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Workforce Scheduling in On-Demand Platforms

Omar Besbes[1] Vineet Goyal[1] Garud Iyengar[1] Raghav Singal[2]

[1]Columbia University [2]Amazon / Dartmouth College

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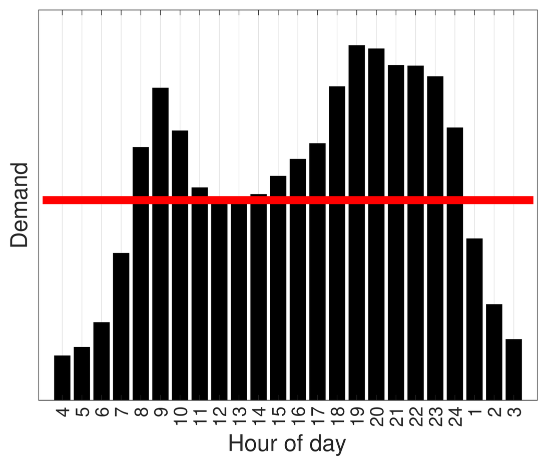
Introduction



Hourly demand pattern in NYC. Observe the morning and evening peaks.

- Platforms such as Uber and Lyft aggregate supply to meet demand
- Too little supply $\implies$ platform profit $\downarrow$
- Too much supply $\implies$ drivers wage $\downarrow$
- Even with regulations, effective wage can be below minimum wage

Question: How to aggregate supply so that drivers are guaranteed minimum wage while ensuring optimal platform profit?

Problem Formulation

Platform

- Time periods $\{1, \ldots, T\}$ with $T = 24$ (one day) for example
- Platform profit maximization (PM) outputs target supply $\boldsymbol{\mu}^* := [\mu_t^*]_t$

Drivers

- Driver $d \in \{1, \ldots, D\}$ has a private type $\mathbb{T}_d := \{s_d, s_d + 1, \ldots, e_d - 1, e_d\}$
- Driver type captures the block of periods she wishes to drive, e.g., 9am to 5pm
- $\boldsymbol{x}_d \in \{0,1\}^T$ denotes periods driver d is allowed to be active (platform decision)
- $\boldsymbol{y}_d \in \{0,1\}^T$ denotes the *contiguous* on-road block of driver d (driver decision)
- Utility of driver d is as follows:

$$v(\boldsymbol{x}_d, \mathbb{T}_d, \boldsymbol{y}_d) := c \sum_t x_{dt} y_{dt} - a \sum_t y_{dt} - \infty \sum_{t \notin \mathbb{T}_d} y_{dt}$$

- Average effective wage of drivers equals

$$\mathsf{w}(\mathbf{X}, \mathbf{Y}) := c \frac{\sum_d \sum_t x_{dt} y_{dt}}{\sum_d \sum_t y_{dt}}$$

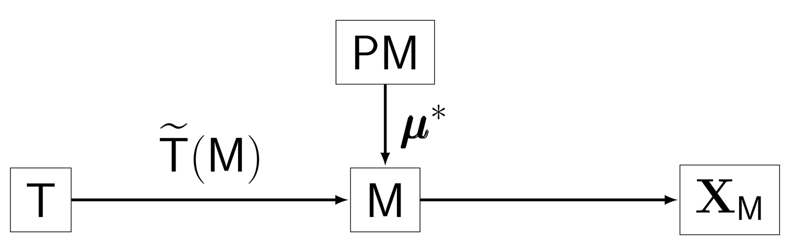
- The set of profit optimal allocations that are *individually rational* (IR) is

$$\mathsf{X}^* := \left\{ \mathbf{X} : \mathbf{X} \text{ IR}, \ \sum_d x_{dt} y_{dt}(\boldsymbol{x}_d) = \mu_t^* \ \forall t \right\}$$

- Maximum possible effective wage while achieving optimal profit equals

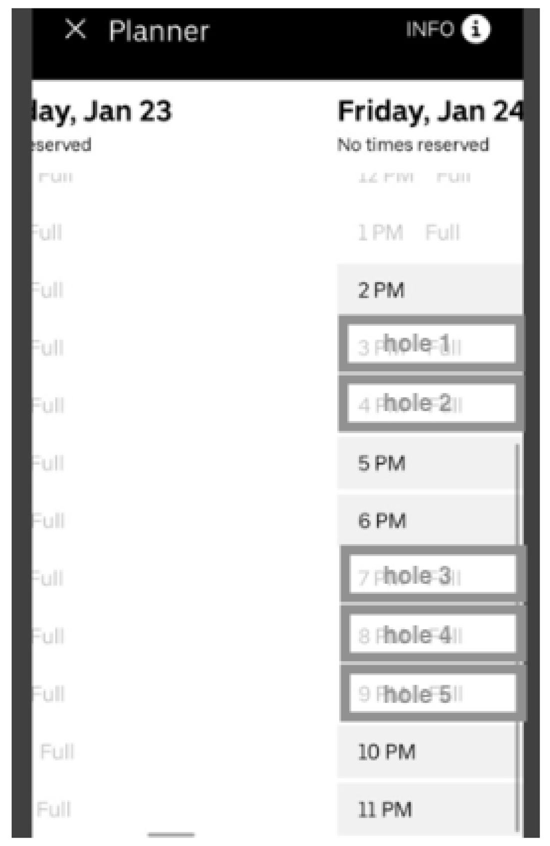
$$\mathsf{w}^* := \max_{\mathbf{X} \in \mathsf{X}^*} \mathsf{w}(\mathbf{X}, \mathbf{Y}(\mathbf{X}))$$

