Predicting and Modulating On-Street Parking in Cities

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Abstract

Finding a parking slot is a serious issue in contemporary urban mobility. It is estimated that the average driver in the U.S., U.K. and Germany wastes 17, 44 and 41 hours a year respectively searching for parking, at an estimated annual cost of \$72.7 billion, £23.3 billion and €40.4 billion in these countries [1]. Despite the importance of the topic (30% of cars might be cruising for parking in many large cities [3]) and the central role given to parking policies, surprisingly little is known about the basic laws governing the search time.

In this work, we present a set of analytical and computational approaches to investigate the role of the drivers' perception of the 'attractiveness' of parking spots (Figure 2C), in determining the occupancy of on-street parking spots in busy downtown districts. Under this concept of attractiveness, we subsume the various factors governing the selection of a place to park, including its distance to the destination, cost, and intrinsic characteristics. We implement this idea in a stochastic agent-based model and simulate it numerically to investigate the cruising phenomenon in the central district of Lyon. We also demonstrate the effect of modulating spot attractiveness on the on-street parking spot occupancies (Figure 1) and the time spend cruising for parking. As a matter of fact, the occupancy in such a model is exactly solvable and we develop an analytic formula to do so. We verify the accuracy of our results by comparing with occupancies generated through *in-silico* experiments (Figure 2).

Case Study: On-street Parking in Downtown Lyon in the evenings

To demonstrate our method, we simulate the on-street parking spot occupancy (n) and search times in the downtown commercial districts of Lyon: the 1st and 2nd arrondissements (Figure 2A), in a typical evening. The network is faithfully reproduced: It consists of $1,835$ directional street portions between nodes or junctions (a two-way street portion would consist of two such directional portions), as well as $8,778$ parking spots distributed over these street portions. For simplicity, we make the assumption here that on each street portion, the spots are placed equidistantly between the two ends. At the beginning of the simulation half of these spots are occupied with equal probability, by cars that remain there for the duration of the simulation.

As a case study, we model the parking dynamics of 200 cars going to the lively neighbourhood of Place des Terreaux/Opera, over a duration of 5.5 hours. The drivers want to park as close to the opera (located at $\mathbf{x_o}$) as possible, with a local parking probability $p(\mathbf{x}) = \exp\Big(-\frac{A_s(\mathbf{x})}{\max A_s}\Big)$ for a car arriving at a vacant spot on a street beginning at the coordinate $\mathbf{x}$. We use the following Ansatz for the attractiveness field $A_s(\mathbf{x})$:

$$A_s(\mathbf{x}) = \exp\Big(-\frac{|\mathbf{x}-\mathbf{x_o}|}{d_{walk}}\Big). \tag{1}$$

The parameter d_{walk} gives the distance from the opera at which the attractiveness field (and therefore the probability to park at an empty spot) falls to e^{-1} relative to the maximum (at the opera). We use this to modulate three different attractiveness fields $d_{walk} = 100m, 200m$ and $400m$ (Figure 1A). We define the search-time as the duration between the instant the driver first arrives within $500m$ of the opera, and the instant that the car finally parks. Once parked, cars stay for an average duration ($\equiv \frac{1}{D}$, where D is the departure rate) of two hours before being removed from the simulation.

We see that increasing the distance d_{walk} affects an almost-tenfold decrease on the average search time, from 19 minutes in the first case, to 4 minutes and 12 seconds in the intermediate, to 2 minutes in the last one (Figure 1B).

Based on realistic fluxes in this district of Lyon, drivers enter the simulation volume through entry nodes i, over the bridges of the two rivers surrounding the area to the East and West, and a high volume tunnel in the

