Statistical Analysis of Electric Vehicle Charging Traffic and Charging Station Electrical Demand

Shi Huang

University of British Columbia

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Terry Shi Huang

Technical Supervisor: Dr. Vincent Wong
Direct Supervisor: Dr. Paul Lusina

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ABSTRACT

Electric vehicles (EVs) have a great potential to reduce greenhouse gas (GHG) emissions. As a step towards the goal of reducing GHG emissions to zero, UBC Vancouver campus has initiated its EV fleet. This project provides estimations of the utilization rate, rejection rate, station capacity, and electrical demand of the EV system at UBC through the analysis of the UBC EV charging session data and the power consumption data. An M/M/k/k queuing model was adopted to facilitate the UBC EV charging traffic analysis. In addition, to help British Columbia assess its public EV usage behaviours, analysis of EV charging session data retrieved from seven different locations across the province was made in the last phase of the project. This includes the graphical and numerical presentation of arrival frequency, occupancy frequency, service duration, and energy consumption. Statistical analysis software such as RStudio, STATA, and Microsoft Excel, was used to generate tables and plots in this report. Suggestions for future development of the project include increasing active EV number in the system, and developing a study to practically estimate the correlation between EV number and EV arrival rate.

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LIST OF ABBREVIATIONS

EV	Electric Vehicle
SOC	State of Charge
GHG	Greenhouse Gases
KW	Kilowatt
PDF	Probability Density Function
PMF	Probability Mass Function
USB	University Services Building
UBC	The University of British Columbia

1.0 INTRODUCTION

This report presents a statistical analysis of the UBC and provincial EV charging traffic data and the UBC charging station power consumption data. My objectives throughout the report are to produce a statistical model for the UBC EV charging traffic, estimate the University Services Building (USB) Station system capacity, calculate and graphically present the UBC charging station electrical demand, and analyze the provincial EV cloud data.

Electric vehicles were first introduced in the late-19th century, but it is until now that they have truly stepped into our day-to-day life. Governments, institutions, environmental organizations, and corporations have realized the potential of EV implementations in GHG emission reduction. Being one of the leading educational institutions, UBC has brought EVs to its vehicle fleet. The results of the EV charging traffic model will provide support for generating optimal EV charging schedules and estimate the UBC charging station capacity. The outcomes of the charging station electrical demand calculation will provide UBC Utilities with information on how the expansion of an EV fleet will impact the existing electrical grid infrastructure. The analysis of the provincial EV cloud data will help the province capture specific public EV usage characteristics.

The project began with a preliminary study of the UBC EV charging session data. A feasible time window of interest was selected based on the results of the preliminary study. Average EV service time and service rate in the time window of interest were calculated. Using the EV service rate and the arrival rate, an M/M/k/k queuing model was constructed and the utilization and rejection rates of the UBC EV system were produced. Consequently, the capacity of the UBC EV system was also estimated. By generating a STATA script to statistically treat the EV power consumption data, the per-station and aggregate electrical demand plots at Kaiser and USB stations were produced. The maximum power consumption at these two locations was then estimated. Lastly, with the plots of EV arrival frequency, occupancy frequency, service duration, and energy consumption, the provincial EV usage characteristics were analyzed and contrasted. As UBC currently has a comparatively small number of EVs, an EV queue was not able to be formed. Therefore, a multi-server no-queue queuing model was chosen for the UBC EV charging traffic modelling. In addition, due to time constraints, the EV arrival rate was assumed to be proportional to the EV number in the estimation of the USB Station system capacity. This report divides into the following primary sections: equipment and methodology, designs and experiments, results, and conclusions.

2.0 EQUIPMENT AND METHODOLOGY

2.1 Equipment/Software

The statistical analysis software used in this project includes RStudio, STATA, and Microsoft Excel. RStudio was used to generate scripts to plot the PMFs of the EV arrivals and departures for the preliminary study of the UBC EV charging traffic data. It was also used to plot the hourly Poisson distribution density function of the EV arrivals. STATA was used to calculate the hourly EV arrival rates and mean service time, plot the occupancy histograms of EV charging stations, and process the electrical demand data at 15-min intervals. The M/M/k/k Queuing Model configured in Microsoft Excel was adopted to calculate the utilization and rejection rates of the UBC EV system and plot the utilization rate and rejection rate diagram.

2.2 Methodology

This section discusses the tasks involved in the completion of the project. The first task emerged was a preliminary study of the UBC EV charging session data. The preliminary analysis unveiled several types of EV charging sessions containing biased and inaccurate data sets. After removing these sessions from the original data, the PMF plots of the EV arrivals and departures were generated to exam the specific patterns of UBC EV charging traffic. Section 3.1 discusses the details of the preliminary study.

The second task was to determine and set up a suitable statistical model for the UBC EV charging traffic. Dr. Lusina recommended using a queuing model to model the EV behavior. As described in *Fundamentals of Queuing Systems*, an M/M/k/k queuing model can be applied to systems with multi servers and no queue [1]. The UBC EV charging traffic specifically resembles the characteristic of the M/M/K/K model as no queue has been formed based on the data retrieved from the UBC charging stations. The detailed approach of calculating the arrival rate and service rate, two parameters of the queuing model, is discussed in section 3.2.

The third task involved a data analysis of the aggregate and per-station electrical demand at 15-min intervals for the stations at University Services Building and Kaiser Building. The 15-min-cycle power consumption data of all the charging sessions was retrieved from Chargepoint. The task was to generate a STATA script to visualize and plot the per-station and aggregate average electrical demand. Detailed procedure of this analysis is discussed in section 3.3.

The fourth task was to analyze the provincial EV data retrieved from seven different locations in BC by using the similar techniques derived from analyzing the UBC data. Section 3.4 is an elaboration of this task.

3.0 DESIGNS AND EXPERIMENTS

3.1 Preliminary Analysis of UBC EV Charging Traffic

In the preliminary study, ambiguous and inaccurate charging sessions such as zero energy consumption session, “Holster Plugin” session, and “Timeout” session were identified and removed from the original data set. In addition, since Thunderbird Station is used as a pubic charging station, the charging session data at this location were also removed. As Kaiser Station had been only used for research purposes, the charging sessions at this location could not represent the general EV system usage. Therefore, only the data sets at USB location are interested to this study. Two PMF plots of the hourly EV arrivals and departures at USB location are shown below in Figure 1 and Figure 2 respectively. The R script for generating these two plots is attached in Appendix B Part 1.

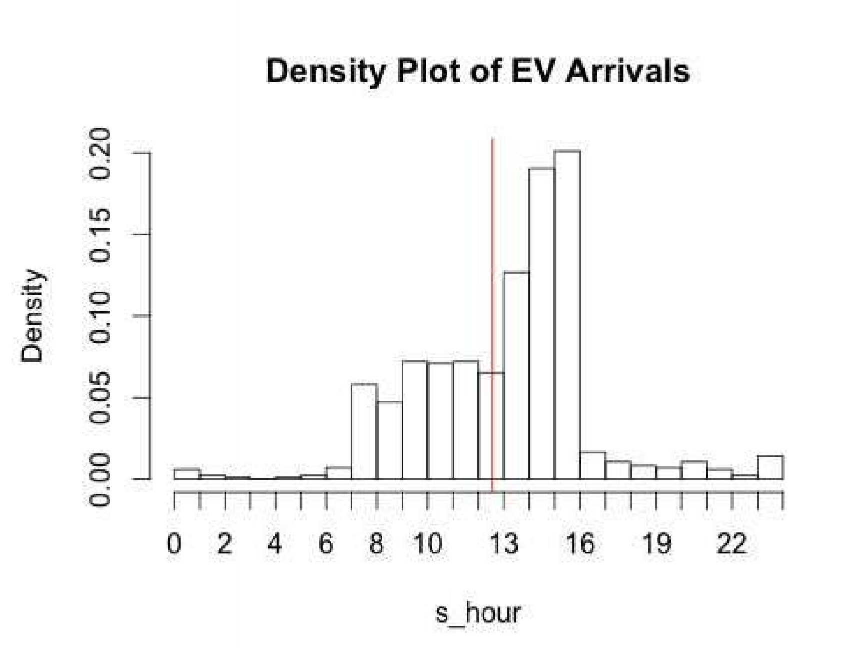

Figure 1: PMF of UBC EV Arrivals

The PMF of EV Arrivals is negative (left) skewed with mean (indicated with red line) at 12:34 pm. Most of the plug-in events happened in day time and reached its peak between 3 and 4 pm. The PMF of EV Departures is positive (right) skewed with mean (indicated with green line) at 9:51 am. Most of the plug-out events also happened in day time and reached its peak between 7 and 8 am.

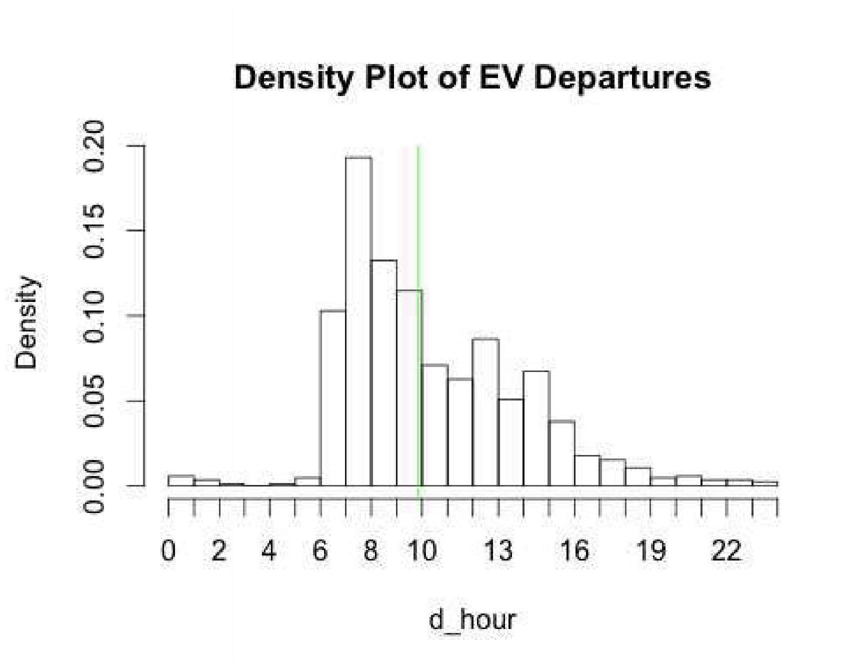

Figure 2: PMF of UBC EV Departures

As shown in these two PMF plots, the EV charging traffic activities mainly happened between 6:00 am to 6:00 pm. This set up the time window of interest for the project.

Table 1: Daily Arrival Rate of UBC EV

Weekday	Number of Arrivals	Rate of Arrivals
1	130	2.879747
2	174	3.85443
3	158	3.5
4	169	3.743671
5	179	3.96519
6	21	0.46519
7	9	0.199367

The daily EV arrival rates, shown in Table 1, were also calculated to exam the day-to-day EV charging traffic behaviour differences. As expected, the arrival rates on the weekends were significantly lower than the rates on the weekdays, which further narrowed down the range of interested data to the charging sessions happened between 6 am and 6 pm on weekdays. The STATA script for calculating the daily EV arrival rates can be found in Appendix B Part 2.

3.2 Calculation of Arrival Rate and Average Service Time

By only considering the charging sessions happened from 6 am to 6 pm on weekdays, I created a new STATA script to calculate the 6am-to-6pm hourly EV arrival rate at USB location for the past 365 days. Table 2 below presents the Rate of Arrivals in the time window of interest.

Table 2: 6am-to-6pm Hourly EV Arrival Rate

Time	Number of Arrivals	Rate of Arrivals
6-7	6	0.018461538
7-8	49	0.150769234
8-9	41	0.126153842
9-10	60	0.184615389
10-11	59	0.181538463
11-12	57	0.175384611
12-13	55	0.169230774
13-14	111	0.341538459
14-15	160	0.492307693
15-16	168	0.51692307
16-17	12	0.036923077
17-18	9	0.027692307

Since the occurrence rate of EV arrivals follows a Poisson distribution, 12 Poisson PMF plots for the 6am-to-6pm hourly EV arrivals were generated. As all of the arrival rates are comparatively low, all 12 plots process similar patterns. The Poisson PMF plot for EV arrival occurrence between 3 am and 4 am is presented in Figure 3 below as an example. During the busiest EV arrival hour, the probability of having 2 arrivals is around 8% and the probability of having 3 arrivals is almost zero. This implied that the existing EV system was operating under its capacity. The re ults of EV charging traffic modelling discussed in section 4.1 confirmed this implication. The rest of the Poisson PMF plots can be found in Appendix A Part I. The R script for generating Poisson PMF plots is attached in Appendix B P rt 6.

