18	22.5	23.25	-0.75	0.75	-0.03226	0.032258
2022-02-24	4	9:55 AM	4 min	24	30	30				
2022-02-24	4	11:30 AM	4 min	14	17.5	17.375	0.125	0.125	0.007194	0.007194
2022-02-24	4	11:35 AM	4 min	13	16.25	17.125	-0.875	0.875	-0.05109	0.051095
2022-02-24	4	11:40 AM	4 min	20	25	24.5	0.5	0.5	0.020408	0.020408
2022-02-24	4	11:45 AM	4 min	16	20	19.5	0.5	0.5	0.025641	0.025641
2022-02-24	4	11:50 AM	4 min	12	15	16.5	-1.5	1.5	-0.09091	0.090909
2022-02-24	4	11:55 AM	4 min	24	30	28.875	1.125	1.125	0.038961	0.038961
2022-02-28	1	11:30 AM	4 min	15	18.75	19.125	-0.375	0.375	-0.01961	0.019608
2022-02-28	1	11:35 AM	4 min	18	22.5	22.125	0.375	0.375	0.016949	0.016949
2022-02-28	1	11:40 AM	4 min	15	18.75	18.375	0.375	0.375	0.020408	0.020408
2022-02-28	1	11:45 AM	4 min	12	15	15.625	-0.625	0.625	-0.04	0.04
2022-02-28	1	11:50 AM	4 min	17	21.25	22	-0.75	0.75	-0.03409	0.034091
2022-02-28	1	11:55 AM	4 min	23	28.75	28.5	0.25	0.25	0.008772	0.008772
2022-02-28	1	12:00 PM	4 min	21	26.25	26.375	-0.125	0.125	-0.00474	0.004739
2022-02-28	1	12:05 PM	4 min	22	27.5	26.875	0.625	0.625	0.023256	0.023256
2022-02-28	1	12:10 PM	4 min	17	21.25	22.875	-1.625	1.625	-0.07104	0.071038
2022-02-28	1	12:15 PM	4 min	30	37.5	37.625	-0.125	0.125	-0.00332	0.003322

2022-02-28	1	12:20 PM	4 min	31	38.75	38.125	0.625	0.625	0.016393	0.016393
2022-02-28	1	12:25 PM	4 min	26	32.5	32.5				
2022-03-02	3	9:30 AM	4 min	26	32.5	31	1.5	1.5	0.048387	0.048387
2022-03-02	3	9:35 AM	4 min	14	17.5	19.5	-2	2	-0.10256	0.102564
2022-03-02	3	9:40 AM	4 min	30	37.5	35.875	1.625	1.625	0.045296	0.045296
2022-03-02	3	9:45 AM	4 min	17	21.25	23.375	-2.125	2.125	-0.09091	0.090909
2022-03-02	3	9:50 AM	4 min	34	42.5	41	1.5	1.5	0.036585	0.036585
2022-03-02	3	9:55 AM	4 min	22	27.5	27.625	-0.125	0.125	-0.00452	0.004525
2022-03-02	3	10:00 AM	4 min	23	28.75	29.875	-1.125	1.125	-0.03766	0.037657
2022-03-02	3	10:05 AM	4 min	32	40	40.625	-0.625	0.625	-0.01538	0.015385
2022-03-02	3	10:10 AM	4 min	37	46.25	46.25				
2022-03-03	4	9:30 AM	4 min	27	33.75	33.125	0.625	0.625	0.018868	0.018868
2022-03-03	4	9:35 AM	4 min	22	27.5	27.625	-0.125	0.125	-0.00452	0.004525
2022-03-03	4	9:40 AM	4 min	23	28.75	28	0.75	0.75	0.026786	0.026786
2022-03-03	4	9:45 AM	4 min	17	21.25	22.125	-0.875	0.875	-0.03955	0.039548
2022-03-03	4	9:50 AM	4 min	24	30	28.625	1.375	1.375	0.048035	0.048035
2022-03-03	4	9:55 AM	4 min	13	16.25	16.25				
2022-03-03	4	11:30 AM	4 min	10	12.5	14	-1.5	1.5	-0.10714	0.107143
2022-03-03	4	11:35 AM	4 min	22	27.5	26.375	1.125	1.125	0.042654	0.042654
2022-03-03	4	11:40 AM	4 min	13	16.25	16.5	-0.25	0.25	-0.01515	0.015152
2022-03-03	4	11:45 AM	4 min	15	18.75	18.625	0.125	0.125	0.006711	0.006711
2022-03-03	4	11:50 AM	4 min	14	17.5	18.5	-1	1	-0.05405	0.054054
2022-03-03	4	11:55 AM	4 min	22	27.5	27.25	0.25	0.25	0.009174	0.009174
2022-03-03	4	12:00 PM	4 min	20	25	24.5	0.5	0.5	0.020408	0.020408
2022-03-03	4	12:05 PM	4 min	16	20	21.5	-1.5	1.5	-0.06977	0.069767
2022-03-03	4	12:10 PM	4 min	28	35	35				
2022-03-07	1	11:30 AM	4 min	16	20	20.75	-0.75	0.75	-0.03614	0.036145
2022-03-07	1	11:35 AM	4 min	22	27.5	27.25	0.25	0.25	0.009174	0.009174
2022-03-07	1	11:40 AM	4 min	20	25	24.875	0.125	0.125	0.005025	0.005025

2022-03-07	1	11:45 AM	4 min	19	23.75	22.5	1.25	1.25	0.055556	0.055556
2022-03-07	1	11:50 AM	4 min	9	11.25	12.625	-1.375	1.375	-0.10891	0.108911
2022-03-07	1	11:55 AM	4 min	20	25	25.5	-0.5	0.5	-0.01961	0.019608
2022-03-07	1	12:00 PM	4 min	24	30	30.5	-0.5	0.5	-0.01639	0.016393
2022-03-07	1	12:05 PM	4 min	28	35	33.375	1.625	1.625	0.048689	0.048689
2022-03-07	1	12:10 PM	4 min	15	18.75	19.5	-0.75	0.75	-0.03846	0.038462
2022-03-07	1	12:15 PM	4 min	21	26.25	26.875	-0.625	0.625	-0.02326	0.023256
2022-03-07	1	12:20 PM	4 min	26	32.5	32.75	-0.25	0.25	-0.00763	0.007634
2022-03-07	1	12:25 PM	4 min	28	35	35				
2022-03-09	3	9:30 AM	4 min	28	35	35	0	0	0	0
2022-03-09	3	9:35 AM	4 min	28	35	34.25	0.75	0.75	0.021898	0.021898
2022-03-09	3	9:40 AM	4 min	22	27.5	27.75	-0.25	0.25	-0.00901	0.009009
2022-03-09	3	9:45 AM	4 min	24	30	30.25	-0.25	0.25	-0.00826	0.008264
2022-03-09	3	9:50 AM	4 min	26	32.5	32.5	0	0	0	0
2022-03-09	3	9:55 AM	4 min	26	32.5	33.25	-0.75	0.75	-0.02256	0.022556
2022-03-10	4	9:30 AM	4 min	32	40	38.75	1.25	1.25	0.032258	0.032258
2022-03-10	4	9:35 AM	4 min	22	27.5	26.25	1.25	1.25	0.047619	0.047619
2022-03-10	4	9:40 AM	4 min	12	15	16.125	-1.125	1.125	-0.06977	0.069767
2022-03-10	4	9:45 AM	4 min	21	26.25	26.125	0.125	0.125	0.004785	0.004785
2022-03-10	4	9:50 AM	4 min	20	25	25.5	-0.5	0.5	-0.01961	0.019608
2022-03-10	4	9:55 AM	4 min	24	30	29.625	0.375	0.375	0.012658	0.012658
2022-03-10	4	10:00 AM	4 min	21	26.25	27.125	-0.875	0.875	-0.03226	0.032258
2022-03-10	4	10:05 AM	4 min	28	35	34.875	0.125	0.125	0.003584	0.003584
2022-03-10	4	10:10 AM	4 min	27	33.75	32.125	1.625	1.625	0.050584	0.050584
2022-03-10	4	10:15 AM	4 min	14	17.5	17.75	-0.25	0.25	-0.01408	0.014085
2022-03-10	4	10:20 AM	4 min	16	20	20.875	-0.875	0.875	-0.04192	0.041916
2022-03-10	4	10:25 AM	4 min	23	28.75	28.75				
2022-03-10	4	11:30 AM	4 min	16	20	20	0	0	0	0
2022-03-10	4	11:35 AM	4 min	16	20	20.125	-0.125	0.125	-0.00621	0.006211

