Queuing Models to Analyze Electric Vehicle Usage Patterns

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About Me

- Completed Master’s in Statistics at University of British Columbia (2015)
- Currently work at Alberta’s Gaming and Liquor Commission (AGLC)
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Outline

1. Examples of data science work at AGLC

2. Queuing Models to Analyze Electric Vehicle Usage Patterns:
   - Data
   - Exploratory Analysis
   - Model
   - Results

AGLC – Background

AGLC
Alberta Gaming and Liquor Commission

aglc.ca

Regulates → **Liquor**

Regulates → **Gaming**

Charitable Gaming:
Bingo, casinos, raffles, and pull tickets

Electronic Gaming and Lotteries:
Slot machines, VLTs, ticket lotteries, and electronic bingo

From You to the Community

Slot machine net sales $

15% Charitable Group

15% Casino Facility Operator

70% Alberta Lottery Fund (After Expenses)

1. Examples of Data Science Work at AGLC

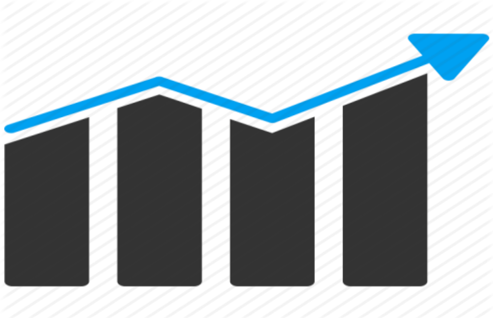
Predicting the impact of new games on slots on player's experience.

http://slotsnmore.com/zeus-slots/

Do people like this game?

Should we purchase more of these games?

Amount of Play



http://www.freeiconspng.com/images/graph-with-arrow-icon

Optimizing Slot Placements in Network

https://en.wikipedia.org/wiki/Alberta

Which site should I put this slot at?

A lot of factors to consider:

- Number of slots at site
- Game mix at site
- Amount of play at site
- Many more..

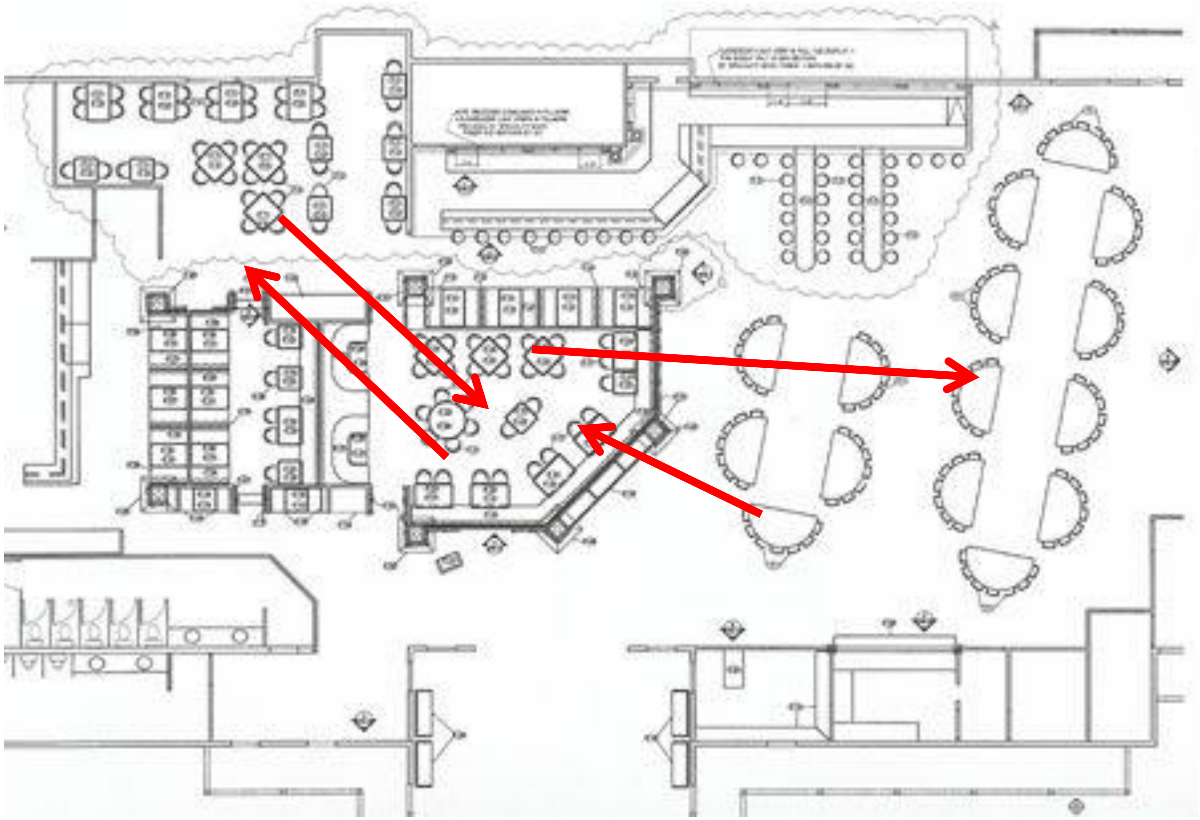
Predicting the impact of casino floor changes or re-organization

Activities:

- Moves
- Swaps
- Addons
- Removals
- Conversions

Estimated Increase in game play?

Casino Floor



https://www.pinterest.com/pin/378091331198152887/

Work Breakdown and Methods

- Lots of exploratory data analysis
- Lots of data cleaning
- Standard statistical/machine learning methods:
  - Linear regression
  - Random Forest
  - Time Series (ARIMA)
  - Mixed Effects Models
- Most used programs: R, SQL, Javascript, Python.

2. Stats Project on Queuing Models to Analyze Electric Vehicle Usage Patterns

https://www.bchydro.com/powersmart/electric-vehicles.html

http://www.upsbatterycenter.com/blog/electric-vehicle-charging-options/

Background On Project

- Statistical consulting project for STAT 550 at UBC – Techniques of Statistical Consulting
- Most projects are done in groups of 2-3
- Motivation:
  - UBC have been promoting the use of Electric Vehicles (EV) to reduce green house gas emissions.

Task

When to expand current infrastructure in higher traffic.

https://www.youtube.com/watch?v=sLrbNHswAvA

Show Demo

Data and Challenges

- At the time, 10 stations and 14 Electric Vehicles that were tracked

- What if we have 20, 30, 50+ cars?

Data after some cleaning

Station	Car ID	Start Charge Time	End Charge Time	Average Power Use AC kW	Peak Power Use AC kW	.....
1	1314	2015-02-15 10:00:00	2015-02-15 11:30:00	4	16	…
1	2940	2015-02-15 12:30:00	2015-02-15 12:45:00	5	8	…
2	5612	2015-02-15 9:30:00	2015-02-15 10:00:00	3	12	…
…	…	…	…	…	…	…

Lots of other columns in the raw data for other analysis

When to expand current infrastructure in case of queuing.

Solve this by:

- Calculating the probability a car has to wait before charging.
- Calculating the wait time.