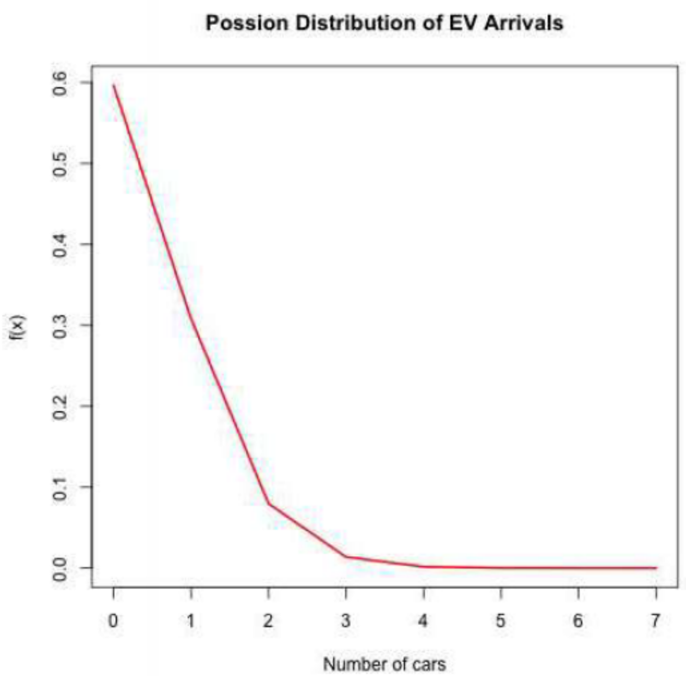

Figure 3: Poisson PMF Plot of EV Arrival Occurrence between 3pm and 4pm

Based on the hourly rate f arrivals, different arrival rates for larger time windows can be easily calculated b adding the corresponding hourly rates in the specified time window. The selection of an appropriate time window directly depends on the size of the average E service time since the average service time has to be smaller than the chosen ti ne window. By examining the service duration data, I found that a number of EVs had been left idle in the charging stations over 300 hours. An even larger am unt of EVs were plugged-in over 24 hours. Such EV behaviours resulted in an unreasonably large average service time and a considerably small service rate. As suggested by Dr. Lusina, 90% quantile of the EV charging session data was taken to mitigate the impact of these unusual EV behaviours. After discarding the top 10% service duration data, the calculated mean service time decreased to 9.17 hours. Considering the interested time window is only from 6:00 am to 6:00 pm, I further reduced the mean service time by subtracting the time outside of the interested time window from all the service sessions. The average service time resulting from this approach was calculated to be 3.414 hours. With this reasonable mean service time and the hourly arrival rates, a queuing model for the EV charging traffic can be set up. The STATA script for the above calculation can be found in Appendix B Part 3. The results of the EV traffic queuing model and the estimated capacity of USB Station are presented in section 4.1 of the report.

3.3 Procedure of Calculating the EV Station Electrical Demand

The energy consumption data retrieved from Chargepoint is a record tracking the rolling average power delivered by the charging ports at 15-min intervals. For an ideal one-hour-long charging session, the charging station server stores the rolling average power of the session respectively at 0-15min, 15-30min, 30-45min, and 45-60min. Therefore, the total electrical demand is spread over 96 15-min time slots in a day. Prior to sorting the energy consumption data, an excel file containing 96 time slots was manually prepared. By fitting the per-port rolling average power data into the 96 corresponding time slots, a 15-min-cycle aggregate electrical demand for each port of all the stations was produced. The 15-min-cycle per-port average electrical demand was generated by dividing the per-port aggregate electrical demand by the total number of active sessions in the corresponding 15-min time slots. Then the average electrical demand of different ports at common stations was summed to produce the per-station average electrical demand plots. Lastly, the USB aggregate demand was processed by adding up all the per-station average demand at the USB location. The Kaiser building per-port demand is equivalent to its per-station demand since only one port was available at this location. The STATA script for generating the electrical demand plots is attached in Appendix B Part 4. Results of this task are presented in section 4.2 of the report.

3.4 Provincial EV Cloud Data Analysis

In the provincial EV Cloud data analysis, the PMF plot of EV arrivals, frequency plot of station occupancy, frequency plot of service duration, and frequency plot of energy consumption were generated for each of the seven locations. Also, the mean, standard deviation, minimum, and maximum values of the service duration time and session energy consumption for all of the seven provincial locations were calculated and contrasted. Results of this part of the analysis are presented in section 4.3 of the report. The STATA script for generating the plots can be found in Appendix B Part 4.

4.0 RESULTS

4.1 UBC EV Charging Traffic Modeling Results

Because the calculated UBC EV average service time is 3.414 hours, a 4-hour time window was selected to model the EV charging traffic. The service rate in the 4-hour time window was calculated to be 1.1716 (4x1/3.414). Since we were interested in the EV behaviour in the busiest consecutive 4 hours, the hourly arrival rates from 12:00 pm to 4:00 pm in Table 2 were chosen to calculate the aggregate arrival rate in the 4-hour time window. The aggregate arrival rate was calculated to be 1.52 vehicle/4hour. By adopting the queuing model calculator from the website of California State University Northridge [2], a series of results were generated and listed in Table 3.

Table 3: Queuing Model Results

Inputs			
	Unit of time	4 hour	
	Arrival rate (lambda)	1.52000000	customers per
	Service rate (mu)	1.171646163	customers per
	Number of identical servers (s)	10	Servers
	Buffer (waiting room) size	0	waiting room
Outputs			
	Direct outputs from inputs		
	Mean time between arrivals	0.658	X 4 hours
	Mean time per service	0.8535	X 4 hours
	Traffic intensity	0.129732	
Summary measures			
	Average utilization rate of servers	13.0%	
	Average number of customers waiting in line (Lq)	0.0000	customers
	Average number of customers in system (L)	1.2973	customers
	Average time waiting in line (Wq)	0.0000	X 4 hours
	Average time in system (W)	0.8535	V
	Probability of no customers in system (P0)	0.2733	(Probability of empty system)
	Probability of rejecting a customer (balking rate)	0.00%	(Reject rate)
	Effective arrival rate	1.51999845	(Entering rate)

As shown in Table 3, the average utilization rate of the charging stations is 13% and the probability of rejection is zero. This illustrates that the UBC EV system has been operating under its capacity. Since only 10 Smart Fortwo EVs were using the USB charging stations (10 charging ports) in the past 365 days, there was no congestion formed in the system. By assuming that the relationship between the total number of active EVs and the arrival rate is proportional, I generated a plot depicting the impact of increased EVs on the utilization and rejection rates. As shown in Figure 4, an increase of the rejection rate will be expected if the charging system reaches its potential capacity of 30 EVs. That is to say, we will probably see a moderate congestion in the system with 30 active EVs based on the assumption that the arrival rate is proportional to the number of EVs.

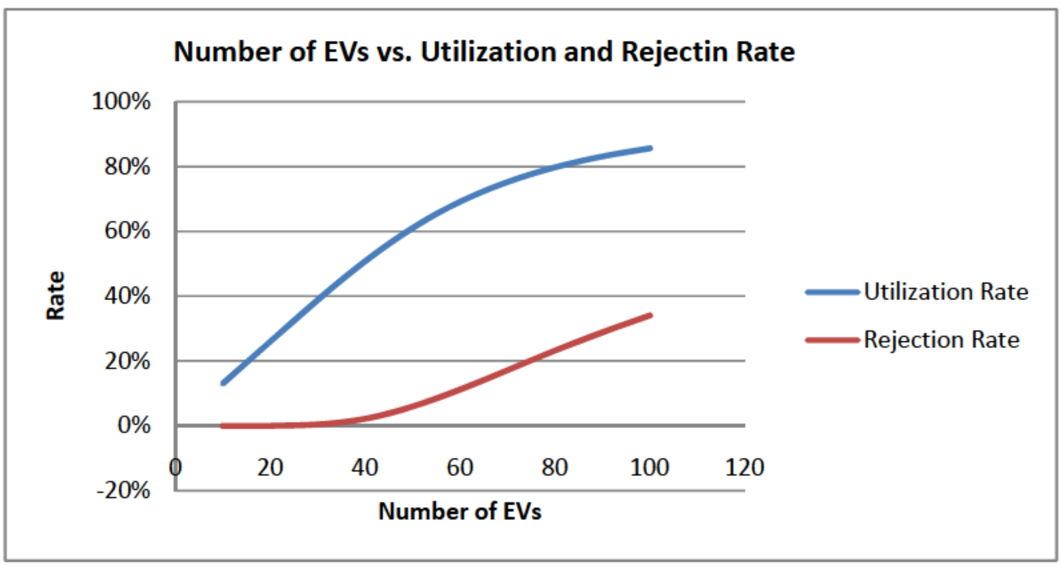

Figure 4: Impact of EV Number on Utilization Rate and Rejection Rate

Figure 5 below shows the occupancy frequency at USB station over the past 365 days. It can be interpreted that the system almost remained idle from 9:00 am to 12:30 pm as only a small portion of the EVs were plugged in during this time. Also, the occupancy frequency plot concurs with the plots of EV arrivals and departures shown in Figure 1 and 2, as an increase in EV departures results in a decrease in station occupancy and an increase in EV arrivals results in a consequent increase in station occupancy. The STATA script for plotting the occupancy frequency can be found in Appendix B Part 3.

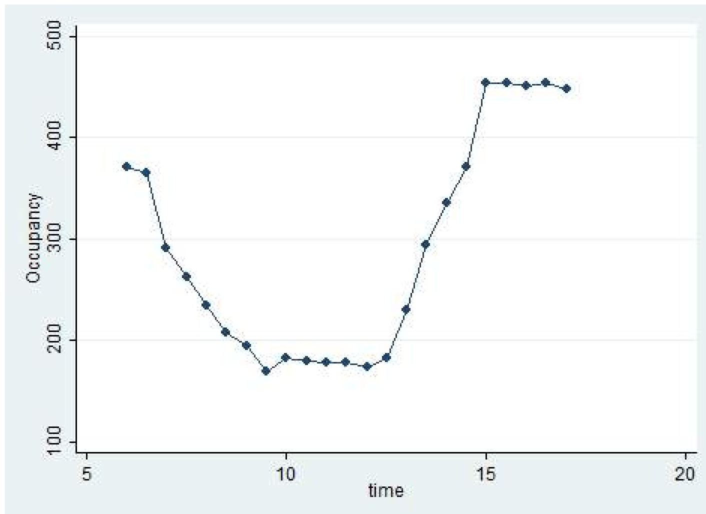

Figure 5: Frequency Plot of USB Station Occupancy

4.2 Results of EV Station Electrical Demand Calculation

The aggregate average electrical demand (in KW) of Kaiser Station and USB Station is presented in this section. The Time_15min axis in the plots is marked according to the corresponding time slot. As aforementioned in section 3.3, the time over 24 hours was divided into 96 slots in order to fit in the 15-min-cycle session power consumption data. Therefore, the n^{th} time slot in the graph repents the time period at n times 15 minutes to n+1 times 15 minutes.

The average electrical demand (in KW) at Kaiser Station for the past 365 days is depicted in Figure 6 below. Because this station has barely been used in the past year, the average electrical demand shown in the plot is fairly low compared to other stations at USB. The spike at the end of the plot is due to a “high-demand” session happened on February 8, 2014 between 23:45 to 23:59. The rolling average power was recorded as 48.414 KW during this 15-min period. This abrupt high energy consumption might be caused by a system error. Nonetheless, in spite of the presence of the spike, it is still clear to see that the maximum electrical demand at this station was around 4 KW over the past year.