2022-03-10	4	11:40 AM	4 min	17	21.25	20.75	0.5	0.5	0.024096	0.024096
2022-03-10	4	11:45 AM	4 min	13	16.25	17.25	-1	1	-0.05797	0.057971
2022-03-10	4	11:50 AM	4 min	21	26.25	25.25	1	1	0.039604	0.039604
2022-03-10	4	11:55 AM	4 min	13	16.25	17.125	-0.875	0.875	-0.05109	0.051095
2022-03-10	4	12:00 PM	4 min	20	25	24.75	0.25	0.25	0.010101	0.010101
2022-03-10	4	12:05 PM	4 min	18	22.5	23.125	-0.625	0.625	-0.02703	0.027027
2022-03-10	4	12:10 PM	4 min	23	28.75	28.25	0.5	0.5	0.017699	0.017699
2022-03-10	4	12:15 PM	4 min	19	23.75	24.875	-1.125	1.125	-0.04523	0.045226
2022-03-10	4	12:20 PM	4 min	28	35	35	0	0	0	0
2022-03-10	4	12:25 PM	4 min	28	35	35				
2022-03-21	1	11:30 AM	4 min	22	27.5	27.375	0.125	0.125	0.004566	0.004566
2022-03-21	1	11:35 AM	4 min	21	26.25	26.25	0	0	0	0
2022-03-21	1	11:40 AM	4 min	21	26.25	26.875	-0.625	0.625	-0.02326	0.023256
2022-03-21	1	11:45 AM	4 min	26	32.5	32	0.5	0.5	0.015625	0.015625
2022-03-21	1	11:50 AM	4 min	22	27.5	26.25	1.25	1.25	0.047619	0.047619
2022-03-21	1	11:55 AM	4 min	12	15	15.625	-0.625	0.625	-0.04	0.04
2022-03-21	1	12:00 PM	4 min	17	21.25	21.875	-0.625	0.625	-0.02857	0.028571
2022-03-21	1	12:05 PM	4 min	22	27.5	27.875	-0.375	0.375	-0.01345	0.013453
2022-03-21	1	12:10 PM	4 min	25	31.25	30.875	0.375	0.375	0.012146	0.012146
2022-03-21	1	12:15 PM	4 min	22	27.5	27.875	-0.375	0.375	-0.01345	0.013453
2022-03-21	1	12:20 PM	4 min	25	31.25	31.625	-0.375	0.375	-0.01186	0.011858
2022-03-21	1	12:25 PM	4 min	28	35	35				
2022-03-24	4	9:30 AM	4 min	22	27.5	27.625	-0.125	0.125	-0.00452	0.004525
2022-03-24	4	9:35 AM	4 min	23	28.75	28.75	0	0	0	0
2022-03-24	4	9:40 AM	4 min	23	28.75	29.125	-0.375	0.375	-0.01288	0.012876
2022-03-24	4	9:45 AM	4 min	26	32.5	32.875	-0.375	0.375	-0.01141	0.011407
2022-03-24	4	9:50 AM	4 min	29	36.25	37	-0.75	0.75	-0.02027	0.02027
2022-03-24	4	9:55 AM	4 min	35	43.75	43.625	0.125	0.125	0.002865	0.002865
2022-03-24	4	10:00 AM	4 min	34	42.5	42	0.5	0.5	0.011905	0.011905

2022-03-24	4	10:05 AM	4 min	30	37.5	36	1.5	1.5	0.041667	0.041667
2022-03-24	4	10:10 AM	4 min	18	22.5	23	-0.5	0.5	-0.02174	0.021739
2022-03-24	4	10:15 AM	4 min	22	27.5	27.25	0.25	0.25	0.009174	0.009174
2022-03-24	4	10:20 AM	4 min	20	25	25.125	-0.125	0.125	-0.00498	0.004975
2022-03-24	4	10:25 AM	4 min	21	26.25	26.25				
2022-03-24	4	11:30 AM	4 min	24	30	29.25	0.75	0.75	0.025641	0.025641
2022-03-24	4	11:35 AM	4 min	18	22.5	22.375	0.125	0.125	0.005587	0.005587
2022-03-24	4	11:40 AM	4 min	17	21.25	22.25	-1	1	-0.04494	0.044944
2022-03-24	4	11:45 AM	4 min	25	31.25	31.125	0.125	0.125	0.004016	0.004016
2022-03-24	4	11:50 AM	4 min	24	30	29.125	0.875	0.875	0.030043	0.030043
2022-03-24	4	11:55 AM	4 min	17	21.25	21.25	0	0	0	0
2022-03-24	4	12:00 PM	4 min	17	21.25	21.875	-0.625	0.625	-0.02857	0.028571
2022-03-24	4	12:05 PM	4 min	22	27.5	28	-0.5	0.5	-0.01786	0.017857
2022-03-24	4	12:10 PM	4 min	26	32.5	32.375	0.125	0.125	0.003861	0.003861
2022-03-24	4	12:15 PM	4 min	25	31.25	33.75	-2.5	2.5	-0.07407	0.074074
2022-03-24	4	12:20 PM	4 min	45	56.25	54.375	1.875	1.875	0.034483	0.034483
2022-03-24	4	12:25 PM	4 min	30	37.5	37.5				
2022-03-28	1	11:30 AM	4 min	19	23.75	25	-1.25	1.25	-0.05	0.05
2022-03-28	1	11:35 AM	4 min	29	36.25	36.25	0	0	0	0
2022-03-28	1	11:40 AM	4 min	29	36.25	34.875	1.375	1.375	0.039427	0.039427
2022-03-28	1	11:45 AM	4 min	18	22.5	22.125	0.375	0.375	0.016949	0.016949
2022-03-28	1	11:50 AM	4 min	15	18.75	19.875	-1.125	1.125	-0.0566	0.056604
2022-03-28	1	11:55 AM	4 min	24	30	29.875	0.125	0.125	0.004184	0.004184
2022-03-28	1	12:00 PM	4 min	23	28.75	29.375	-0.625	0.625	-0.02128	0.021277
2022-03-28	1	12:05 PM	4 min	28	35	34.875	0.125	0.125	0.003584	0.003584
2022-03-28	1	12:10 PM	4 min	27	33.75	33.75	0	0	0	0
2022-03-28	1	12:15 PM	4 min	27	33.75	34.5	-0.75	0.75	-0.02174	0.021739
2022-03-28	1	12:20 PM	4 min	33	41.25	42.625	-1.375	1.375	-0.03226	0.032258
2022-03-28	1	12:25 PM	4 min	44	55	55				