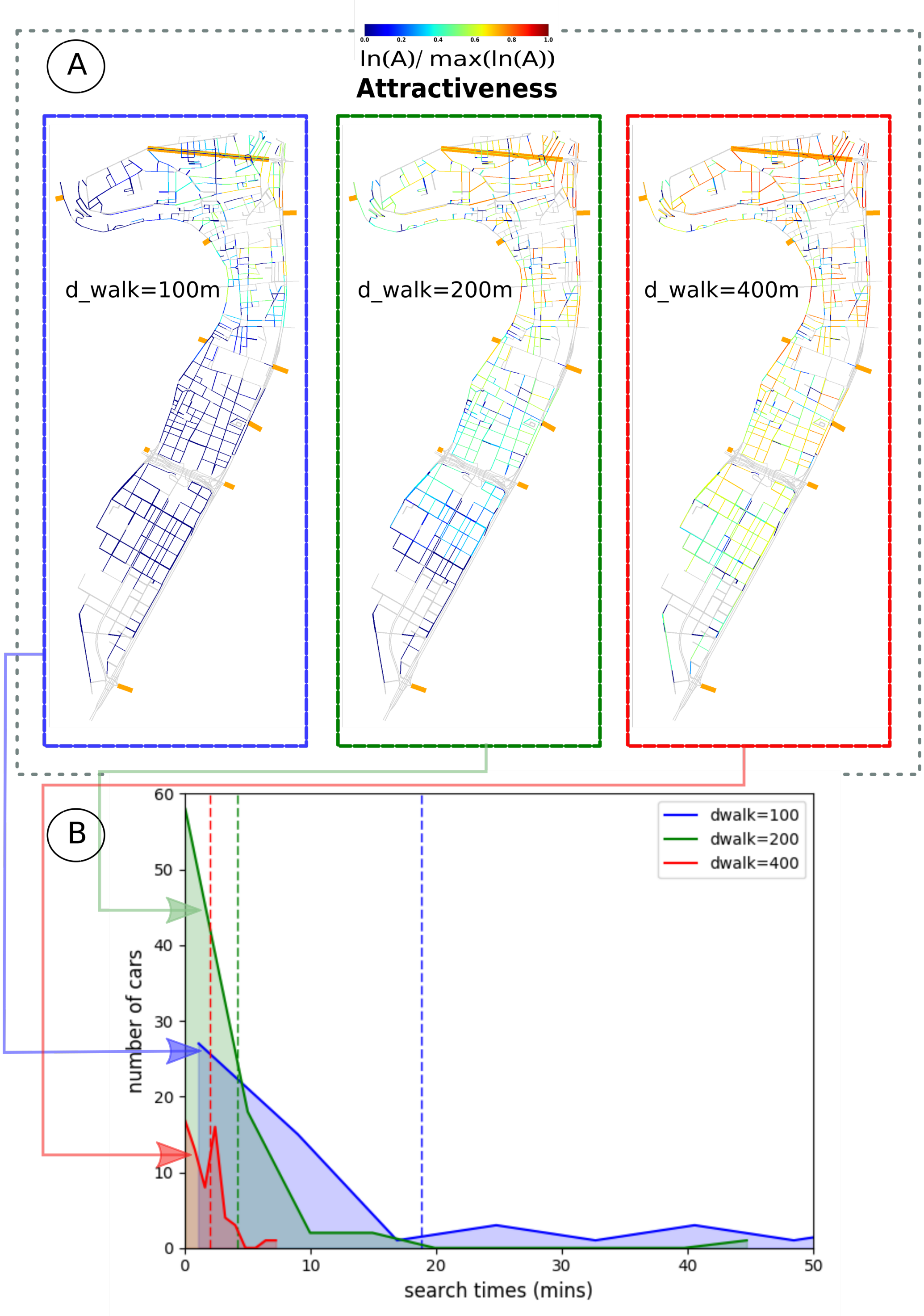

Figure 1: **Modulating search times through spot attractiveness**
Panel A: Three different attractiveness fields, obtained by modulating $d_{walk} = 100m, 200m, 400m$ in blue, green and red respectively
Panel B: Distributions of search times for each sub-panel in A, with the average shown in dashed vertical lines in each case. By modulating d_{walk}, the maximum search time is reduced from 75min in first case (not shown in plot) , to 8min in the last one

North, with equal probabilities (orange bars in Figure 2A) I_i . Cars are 'driven' to their destination by turning with higher probabilities towards the opera at street ends. For instance, at a junction with n possible choices street choices, $\mathbf{S} = \{s_1, s_2..s_n\}$ the transition from street $s' \longrightarrow s_k$ is given as:

$$T_{s_k}^{s'}(\mathbf{x}) = \frac{\exp -|\mathbf{x_{s_k}} - \mathbf{x_o}|}{\sum_{s_i \in \mathbf{S}} \exp -|\mathbf{x_{s_i}} - \mathbf{x_o}|} \quad (2)$$

where $\mathbf{x_{s_i}}$ is the location of the end node of street s_i, and all other variables retain their usual significance. Cars can exit from the network only if they arrive at a cul-de-sac street, where a U-turn is not legally possible.

Having thus defined all parameters, the probability $P(x|i)$ to park at location x after being injected at entry i can now be solved analytically by the formula :

$$P(x|i) = \sum_{\pi} [I_i \prod_{x' \in X} (1 - \tilde{n}(x')A(x'))T_x^{x'}]\tilde{n}'(x) \quad (3)$$

where $\tilde{n}(x) \equiv 1 - n(x)$ is the vacancy at that location, and where i is the set of all 'entry nodes' where cars enter the network with probability I_i

Since at any given spot x the, the change in occupancy $n(x)$ is given by the differential equation

$$\frac{dn(x)}{dt} = IP(x) - Dn(x) \quad (4)$$

In the steady state, the analytical occupancies can then be obtained simply by setting the left hand side of this equation to zero (Figure 2B).

In this work, the method is shown for the case where $d_{walk} = 100m$, (Figure 2C). We find that the simulated equilibrium occupancies can be determined with a high degree of accuracy, with the mean error over spots being 0.0025 ((Figure 2D).