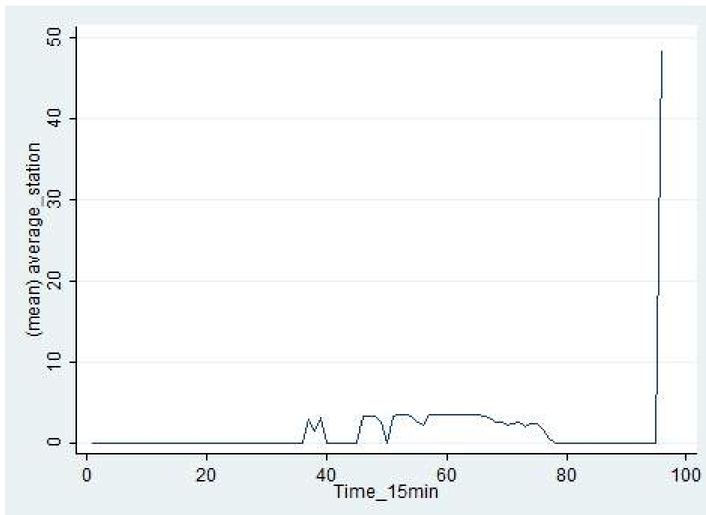

Figure 6: Kaiser Station Electrical Demand

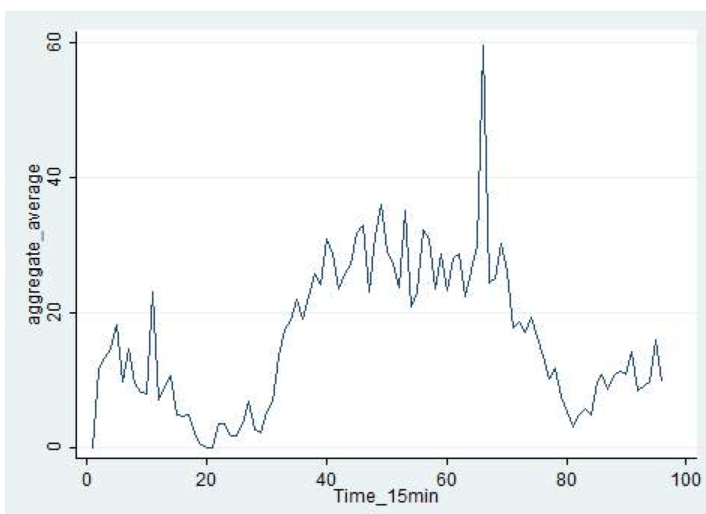

Figure 7: USB Station Aggregate Electrical Demand

Figure 7 above shows the aggregate electrical demand (in KW) at USB Station. Similar to the Kaiser Station case, a "high-demand" session with 34.43 KW rolling average power at USB station 4 caused the spike in the graph. Regardless of the spike, the plot shows a maximum aggregate electrical demand around 35 KW over the past 365 days. The per-station electrical demand at USB location can be found in Appendix A Part 2.

4.3 Results of Provincial EV Cloud Data Analysis

The provincial EV charging traffic data provided by Powertech was collected from seven different locations in British Columbia. As shown in Table 4 below, location

Table 4: Service Duration and Energy Consumption Summary of the Provincial EV Cloud Data

Location Number	Location Type	Service Duration (hrs)				Energy Consumption (KWh)			
		Mean	Std.Dev.	Min	Max	Mean	Std.Dev.	Min	Max
1	Restaurant /Market	1.667	1.498	0	11.57	4.895	4.564	0	24.36
2	Mall	1.608	1.329	0.000556	8.876	5.110	4.085	0	22.58
3	Mall	1.345	1.323	0.00139	9.112	3.938	3.492	0	25.14
4	Mall	1.846	1.610	0	11.23	6.431	7.941	0	54.72
5	Munipall Hall /Library	2.639	4.472	0.00139	23.28	6.216	5.685	0	63.21
6	Community Centre/Pool	2.649	1.878	0.00194	11.50	7.487	5.052	0	48.33
7	Municipall Hall/Library	2.837	4.344	0.00833	23.74	6.161	4.723	0	24.30

5, 6, and 7 have higher mean service duration than that of location 1, 2, 3, and 4. Locations 4, 5, 6, and 7 have slightly higher average energy consumption than that of location 1, 2, and 3. These may be caused by the demographic peculiarities of the users using the charging stations. Though each location has a different usage characteristic, the plot shapes of hourly arrival rate, station occupancy, service duration, and energy consumption at different locations all bear similar patterns. All of the aforementioned plots of location 1 are shown below as an example of the provincial EV charging traffic characteristic. The plots of the other locations can be found in Appendix A Part 3.

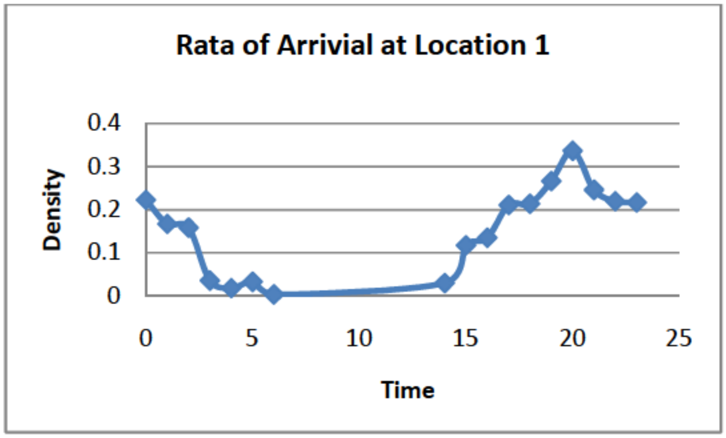

Figure 8: PMF of Arrival Rate at Location 1

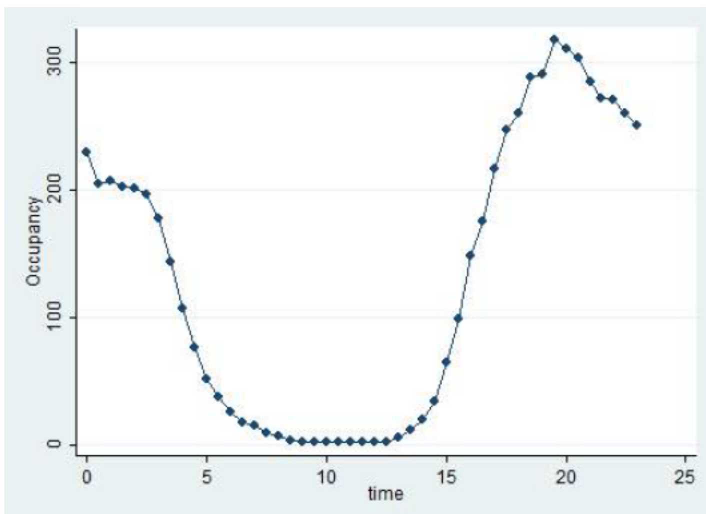

Figure 9: Frequency Plot of Station Occupancy at Location 1

Both Figure 8 and Figure 9 have their peaks centered at 8:00 in the afternoon, which indicates an EV charging traffic “rush hour” around that time. Moreover, both graphs unveil that the charging stations were mostly idle between 8:00 am and 12:30 pm as almost no EV was plugged in during this time period. The resemblance of the PMF of arrival rate and the station occupancy frequency plot is due to the short service duration at this location. As shown in Figure 10 below, most of the EVs at this location were only plugged in for a couple of hours.

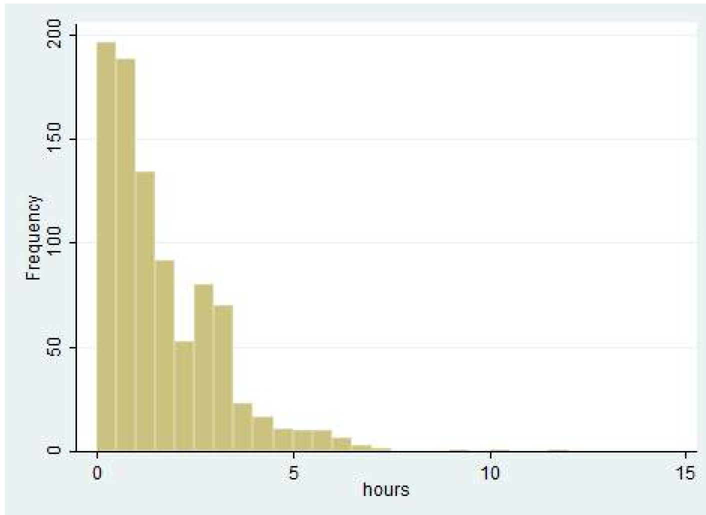

Figure 10: Frequency Plot of Service Duration at Location 1

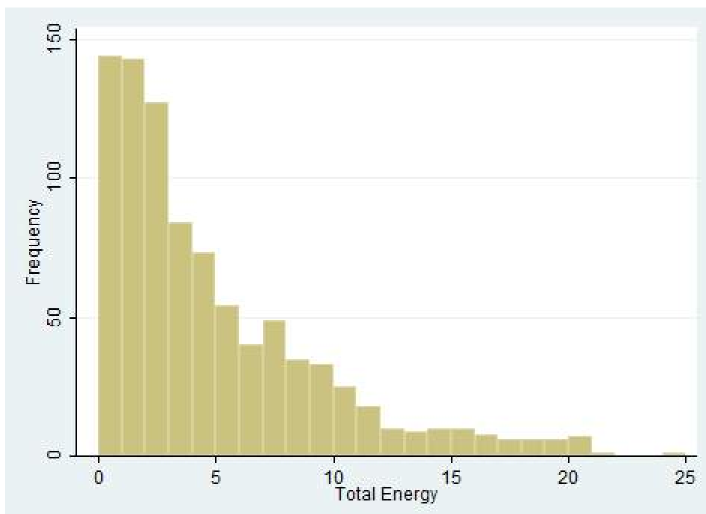

Figure 11: Frequency Plot of Energy Consumption at Location 1

The shape of the energy consumption plot in Figure 11 greatly resembles the shape of the service duration plot. This implies a possible propotional relationship between the session service time and the seesion energy consumption. In other words, the charging power at this location very likely remained constant or stable during all the charging sessions. According to Mr. Dan Oshea, and Mr. Jeremy Hall from Chargepoint, EV charging power normally remains constant when the EV SOC is below 80%. Being said that the charging power at location 1 was stable, it can be interpreted that the SOC of EVs coming to this location was most likely below 80%.

4.4 Overall Performance

The overall performance of the project was fairly well as I have completed all the assigned tasks within the specified deadlines. Although the project objectives varied along the evolvement of the project, all of them were successfully achieved. The achieved objectives include estimation of the USB Station system capacity through UBC EV charging traffic modeling, UBC charging station electrical demand calculation, and provincial EV cloud data analysis. Minor issues in generating the scripts for the data analysis and calculating the reasonable average service time were encountered, but all of them were satisfyingly overcome.

4.5 Suggestions for Future Development

The suggestion for future development could be having more active EVs employed in the system. The charging session data studied in this project only represents the usage of 10 EVs. With 10 charging ports available, an EV charging traffic queue could not be formed. Another suggestion could be a study of the relationship between the number of active EVs and the EV arrival rate. Due to time constraints, the assumption of a proportional relationship between the EV number and the EV arrival rate was made to estimate the system capacity of USB Station. However, a different correlation of the number of active EVs and the EV arrival rate could result in a dramatically different estimated system capacity.

5.0 CONCLUTIONS

This report investigated the UBC EV charging session data, the UBC EV power consumption data, and the provincial EV charging session data. The project objectives included modelling the UBC EV charging traffic, estimating the USB Station system capacity, calculating and presenting the UBC charging station electrical demand, and analyzing the provincial EV cloud data.

The study of UBC EV charging session data focused on the charging events happened from 6 am to 6 pm on weekdays. A 4-hour time window was selected to compensate the 3.414-hour average service time. As a result of applying the M/M/k/k queuing model, the utilization rate and rejection rate of USB Station over the busiest consecutive 4 hours were estimated to be 13% and 0% respectively. By assuming a proportional relationship between the number of EVs and the EV arrival rate, it was estimated that the current system at USB could compensate around 30 EVs with 0% probability of rejection.