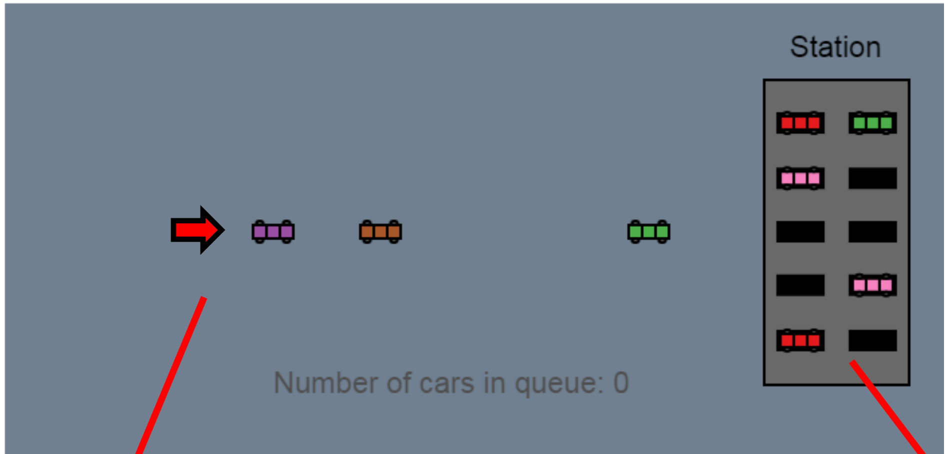
How?

M/M/c – Queuing Model

Stochastic process {X(t), t >= 0}

Continuous time Markov chains

How to use M/M/c?



Rate in which cars arrive

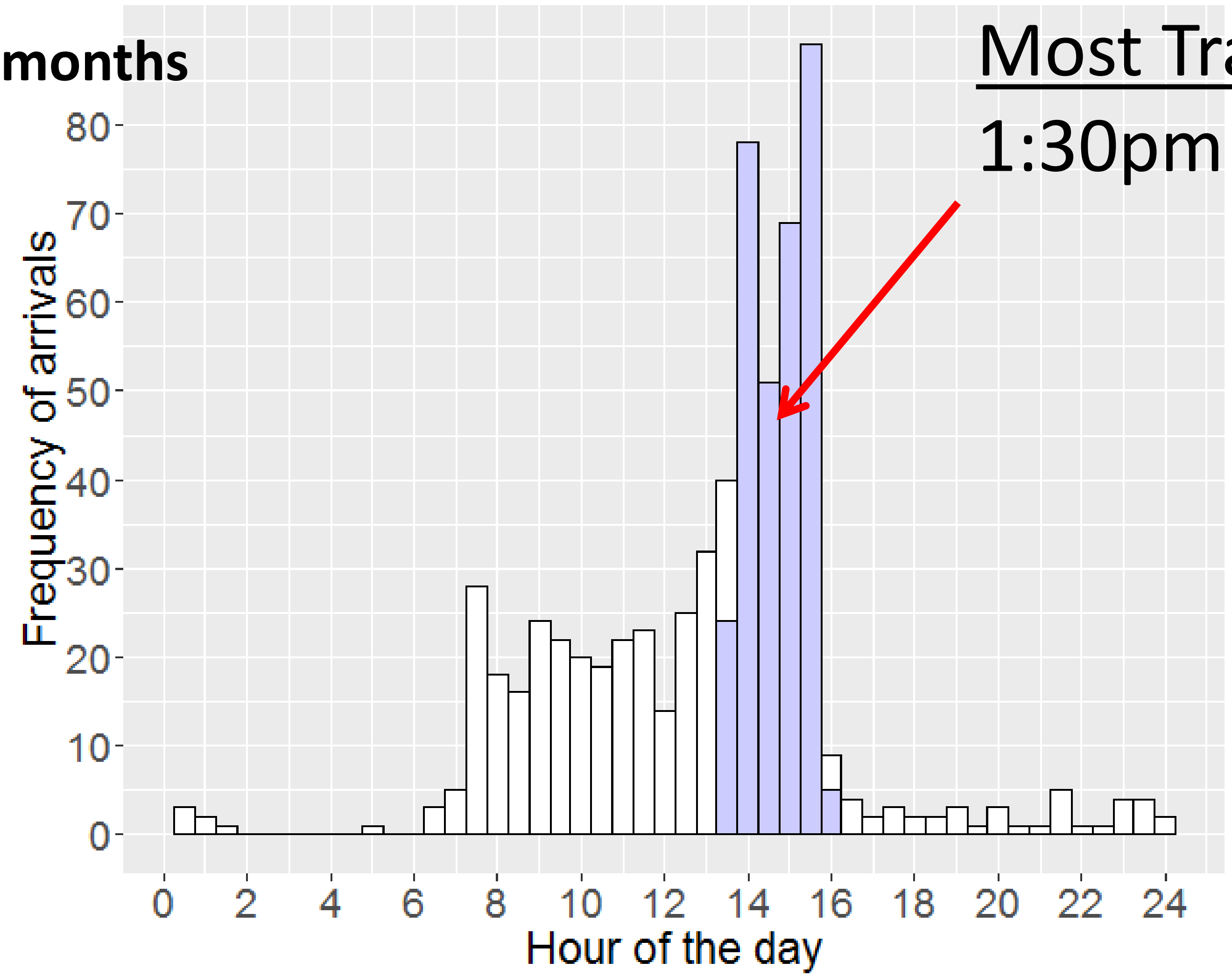
How long it takes to charge

M/M/c – Queuing Model

- Probability a car has to wait before charging.
- Wait time in queue.