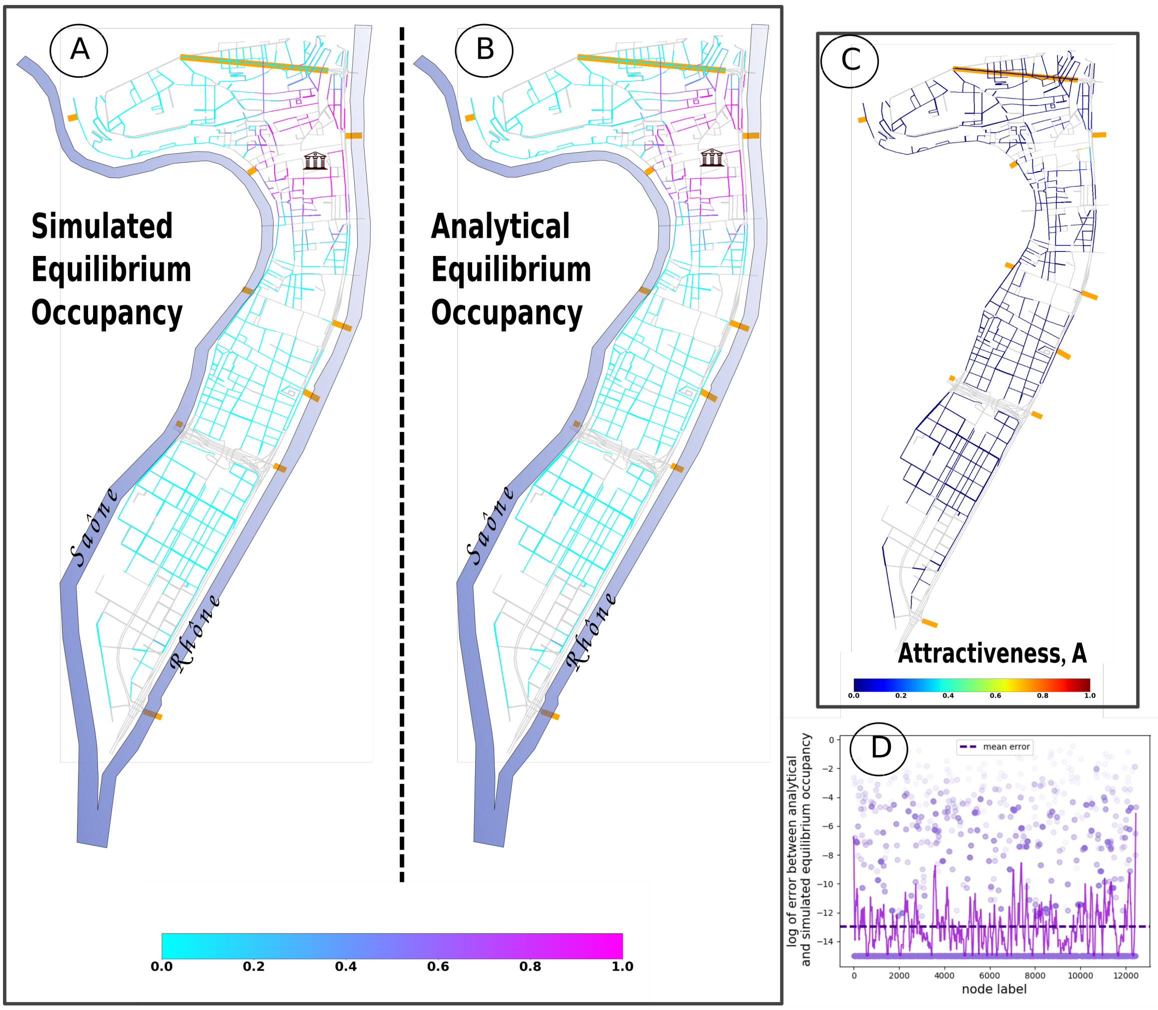

Figure 2: **Predicting equilibrium street occupancy through mathematical model**:
Panel A, B: Simulated and analytical on-street stationary occupancies in downtown Lyon. Location of the opera is indicated by the icon, and the entry streets into the simulation are indicated by orange bars
Panel C: Relative spot attractiveness A, averaged over street portions
Panel D: Error, in log scale between Panels A and B

Surveys show that long cruising for extended periods of time can be effectively alleviated by providing more information to the drivers about the local traffic and parking conditions [2]. With data from on-street parking in cities increasingly available, our approach paves the way for an assessment of how transparent and targeted parking policies at the level of individual streets can modulate the relative attractiveness of spots, leading to more efficiently occupied on-street parking networks, and smaller cruising times.

Here, we have shown that, knowing such attractiveness fields and transitions between streets *ex ante*, one can analytically predict the steady state on-street occupancies. Given that the inverse problem is also solvable (making it possible to deduce the attractiveness from the occupancies), this method could be a useful tool for city-planners and transport officials to design policies to effectively control on-street parking.

References

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