In the EV station electrical demand calculation, average power consumption over 96 15-min time slots was first generated in a per-port manner. Then the consumption at different port under the same station was summed to generate the per-station average power consumption. In the end, consumption of stations at the same location was added to form the aggregate electrical demand over 24 hours. The maximum electrical demand at Kaiser Station and USB Station was estimated to be 4 KW and 35 KW respectively.

Through the comparison of service time and energy consumption at seven different locations in the analysis of provincial EV cloud data, location 5, 6, and 7 were estimated to have longer service time and higher energy consumption while location 4 was unveiled with shorter service time and higher energy consumption. Most of the EVs charging sessions at location 1 are within 2 hours. The resemblance of service time and energy consumption plots implied that the SOC of EVs charging at location 1 were fairly low.

For the continuation or future development of the project, more EVs could be added into the system to produce a more intact data set for developing a queuing model with queues. Moreover, a study of the correlation between EV number and EV arrival rate could be developed to derive a more practical function of EV arrival rate with EV number as the variable and estimate the capacity of the UBC EV charging stations more accurately.

REFERENCES

[1] Nick T. Thomopoulos, “Multi Servers, No Queue,” in *Fundamentals of Queuing Systems,* New York: Springer, 2012, pp. 57-60.

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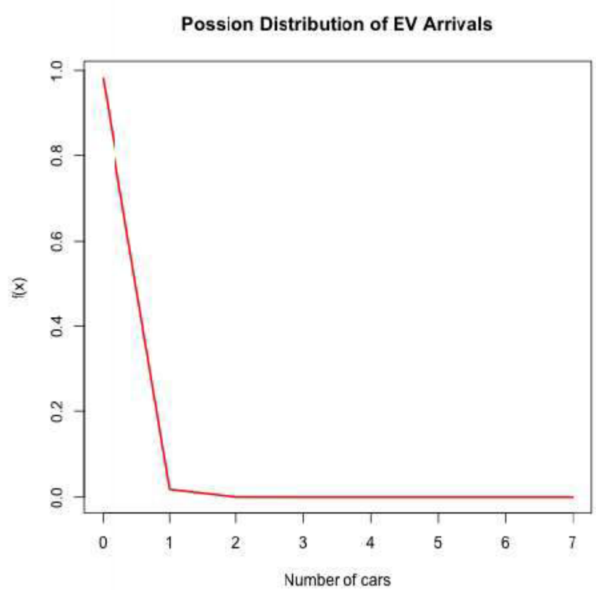
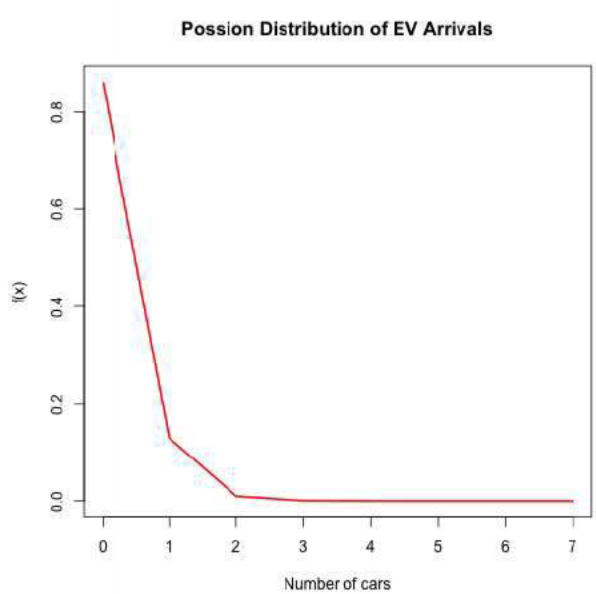
APPENDIX A: PLOTS

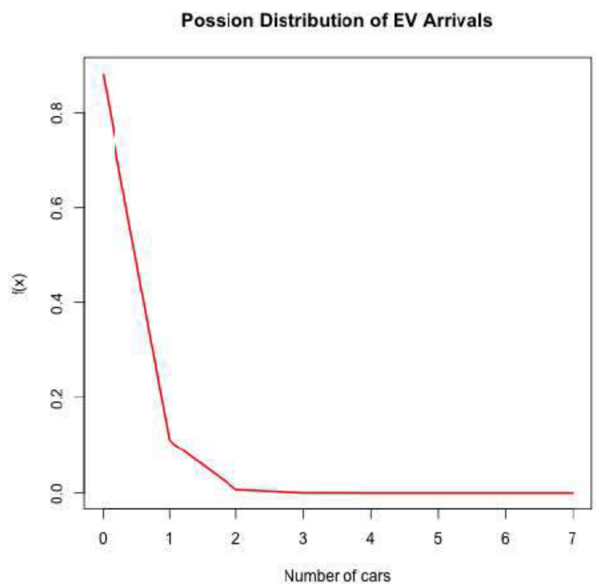
Part 1: Poisson PMF Pl ts of EV Arrivals



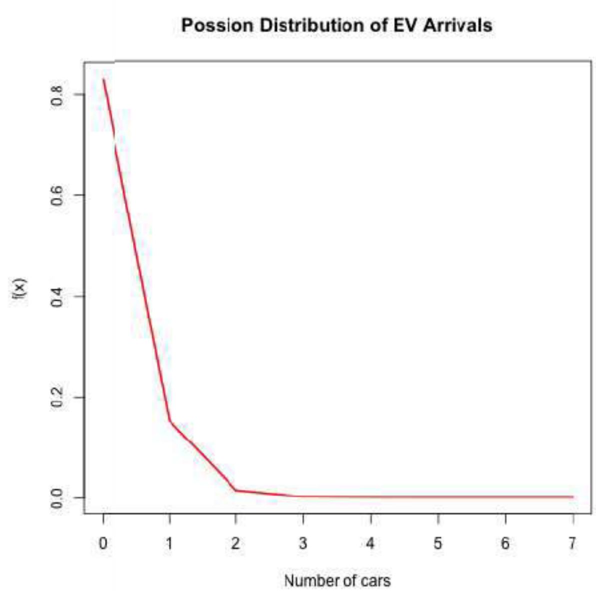
6am – 7am



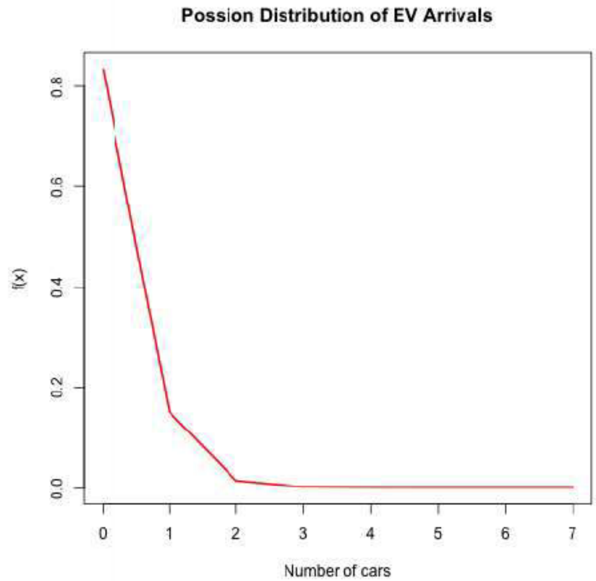
7am – 8am



8am – 9am



9am – 10am



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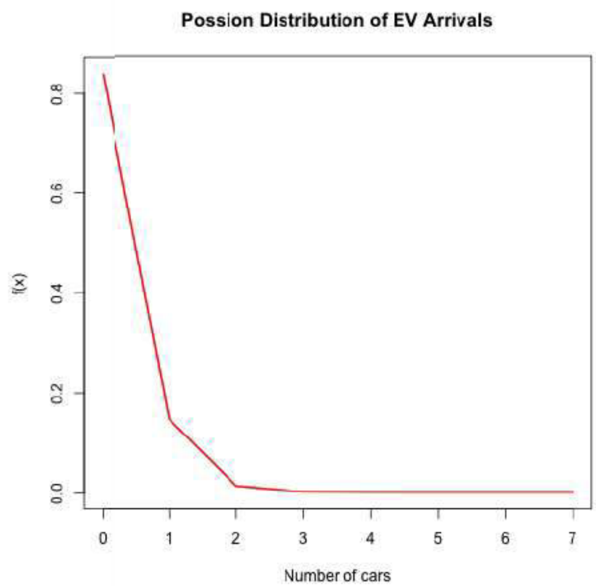
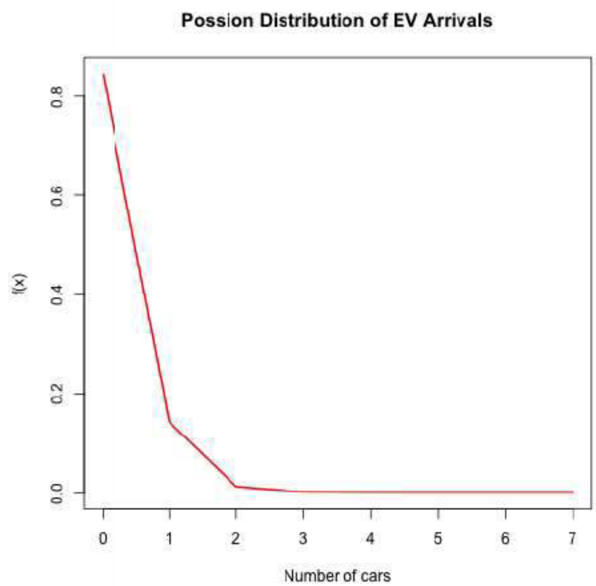
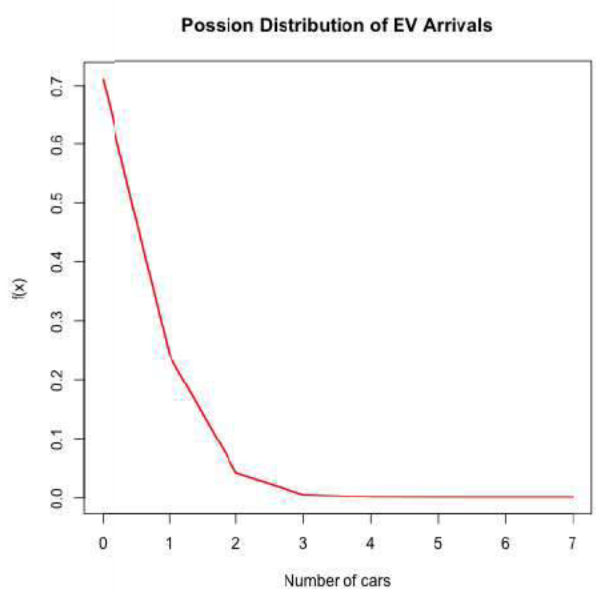


