Optimal Frequency Setting for Large-Scale Urban Transit Networks: A Data-Driven Approach

CHALLENGE
Transit agencies in large metropolitan areas, such as the Chicago Transit Authority (CTA) are seeking ways to utilize the growing data bases available through automated fare collection and other sources of ridership information to better allocate resources to improve service and the resulting user experience. The Northwestern University Transportation Center (NUTC) has partnered with the CTA in developing data-driven approaches and decision support tools for service planning and allocation.

While it is desirable from the user’s perspective to increase frequencies over the entire network, transportation agencies have limited resources in terms of budget, fleet (number of available buses) and personnel. Agencies need to make allocation decisions that provide the greatest benefit in terms of quality of service for the most riders, subject to various requirements that are essential to their public mandate.

Better decisions call for maximal use of available information, and mathematical techniques that consider service patterns and ridership responses across the entire system rather than on an individual route basis.

APPROACH
The project entailed understanding and integrating both the demand side and supply side of the problem. On the demand side, likely ridership response (elasticity) to frequency changes needs to be captured. On the supply side, a mathematical model is formulated to optimally allocate available resources (e.g. budget and fleet) over the routes in order to increase ridership, reduce waiting times and limit overcrowding.

Service Elasticity Estimation
Lower service frequencies generally discourage ridership, whereas higher frequencies attract additional riders. However, the extent of the ridership response depends on several factors that vary with the availability of convenient and affordable alternatives at different locations and by time of day. The demand response to changes is captured by the elasticity of demand to the provided service frequency. Typical agency practice has been to use across-the-board elasticity estimates. In this project, NUTC researchers estimated elasticities at a finer resolution, using detailed boarding and alighting data over multiple years provided by the CTA. The NUTC elasticity estimation model provides elasticities for every route, stop, and half hour while capturing the effects of land use, socio-demographics, walkability and accessibility.

Understanding and Modeling Service Patterns
Transit agencies in large urban areas use multiple “service patterns” for most of their routes to improve service along certain segments. A service pattern is defined over a subset of stops along a route. A commonly used pattern is the “short-turn” pattern, which provides additional service along a higher demand segment of a route; it typically overlaps the “full-length” pattern, which serves the entire route (including the higher demand segment). The CTA also schedules specific patterns for sports events, sponsoring companies and major schools. The modeling challenge arises from the fact that riders are mostly unaware of the details of such patterns, which are not directly relevant to their choice, as they perceive only the overall service resulting from the juxtaposition of these different patterns. NUTC researchers introduced a mathematical formulation that recognizes the pattern frequencies as the key decision variable for the agency, while capturing the ridership response to resulting overall service using the detailed elasticity estimates mentioned previously.

Setting Frequencies: Exploring Trade-offs
Given the detailed elasticity estimates and modeling the pattern-route coupling, NUTC developed a mathematical decision model with two main formulations. The first formulation seeks to increase ridership and reduce wait time subject to operational budget, fleet, policy headway and overcrowding prevention constraints. The second formulation seeks to minimize the net operational cost subject to the same constraints, while retaining certain minimum ridership levels and not exceeding maximum waiting time constraints in order to not compromise existing quality of service. The two formulations can be used in concert to explore trade-offs amongst agency cost, ridership and wait time (user cost) under varying funding and service quality scenarios in order to make better informed decisions.

FINDINGS
The study concluded that it is possible to improve the quality of service by serving more riders and reducing waiting times, and still save on the operational cost by using a network-wide mathematical optimization approach. The study is unique in

- Estimating the ridership response at a very fine spatial and temporal resolution relative to existing agency practices,
- Capturing the complicated structure of multiple patterns serving a route, and
- Estimating crowding levels in transit vehicles as the combined result of changing pattern frequencies and the ridership response to these frequencies in a time-dependent manner.

(more)
FINDINGS (cont.)

With improving data collection capabilities and computational advancements, more transit agencies today can utilize network-wide optimization models in order to assess their existing service and improve it by changing service schedules at the operational level and restructuring their service patterns at the strategic level.

MORE

This research was funded by Chicago Transit Authority (CTA) and conducted by Professor Hani S. Mahmassani, William A. Patterson Distinguished Chair of Transportation; Director, Transportation Center and Professor Joseph L. Schofer, Professor of Civil and Environmental Engineering; Associate Dean for Faculty Affairs. Omer I. Verbas, Charlotte Frei and Raymond Chang were the principal graduate student researchers on the project.