Mechanism design problem



Drivers have a true type $\mathsf{T} := (\mathbb{T}_1, \ldots, \mathbb{T}_D)$ but reveal $\widetilde{\mathsf{T}}$ as a function of the scheduling mechanism M, in order to maximize their expected utility. The mechanism M outputs an allocation $\mathbf{X}_{\mathsf{M}}$ as a function of the revealed types $\widetilde{\mathsf{T}}$ and target supply $\boldsymbol{\mu}^*$. How does one design a mechanism to maximize effective wage while ensuring optimal platform profit?

Existing Approach I: First-Come-First-Serve (FCFS)



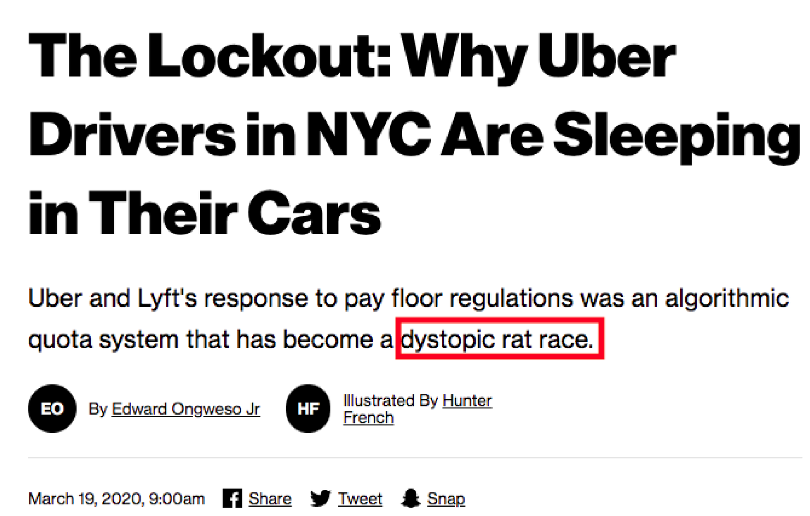
FCFS policy as seen from a driver's Uber app. The slots for certain hours on Friday are full (e.g. 1pm and 3pm) whereas certain slots are available for the driver to sign-up (e.g. 2pm and 5pm).

- Platform releases the $\boldsymbol{\mu}^*$ slots in advance
- Drivers claim the slots on a first-come-first-serve basis
- Example: In the figure above, a driver might claim all 5 slots with 5 holes
- Drawback: Part-time drivers creating holes in the schedule of full-time drivers

Effective wage can decay linearly under FCFS

There exists a market E such that $\frac{\mathsf{w}_{\mathsf{FCFS}}(\mathsf{E})}{\mathsf{w}^*(\mathsf{E})} = \frac{2}{T}$ (and this result is tight)

Existing Approach II: Dynamic Control (DC)


The Lockout: Why Uber Drivers in NYC Are Sleeping in Their Cars

Uber and Lyft's response to pay floor regulations was an algorithmic quota system that has become a dystopic rat race.