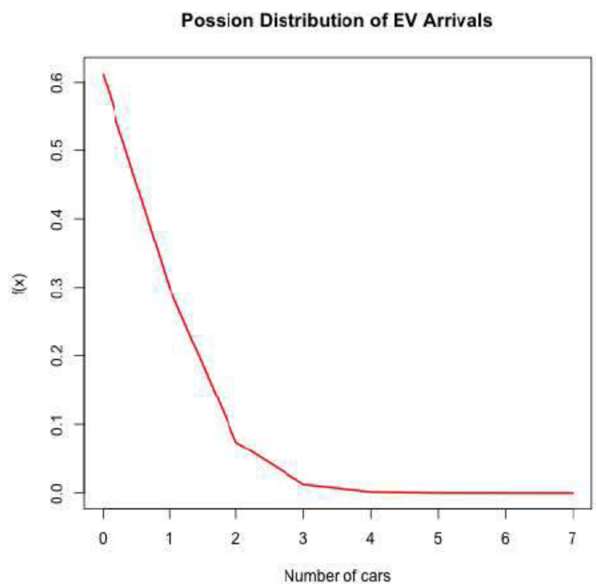
11am – 12pm



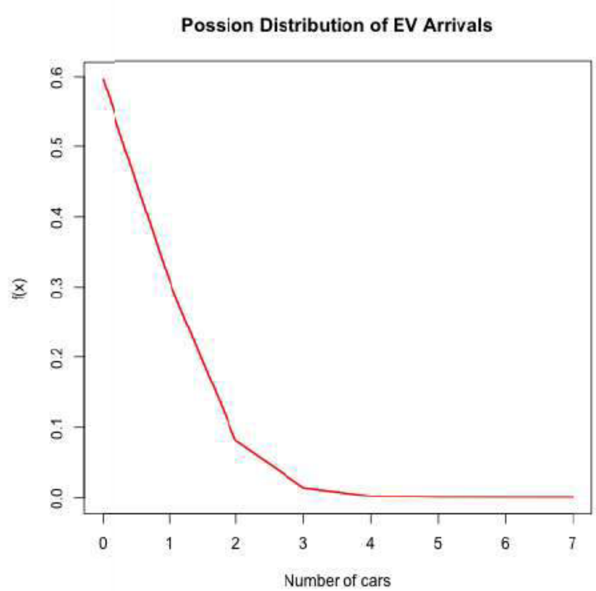
12pm – 1pm



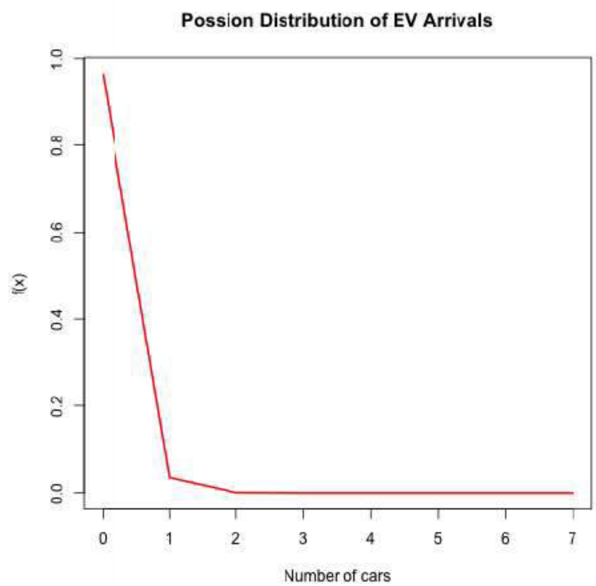
1pm – 2pm



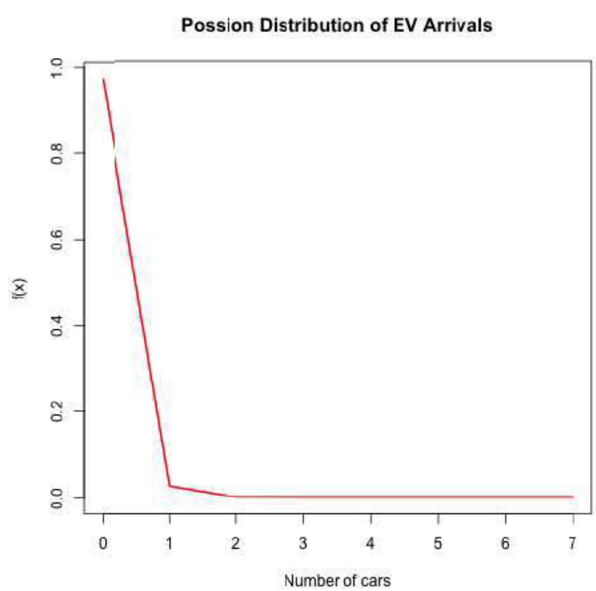
2pm – 3pm



3pm – 4pm

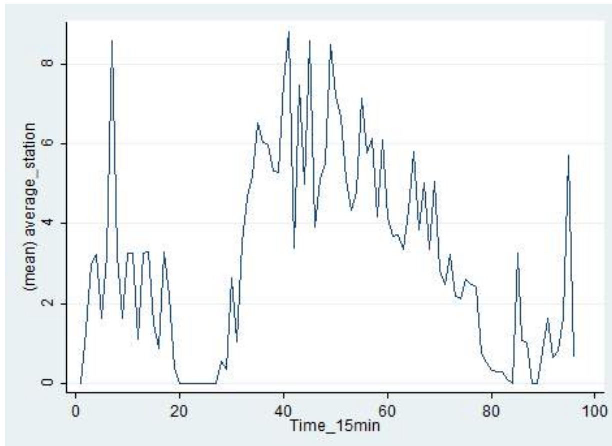


4pm – 5pm

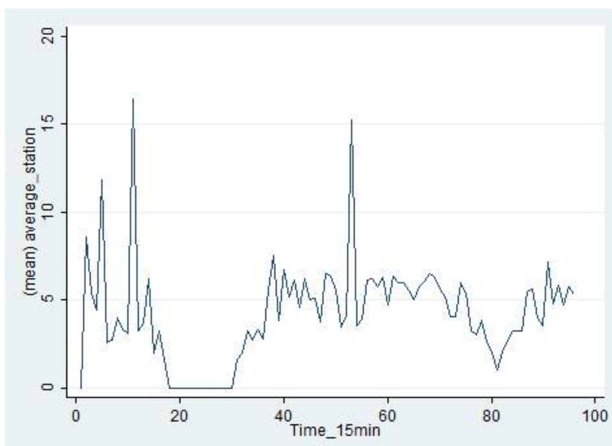


5pm – 6pm

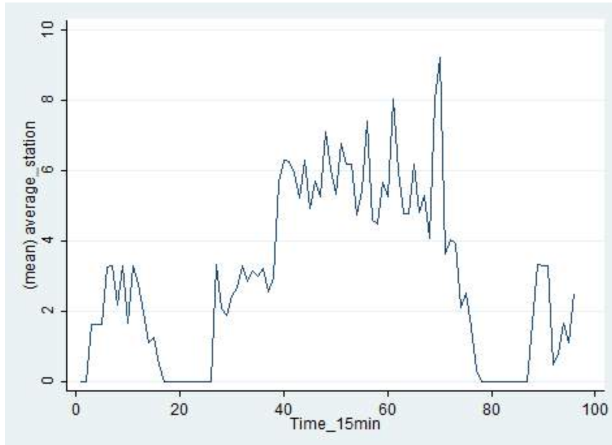
Part 2: USB Per-station Electrical Demand



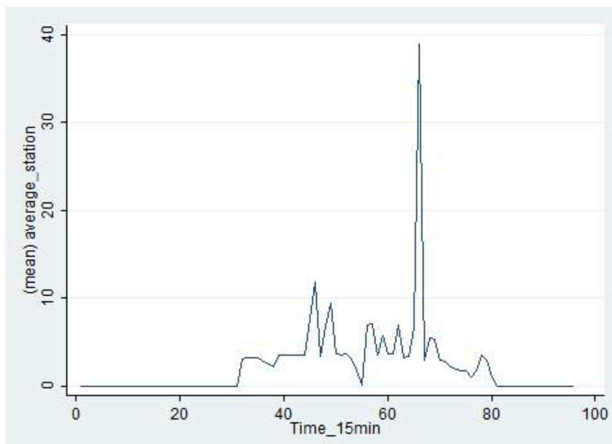
USB Station 1



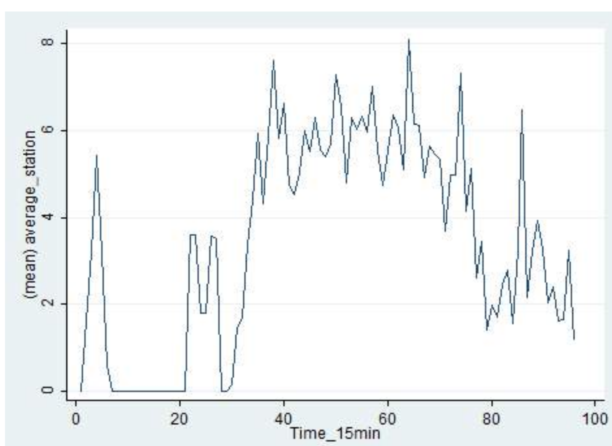
USB Station 2



USB Station 3



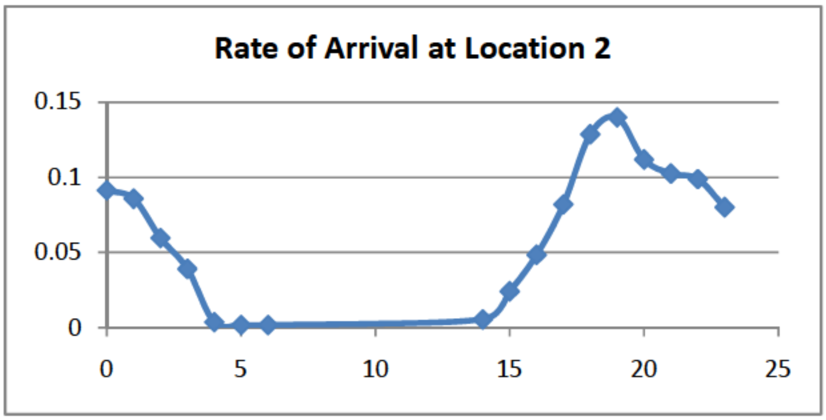
USB Station 4

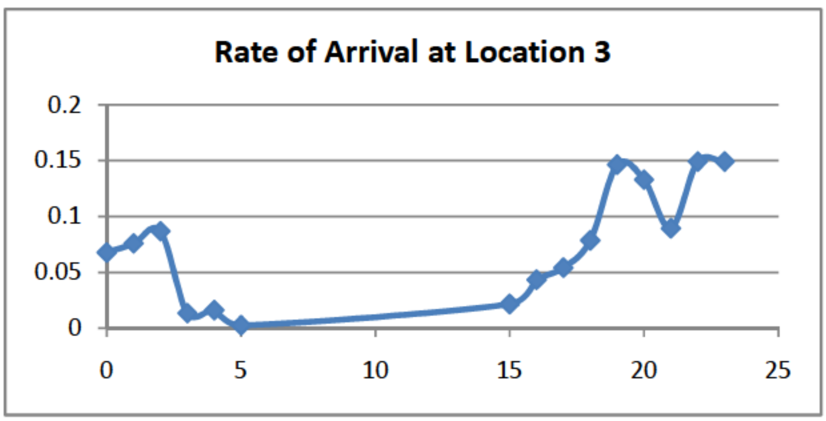


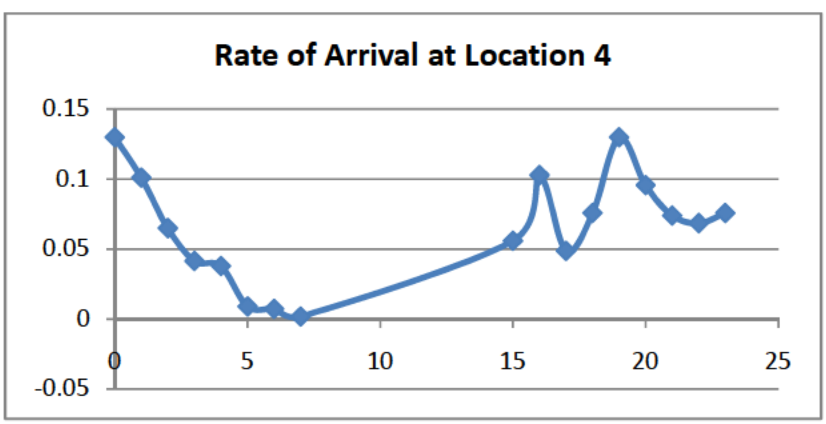
USB Station 5

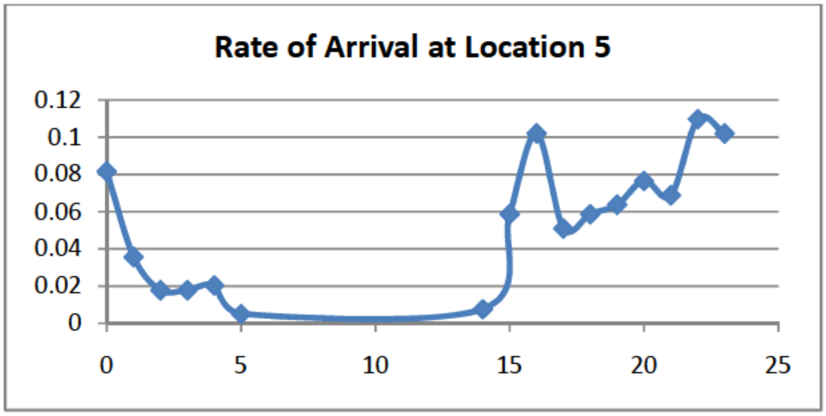
Part 3: Plots for Provincial Location 2, 3, 4, 5, 6, and 7