Explore Rate in which cars arrive

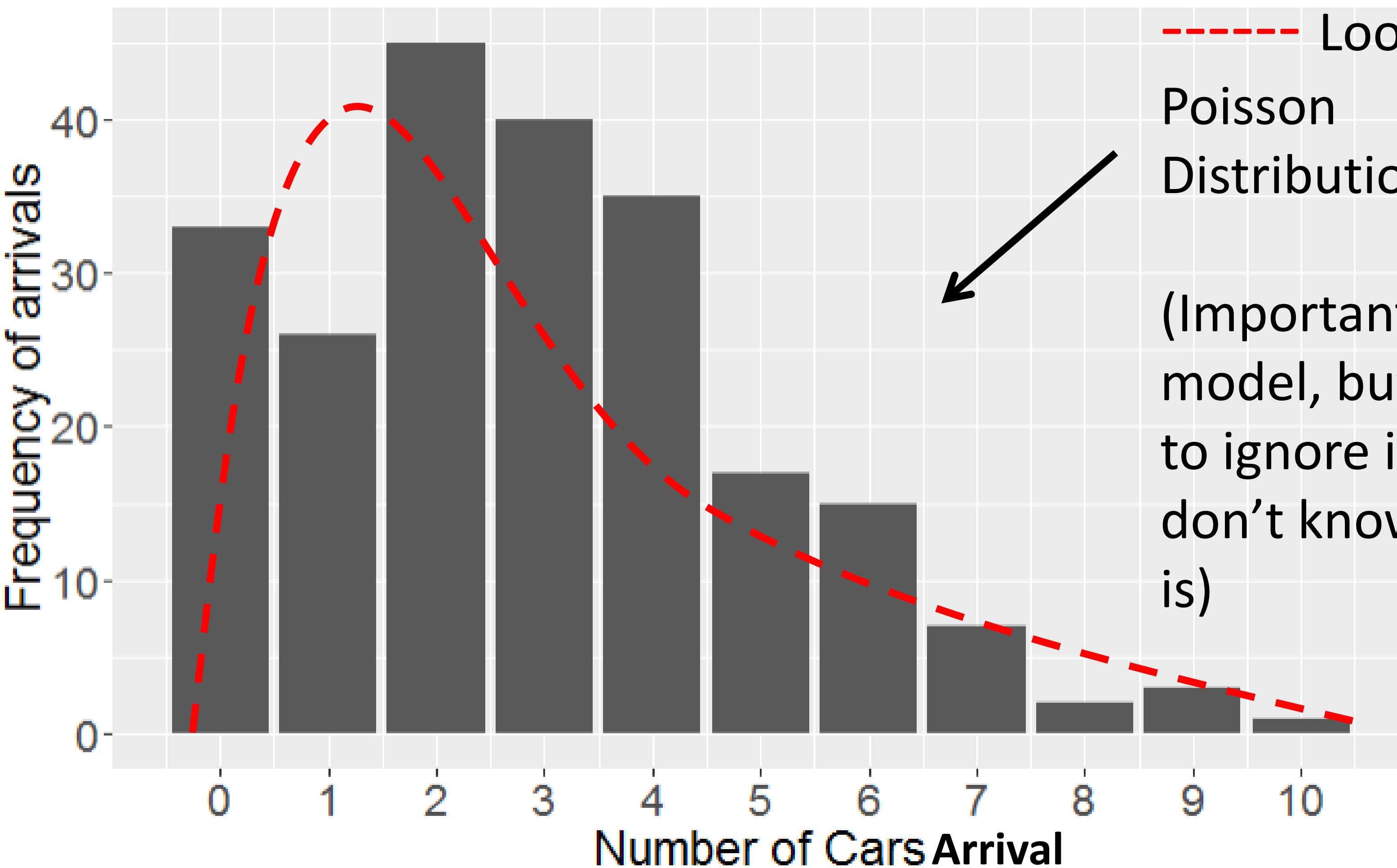
~ 8 months



Most Traffic:

1:30pm - 4pm

Looking at only the times with highest traffic from 1:30pm - 4pm

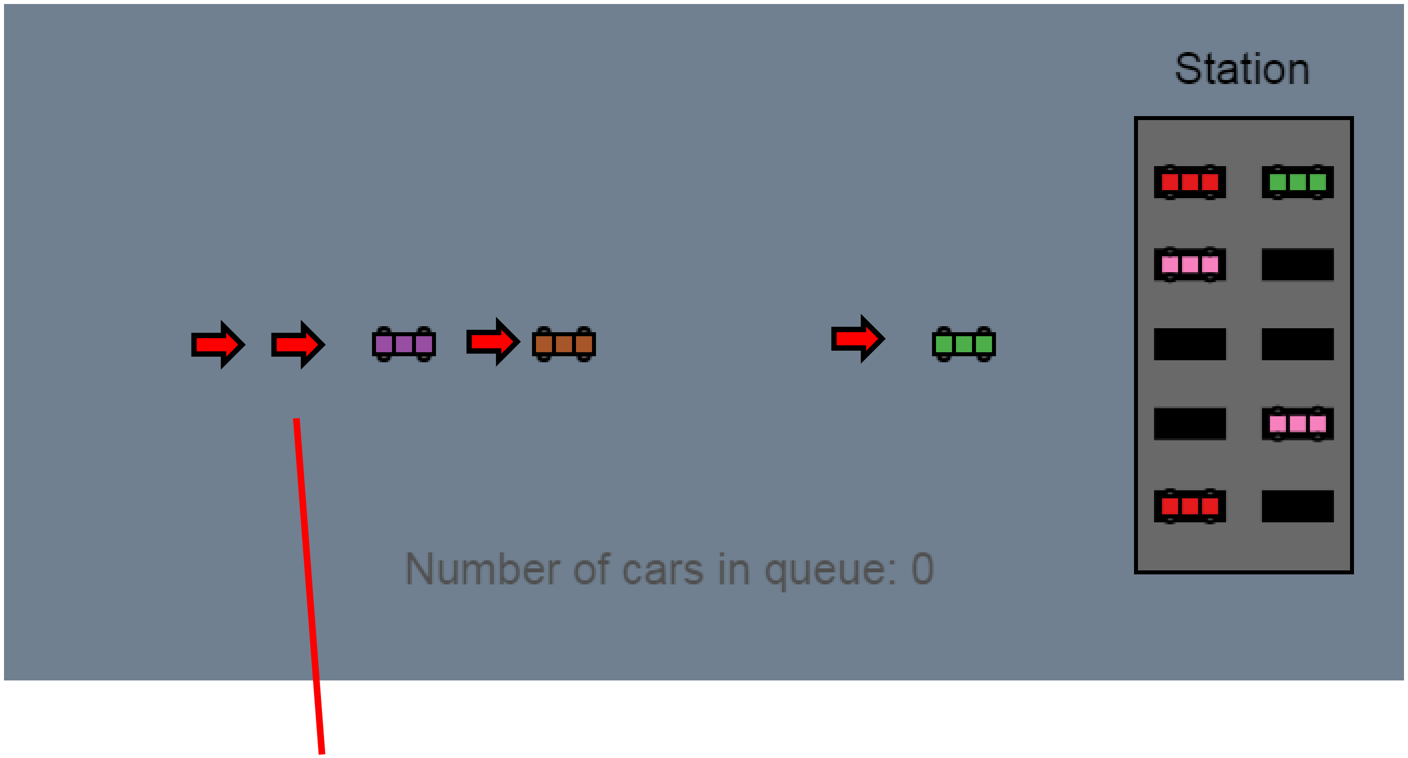


Looks like a Poisson Distribution

(Important for the model, but is okay to ignore if you don't know what it is)