2022-03-30	3	9:30 AM	4 min	27	33.75	33.5	0.25	0.25	0.007463	0.007463
2022-03-30	3	9:35 AM	4 min	25	31.25	31.75	-0.5	0.5	-0.01575	0.015748
2022-03-30	3	9:40 AM	4 min	29	36.25	36.125	0.125	0.125	0.00346	0.00346
2022-03-30	3	9:45 AM	4 min	28	35	34.875	0.125	0.125	0.003584	0.003584
2022-03-30	3	9:50 AM	4 min	27	33.75	34.375	-0.625	0.625	-0.01818	0.018182
2022-03-30	3	9:55 AM	4 min	32	40	40.625	-0.625	0.625	-0.01538	0.015385
2022-03-30	3	10:00 AM	4 min	37	46.25	45.625	0.625	0.625	0.013699	0.013699
2022-03-30	3	10:05 AM	4 min	32	40	40	0	0	0	0
2022-03-30	3	10:10 AM	4 min	32	40	38.875	1.125	1.125	0.028939	0.028939
2022-03-30	3	10:15 AM	4 min	23	28.75	29.125	-0.375	0.375	-0.01288	0.012876
2022-03-30	3	10:20 AM	4 min	26	32.5	32.125	0.375	0.375	0.011673	0.011673
2022-03-30	3	10:25 AM	4 min	23	28.75	28.75				
2022-03-31	4	9:30 AM	4 min	31	38.75	37.625	1.125	1.125	0.0299	0.0299
2022-03-31	4	9:35 AM	4 min	22	27.5	28.125	-0.625	0.625	-0.02222	0.022222
2022-03-31	4	9:40 AM	4 min	27	33.75	33.75				
2022-04-04	1	11:30 AM	4 min	15	18.75	18.875	-0.125	0.125	-0.00662	0.006623
2022-04-04	1	11:35 AM	4 min	16	20	20.25	-0.25	0.25	-0.01235	0.012346
2022-04-04	1	11:40 AM	4 min	18	22.5	22.75	-0.25	0.25	-0.01099	0.010989
2022-04-04	1	11:45 AM	4 min	20	25	25	0	0	0	0
2022-04-04	1	11:50 AM	4 min	20	25	25	0	0	0	0
2022-04-04	1	11:55 AM	4 min	20	25	25.25	-0.25	0.25	-0.0099	0.009901
2022-04-04	1	12:00 PM	4 min	22	27.5	27.375	0.125	0.125	0.004566	0.004566
2022-04-04	1	12:05 PM	4 min	21	26.25	27.25	-1	1	-0.0367	0.036697
2022-04-04	1	12:10 PM	4 min	29	36.25	36.875	-0.625	0.625	-0.01695	0.016949
2022-04-04	1	12:15 PM	4 min	34	42.5	42.75	-0.25	0.25	-0.00585	0.005848
2022-04-04	1	12:20 PM	4 min	36	45	44.5	0.5	0.5	0.011236	0.011236
2022-04-04	1	12:25 PM	4 min	32	40	40				
2022-04-06	3	9:30 AM	4 min	34	42.5	41.75	0.75	0.75	0.017964	0.017964
2022-04-06	3	9:35 AM	4 min	28	35	34.375	0.625	0.625	0.018182	0.018182

2022-04-06	3	9:40 AM	4 min	23	28.75	28.25	0.5	0.5	0.017699	0.017699
2022-04-06	3	9:45 AM	4 min	19	23.75	26.25	-2.5	2.5	-0.09524	0.095238
2022-04-06	3	9:50 AM	4 min	39	48.75	47.125	1.625	1.625	0.034483	0.034483
2022-04-06	3	9:55 AM	4 min	26	32.5	32.75	-0.25	0.25	-0.00763	0.007634
2022-04-06	3	10:00 AM	4 min	28	35	35.25	-0.25	0.25	-0.00709	0.007092
2022-04-06	3	10:05 AM	4 min	30	37.5	36.875	0.625	0.625	0.016949	0.016949
2022-04-06	3	10:10 AM	4 min	25	31.25	31.875	-0.625	0.625	-0.01961	0.019608
2022-04-06	3	10:15 AM	4 min	30	37.5	36.375	1.125	1.125	0.030928	0.030928
2022-04-06	3	10:20 AM	4 min	21	26.25	26.375	-0.125	0.125	-0.00474	0.004739
2022-04-06	3	10:25 AM	4 min	22	27.5	27.5				
2022-04-07	4	9:30 AM	4 min	29	36.25	36.75	-0.5	0.5	-0.01361	0.013605
2022-04-07	4	9:35 AM	4 min	33	41.25	39.875	1.375	1.375	0.034483	0.034483
2022-04-07	4	9:40 AM	4 min	22	27.5	28.625	-1.125	1.125	-0.0393	0.039301
2022-04-07	4	9:45 AM	4 min	31	38.75	39.25	-0.5	0.5	-0.01274	0.012739
2022-04-07	4	9:50 AM	4 min	35	43.75	41.5	2.25	2.25	0.054217	0.054217
2022-04-07	4	9:55 AM	4 min	17	21.25	23.625	-2.375	2.375	-0.10053	0.100529
2022-04-07	4	10:00 AM	4 min	36	45	43.5	1.5	1.5	0.034483	0.034483
2022-04-07	4	10:05 AM	4 min	24	30	29.125	0.875	0.875	0.030043	0.030043
2022-04-07	4	10:10 AM	4 min	17	21.25	22.375	-1.125	1.125	-0.05028	0.050279
2022-04-07	4	10:15 AM	4 min	26	32.5	30.75	1.75	1.75	0.056911	0.056911
2022-04-07	4	10:20 AM	4 min	12	15	15.125	-0.125	0.125	-0.00826	0.008264
2022-04-07	4	10:25 AM	4 min	13	16.25	16.25				
2022-04-07	4	11:30 AM	4 min	17	21.25	21	0.25	0.25	0.011905	0.011905
2022-04-07	4	11:35 AM	4 min	15	18.75	19.25	-0.5	0.5	-0.02597	0.025974
2022-04-07	4	11:40 AM	4 min	19	23.75	23.625	0.125	0.125	0.005291	0.005291
2022-04-07	4	11:45 AM	4 min	18	22.5	22.625	-0.125	0.125	-0.00552	0.005525
2022-04-07	4	11:50 AM	4 min	19	23.75	23.875	-0.125	0.125	-0.00524	0.005236
2022-04-07	4	11:55 AM	4 min	20	25	25.25	-0.25	0.25	-0.0099	0.009901
2022-04-07	4	12:00 PM	4 min	22	27.5	27.625	-0.125	0.125	-0.00452	0.004525

