Reducing Bus Crowding Using Simulations

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Abstract
The Chicago Transit Authority (CTA) has launched a crowding reduction initiative to make its transit service more comfortable and reliable. At present, the agency implements schedule changes to reduce crowding, and then evaluates their effects after the fact. The DSSG Fellows created a tool to simulate bus routes and forecast crowding levels, allowing the CTA to make more proactive service decisions that anticipate changes in ridership, and thereby reducing crowding before it starts.

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The Problem
Crowded buses aren’t just uncomfortable to ride—they can also lead to schedule deviations and skipped stops. However, a certain amount of crowding is virtually inevitable: to avoid it entirely, transit agencies would need to set their service levels based on peak rush hour loads, which would leave them with far more vehicles and personnel than they need to satisfy off-peak demand. The goal is instead to make the best possible use of the capacity they have.

The CTA tracks the performance of its buses in several ways. Each vehicle has a GPS transponder that reports its position as a function of time. Each bus door also has two sensors used to detect boarding and alighting passengers. The CTA uses this data to provide real-time arrival information, track driver performance, and watch for problems such as bunching and crowding. It also makes use of historical data when proposing schedule changes, such as altering the gaps between buses on a given route or re-allocating buses between different routes.

Once the CTA has settled on a set of schedule changes, it implements them and measures the change in crowding over the next quarter. If the CTA had a realistic simulation of their transit system, changes could be proposed and tested without having to wait several months to see the results, increasing the system’s efficiency and responsiveness.

The Project
The DSSG fellows implemented a bus route simulation and a web-based interface that CTA staff can use to propose schedule changes and view the expected results. It predicts both the average crowding for a given bus route and its expected variation, taking into account the time of day, day of week, season, etc. The simulation has three components: people arriving at bus stops, passengers getting off buses, and bus arrival times. Individuals arriving at bus stops are modeled as a Poisson process with a rate parameter $\lambda$ that is a function of time-dependent covariates: $\log \lambda = \alpha + \beta + \gamma$. Alightings are modeled using a binomial distribution $\text{Bin}(n, p)$ where

$\log p/(1 - p) = \alpha + \beta + \gamma$. Schedule deviations are assumed to be governed by a Gaussian process.

The parameter values in each of these three processes are determined by fitting to the CTA’s historical data. Once the parameters are determined, a Monte Carlo simulation is used to predict the distribution of passengers aboard the bus at each stop as a function of time. A web-based application provides CTA staff an easy-to-navigate portal through which they can visualize and interact with the simulation output.

The model performs well on an MSE basis. The predicted values are only slightly biased ($< 1\sigma$), and in the direction of excess crowding—they accurately anticipate the worst-case scenarios. Future improvements could include improving the accuracy of the simulation by incorporating weather, traffic, holiday schedules, and special events. A system-wide simulation could also allow the CTA to consider more drastic schedule changes, such as adding/removing routes or incorporating Bus Rapid Transit service.

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