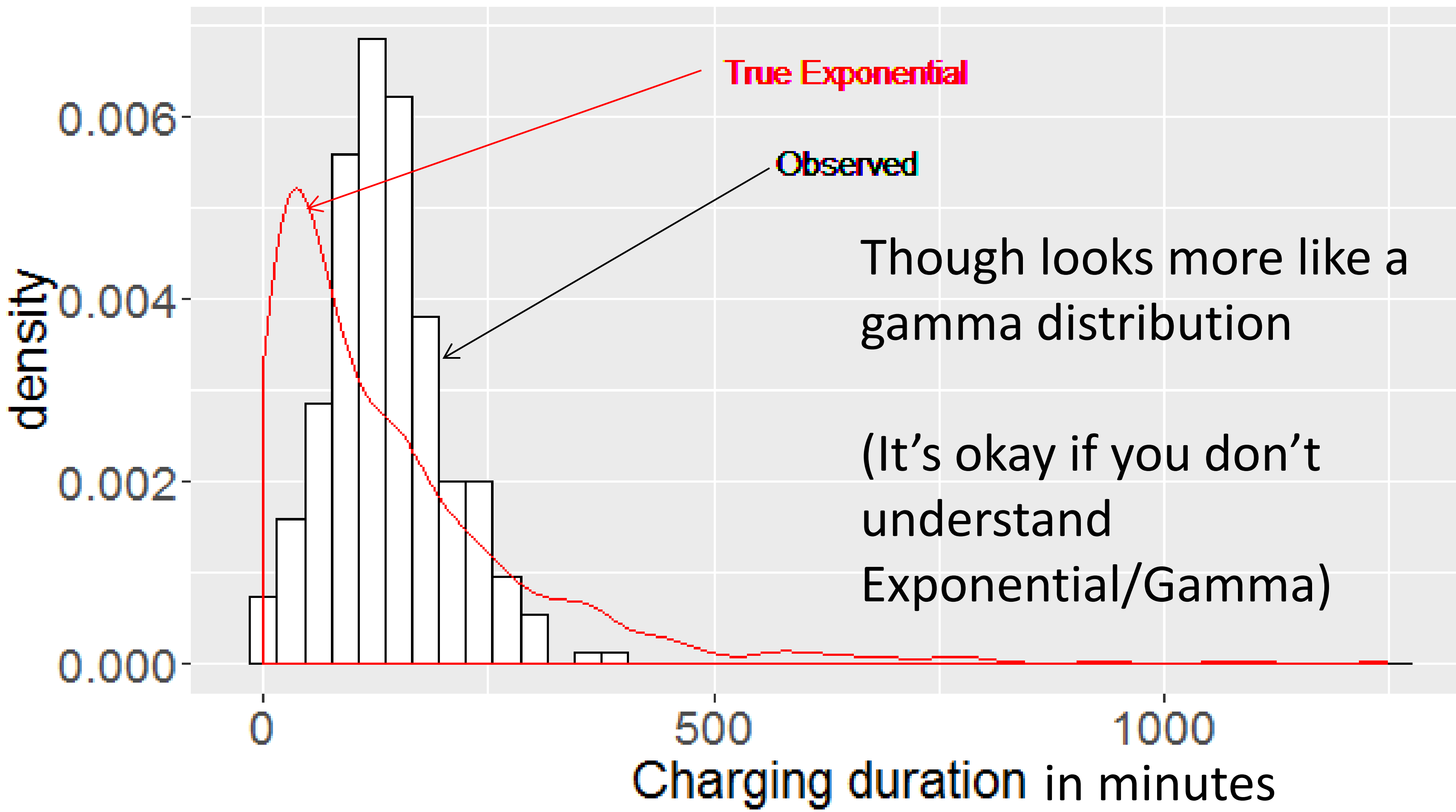
Rate of Arrival

- Number of cars arrive ~ Poisson(lambda)
- lambda = Average number of cars arriving per hour
- Can be estimated by calculating the average number of arrivals divided by 2.5 hours (time from 1:30pm - 4pm)
- lambda = 1.17 cars per hour



Cars Arrive ~ Poisson(1.17 cars/hour)