2022-04-07	4	12:05 PM	4 min	23	28.75	28.25	0.5	0.5	0.017699	0.017699
2022-04-07	4	12:10 PM	4 min	19	23.75	23.875	-0.125	0.125	-0.00524	0.005236
2022-04-07	4	12:15 PM	4 min	20	25	27.125	-2.125	2.125	-0.07834	0.078341
2022-04-07	4	12:20 PM	4 min	37	46.25	45.125	1.125	1.125	0.024931	0.024931
2022-04-07	4	12:25 PM	4 min	28	35	35				
2022-04-11	1	11:30 AM	4 min	25	31.25	30.125	1.125	1.125	0.037344	0.037344
2022-04-11	1	11:35 AM	4 min	16	20	21.75	-1.75	1.75	-0.08046	0.08046
2022-04-11	1	11:40 AM	4 min	30	37.5	36	1.5	1.5	0.041667	0.041667
2022-04-11	1	11:45 AM	4 min	18	22.5	23	-0.5	0.5	-0.02174	0.021739
2022-04-11	1	11:50 AM	4 min	22	27.5	26.125	1.375	1.375	0.052632	0.052632
2022-04-11	1	11:55 AM	4 min	11	13.75	15.25	-1.5	1.5	-0.09836	0.098361
2022-04-11	1	12:00 PM	4 min	23	28.75	27.625	1.125	1.125	0.040724	0.040724
2022-04-11	1	12:05 PM	4 min	14	17.5	18.125	-0.625	0.625	-0.03448	0.034483
2022-04-11	1	12:10 PM	4 min	19	23.75	24.875	-1.125	1.125	-0.04523	0.045226
2022-04-11	1	12:15 PM	4 min	28	35	35	0	0	0	0
2022-04-11	1	12:20 PM	4 min	28	35	35.625	-0.625	0.625	-0.01754	0.017544
2022-04-11	1	12:25 PM	4 min	33	41.25	41.25				
2022-04-13	3	9:30 AM	4 min	20	25	24.875	0.125	0.125	0.005025	0.005025
2022-04-13	3	9:35 AM	4 min	19	23.75	25.125	-1.375	1.375	-0.05473	0.054726
2022-04-13	3	9:40 AM	4 min	30	37.5	36.625	0.875	0.875	0.023891	0.023891
2022-04-13	3	9:45 AM	4 min	23	28.75	28.875	-0.125	0.125	-0.00433	0.004329
2022-04-13	3	9:50 AM	4 min	24	30	31.75	-1.75	1.75	-0.05512	0.055118
2022-04-13	3	9:55 AM	4 min	38	47.5	47.25	0.25	0.25	0.005291	0.005291
2022-04-13	3	10:00 AM	4 min	36	45	45.375	-0.375	0.375	-0.00826	0.008264
2022-04-13	3	10:05 AM	4 min	39	48.75	48.375	0.375	0.375	0.007752	0.007752
2022-04-13	3	10:10 AM	4 min	36	45	44.125	0.875	0.875	0.01983	0.01983
2022-04-13	3	10:15 AM	4 min	29	36.25	33.75	2.5	2.5	0.074074	0.074074
2022-04-13	3	10:20 AM	4 min	9	11.25	12.125	-0.875	0.875	-0.07216	0.072165
2022-04-13	3	10:25 AM	4 min	16	20	20				

2022-04-14	4	9:30 AM	4 min	16	20	22.125	-2.125	2.125	-0.09605	0.096045
2022-04-14	4	9:35 AM	4 min	33	41.25	40.5	0.75	0.75	0.018519	0.018519
2022-04-14	4	9:40 AM	4 min	27	33.75	34	-0.25	0.25	-0.00735	0.007353
2022-04-14	4	9:45 AM	4 min	29	36.25	35.875	0.375	0.375	0.010453	0.010453
2022-04-14	4	9:50 AM	4 min	26	32.5	31.625	0.875	0.875	0.027668	0.027668
2022-04-14	4	9:55 AM	4 min	19	23.75	23.625	0.125	0.125	0.005291	0.005291
2022-04-14	4	10:00 AM	4 min	18	22.5	23.875	-1.375	1.375	-0.05759	0.057592
2022-04-14	4	10:05 AM	4 min	29	36.25	36.5	-0.25	0.25	-0.00685	0.006849
2022-04-14	4	10:10 AM	4 min	31	38.75	38.625	0.125	0.125	0.003236	0.003236
2022-04-14	4	10:15 AM	4 min	30	37.5	36.5	1	1	0.027397	0.027397
2022-04-14	4	10:20 AM	4 min	22	27.5	26.625	0.875	0.875	0.032864	0.032864
2022-04-14	4	10:25 AM	4 min	15	18.75	18.75				
2022-04-14	4	11:30 AM	4 min	20	25	25.125	-0.125	0.125	-0.00498	0.004975
2022-04-14	4	11:35 AM	4 min	21	26.25	26	0.25	0.25	0.009615	0.009615
2022-04-14	4	11:40 AM	4 min	19	23.75	23.5	0.25	0.25	0.010638	0.010638
2022-04-14	4	11:45 AM	4 min	17	21.25	22.125	-0.875	0.875	-0.03955	0.039548
2022-04-14	4	11:50 AM	4 min	24	30	29.75	0.25	0.25	0.008403	0.008403
2022-04-14	4	11:55 AM	4 min	22	27.5	26.875	0.625	0.625	0.023256	0.023256
2022-04-14	4	12:00 PM	4 min	17	21.25	22.25	-1	1	-0.04494	0.044944
2022-04-14	4	12:05 PM	4 min	25	31.25	32.125	-0.875	0.875	-0.02724	0.027237
2022-04-14	4	12:10 PM	4 min	32	40	40.625	-0.625	0.625	-0.01538	0.015385
2022-04-14	4	12:15 PM	4 min	37	46.25	44.75	1.5	1.5	0.03352	0.03352
2022-04-14	4	12:20 PM	4 min	25	31.25	33.25	-2	2	-0.06015	0.06015
2022-04-14	4	12:25 PM	4 min	41	51.25	51.25				
2022-04-21	4	9:30 AM	4 min	38	47.5	44.5	3	3	0.067416	0.067416
2022-04-21	4	9:35 AM	4 min	14	17.5	20.125	-2.625	2.625	-0.13043	0.130435
2022-04-21	4	9:40 AM	4 min	35	43.75	43.5	0.25	0.25	0.005747	0.005747
2022-04-21	4	9:45 AM	4 min	33	41.25	38.75	2.5	2.5	0.064516	0.064516
2022-04-21	4	9:50 AM	4 min	13	16.25	17.75	-1.5	1.5	-0.08451	0.084507