By Edward Ongweso Jr Illustrated By Hunter French

March 19, 2020, 9:00am Share Tweet Snap

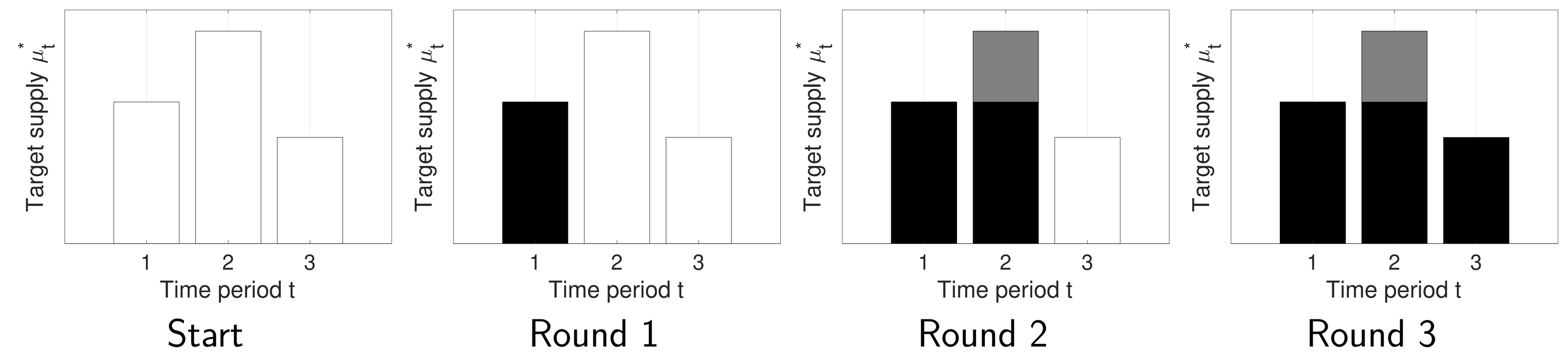
- Drivers show up on road
- In period t, platform turns on μ_t^* drivers
- Key difference: $\mathbf{X}$ is a function of $\mathbf{Y}$ as opposed to $\mathbf{Y}$ being a function of $\mathbf{X}$
- Example: D drivers but 1 slot, all would show up if reservation wage low enough
- Drawback: Lack of communication resulting in a "dystopic rat race"

Effective wage can be arbitarily bad under DC

DC can be arbitrarily bad in terms of effective wage, i.e., $\inf_{\mathsf{E}} \frac{\mathsf{w}_{\mathsf{DC}}(\mathsf{E})}{\mathsf{w}^*(\mathsf{E})} = 0$

Proposed Mechanism: Sequential FCFS (SFCFS)

- Drivers communicate their preferences and are prioritized accordingly
- In round $t \in \{1, \ldots, T\}$, release μ_t^* slots for reservation
- Key 1: Drivers who are allocated a slot in round $t-1$ get priority
- Key 2: Among those drivers, drivers with a later end period get priority

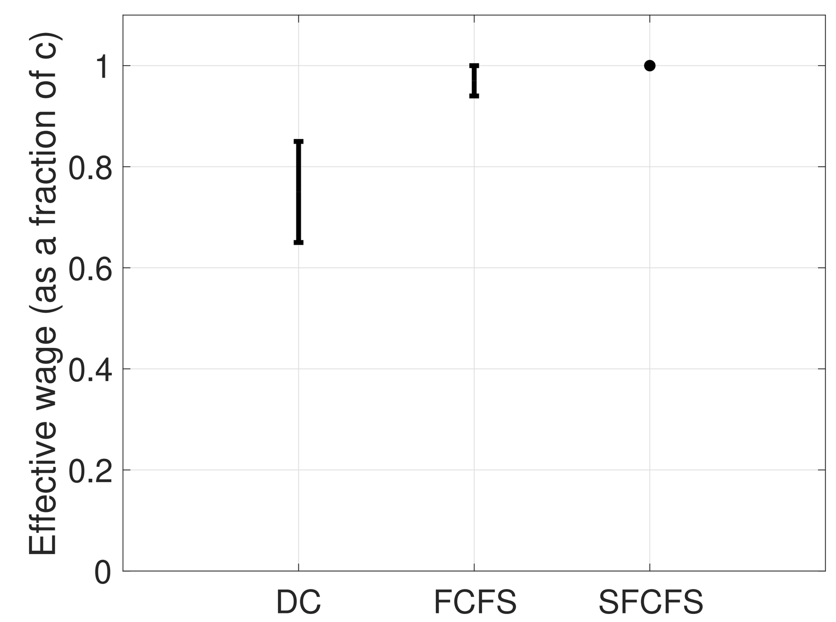


- Demand in urban areas has morning and evening peaks
- **Assumption**: Full-time drivers can cover base demand
- **Assumption**: There exist sufficient part-time drivers to cover peak demand
- Denote the corresponding set of markets by $\mathbb{E}_{\text{peak}}$

SFCFS optimal under "peak" supply

$\forall \mathsf{E} \in \mathbb{E}_{\text{peak}}$, $\mathsf{w}_{\mathsf{SFCFS}}(\mathsf{E}) = \mathsf{w}^*(\mathsf{E})$ and platform achieves optimal profit

Simulation Results



Parameters calibrated using NYC data. Effective wage highest under SFCFS. Under DC, effective wage takes a hit of 15-35%. Under FCFS, effective wage drops by 0-6%. Full-time drivers suffer more than part-time drivers. Platform profit (near-)optimal under all policies.

Concluding Remarks

- Driver welfare is of critical importance in on-demand platforms
- Multiple governments have imposed minimum wage regulations
- These regulations are ineffective when the admission control policy is poor
- Propose a mechanism design framework to analyze admission control policies
- Both FCFS and DC can be highly sub-optimal in terms of effective wage
- SFCFS increases drivers effective wage without hurting platform profit