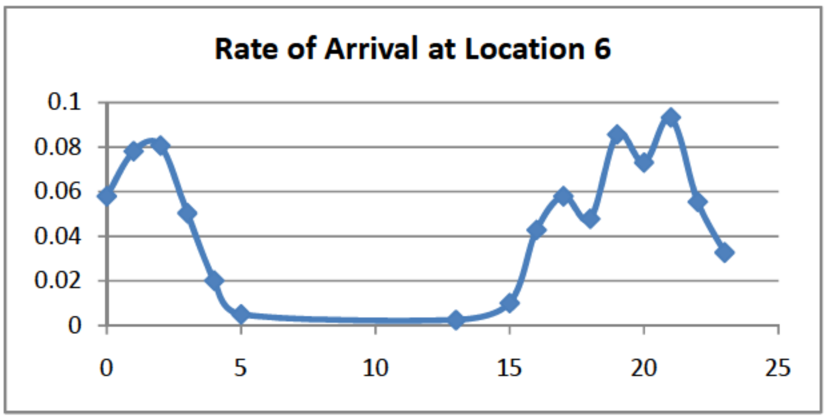
PMF Plots of Arrival Rate

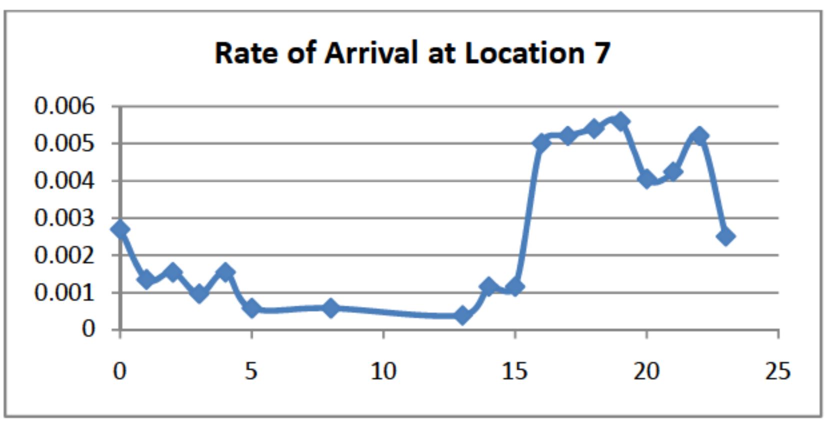




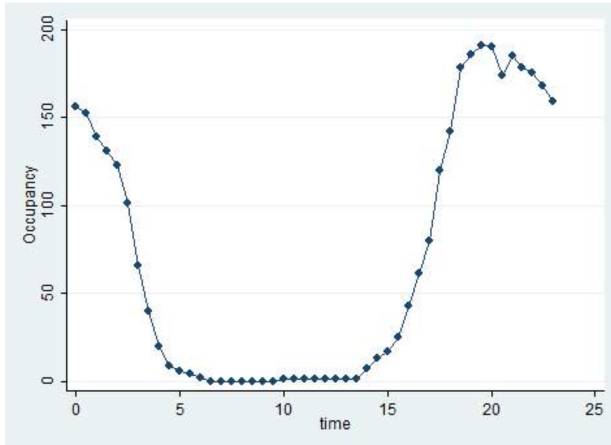




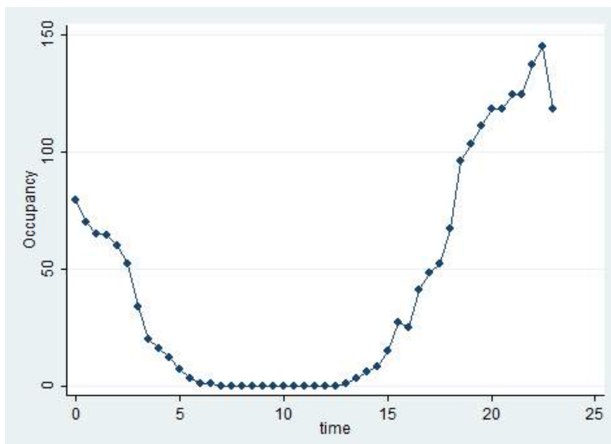




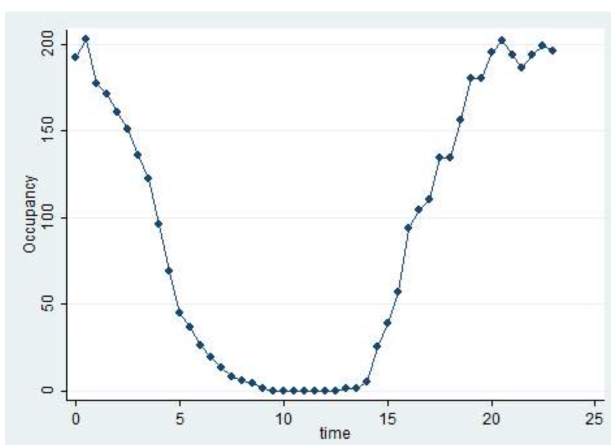
Frequency Plots of Station Occupancy



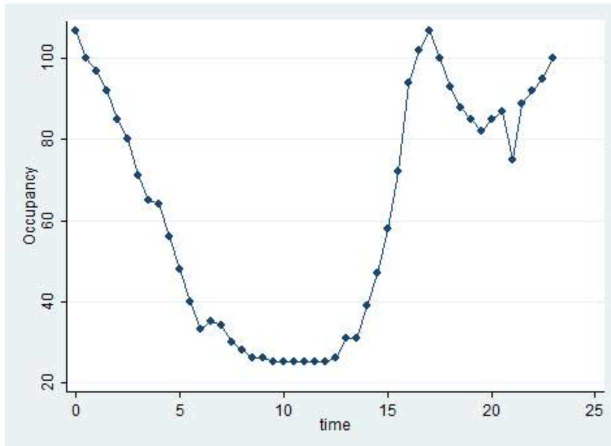
Location 2



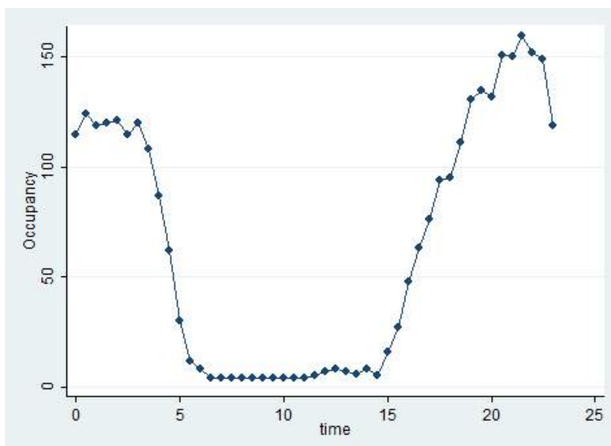
Location 3



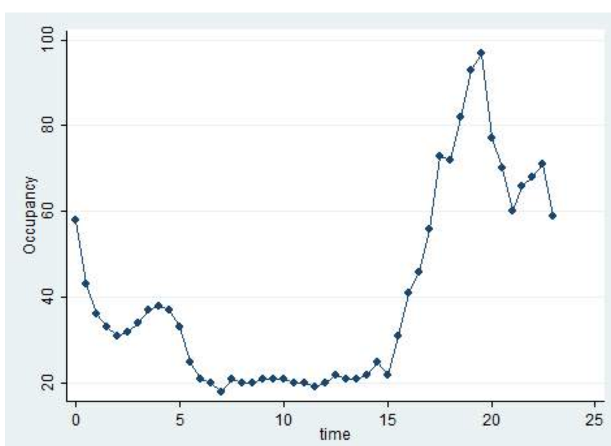
Location 4



Location 5

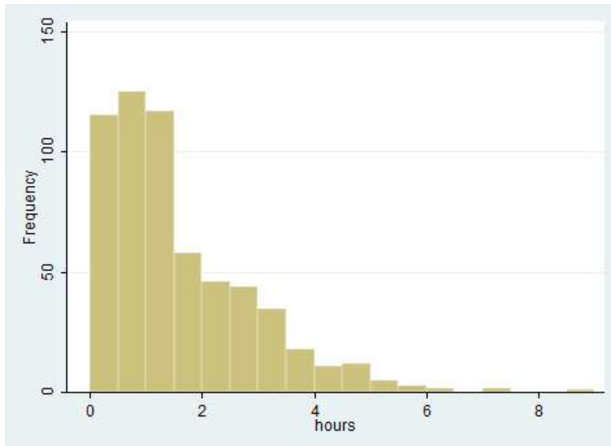


Location 6

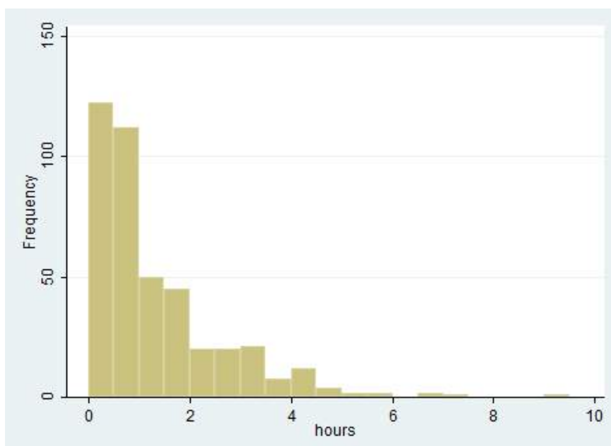


Location 7

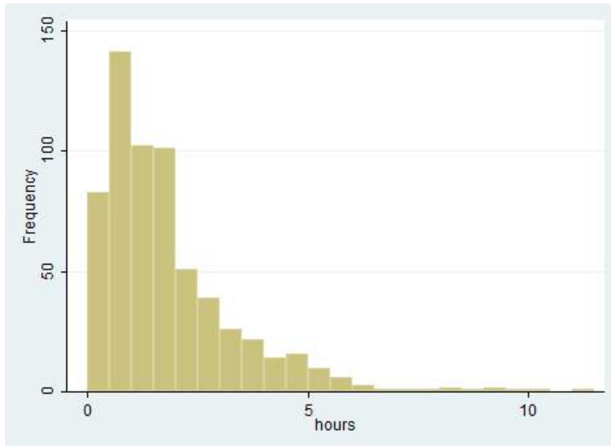
Frequency Plots of Service Duration



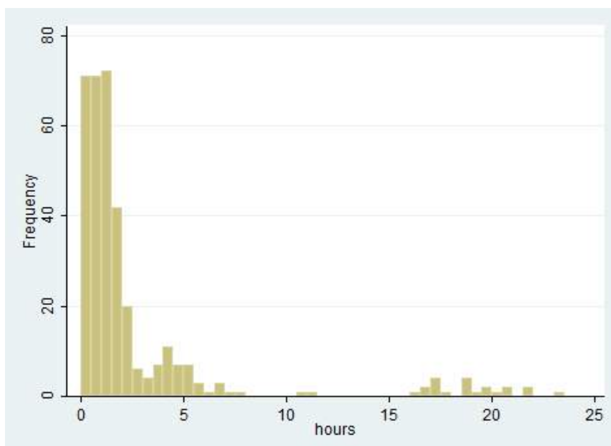
Location 2



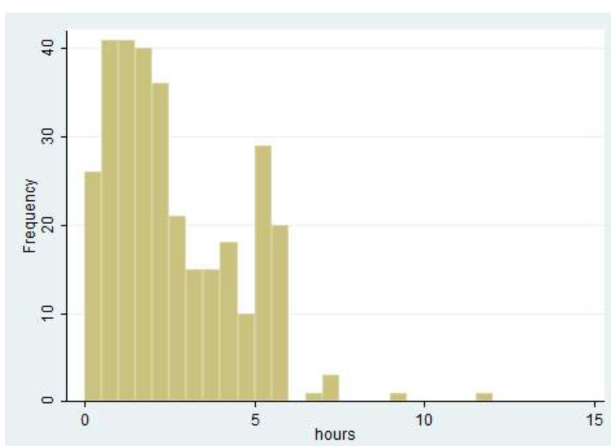
Location 3



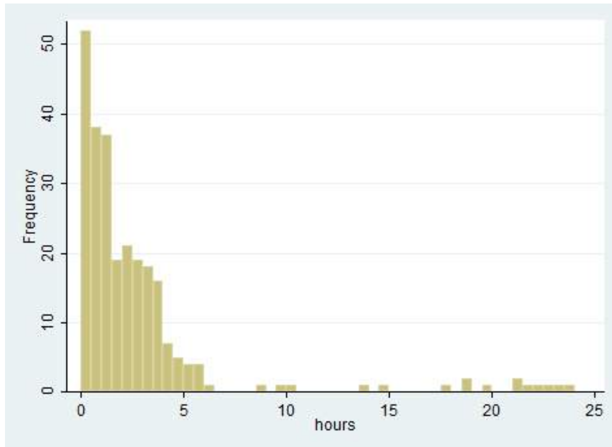
Location 4



Location 5

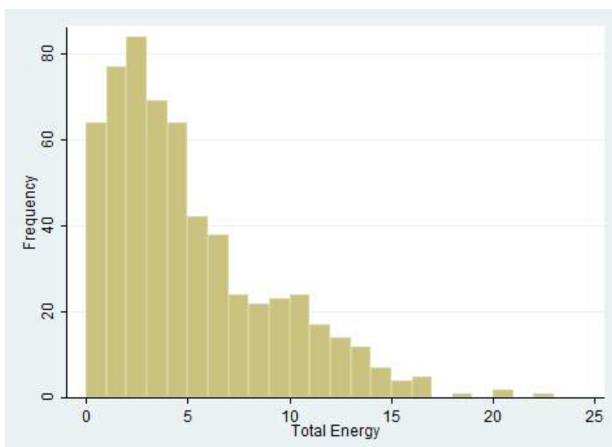


Location 6

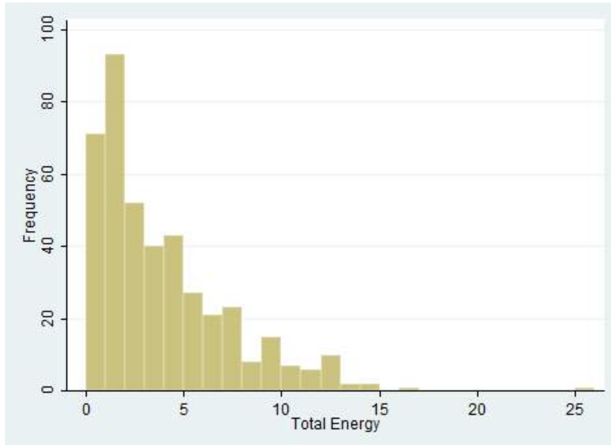


Location 7

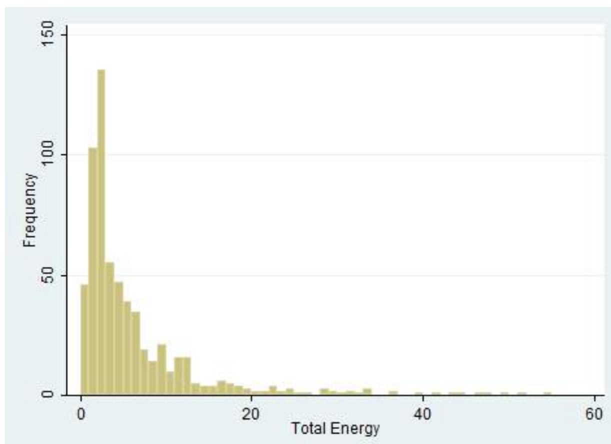
Frequency Plots of Energy Consumption



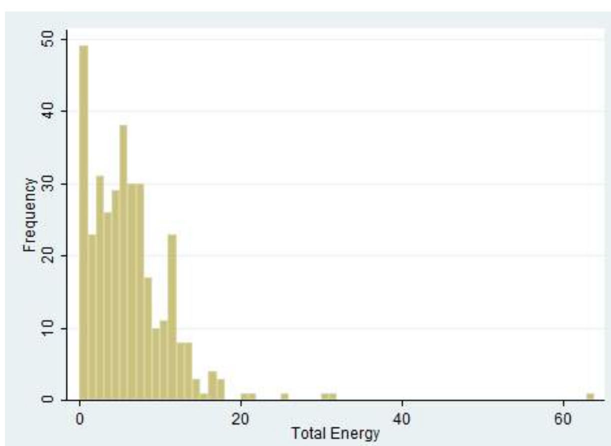
Location 2



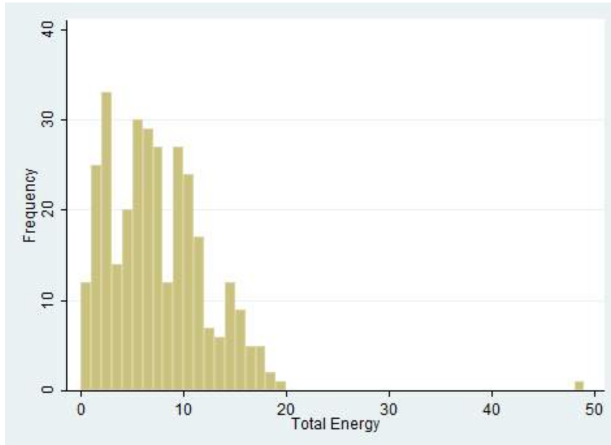
Location 3



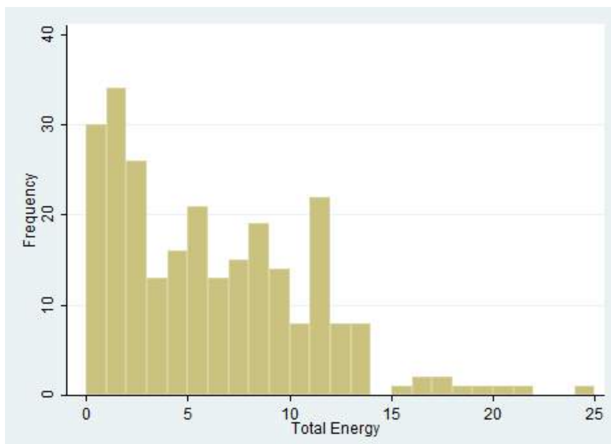
Location 4



Location 5



Location 6



Location 7

APPENDIX B: R and STATA SCRIPTS

Part 1: R Script for EV Arrival and Departure PMF Plots

```
getwd()
rm(list=ls())
ubcev<-read.csv('Session-Details-Summary-20140225.csv',as.is=FALSE,header=TRUE)
str(ubcev)
ubcev<-subset(ubcev,Ended.By !=""& Ended.By !="Holster Plugin"&Ended.By !="Timeout")
ubcev<-subset(ubcev,Station.Name !="UBC EV STATION / THUNDERBIRD
4"&Station.Name !="UBC EV STATION / THUNDERBIRD 3" &Station.Name !="UBC EV STATION /
THUNDERBIRD 2"&Station.Name !="UBC EV STATION / THUNDERBIRD 1"&Station.Name !="UBC
EV STATION / KAISER")
print(ubcev[1:10,]) # pirnt data row 1 to 10 for checking
nrow(ubcev) #show number of data set
#StartDateExtraction
s_time<-ubcev$StartDateTime<-as.POSIXct(ubcev$Start.Date,format="%Y-%m-%d %H:%M:%S")
# date-time conversion
str(s_time) #show structure of start time
s_hour<-ubcev$StartHour<-as.numeric(format(s_time,"%H"))
str(s_hour) #show structure of start hour
str(ubcev) #show new data saved to ubcev
plot(s_hour)
boxplot(s_hour)
bins=seq(0,24,by=1)
str(bins)
table(s_hour)
hist(s_hour,breaks=bins,xaxt='n',right=FALSE,main="Density Plot of EV Arrivals",prob=TRUE)
axis(side=1,at=seq(0,24,1))
mean_start_hour=mean(s_hour,na.rm=TRUE) #calculate mean
mean_start_hour
abline(v=(mean_start_hour),col="red") #darw mean
d_time<-ubcev$EndDateTime<-as.POSIXct(ubcev$End.Date,format="%Y-%m-%d %H:%M:%S")
str(d_time)
d_hour<-ubcev$DepartureHour<-as.numeric(format(d_time,"%H"))
str(d_hour)
str(ubcev)
plot(d_hour)
boxplot(d_hour)
mean_departure_hour=mean(d_hour,na.rm=TRUE)
```

```
mean_departure_hour
hist(d_hour,breaks=bins,xaxt='n',right=FALSE,main="Density Plot of EV Departures",prob=TRUE)
axis(side=1,at=seq(0,24,1))
abline(v=mean_departure_hour,col="green")
```

Part 2: STATA Script for Daily EV Arrival Rate

```
clear
cd "C:\Users\terryhuang\Desktop\EV Project V2"
import excel using Queue.xls,  firstrow
*Drop THUNDERBIRD+KAISER and other variables
drop if StationName =="UBC EV STATION / THUNDERBIRD 1"
drop if StationName =="UBC EV STATION / THUNDERBIRD 2"
drop if StationName =="UBC EV STATION / THUNDERBIRD 3"
drop if StationName =="UBC EV STATION / THUNDERBIRD 4"
drop if StationName == "UBC EV STATION / KAISER"
drop if EndedBy == ""