2022-04-21	4	9:55 AM	4 min	25	31.25	31.625	-0.375	0.375	-0.01186	0.011858
2022-04-21	4	10:00 AM	4 min	28	35	34.25	0.75	0.75	0.021898	0.021898
2022-04-21	4	10:05 AM	4 min	22	27.5	28.5	-1	1	-0.03509	0.035088
2022-04-21	4	10:10 AM	4 min	30	37.5	36.375	1.125	1.125	0.030928	0.030928
2022-04-21	4	10:15 AM	4 min	21	26.25	27.125	-0.875	0.875	-0.03226	0.032258
2022-04-21	4	10:20 AM	4 min	28	35	34.25	0.75	0.75	0.021898	0.021898
2022-04-21	4	10:25 AM	4 min	22	27.5	27.5				
2022-04-21	4	11:30 AM	4 min	10	12.5	13.625	-1.125	1.125	-0.08257	0.082569
2022-04-21	4	11:35 AM	4 min	19	23.75	23.5	0.25	0.25	0.010638	0.010638
2022-04-21	4	11:40 AM	4 min	17	21.25	22.5	-1.25	1.25	-0.05556	0.055556
2022-04-21	4	11:45 AM	4 min	27	33.75	33.25	0.5	0.5	0.015038	0.015038
2022-04-21	4	11:50 AM	4 min	23	28.75	27.375	1.375	1.375	0.050228	0.050228
2022-04-21	4	11:55 AM	4 min	12	15	15.75	-0.75	0.75	-0.04762	0.047619
2022-04-21	4	12:00 PM	4 min	18	22.5	22.375	0.125	0.125	0.005587	0.005587
2022-04-21	4	12:05 PM	4 min	17	21.25	22.5	-1.25	1.25	-0.05556	0.055556
2022-04-21	4	12:10 PM	4 min	27	33.75	32.375	1.375	1.375	0.042471	0.042471
2022-04-21	4	12:15 PM	4 min	16	20	22.25	-2.25	2.25	-0.10112	0.101124
2022-04-21	4	12:20 PM	4 min	34	42.5	42	0.5	0.5	0.011905	0.011905
2022-04-21	4	12:25 PM	4 min	30	37.5	37.5				
2022-04-25	1	11:30 AM	4 min	15	18.75	18.625	0.125	0.125	0.006711	0.006711
2022-04-25	1	11:35 AM	4 min	14	17.5	18.5	-1	1	-0.05405	0.054054
2022-04-25	1	11:40 AM	4 min	22	27.5	27.75	-0.25	0.25	-0.00901	0.009009
2022-04-25	1	11:45 AM	4 min	24	30	30.625	-0.625	0.625	-0.02041	0.020408
2022-04-25	1	11:50 AM	4 min	29	36.25	34.875	1.375	1.375	0.039427	0.039427
2022-04-25	1	11:55 AM	4 min	18	22.5	23.5	-1	1	-0.04255	0.042553
2022-04-25	1	12:00 PM	4 min	26	32.5	31.375	1.125	1.125	0.035857	0.035857
2022-04-25	1	12:05 PM	4 min	17	21.25	21.875	-0.625	0.625	-0.02857	0.028571
2022-04-25	1	12:10 PM	4 min	22	27.5	28.25	-0.75	0.75	-0.02655	0.026549
2022-04-25	1	12:15 PM	4 min	28	35	34.5	0.5	0.5	0.014493	0.014493

2022-04-25	1	12:20 PM	4 min	24	30	31.625	-1.625	1.625	-0.05138	0.051383
2022-04-25	1	12:25 PM	4 min	37	46.25	46.25				
2022-04-27	3	9:30 AM	4 min	30	37.5	36	1.5	1.5	0.041667	0.041667
2022-04-27	3	9:35 AM	4 min	18	22.5	23.25	-0.75	0.75	-0.03226	0.032258
2022-04-27	3	9:40 AM	4 min	24	30	30	0	0	0	0
2022-04-27	3	9:45 AM	4 min	24	30	30.25	-0.25	0.25	-0.00826	0.008264
2022-04-27	3	9:50 AM	4 min	26	32.5	31.5	1	1	0.031746	0.031746
2022-04-27	3	9:55 AM	4 min	18	22.5	22.125	0.375	0.375	0.016949	0.016949
2022-04-27	3	10:00 AM	4 min	15	18.75	19.875	-1.125	1.125	-0.0566	0.056604
2022-04-27	3	10:05 AM	4 min	24	30	29.25	0.75	0.75	0.025641	0.025641
2022-04-27	3	10:10 AM	4 min	18	22.5	22.625	-0.125	0.125	-0.00552	0.005525
2022-04-27	3	10:15 AM	4 min	19	23.75	22.875	0.875	0.875	0.038251	0.038251
2022-04-27	3	10:20 AM	4 min	12	15	16.75	-1.75	1.75	-0.10448	0.104478
2022-04-27	3	10:25 AM	4 min	26	32.5	32.5				
2022-04-28	4	9:30 AM	4 min	39	48.75	46.75	2	2	0.042781	0.042781
2022-04-28	4	9:35 AM	4 min	23	28.75	29.875	-1.125	1.125	-0.03766	0.037657
2022-04-28	4	9:40 AM	4 min	32	40	37.75	2.25	2.25	0.059603	0.059603
2022-04-28	4	9:45 AM	4 min	14	17.5	18.875	-1.375	1.375	-0.07285	0.072848
2022-04-28	4	9:50 AM	4 min	25	31.25	31.375	-0.125	0.125	-0.00398	0.003984
2022-04-28	4	9:55 AM	4 min	26	32.5	31.25	1.25	1.25	0.04	0.04
2022-04-28	4	10:00 AM	4 min	16	20	19.875	0.125	0.125	0.006289	0.006289
2022-04-28	4	10:05 AM	4 min	15	18.75	19.375	-0.625	0.625	-0.03226	0.032258
2022-04-28	4	10:10 AM	4 min	20	25	25				
2022-04-28	4	11:30 AM	4 min	19	23.75	23.875	-0.125	0.125	-0.00524	0.005236
2022-04-28	4	11:35 AM	4 min	20	25	25	0	0	0	0
2022-04-28	4	11:40 AM	4 min	20	25	24.25	0.75	0.75	0.030928	0.030928
2022-04-28	4	11:45 AM	4 min	14	17.5	17.875	-0.375	0.375	-0.02098	0.020979
2022-04-28	4	11:50 AM	4 min	17	21.25	22	-0.75	0.75	-0.03409	0.034091
2022-04-28	4	11:55 AM	4 min	23	28.75	27.75	1	1	0.036036	0.036036

