Forecasting and Optimization of Unfulfilled Demand in Bike Sharing Systems on the Example of MVG Rad in Munich

Bachelor's Thesis of Kilian Steinberg

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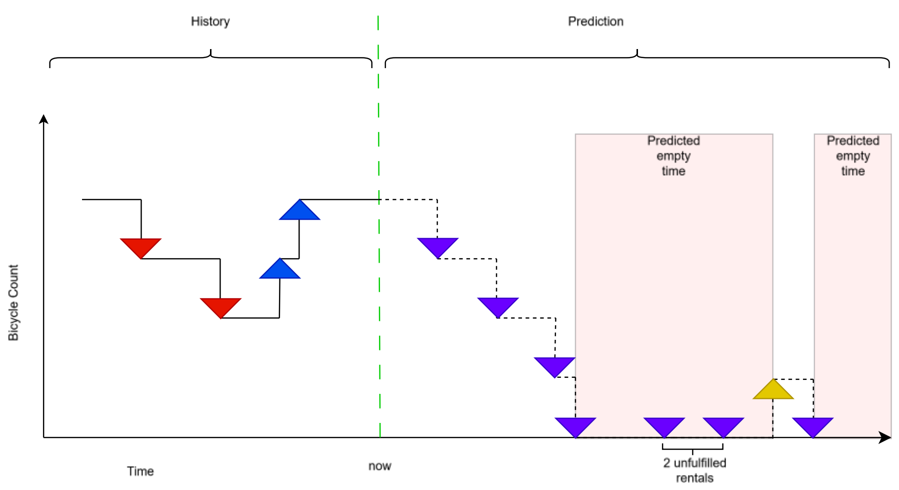


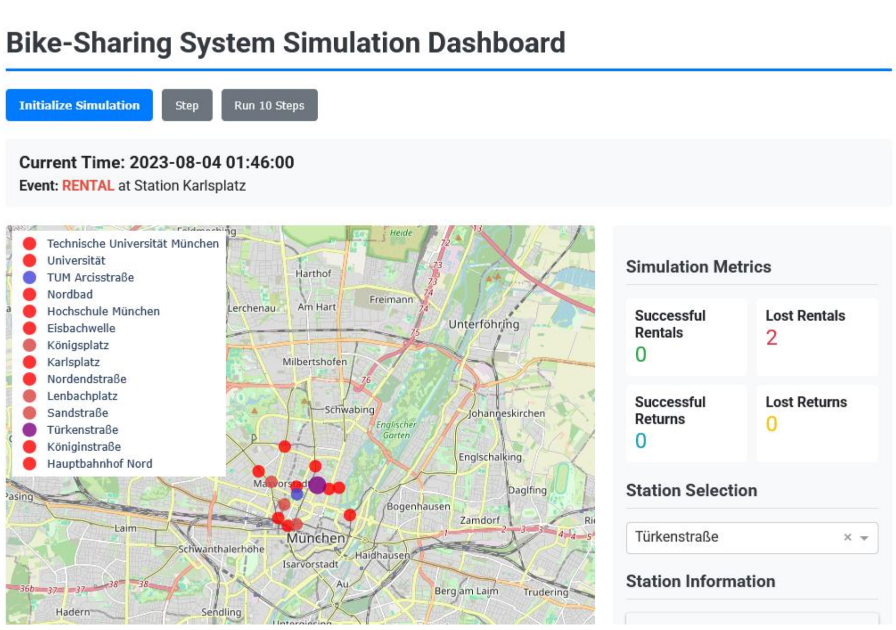
Forecasting Example. The Model predicts rental/return events (purple/yellow) from a station's booking history (red/blue) and other data.

Bike-sharing stations in Munich are regularly empty, especially during commute hours with peak demand. Operators re-fill stations frequently but do not supply enough bikes at some stations, which become empty quickly after a re-fill. I trained a neural network demand model on MVG Rad data that predicts individual bike rentals and returns. It can iteratively forecast when a station becomes empty how many rentals would be unfulfilled while it is empty. While the model converges during training, it does not outperform a statistical baseline model, which returns the average hourly demand at a station. I integrated these predictions into a Re-Balancing simulation framework to compare the performance of re-balancing strategies in realistic scenarios. I thereby optimize when and how many bikes should be re-filled at which stations. To evaluate these operations, I introduced an operator-cost objective function, determining how much profit or loss re-balancing causes. This forecasting framework can provide real-time information on expected demand and profit for bike-sharing operators.

The neural network model uses a station's booking history, nearby stations' histories, and temporal information as input. As illustrated above, the model predicts when bikes will be next rented/returned. With this information, I determine when the station will become empty and how many rentals would have happened during empty periods (unfulfilled demand). I evaluated the models over a series of practical tasks: Predicting the total number of rentals/returns in a day, predicting the total number of unfulfilled demand in a day, and predicting if and when a station becomes empty in a day. I trained and evaluated this model for 14 stations from the MVG Rad system. The table to the right shows that the model is generally outperformed by a baseline model on all tasks, which is exemplary for all stations. However, the results mostly vary by 2-4 bookings on average and tend to overestimate the correct value. For now, operators could use the predictions as an upper bound for re-fills. Future research could improve the model by using more data points and a transformer neural network architecture .

Station	Task	RMSE		MAE	
		NN	Baseline	NN	Baseline
Eisbachwelle	Rental Demand	8.18	6.67	-1.88	-1.79
	Return Demand	11.04	6.50	3.39	-0.64
	Unfulfilled Demand	3.92	0.38	1.99	-0.07
	Empty Periods	14.67	6.79	9.02	1.92
Hauptbahnhof Nord	Rental Demand	11.50	6.60	1.75	0.25
	Return Demand	8.20	6.92	-2.96	1.17
	Unfulfilled Demand	8.61	0.50	5.52	-0.09
	Empty Periods	17.65	5.82	13.16	1.41
Hochschule	Rental Demand	5.77	6.02	1.59	-4.72
	Return Demand	5.72	5.21	-1.83	-3.66
	Unfulfilled Demand	3.85	0.38	2.52	-0.06
	Empty Periods	17.79	4.03	13.19	0.68
Karlsplatz (Stachus)	Rental Demand	6.79	7.14	-1.42	-4.22
	Return Demand	7.47	6.66	1.32	-3.28
	Unfulfilled Demand	2.65	0.11	1.22	-0.01
	Empty Periods	12.65	5.06	6.67	1.07

Evaluation Results. RMSE and MAE in *hours* for practical prediction tasks.



The bike-sharing simulation framework lets the user configure a re-balancing scenario with stations, re-balancing vehicles, upcoming demand, and a re-balancing strategy. I created 24h test scenarios with MVG Rad data and compared two Re-Balancing strategies: an Ant Colonization Algorithm (ACO) and a rule-based strategy. The ACO constructs re-balancing routes for multiple vehicles in parallel, mimicking the route-finding behavior of ants. The rule-based strategy schedules the re-balancing of a station when it is expected to be empty for at least two hours. For both approaches, I used the forecasting model to predict empty times and unfulfilled demand, and the simulation framework to observe the actual values. With my setup, the rule-based strategy caused less unfulfilled demand than the ACO algorithm. Additionally, I introduced an operator-cost objective function. It uses the price of bike rentals as revenue and the staff, fuel, and maintenance costs as costs. It determines the profit of a re-balancing schedule, but its parameters need to be researched to match real operations.