drop if EndedBy == "Timeout"
drop if EndedBy == "Holster Plugin"
* Creat daily in and out rate
save CleanData, replace
bysort Weekday  : egen count_in = count(Weekday)
collapse (first) count_in Date_between, by(Weekday)
gen rate_in = count_in /(Date_between/7)
drop Date_between
save in, replace
use CleanData, clear
sort Weekday
gen hours = hhC(ChargingTimehhmmss) + mmC(ChargingTimehhmmss)/60 +
ssC(ChargingTimehhmmss)/3600
gen hours_duration = hhC(TotalDurationhhmmss) + mmC(TotalDurationhhmmss)/60 +
ssC(TotalDurationhhmmss)/3600
replace hours = hours/24
replace hours_duration = hours_duration/ 24
bysort Weekday: egen service_time = mean(hours)
bysort Weekday: egen duration_time = mean(hours_duration)
gen rate_out = 1/service_time
gen rate_out_duration = 1/duration_time
collapse (first) rate_out rate_out_duration, by(Weekday)
joinby Weekday using in
export excel rate.xls, firstrow(var) replace
```

```
erase in.dta
erase CleanData.dta
```

Part 3: STATA Script for 6am-to-6pm Arrival Rate, Service Duration, and Station Occupancy Frequency Plot

```
clear
cd "C:\Users\terryhuang\Desktop\From 6 to 6pm"
import excel using Session-Details-Summary-20140309.xls,  firstrow

*Drop THUNDERBIRD and other variables
drop if StationName =="UBC EV STATION / THUNDERBIRD 1"
drop if StationName =="UBC EV STATION / THUNDERBIRD 2"
drop if StationName =="UBC EV STATION / THUNDERBIRD 3"
drop if StationName =="UBC EV STATION / THUNDERBIRD 4"
drop if StationName == "UBC EV STATION / KAISER"
drop if EndedBy == ""
drop if EndedBy == "Timeout"
drop if EndedBy == "Holster Plugin"
format StartDate %tc
gen StartDateD =  dofc(StartDate)
format StartDateD %td
gen EndDateD =  dofc(EndDate)
format EndDateD %td
egen maxday = max(StartDateD)
egen minday = min(StartDateD)
gen Date_between = maxday - minday
drop maxday minday
gen StartDateH = hhC(StartDate)
gen EndDateH = hhC(EndDate)
gen Weekday = dow(StartDateD)
drop if Weekday == 0 | Weekday == 6
drop if StartDateH > 18 | StartDateH < 6
save CleanData, replace
save CleanData, replace
bysort StartDateH  : egen count_in = count(StartDateH)
collapse (first) count_in Date_between, by(StartDateH StartDateD)
gen rate_in_365 = count_in /Date_between
collapse (first) count_in rate_in_365, by(StartDateH)
ren StartDateH Time
save in, replace
```

```
use CleanData, replace
gen hours_duration = hhC(TotalDurationhhmmss) + mmC(TotalDurationhhmmss)/60 +
ssC(TotalDurationhhmmss)/3600
egen cut90=pctile(hours_duration), p(90)
drop if hours_duration > cut90
gen StartTime = hhC(StartDate) + mmC(StartDate)/60 + ssC(StartDate)/3600
gen EndTime =  hhC(EndDate) + mmC(EndDate)/60 + ssC(EndDate)/3600
gen ParkHourEvening = 18 - StartTime if EndTime < StartTime  | EndTime > 18
replace ParkHourEvening = EndTime - StartTime if ParkHourEvening >=.
gen ParkHourMorning = EndTime - 6 if hours_duration>12 & EndTime < 18
replace ParkHourMorning  = 0 if ParkHourMorning>=. | ParkHourMorning < 0
gen ParkHour = ParkHourMorning + ParkHourEvening
hist ParkHour, w(1) frequency
graph export hist.png, replace
logout, save(result) excel replace: summarize ParkHour
bysort EndDateH  : egen count_out = count(EndDateH)
collapse (first) count_out Date_between, by(EndDateH EndDateD)
gen rate_out_365 = count_out /Date_between
collapse (first) count_out rate_out_365, by(EndDateH)
ren EndDateH Time
joinby Time using in
export excel rate.xls, firstrow(var) replace
erase in.dta
```