2022-04-28	4	12:00 PM	4 min	15	18.75	18.75	0	0	0	0
2022-04-28	4	12:05 PM	4 min	15	18.75	19.875	-1.125	1.125	-0.0566	0.056604
2022-04-28	4	12:10 PM	4 min	24	30	29.5	0.5	0.5	0.016949	0.016949
2022-04-28	4	12:15 PM	4 min	20	25	24.625	0.375	0.375	0.015228	0.015228
2022-04-28	4	12:20 PM	4 min	17	21.25	21.25	0	0	0	0
2022-04-28	4	12:25 PM	4 min	17	21.25	21.25				
2022-05-02	1	11:30 AM	4 min	14	17.5	17.75	-0.25	0.25	-0.01408	0.014085
2022-05-02	1	11:35 AM	4 min	16	20	20.125	-0.125	0.125	-0.00621	0.006211
2022-05-02	1	11:40 AM	4 min	17	21.25	20.75	0.5	0.5	0.024096	0.024096
2022-05-02	1	11:45 AM	4 min	13	16.25	16.25	0	0	0	0
2022-05-02	1	11:50 AM	4 min	13	16.25	16.375	-0.125	0.125	-0.00763	0.007634
2022-05-02	1	11:55 AM	4 min	14	17.5	18	-0.5	0.5	-0.02778	0.027778
2022-05-02	1	12:00 PM	4 min	18	22.5	22.375	0.125	0.125	0.005587	0.005587
2022-05-02	1	12:05 PM	4 min	17	21.25	20.875	0.375	0.375	0.017964	0.017964
2022-05-02	1	12:10 PM	4 min	14	17.5	17.875	-0.375	0.375	-0.02098	0.020979
2022-05-02	1	12:15 PM	4 min	17	21.25	20.375	0.875	0.875	0.042945	0.042945
2022-05-02	1	12:20 PM	4 min	10	12.5	13.125	-0.625	0.625	-0.04762	0.047619
2022-05-02	1	12:25 PM	4 min	15	18.75	18.75				
2022-05-05	4	9:30 AM	4 min	27	33.75	32.375	1.375	1.375	0.042471	0.042471
2022-05-05	4	9:35 AM	4 min	16	20	21.875	-1.875	1.875	-0.08571	0.085714
2022-05-05	4	9:40 AM	4 min	31	38.75	36.75	2	2	0.054422	0.054422
2022-05-05	4	9:45 AM	4 min	15	18.75	18.5	0.25	0.25	0.013514	0.013514
2022-05-05	4	9:50 AM	4 min	13	16.25	16.75	-0.5	0.5	-0.02985	0.029851
2022-05-05	4	9:55 AM	4 min	17	21.25	21.25	0	0	0	0
2022-05-05	4	10:00 AM	4 min	17	21.25	21.25	0	0	0	0
2022-05-05	4	10:05 AM	4 min	17	21.25	20.5	0.75	0.75	0.036585	0.036585
2022-05-05	4	10:10 AM	4 min	11	13.75	14.125	-0.375	0.375	-0.02655	0.026549
2022-05-05	4	10:15 AM	4 min	14	17.5	17.625	-0.125	0.125	-0.00709	0.007092
2022-05-05	4	10:20 AM	4 min	15	18.75	18.5	0.25	0.25	0.013514	0.013514

2022-05-05	4	10:25 AM	4 min	13	16.25	16.25				
2022-05-05	4	11:30 AM	4 min	15	18.75	18.125	0.625	0.625	0.034483	0.034483
2022-05-05	4	11:35 AM	4 min	10	12.5	13.25	-0.75	0.75	-0.0566	0.056604
2022-05-05	4	11:40 AM	4 min	16	20	19	1	1	0.052632	0.052632
2022-05-05	4	11:45 AM	4 min	8	10	10.875	-0.875	0.875	-0.08046	0.08046
2022-05-05	4	11:50 AM	4 min	15	18.75	19.625	-0.875	0.875	-0.04459	0.044586
2022-05-05	4	11:55 AM	4 min	22	27.5	26.875	0.625	0.625	0.023256	0.023256
2022-05-05	4	12:00 PM	4 min	17	21.25	21.5	-0.25	0.25	-0.01163	0.011628
2022-05-05	4	12:05 PM	4 min	19	23.75	23.25	0.5	0.5	0.021505	0.021505
2022-05-05	4	12:10 PM	4 min	15	18.75	18.375	0.375	0.375	0.020408	0.020408
2022-05-05	4	12:15 PM	4 min	12	15	15.875	-0.875	0.875	-0.05512	0.055118
2022-05-05	4	12:20 PM	4 min	19	23.75	23.25	0.5	0.5	0.021505	0.021505
2022-05-05	4	12:25 PM	4 min	15	18.75	18.75				
2022-05-11	3	9:30 AM	4 min	16	20	19.875	0.125	0.125	0.006289	0.006289
2022-05-11	3	9:35 AM	4 min	15	18.75	19.5	-0.75	0.75	-0.03846	0.038462
2022-05-11	3	9:40 AM	4 min	21	26.25	26.25	0	0	0	0
2022-05-11	3	9:45 AM	4 min	21	26.25	26.5	-0.25	0.25	-0.00943	0.009434
2022-05-11	3	9:50 AM	4 min	23	28.75	28.75	0	0	0	0
2022-05-11	3	9:55 AM	4 min	23	28.75	28.625	0.125	0.125	0.004367	0.004367
2022-05-11	3	10:00 AM	4 min	22	27.5	26.25	1.25	1.25	0.047619	0.047619
2022-05-11	3	10:05 AM	4 min	12	15	15.75	-0.75	0.75	-0.04762	0.047619
2022-05-11	3	10:10 AM	4 min	18	22.5	22.75	-0.25	0.25	-0.01099	0.010989
2022-05-11	3	10:15 AM	4 min	20	25	25.25	-0.25	0.25	-0.0099	0.009901
2022-05-11	3	10:20 AM	4 min	22	27.5	26.75	0.75	0.75	0.028037	0.028037
2022-05-11	3	10:25 AM	4 min	16	20	20				
2022-05-12	4	9:30 AM	4 min	22	27.5	26.875	0.625	0.625	0.023256	0.023256
2022-05-12	4	9:35 AM	4 min	17	21.25	21.25	0	0	0	0
2022-05-12	4	9:40 AM	4 min	17	21.25	21.75	-0.5	0.5	-0.02299	0.022989
2022-05-12	4	9:45 AM	4 min	21	26.25	25.75	0.5	0.5	0.019417	0.019417

2022-05-12	4	9:50 AM	4 min	17	21.25	21.5	-0.25	0.25	-0.01163	0.011628
2022-05-12	4	9:55 AM	4 min	19	23.75	23.125	0.625	0.625	0.027027	0.027027
2022-05-12	4	10:00 AM	4 min	14	17.5	18	-0.5	0.5	-0.02778	0.027778
2022-05-12	4	10:05 AM	4 min	18	22.5	22	0.5	0.5	0.022727	0.022727
2022-05-12	4	10:10 AM	4 min	14	17.5	18.125	-0.625	0.625	-0.03448	0.034483
2022-05-12	4	10:15 AM	4 min	19	23.75	23.5	0.25	0.25	0.010638	0.010638
2022-05-12	4	10:20 AM	4 min	17	21.25	20.5	0.75	0.75	0.036585	0.036585
2022-05-12	4	10:25 AM	4 min	11	13.75	13.75				

Appendix C: 15-, 30-, and 60-minute Volumes from Manual Data

Table C.1 presents the aggregated 15-, 30-, and 60-minute volumes determined from the manual traffic counts.