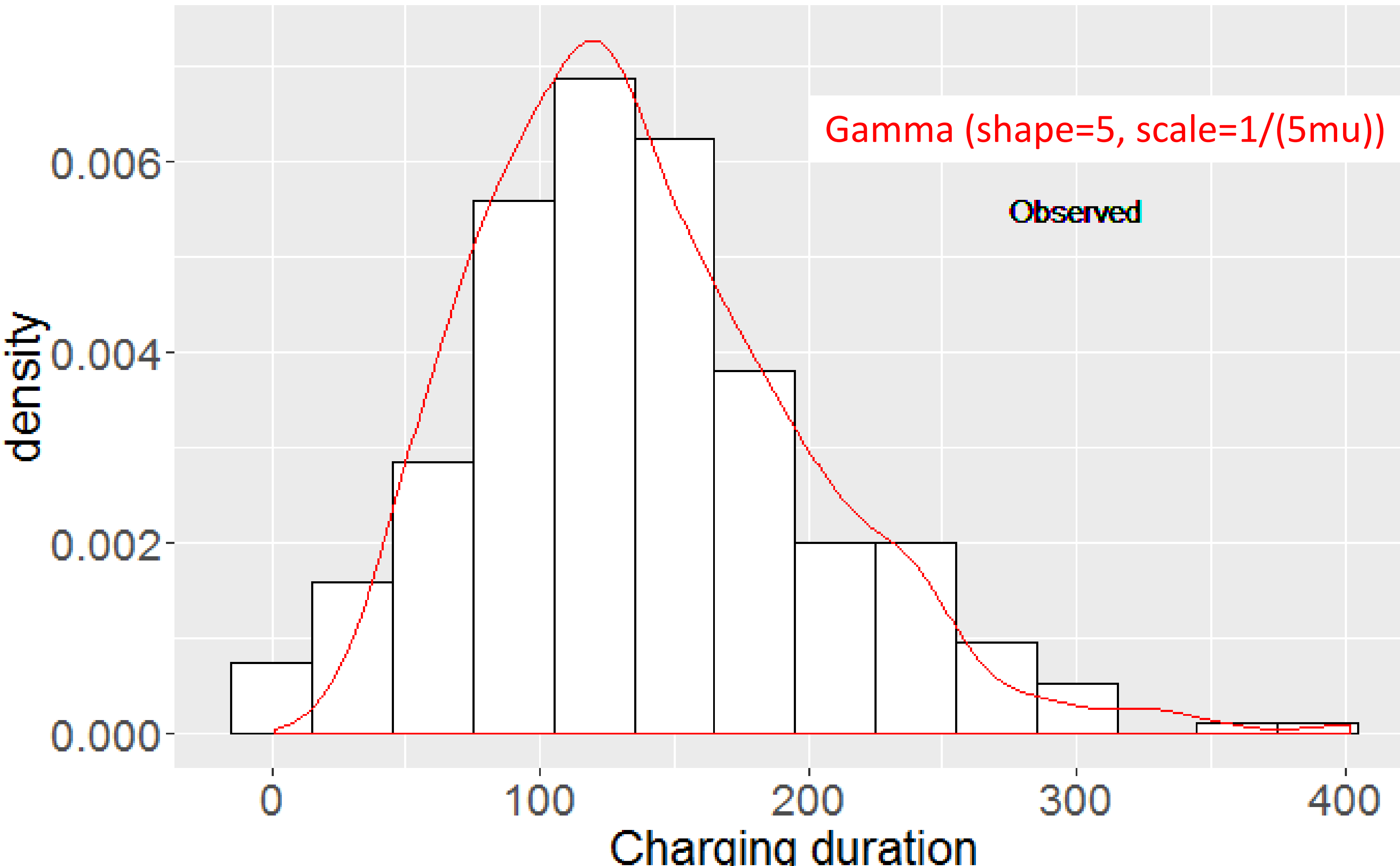
How long it takes cars to charge



Though looks more like a gamma distribution

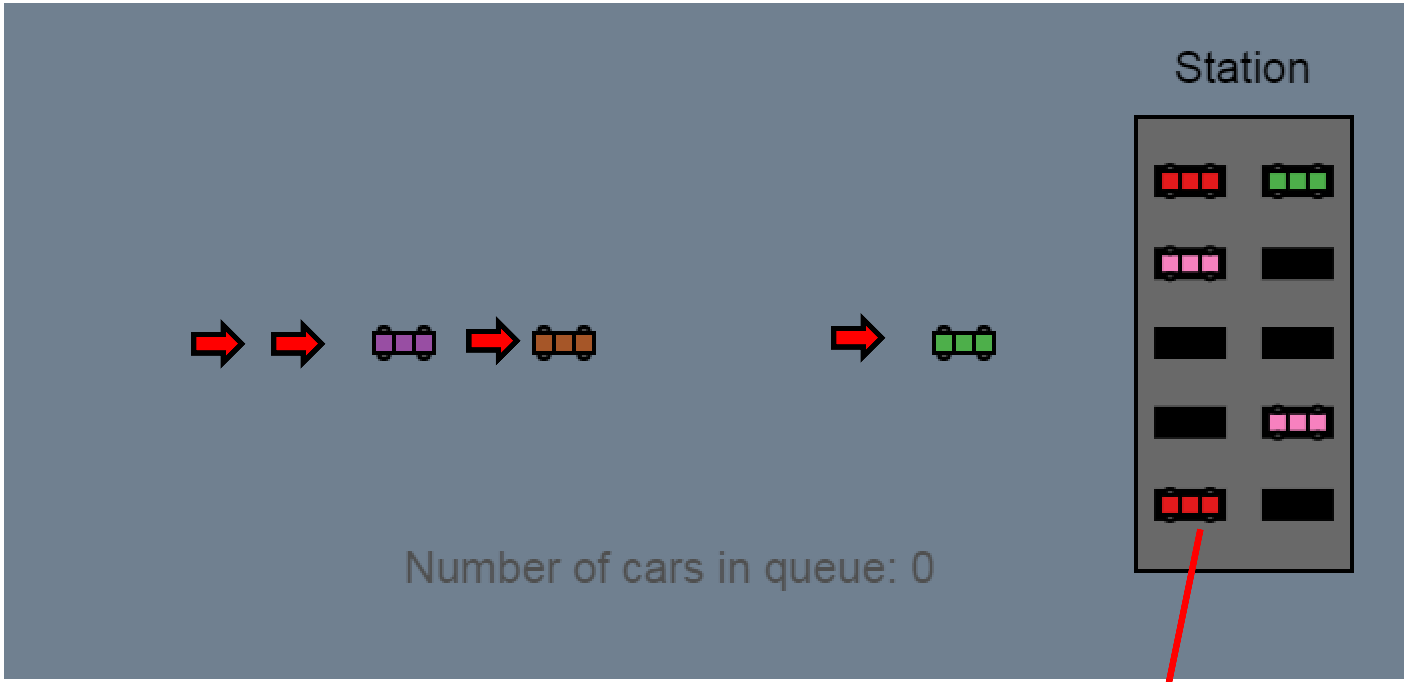
(It’s okay if you don’t understand Exponential/Gamma)

Gamma Distribution Fits much Better



How long it takes cars to charge

- For the queuing model, we assume exponential distribution.
- Charge Duration ~ Exponential(mu)
- mu = Average charging duration
- mu = 136 minutes (2.27 hours)



Charging Duration ~ Exponential(2.27 hours)

M/M/c Queuing Model

- Requires:
  - Rate in which cars arrive → Poisson(lambda=1.17)
  - How long cars charge→ Exponential(mu=2.27)
  - c = Number of stations = 10

- Extra detail:
  - M/M because the inter-arrival and service distributions are memoryless
  - c refers to the number of stations

M/M/c Queuing Model Technical

- Probability a car enters queue upon arrival = $\mathrm{C}\left(c, \lambda/\mu\right)$
- Average wait time in the queue = $\dfrac{\mathrm{C}\left(c, \lambda/\mu\right)}{c\mu - \lambda}$

$$\mathrm{C}\left(c, \lambda/\mu\right) = \frac{\left(\frac{(c\rho)^c}{c!}\right)\left(\frac{1}{1-\rho}\right)}{\sum_{k=0}^{c-1} \frac{(c\rho)^k}{k!} + \left(\frac{(c\rho)^c}{c!}\right)\left(\frac{1}{1-\rho}\right)} = \frac{1}{1 + (1-\rho)\left(\frac{c!}{(c\rho)^c}\right)\sum_{k=0}^{c-1} \frac{(c\rho)^k}{k!}}$$

https://en.wikipedia.org/wiki/M/M/c_queue

Code implemented in R:
https://github.com/kenlau177/Electric-Vehicle-App/blob/master/queuing-modeller.R

Rate Cars Arrive

Cars Arrive ~ Poisson(1.17 cars/hour)

Rate Cars Charge

Charging Duration ~ Exp(2.27 hr)

M/M/c : Model

- Probability a car enters queue upon arrival = 0.045%
- Average wait time in the queue = 0.0084 minutes

Decide whether to expand stations or not

What if there were more cars?

- Recall, currently only 14 cars.
  - Giving us an Arrival ~ Poisson(1.17 cars/hour)

- Consider the same but independent process with 14 cars.
  - Also gives us Arrival ~ Poisson(1.17 cars/hour)

- If we add two independent Poisson random variables, we get another Poisson

What do we get?

14 cars

Cars Arrive ~ Poisson(1.17 cars/hour)

+

Cars Arrive ~ Poisson(1.17 cars/hour)

