

# **Application of Multi-Arm Bandits for Optimal Parking Search on UNC Campus**

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The problem that we are solving is the best way to find parking on campus during a weekday at UNC. We wanted to find the optimal route to search chosen visitor parking lots. This effectively would work as a recommendation system based on the time of the day. We chose ten visitor lots. These were Rams Head Deck, Morehead Lot, Raleigh Road Lot, Raleigh Rd Street parking, Raleigh St street parking, Country Club street parking, Wilson Library Lot, UL Lot, FedEx Lot and Davis Library Lot. These are the lots we searched and looked through for optimal routes. We decided to implement an MAB to come up with an optimal order to figure out which arms to pull. The arms in this case were each specific lot.

In order to do this we had to come up with a way to simulate the data. This was done by finding the total amount of spaces in each lot. Once that was done, we decided to model each lot as an M/M/K queue. K is the number of servers which is the total number of spots in the lot. The arrival and leaving rate were just estimated based on what we knew about the lots and the total number of spots available. We had a unique arrival and departure rate for every hour from 7 a.m. to 5 p.m. for every lot. This was also done based on general estimation. The next thing we did was that we used an Erlang B formula to find the probability that the servers are all full which in this case means that the lot is completely full.

$$B = \frac{\frac{A^N}{N!}}{\sum_{i=0}^N \frac{A^i}{i!}}$$

The table below shows how we formatted the blocking probability into our table.

	Time Period	Lot ID	Lot Name	Arrival Rate	Departure Rate	Blocking Probability
0	7-8	1	Rams	90	6	0.934108
1	8-9	1	Rams	70	10	0.859437
2	9-10	1	Rams	60	10	0.836518
3	10-11	1	Rams	50	10	0.804716
4	11-12	1	Rams	20	15	0.329997

Lot	Rams 7-8	Rams 8-9	Rams 9-10	Rams 10-11	Rams 11-12	Rams 12-1	Rams 1-2	Rams 2-3	Rams 3-4	Rams 4-5	...
0	0	0	1	0	1	1	1	1	1	1	...
1	1	0	0	0	1	1	1	1	1	1	...
2	0	0	0	1	0	1	1	1	1	1	...
3	0	0	0	0	1	1	1	1	1	1	...
4	0	0	0	0	1	1	1	1	1	1	...

That probability was used to generate data. For every hour we came up with a probability that the lot was full when an observer arrived (see table above). This was then used to generate 1000 trials where 1 was generated if the lot was not full. This meant that the observer found a spot. 0 was generated when the lot was full. This was fed into a simple MAB algorithm, EXP3 algorithm, UCB algorithm, and a Thompson Sampling Algorithm. Below is a table containing the payouts and variations for each algorithm.

Time Group	MAB Avg. Payout	MAB Var.	EXP3 Avg. Payout	EXP3 Var.	UCB Payout	TS Avg. Payout	TS Var.
7-8	60	55	84	347	79	157	155
8-9	115	100	165	340	159	219	149
9-10	218	216	442	541	432	581	57
10-11	293	246	536	381	531	660	295
11-12	431	173	623	238	612	685	251
12-1	589	181	841	55	834	936	25
1-2	661	149	925	13	923	991	1
2-3	767	125	957	3	950	994	1
3-4	932	43	990	0	989	998	0
4-5	1000	0	1000	0	1000	1000	0

Of all the algorithms, the Thompson Sampling Algorithm gave us the highest payout. This was why we chose it to give us optimal searching routes based on the time of day. These came out to be as follows, with lot 1 being the first to try and lot 10 being the last:

Time Group	7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5
Lot 1	Rams	Raleigh Rd	Raleigh St	Raleigh St	Raleigh St	Rams	Raleigh Road Lot	Davis	Rams	Wilson
Lot 2	Morehead	Rams	Rams	Rams	Rams	Morehead	Rams	Rams	Morehead	Rams
Lot 3	Raleigh Road Lot	Morehead	Morehead	Morehead	Morehead	Raleigh Road Lot	Morehead	Morehead	Raleigh Road Lot	Morehead
Lot 4	Raleigh Rd	Raleigh Road Lot	Raleigh Road Lot	Raleigh Road Lot	Raleigh Road Lot	Raleigh Rd	Raleigh Rd	Raleigh Road Lot	Raleigh Rd	Raleigh Road Lot
Lot 5	Country Club	Country Club	Raleigh Rd	Raleigh Rd	Raleigh Rd	Country Club	Country Club	Raleigh Rd	Country Club	Raleigh Rd
Lot 6	Raleigh St	Raleigh St	Country Club	Country Club	Country Club	Raleigh St	Raleigh St	Country Club	Raleigh St	Country Club
Lot 7	Wilson	Wilson	Wilson	Wilson	Wilson	Wilson	Wilson	Raleigh St	Wilson	Raleigh St
Lot 8	UL	UL	UL	UL	UL	UL	UL	Wilson	UL	UL
Lot 9	FedEx	FedEx	FedEx	FedEx	FedEx	FedEx	FedEx	UL	FedEx	FedEx
Lot 10	Davis	Davis	Davis	Davis	Davis	Davis	Davis	FedEx	Davis	Davis

These results show the route to check parking lots to get a spot in the quickest way possible, listed from best to worst per vector. In each vector you can see the associated time beside the name of the lot. In this case the best route is found by checking the least number of lots, yielding to a higher payout. Based on the data Rams Head Deck and Raleigh St street parking are the best bets in the early hours and the other lots tend to be better later. While the data is not guaranteed to be representative of the real world since it was estimated, the algorithmic approach should work once data is collected. The route searching tree should yield correct and applicable results once given accurate hourly arrival and departure rates for every lot in the list.