Table C.1 15-, 30-, and 60-minute Volumes from Manual Data

Date	Start Hour	Day of Week	15 min 1	15 min 2	15 min 3	15 min 4	30 min 1	30 min 2	60 min
2022-01-31	1130	1	66.125	63.125	90		129.25		
2022-02-07	1130	1	63.25	64.25	85.125	101.125	127.5	186.25	313.75
2022-02-09	930	3	74.125	84			158.125		
2022-02-10	930	4	77.375	76.75	72.875		154.125		
2022-02-10	1130	4	46.875	59.125	94.5	110.75	106	205.25	311.25
2022-02-14	1130	1	63.625	70.5	73.875	86.25	134.125	160.125	294.25
2022-02-16	930	3	84.25	114.75	113.25	70.875	199	184.125	383.125
2022-02-21	1130	1	61.625	71.125	102.25	95.375	132.75	197.625	330.375
2022-02-23	930	3			109.25	80.875		190.125	
2022-02-24	930	4	79.5	73.5			153		
2022-02-24	1130	4	59	66			125		
2022-02-28	1130	1	59.625	66.125	76.125	108.25	125.75	184.375	310.125
2022-03-02	930	3	86.375	92	112.125		178.375		
2022-03-03	930	4	88.75	65.375			154.125		
2022-03-03	1130	4	56.875	64.375	77.5		121.25		
2022-03-07	1130	1	72.875	60.625	83.375	94.625	133.5	178	311.5
2022-03-09	930	3	97	92			189		
2022-03-10	930	4	81.125	81.25	94.125	67.375	162.375	161.5	323.875
2022-03-10	1130	4	60.875	59.625	76.125	94.875	120.5	171	291.5
2022-03-21	1130	1	80.5	73.875	80.625	94.5	154.375	175.125	329.5
2022-03-24	930	4	85.5	113.5	101	78.625	199	179.625	378.625
2022-03-24	1130	4	73.875	81.5	82.25	125.625	155.375	207.875	363.25
2022-03-28	1130	1	96.125	71.875	98	132.125	168	230.125	398.125
2022-03-30	930	3	101.375	109.875	124.5	90	211.25	214.5	425.75
2022-04-04	1130	1	61.875	75.25	91.5	127.25	137.125	218.75	355.875
2022-04-06	930	3	104.375	106.125	104	90.25	210.5	194.25	404.75

2022-04-07	930	4	105.25	104.375	95	62.125	209.625	157.125	366.75
2022-04-07	1130	4	63.875	71.75	79.75	107.25	135.625	187	322.625
2022-04-11	1130	1	87.875	64.375	70.625	111.875	152.25	182.5	334.75
2022-04-13	930	3	86.625	107.875	137.875	65.875	194.5	203.75	398.25
2022-04-14	930	4	96.625	91.125	99	81.875	187.75	180.875	368.625
2022-04-14	1130	4	74.625	78.75	95	129.25	153.375	224.25	377.625
2022-04-21	930	4	108.125	88.125	99.125	88.875	196.25	188	384.25
2022-04-21	1130	4	59.625	76.375	77.25	101.75	136	179	315
2022-04-25	1130	1	64.875	89	81.5	112.375	153.875	193.875	347.75
2022-04-27	930	3	89.25	83.875	71.75	72.125	173.125	143.875	317
2022-04-28	930	4	114.375	81.5	61.75		195.875		
2022-04-28	1130	4	73.125	67.625	68.125	67.125	140.75	135.25	276
2022-05-02	1130	1	58.625	50.625	61.125	52.25	109.25	113.375	222.625
2022-05-05	930	4	91	56.5	55.875	52.375	147.5	108.25	255.75
2022-05-05	1130	4	50.375	57.375	63.125	57.875	107.75	121	228.75
2022-05-11	930	3	65.625	83.875	64.75	72	149.5	136.75	286.25
2022-05-12	930	4	69.875	70.375	58.125	57.75	140.25	115.875	256.125
2022-09-12	1300	1	63.875	71.75	79.25	55.625	135.625	134.875	270.5
2022-09-15	930	4	89.5	70.75	94.75	76.75	160.25	171.5	331.75
2022-09-15	1300	4	74.625	74.375	77.25	72.25	149	149.5	298.5
2022-09-19	1300	1	73.125	69.625	91.375	69.875	142.75	161.25	304
2022-09-21	930	3	103.125	118.5	125.375	84.875	221.625	210.25	431.875
2022-09-22	930	4	87.25	94	74.375	73.75	181.25	148.125	329.375
2022-09-22	1300	4	62.25	63.375	75.375	88.75	125.625	164.125	289.75
2022-09-26	1300	1	66.625	82.875	87	58.75	149.5	145.75	295.25
2022-09-28	930	3	107.25	100.125	120	93.625	207.375	213.625	421
2022-09-29	930	4	90.625	70.625	98.5	71.25	161.25	169.75	331
2022-09-29	1300	4	65.25	64.375	61.25	91	129.625	152.25	281.875
2022-10-03	1300	1	53.625	79.75	92.125	72.125	133.375	164.25	297.625

2022-10-05	930	3	98.25	103.25	135.5	79.125	201.5	214.625	416.125
2022-10-06	1300	4	83.875	85.875	88.5	65.875	169.75	154.375	324.125
2022-10-10	1300	1	52	78.125	88.25	74.875	130.125	163.125	293.25
2022-10-12	930	3	91.75	101	113.25	75.25	192.75	188.5	381.25
2022-10-13	930	4	47.125	49.875	30	59.25	97	89.25	186.25
2022-10-19	930	3	100	109	132.875		209		
2022-10-20	930	4	91	91.5			182.5		
2022-10-20	1300	4	67.375	45.125	60.25	77	112.5	137.25	249.75
2022-10-24	1300	1	59.25	79.625	105.125	64.125	138.875	169.25	308.125
2022-10-27	930	4	93.75	88.25	96.375	91.75	182	188.125	370.125
2022-10-27	1300	4	55.875	60.75	72.25	78	116.625	150.25	266.875
2022-10-31	1300	1	82.25	93.25	99.75	72.25	175.5	172	347.5
2022-11-02	930	3	106.125	118	133.75	96.125	224.125	229.875	454
2022-11-03	930	4	105.5	94.75	123.5	81.5	200.25	205	405.25
2022-11-03	1300	4	67.375	95.625			163		
2022-11-07	1300	1	80.125	75.25	109.125	78.375	155.375	187.5	342.875
2022-11-08	930	3	119.375	112.375	139.875	78.75	231.75	218.625	450.375
2022-11-10	930	4	107.875	87.625	92.5	84.125	195.5	176.625	372.125
2022-11-10	1300	4	77	67.125	75	100.375	144.125	175.375	319.5
2022-11-14	1300	1	77.75	79.375	97.625	82.875	157.125	180.5	337.625
2022-11-16	930	3	109.625	100.5			210.125		
2022-11-17	930	4	104.875	93.625	98.125	71.75	198.5	169.875	368.375
2022-11-17	1300	4			71.5	76.375		147.875	
2022-11-21	1300	1	77.75	82.125	91.625	68.75	159.875	160.375	320.25
2022-11-28	1300	1	64.375	70	95.25	78.375	134.375	173.625	308
2022-11-30	930	3	107.25	116			223.25		
2022-12-01	930	4	104.5	80.75	78.75	73.75	185.25	152.5	337.75
2022-12-01	1300	4	75.125	87.375			162.5		
2022-12-05	1300	1	62.5	77.875	86.375	61.875	140.375	148.25	288.625

2022-12-07	930	3	114.625	107.75	118.125	103.875	222.375	222	444.375
2022-12-08	930	4	85.5	89.875	65.125	71.75	175.375	136.875	312.25
2022-12-08	1300	4	78	79.125	76.75	88	157.125	164.75	321.875

Appendix D: 15-, 30-, and 60-minute Volumes from Video Data

Table D.1 presents the 15-, 30-, and 60-minute volumes determined from bus-based video imagery.