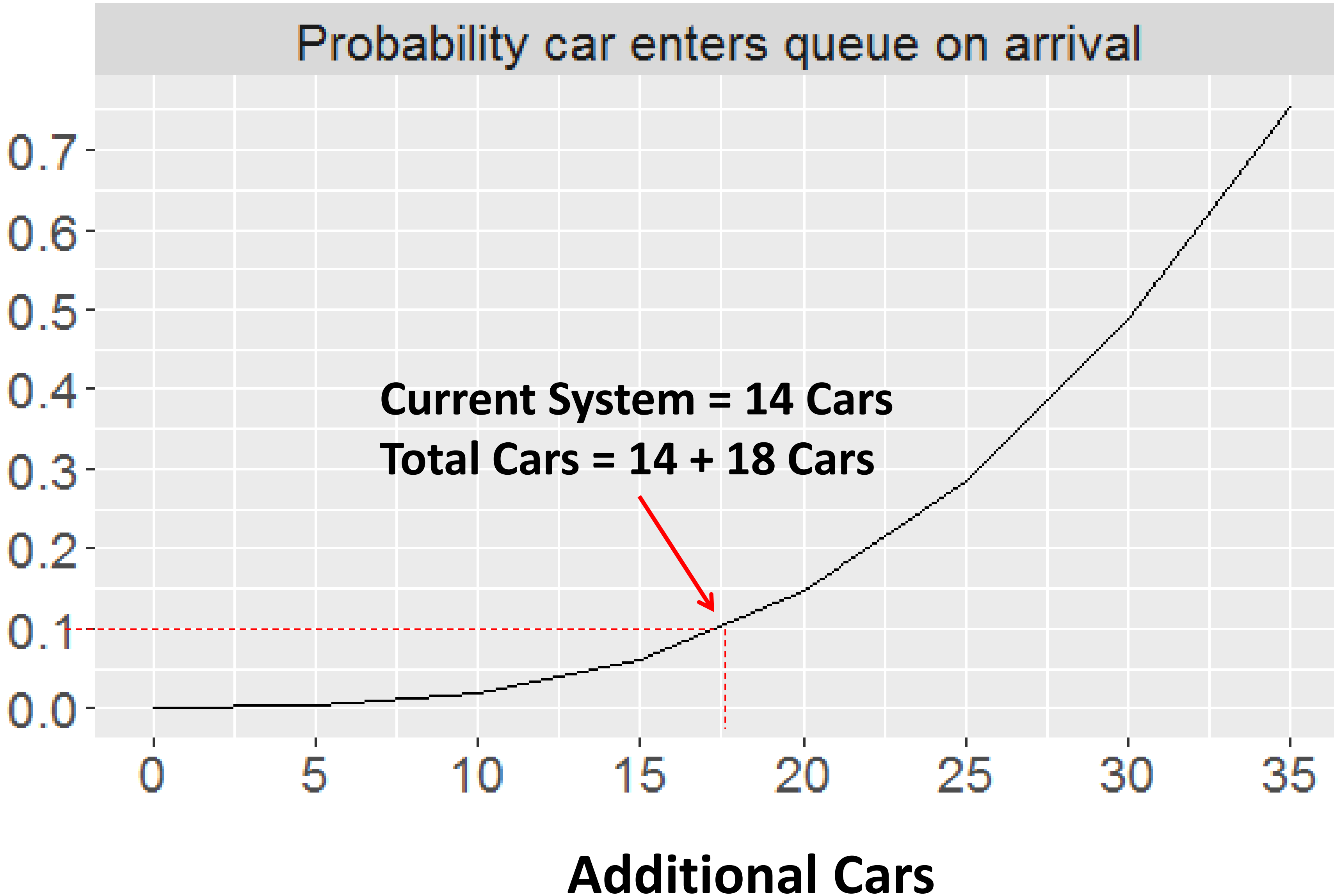
14 cars

$\Rightarrow$ **Cars Arrive ~ Poisson(2.34 cars/hour)**

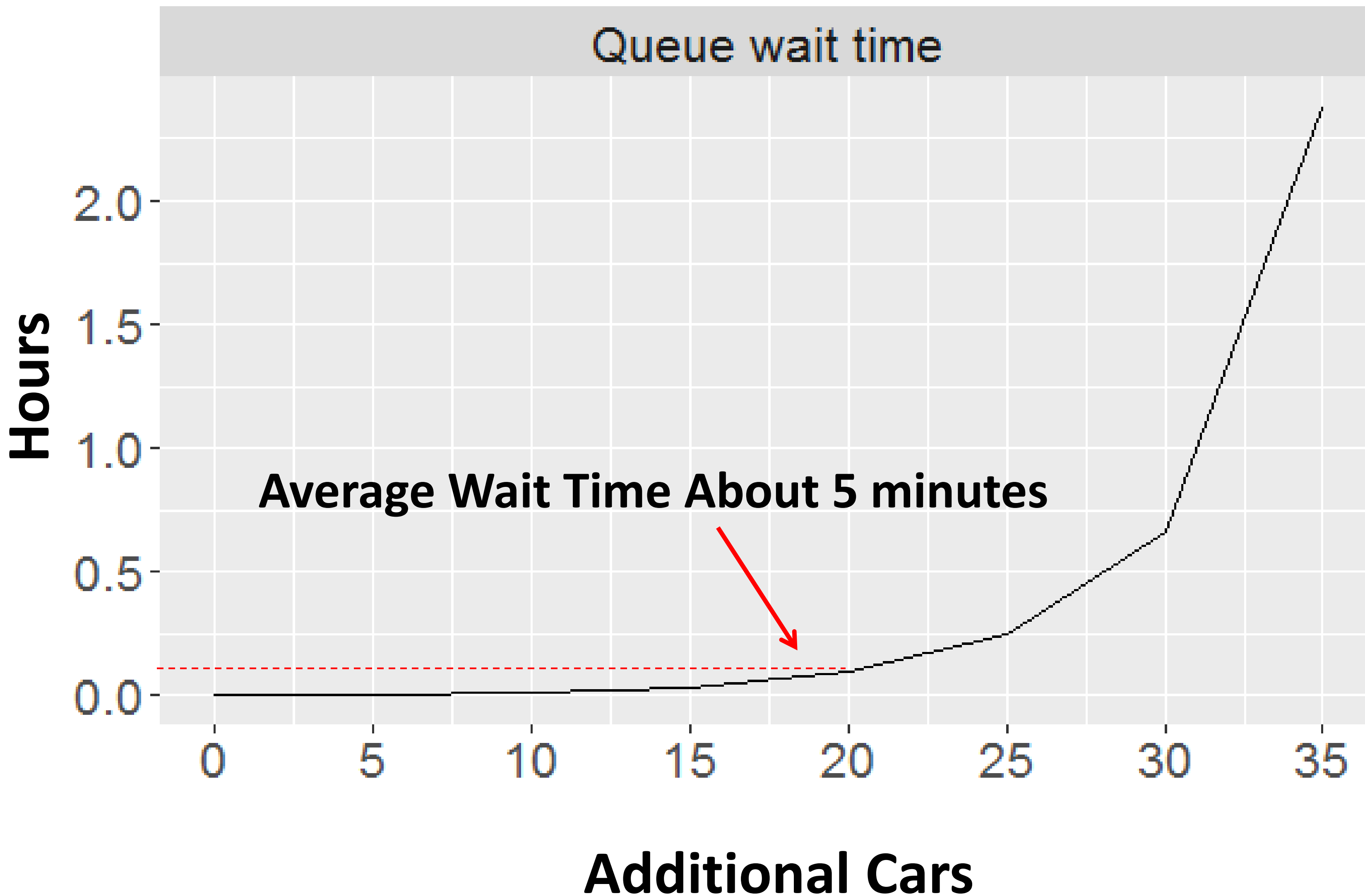
- So, doubling the number of cars doubles the arrival rate
- In reality, it's unlikely the processes are independent
  - The arrival rate should be smaller

Additional Cars	Arrival Rate (cars/hour)
0	1.17
5	1.58
10	2
15	2.42
20	2.83
25	3.24
30	3.66
35	4.08

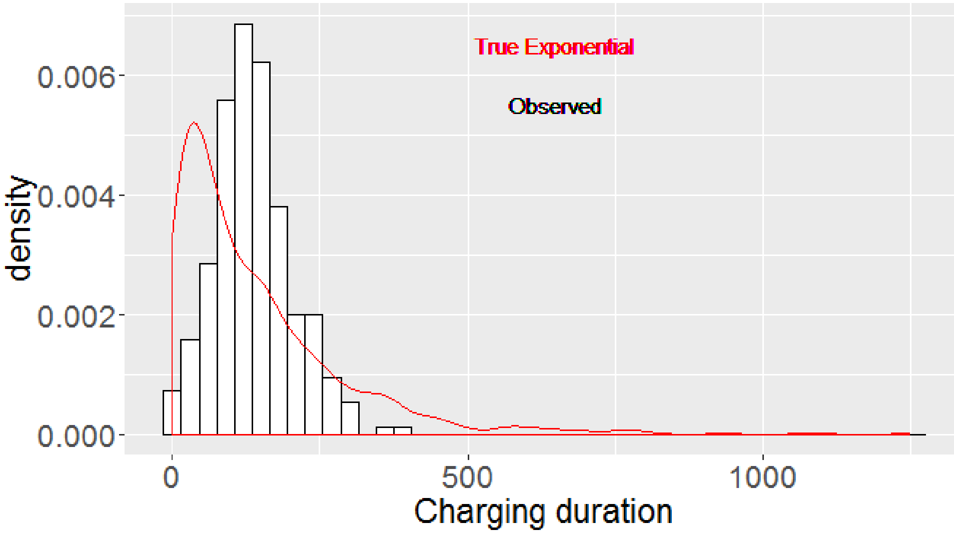
Results



Probability car enters queue on arrival
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Current System = 14 Cars
Total Cars = 14 + 18 Cars
0
5
10
15
20
25
30
35
Additional Cars