Part 4: <u>STATA Script for Per-station and Aggregate Electrical Demand</u>

```
clear
cd "C:\Users\terryhuang\Desktop\15min"
import excel using time.xls,  firstrow clear
drop Slots Year  E F G
ren Time time
gen hours = hhC(time)
gen mins = mmC(time)
replace mins = round(mins, 5)
replace hours = hours + 1 if mins == 60
replace mins = 00 if mins == 60
gen secs = 0
gen time1 = hms(hours, mins,secs)
format time1 %tc
drop mins secs hours time
ren time1 time
```

```
save time_template, replace
import excel using data.xls,  firstrow clear
replace StationName = StationName[_n-1] if StationName == ""
replace EndedBy = EndedBy[_n-1] if EndedBy== ""
drop if StationName =="UBC EV STATION / THUNDERBIRD 1"
drop if StationName =="UBC EV STATION / THUNDERBIRD 2"
drop if StationName =="UBC EV STATION / THUNDERBIRD 3"
drop if StationName =="UBC EV STATION / THUNDERBIRD 4"
drop if EndedBy == ""
drop if EndedBy == "Timeout"
drop if EndedBy == "Holster Plugin"
save Cleandata, replace
use StationName Port PowerStartTime RollingAvgPowerACkW using Cleandata, clear
format PowerStartTime %tc
gen PowerStartD =  dofc(PowerStartTime)
format PowerStartD %td
gen hours = hhC(PowerStartTime)
gen mins = mmC(PowerStartTime)
replace mins = 15 if mins == 14
replace mins = 30 if mins == 29
replace mins = 45 if mins == 44
replace mins = 60 if mins == 59
replace hours = hours + 1 if mins == 60
replace mins = 00 if mins == 60
gen secs = 0
gen time = hms(hours, mins,secs)
format time %tc
gen weekday = dow(PowerStartD)
drop if weekday == 0 | weekday == 6
drop hours mins secs
joinby time using time_template, unmatched(both)
drop if Time_15min >=.
*drop if weekday >=.
drop _merge
sort StationName PowerStartD Time_15min
save graph_data, replace
use graph_data, clear
replace RollingAvgPowerACkW = 0 if RollingAvgPowerACkW>=.
bysort StationName Port Time_15min: egen sum_rolling = sum(RollingAvgPowerACkW)
bysort StationName Port Time_15min: egen num = count(RollingAvgPowerACkW) if
RollingAvgPowerACkW !=0
gsort StationName Time_15min, gen(order0)
by order0: replace num = num[_n-1] if num >=.
gsort -StationName Time_15min, gen(order1)
by order1 : replace num = num[_n-1] if num >=.
```

```
gsort StationName -Time_15min, gen(order2)
by order2 : replace num = num[_n-1] if num >=.
gsort -StationName -Time_15min, gen(order3)
by order3 : replace num = num[_n-1] if num >=.
collapse (first) sum_rolling num, by(StationName Port Time_15min)
tsset, clear
sort  StationName Port
egen id = group( StationName Port)
tsset id Time_15min
tsfill, full
bysort id: carryforward StationName Port , replace
gsort id - Time_15min
bysort id: carryforward StationName Port, replace
sort StationName Port Time_15min
replace sum_rolling = 0 if sum_rolling >=.
gen average = sum_rolling / num if num <.
replace average = 0 if average >=.
egen Station = group(StationName)
save graph_data2, replace
use graph_data2, clear
bysort Station Time_15min: egen average_station = sum(average)
collapse (first) average_station, by(Station Time_15min)
forvalue x = 1/6{ // 6 stations
 line average_station Time_15min if Station == `x'
 graph export `x'_station.png, replace
}
use graph_data2, clear
drop if StationName == "UBC EV STATION / KAISER"
bysort Time_15min: egen aggregate_average = sum(average)
line aggregate_average Time_15min
graph export All_station_aggregate.png, replace
use graph_data2, clear
collapse (first) StationName, by(Station)
export excel Station_Number.xls, replace
```

Part 5: <u>STATA Script for Analyzing Provincial EV Cloud Data</u>

```
clear
set more off
cd "C:\Users\terryhuang\Desktop\evCloud Data for UBC"
clear
import excel using L1S1.xls,  firstrow
```

```
gen Port = 1
save L1S1, replace
clear
import excel using L1S2.xls,  firstrow
gen Port = 2
append using L1S1
save L1, replace
erase L1S1.dta
clear
import excel using L6S1.xls,  firstrow
gen Port = 1
save L6S1, replace
clear
import excel using L6S2.xls,  firstrow
gen Port = 2
append using L6S1
save L6, replace
erase L6S1.dta
clear
import excel using L7S1.xls,  firstrow
gen Port = 1
save L7S1, replace
clear
import excel using L7S2.xls,  firstrow
gen Port = 2
append using L7S1
save L7, replace
erase L7S1.dta
clear
import excel using L4S1.xls,  firstrow
gen Port = 1
save L4S1, replace
clear
import excel using L4S2.xls,  firstrow
gen Port = 2
append using L4S1
save L4, replace
erase L4S1.dta
clear
import excel using L4S3.xls,  firstrow
gen Port = 3
append using L4
save L4, replace
clear
import excel using L2.xls,  firstrow
```

```
save L2, replace
clear
import excel using L3.xls,  firstrow
save L3, replace
clear
import excel using L5.xls,  firstrow
save L5, replace
foreach file in L1 L2 L3 L4 L5 L6 L7{
use `file'.dta, clear
gen double StartDate = clock(StartTime, "MDYhms")
gen double EndDate = clock(EndTime, "MDYhms")
format StartDate %tc
format EndDate %tc
gen Duration = EndDate - StartDate
format Duration %tc
gen hours = hhC(Duration) + mmC(Duration)/60 + ssC(Duration)/3600
gen StartDateD =  dofc(StartDate)
format StartDateD %td
gen EndDateD =  dofc(EndDate)
format EndDateD %td
egen maxday = max(StartDateD)
egen minday = min(StartDateD)
gen Date_between = maxday - minday
drop maxday minday
gen StartDateH = hhC(StartDate)
gen EndDateH = hhC(EndDate)
gen Weekday = dow(StartDateD)
drop if Weekday == 0 | Weekday == 6
hist hours, frequency w(0.5)
graph export Duration_`file'.png, replace
logout, save(Duration_`file') excel replace: summarize hours
hist TotalEnergy, frequency w(1)
graph export Energy_`file'.png, replace
logout, save(Energy_`file') excel replace: summarize TotalEnergy
save CleanData, replace
bysort StartDateH  : egen count_in = count(StartDateH)
collapse (first) count_in Date_between, by(StartDateH StartDateD)
gen rate_in_365 = count_in /Date_between
collapse (first) count_in rate_in_365, by(StartDateH)
ren StartDateH Time
save in, replace
use CleanData, replace
bysort EndDateH  : egen count_out = count(EndDateH)
collapse (first) count_out Date_between , by(EndDateH EndDateD)
gen rate_out_365 = count_out /Date_between
```

```
collapse (first) count_out rate_out_365, by(EndDateH)
ren EndDateH Time
joinby Time using in
export excel rate_`file'.xls, firstrow(var) replace
erase in.dta
erase CleanData.dta
}
use L1, replace
foreach file in L2 L3 L4 L5 L6 L7{
	append using `file'.dta
}
gen double StartDate = clock(StartTime, "MDYhms")
gen double EndDate = clock(EndTime, "MDYhms")
format StartDate %tc
format EndDate %tc
gen Duration = EndDate - StartDate
format Duration %tc
gen hours = hhC(Duration) + mmC(Duration)/60 + ssC(Duration)/3600
gen StartDateD =  dofc(StartDate)
format StartDateD %td
gen EndDateD =  dofc(EndDate)
format EndDateD %td
egen maxday = max(StartDateD)
egen minday = min(StartDateD)
gen Date_between = maxday - minday
drop maxday minday
gen StartDateH = hhC(StartDate)
gen EndDateH = hhC(EndDate)
gen Weekday = dow(StartDateD)
drop if Weekday == 0 | Weekday == 6
hist hours, frequency w(0.5)
graph export Total_Duration.png, replace
logout, save(Total_Duration) excel replace: summarize hours
hist TotalEnergy,frequency w(1)
graph export Total_Energy.png, replace
logout, save(TotalEnergy) excel replace: summarize TotalEnergy
save CleanData, replace
bysort StartDateH  : egen count_in = count(StartDateH)
collapse (first) count_in Date_between, by(StartDateH StartDateD)
gen rate_in_365 = count_in /Date_between
collapse (first) count_in rate_in_365, by(StartDateH)
ren StartDateH Time
save in, replace
use CleanData, replace
bysort EndDateH  : egen count_out = count(EndDateH)
```

```
collapse (first) count_out Date_between , by(EndDateH EndDateD)
gen rate_out_365 = count_out /Date_between
collapse (first) count_out rate_out_365, by(EndDateH)
ren EndDateH Time
joinby Time using in
export excel total_rate.xls, firstrow(var) replace
erase in.dta
*Occupancy Frequency Plot
clear
set more off
cd "C:\Users\terryhuang\Desktop\evCloud Data for UBC XLS"
foreach file in L1 L2 L3 L4 L5 L6 L7{
use `file'.dta, clear
gen double StartDate = clock(StartTime, "MDYhms")
gen double EndDate = clock(EndTime, "MDYhms")
gen duration = EndDate - StartDate
format duration %tc
format StartDate %tc
format EndDate %tc
gen d = hhC(duration) + mmC(duration)/60
gen StartHour =  hhC(StartDate) + mmC(StartDate)/60
gen EndHour = hhC(EndDate) + mmC(EndDate)/60
forvalue i = 0(1)47{
gen time`i'=0
}
forvalue i = 0(1)47{
gen h = `i'/2
replace time`i' = time`i' + 1 if StartHour <= h + 0.5 & h <= EndHour & StartHour <= EndHour
replace time`i' = time`i' + 1 if StartHour > EndHour
replace time`i' = time`i' - 1 if EndHour < h & h < StartHour - 0.5  & StartHour > EndHour
drop h
}
forvalue i =  0(1)47{
gen h = `i'/2
egen sum`i' = total(time`i')
drop h
}
drop StartTime - time47
duplicates drop
sxpose, clear firstnames force
destring _var1, replace
gen n = (_n -1)/2
graph twoway connected _var1 n, ytitle(Occupation) xtitle(time)
graph export Occupancy_`file'.png, replace
}
```

Part 6: R Script for Generating EV Arrival Poisson PMF Plots

```
library(gdata)
library(grDevices)
setwd("~/Desktop/Poisson Distribution")
data = read.xls("rate.xls")
x <- seq(0, 7, length=8)
for(i in 1:12){
  png(file=paste("Poission",i,".png",sep=""))
plot(x, dpois(x,  data$rage_in_365[i]),type = "l", add = TRUE, col = "red", lwd = 2, main= "Possion
Distribution of EV Arrivals", xlab="Number of cars", ylab = "f(x)")
dev.off()
}
```