Table D.1: 15-, 30-, and 60-minute Volumes from Video Data

Date	Start Hour	Day of Week	15 min 1	15 min 2	15 min 3	15 min 4	30 min 1	30 min 2	60 min
2022-01-31	1130	1	79.8788	74.5870	100.6751		154.4742		
2022-02-07	1130	1	55.5979	57.6647	72.9440	105.2252	113.2664	178.1790	291.4539
2022-02-09	930	3	58.5742	81.5764			140.1564		
2022-02-10	930	4	74.5295	71.5405	76.7403		146.0756		
2022-02-10	1130	4	40.3487	59.1738	98.4771	114.4986	99.5270	212.9888	312.5288
2022-02-14	1130	1	77.3851	73.3323	103.4682	87.9967	150.7251	191.4762	342.2111
2022-02-16	930	3	69.1469	78.6025	122.4058	89.2243	147.7557	211.6438	359.4119
2022-02-21	1130	1	72.3167	84.5203	115.4489	110.7735	156.8455	226.2361	383.0902
2022-02-23	930	3			93.8501	62.1629		156.0231	
2022-02-24	930	4	81.8650	82.4142			164.2880		
2022-02-24	1130	4	69.2569	69.0769			138.3432		
2022-02-28	1130	1	71.1463	70.5621	68.4220	66.9144	141.7166	135.3486	277.0764
2022-03-02	930	3	84.6814	102.7894	104.0686		187.4826		
2022-03-03	930	4	51.9631	70.9895			122.9602		
2022-03-03	1130	4	62.3560	55.9065	79.5669		118.2678		
2022-03-07	1130	1	34.2634	29.3517	69.5962	94.0902	63.6202	163.6951	227.3221
2022-03-09	930	3	74.4658	76.7352			151.2084		
2022-03-10	930	4	65.2445	77.1661	105.4584	53.4665	142.4167	158.9313	301.3591
2022-03-10	1130	4	43.8389	72.8885	90.5295	90.3683	116.7345	180.9065	297.6490
2022-03-21	1130	1	37.0613	67.5495	80.4595	104.5079	104.6168	184.9764	289.6018
2022-03-24	930	4	87.9663	111.3243	96.1083	78.0901	199.3017	174.2092	373.5232
2022-03-24	1130	4	58.9645	60.0159	111.5473	99.3533	118.9851	210.9136	329.9070
2022-03-28	1130	1	84.2314	72.9680	95.5148	111.1672	157.2114	206.6961	363.9144
2022-03-30	930	3	114.9032	125.0996	144.7708	80.4328	240.0141	225.2154	465.2465

2022-04-04	1130	1	57.9529	89.7685	101.5647	112.1614	147.7313	213.7381	361.4783
2022-04-06	930	3	55.5016	89.4543	60.3315	95.8747	144.9625	156.2173	301.1883
2022-04-07	930	4	99.9659	87.8341	108.8960		187.8118	215.4898	403.3098
2022-04-07	1130	4	53.1478		50.7855	130.2543	77.9413	181.0501	258.9950
2022-04-11	1130	1		83.2856	83.9469	90.6915	192.0486	174.6494	366.7064
2022-04-13	930	3	81.7611	103.4226	109.4474	71.4243	185.1915	180.8843	366.0887
2022-04-14	930	4	58.5264	68.8819	59.4296	56.8658	127.4175	116.3046	243.7266
2022-04-14	1130	4	64.4469	70.6633	110.5563	101.3249	135.1169	211.8937	347.0164
2022-04-21	930	4	92.2585	90.9642	88.4731	92.2558	183.2302	180.7391	363.9850
2022-04-21	1130	4	43.4958	35.2985	66.6302	135.1200	78.7996	201.7578	280.5611
2022-04-25	1130	1		75.8307	56.9541	93.4954	156.9077	150.4544	307.3698
2022-09-12	1300	1	59.1858	68.3495	54.8308	82.2729	127.5425	137.1121	264.6616
2022-09-15	930	4	95.2973	55.4217	49.2785	95.3214	150.7274	144.6080	295.3414
2022-09-15	1300	4	97.7509	94.4457	118.2834	62.4030	192.2083	180.6944	372.9127
2022-09-19	1300	1	102.3645	98.7841	97.8007	87.1251	201.1593	184.9408	386.1092
2022-09-21	930	3	95.9021	134.5031	100.6204	80.8783	230.4191	181.5084	411.9420
2022-09-22	930	4	114.0060	107.6085	68.8772	78.1868	221.6269	147.0741	368.7094
2022-09-26	1300	1	85.1885	65.5918	75.0445	63.2135	150.7915	138.2652	289.0635
2022-09-28	930	3	105.2147	76.1991	122.2871	108.7064	181.4274	231.0073	412.4441
2022-09-29	930	4	115.2727	86.8683	113.2467	114.5853	202.1501	227.8467	430.0073
2022-09-29	1300	4	73.5259	48.3518	48.2460	54.7599	121.8833	103.0087	224.8979
2022-10-03	1300	1	46.4321	42.3448	65.2629	75.5215	88.7828	140.7924	229.5772
2022-10-05	930	3	87.1506	66.8339	104.3881	69.4960	153.9909	173.8951	327.9000
2022-10-06	1300	4	49.0442	79.6831	71.6091		128.7359	143.2889	272.0315
2022-10-10	1300	1	81.3203	119.3083	104.6067	103.1959	200.6411	207.8180	408.4727
2022-10-12	930	3	105.7911	72.6861	97.9135	84.2915	178.4884	182.2186	360.7137
2022-10-19	930	3	113.1123	164.1837	164.0294		277.3103		

2022-10-20	930	4	116.2687	41.1780			157.4544		
2022-10-20	1300	4	56.8881		88.0053	96.3537	142.8023	184.3698	327.1832
2022-10-24	1300	1	63.9365	116.7417	96.7979	58.8973	180.6850	155.7123	336.4095
2022-10-27	930	4	99.8943	90.5843	123.9129	76.3233	190.4864	200.2441	390.7430
2022-10-27	1300	4	54.2621	77.6767	95.5071	89.4595	131.9454	184.9772	316.9307
2022-10-31	1300	1	85.7978	74.9102	107.2894	73.7518	160.7153	181.0578	341.7823
2022-11-07	1300	1	85.2939	95.8385	128.9925	106.9240	181.1446	235.9336	417.0880
2022-11-10	930	4	133.8656	81.2865	104.6237	94.9945	215.1637	199.6310	414.8027
2022-11-10	1300	4	63.7204	51.9259	62.0360	93.2553	115.6521	155.2975	270.9566
2022-11-14	1300	1	68.2645	68.7162	106.2287	94.7841	136.9865	201.0242	338.0198
2022-11-16	930	3	76.1451	116.8195			192.9755		
2022-11-17	930	4	14.9983	14.9983	14.9983	14.9983	29.9983	29.9983	59.9983
2022-11-17	1300	4			69.3611	58.2617		127.6300	
2022-11-21	1300	1	54.2478	76.4554	90.9780	73.8723	130.7096	164.8605	295.5819
2022-11-28	1300	1	81.7237	57.5686	93.4028	81.3596	139.2995	174.7707	314.0784
2022-11-30	930	3	104.7622	89.4025			194.1734		
2022-12-01	930	4	86.8180	97.5773	81.0606	44.5012	184.4037	125.5706	309.9830
2022-12-01	1300	4	80.9702	55.1136			136.0922		
2022-12-05	1300	1	78.7676	99.9813	96.8478	56.1430	178.7588	153.0000	331.7695
2022-12-07	930	3	127.9995	97.8154	150.8861	132.7373	225.8282	283.6374	509.4788