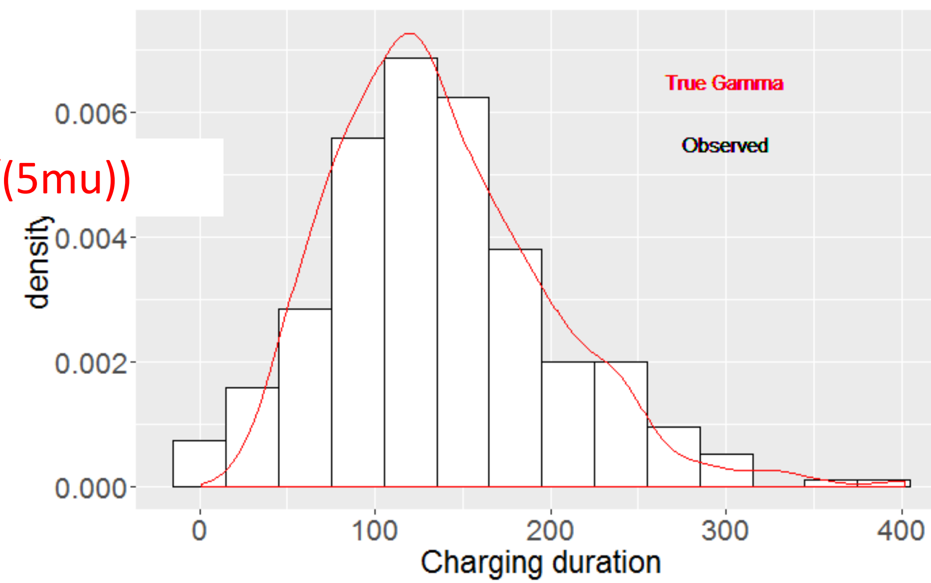

Queue wait time
Hours
2.0
1.5
1.0
0.5
0.0
Average Wait Time About 5 minutes
0
5
10
15
20
25
30
35
Additional Cars

Recall we made a strong assumption on the Charging Distribution



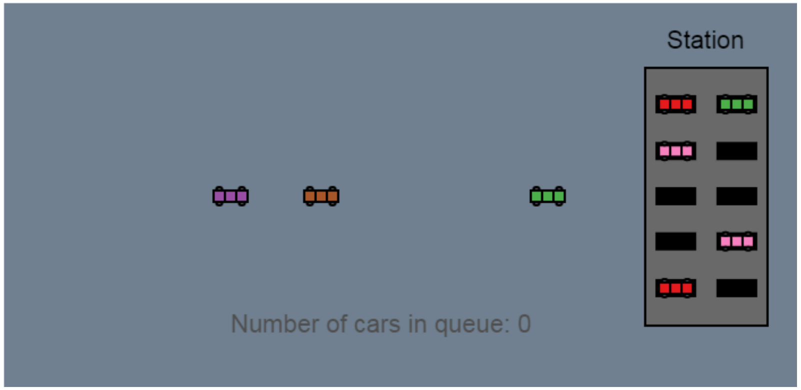
We should use a Gamma distribution instead

Gamma (shape=5, scale=1/(5mu))



To solve this, use Monte Carlo Simulations In the Queuing Model

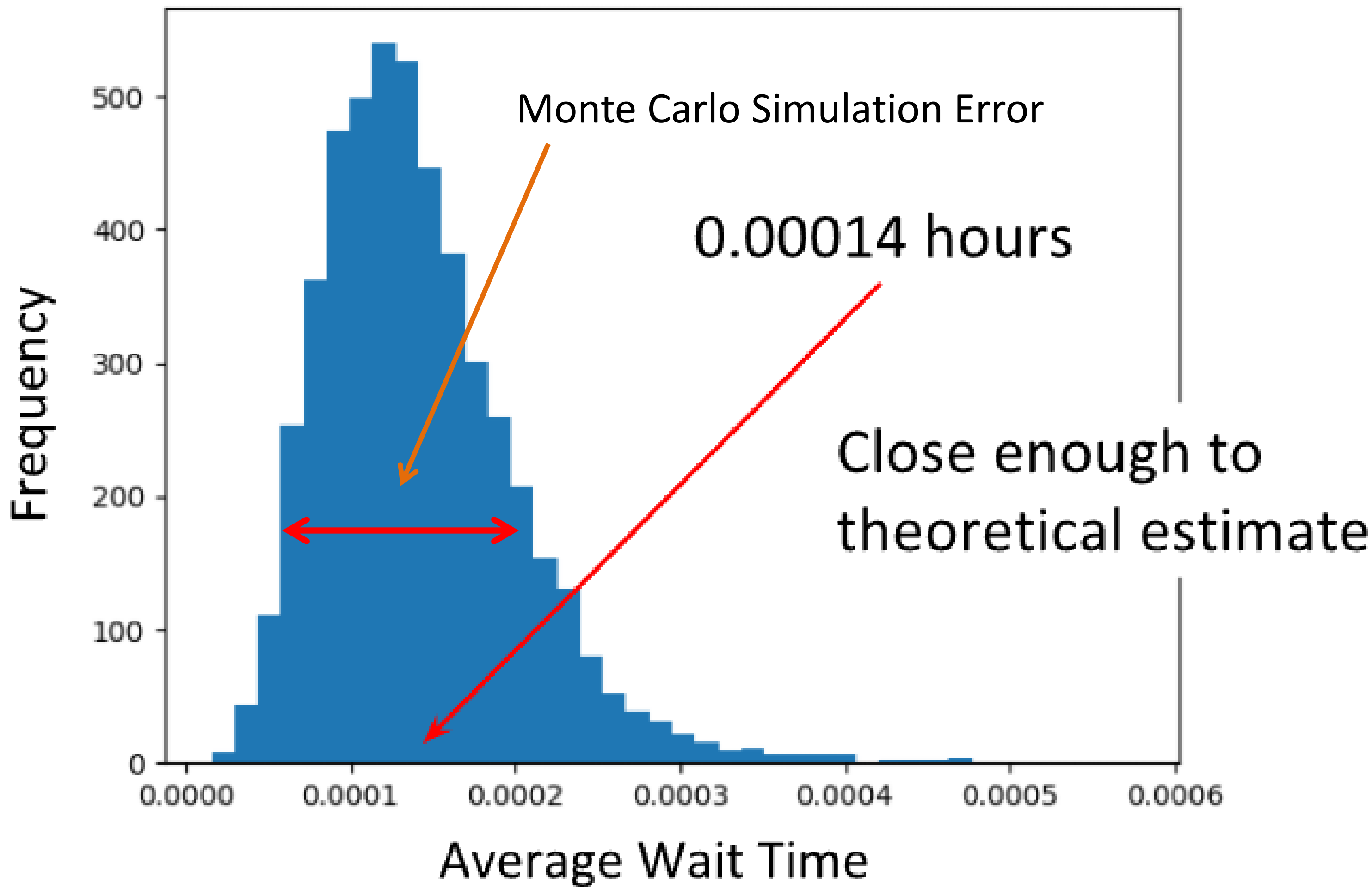
- Use simulation methods when dealing with complex problems
- Trade-offs include simulation errors and computation time

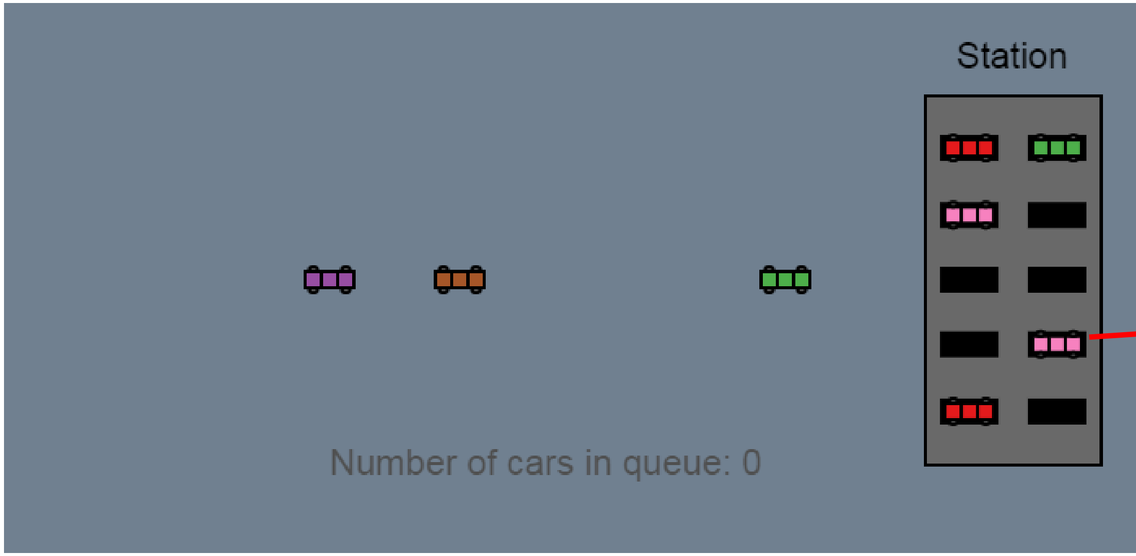


Simulate this in Python

- Test the correctness by comparing with the theoretical estimates of the M/M/c model.

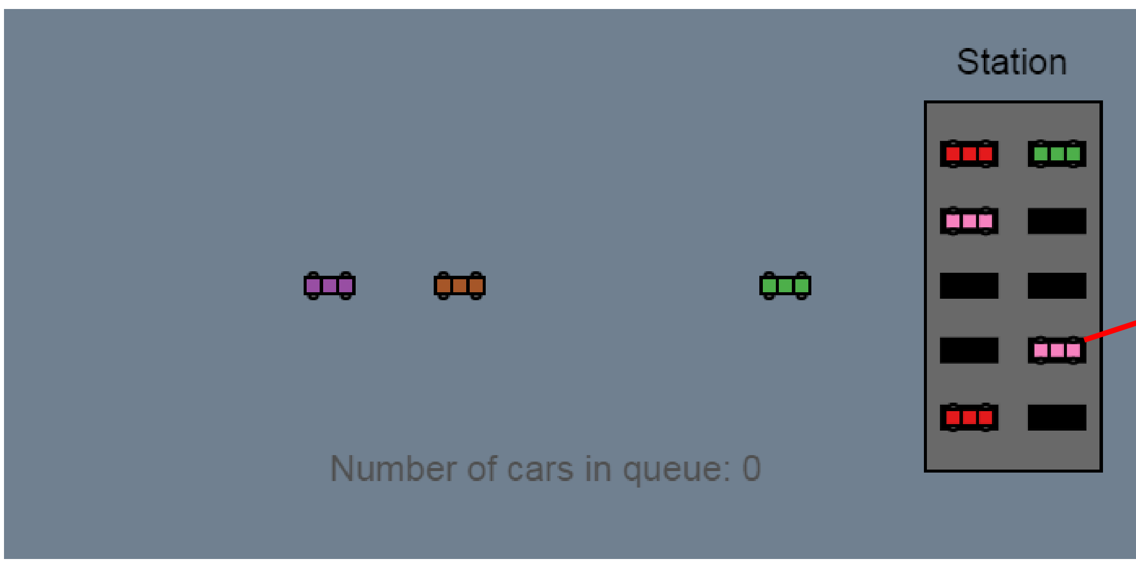
Monte Carlo Simulation of **Average Wait Time** under Exponential Charging Time





Exponential(mu)

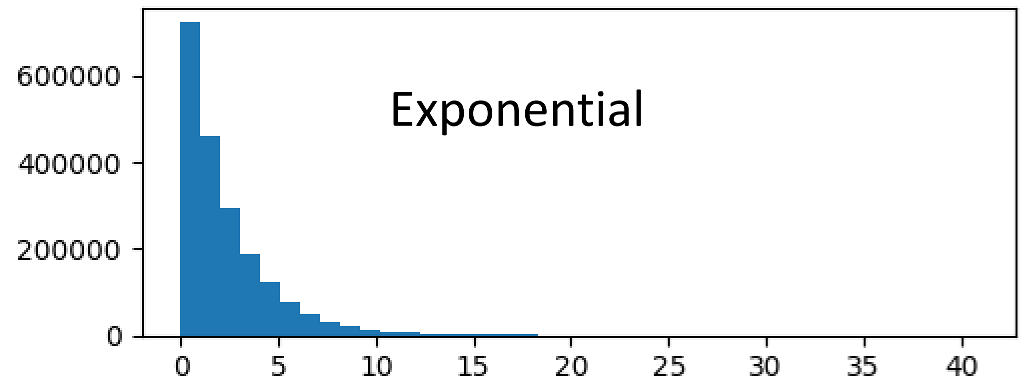
Now Model the Charging Distribution as Gamma Instead

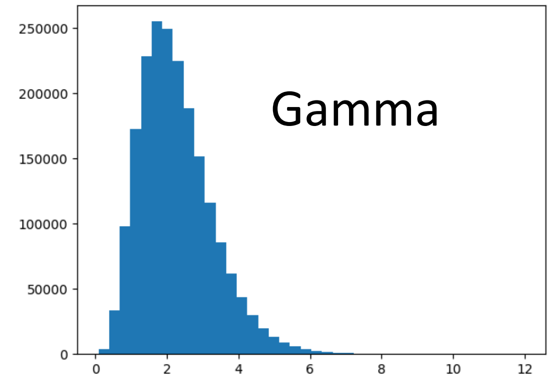


Gamma (shape=5, scale=1/(5mu))

Comparing Probability Car needs to Wait

Arrival Rate (cars/hour)	Additional Cars	Probability Wait Exponential Charging	Probability Wait Gamma Charging
1.17	0	0.000460	0.000425
1.58	5	0.00419	0.00404
2	10	0.02	0.0190
2.42	15	0.0624	0.0593
2.83	20	0.145	0.138
3.24	25	0.28	0.267
3.66	30	0.481	0.466
4.08	35	0.749	0.736





Comparing Average Wait Time

Arrival Rate	Additional Cars	Average Wait Time Exponential Charging	Average Wait Time Gamma
1.17	0	0.000142	0.000112
1.58	5	0.00148	0.00115
2	10	0.00832	0.00621
2.42	15	0.0314	0.0223
2.83	20	0.0919	0.062
3.24	25	0.240	0.156
3.66	30	0.646	0.405
4.08	35	2.30	1.39

Conclusion

- Task:
  - A model to predict when to expand the current infrastructure
- Data:
  - Cars arrival and charging time
- Exploratory Analysis:
  - Isolate busiest time
  - Arrival time seen as Poisson
  - Charging time seen as Exponential or Gamma

Conclusion Continued

- Describe the M/M/c model:
  - Calculate probability cars enter queue
  - Calculate average wait time
- Impact of additional cars on arrival rate
- Results:
  - Probability of enter queue ~0 with 14 cars
  - Probability become 0.1 with another 18 cars
  - Wait time 5 minutes at 20 additional cars
- Describe simulation method if use gamma distribution instead.

Thanks For Not Falling Asleep!