RESEARCH STATEMENT

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I am broadly interested in the design of service systems and the accompanying policies and mechanisms (both operational, e.g., routing, matching, and staffing policies, and economic, e.g., pricing, cost/revenue sharing, and incentive mechanisms) that involve complex interactions among different strategic entities whose objectives do not necessarily align with that of the system manager. Over the last several years, my research portfolio has evolved from primarily methodology-focused work tackling abstract problems that find relevance in multiple application domains, into a more balanced mix that includes recent contributions to the transportation domain, where the goal is to identify ways of applying analytical techniques to address specific problems that impact its major stakeholders. In particular, an emerging focus of my research is to better understand trade-offs between competing economic objectives, and how managing these trade-offs fundamentally constrains the underlying operational decisions and vice versa.

This growing interest began during my time at Xerox/Conduent, where my role was to contribute to, and later lead, research in Algorithms and Optimization that best support the strategic interests of its worldwide customer-facing business groups in transportation (e.g., Parking, Public Transit, Commercial Trucking, Tolling). At the time, the global transformation of urban mobility into a user-centric, service-oriented playing field, from a traditionally vehicle-centric, infrastructure-oriented framework, was an emerging radical trend that posed new challenges, elevating the importance of modeling and analysis of strategic user behavior and its impact on system performance. It is estimated that by 2030, 60% of the world’s population will live in cities, where most users are just a few taps away from accessing a diverse set of mobility options from scheduled modes of transport such as public transit to on-demand modes of transport such as taxicab and ride/bike/car-share services. Users’ strategic mobility choices thus have an enormous impact on various stakeholders such as policy makers and mobility service providers, who in turn make strategic decisions to best serve their diverse interests: users want the best trade-off between cost and convenience; public transit agencies want to increase their ridership; private mobility service providers want to meet their revenue targets; and the city government wants what is best for society. The recent spike in interactions between city government, public transit agencies, and ridesharing services (both ‘friendly’ cooperation and ‘unfriendly’ regulation) is clear evidence of a growing interdependence between their interests, whereby they can no longer afford to ignore each other while making crucial management decisions. This state of affairs presents a huge opportunity for new, highly multi-disciplinary research to make a significant impact in shaping the next generation of urban mobility, by guiding policy and decision-making towards a fair balance of the competing interests while also promoting a sustainable future.

In adapting traditional modelling frameworks and methodologies to take into account strategic agent behavior, my approach is to first characterize the limitations of purely systemic design choices (i.e., excluding external monetary dependencies), and then identify the key trade-offs when also considering (limited) monetary dependencies (e.g., performance-based rewards/penalties, government subsidies, etc.) on the design. I combine tools from multiple subjects such as optimization, probability, queueing theory, decision theory, game theory and mechanism design for obtaining analytical results, as well as numerical methods and, more recently, data-driven simulation for validation in real-world environments. I summarize my research highlights in the next paragraph, following which I briefly discuss my recent work.

I have published an article each in Operations Research [3] and Mathematics of Operations Research [5], and contributions from two pieces of recent work [2, 6] are in the final stages of preparation to be submitted for review. My first published article as a graduate student [4] in 2011 has now reached a citation count of 90. My research at Xerox/Conduent was central to the successful pilot Go Bengaluru, a multi-modal trip planner with peer-to-peer ridesharing for the city of Bangalore, and, together with my sustainability-focused research on electric vehicles, earned me a Scientific Excellence Award. Finally, I am currently leading the design and development of a general-purpose, data-driven, city-scale, multi-modal mobility simulator incorporating both operational and economic control policies, and have initiated discussions with TCAT, the public transit agency that serves Ithaca (and Tompkins County), to identify opportunities for collaboration.

- **Service Operations Management**: My work on Service Systems with Strategic Servers [2, 3] studies the design of service systems when servers have some discretion over their service times, and make strategic choices that maximize some utility function. Such behavior has been observed in the context of journal peer-reviewing (referees enjoy flexibility over scheduling their time towards working on their assignments
and when to submit their reports), call centers (agents have some flexibility over how much time they spend on any given call), and taxicabs (drivers may have flexibility in their route choice and driving speed), to name a few. The servers’ utility functions are directly influenced by the design choices of the system manager, which include (a) system configuration (e.g., pooled with one central queue or dedicated with multiple parallel queues), (b) routing policy (e.g., Random routing or Fastest Server First), and (c) staffing policy (e.g., linear or square-root safety staffing). Traditional queueing theoretic results (for exogenous service rates) may no longer hold when servers are strategic. For example, the Fastest Server First routing policy may lead to servers slowing down to avoid becoming too busy. Similarly, always assigning extra staff to a busiest division of a service system can lead to servers slowing down to ensure that their division is assigned the extra staff. Thus, it is crucial for a system manager to understand the effect of strategic servers on the performance of the service system while making its design decisions. While strategic arrivals may no longer hold when servers are strategic. For example, the Fastest Server First routing policy (e.g., linear or square-root staffing). Traditional queueing theoretic results (for exogenous service rates) may no longer hold when servers are strategic.

In joint work with Sherwin Doroudi, Amy R. Ward, and Adam Wierman [3], published in Operations Research, we introduce a model for strategic servers where they enjoy idle time, but incur a cost of effort/fatigue, under which we study routing and staffing policies in an \( M/M/N \) queueing system that result in symmetric Nash equilibria in the service rates, and minimizes the total system cost (a linear combination of staffing and waiting costs) at equilibrium. First, we show a surprising policy-space-collapse: all “idle-time-order-based” routing policies (e.g., Longest/Shortest Idle Server First and Random) are equivalent. Under any such policy, we then characterize asymptotically optimal staffing policies, which we find must staff strictly more than its counterpart “square-root staffing policy” in the non-strategic setting. Our work has inspired subsequent research in this area and currently has a citation count of 29. Then, in [2], I jointly optimize the routing policy (over a large class of “rate-based” policies, e.g., Fastest/Slowest Server First and Random) and the system configuration (pooled vs. dedicated), finding policies that outperform Random. Interestingly, while servers prefer working faster in the dedicated configuration, it may not be enough to overcome its systemic inefficiency for a superior performance. Moreover, the system-optimal policies also lead to the least utility for the servers, resulting in a ‘moral dilemma’ for a manager who also values employee satisfaction. The approach in obtaining these results consists of a mixture of both analytical and numerical techniques, depending on the tractability of the respective models.

**Pricing & Revenue Management:** My ongoing work with Chamsi Hssaine, Siddhartha Banerjee, and Samitha Samaranayake on Sustainable Market Models for Modern Urban Mobility aims to identify and address the challenges in designing a welfare-maximizing urban mobility market mechanism that simultaneously encourages honest participation from utility-maximizing commuters, non-profit public transit agencies, and profit-sensitive on-demand mobility services. Technology advances that enable Mobility-as-a-Service (MaaS) and the sharing economy, transform the underlying problem space and expand the design space along new dimensions. For example, multi-modal travel (involving more than one mobility service provider) with a single-payment system and seamless transfers is possible today, which not only introduces new real-time pricing and capacity/revenue sharing problems, but also connects economic objectives, e.g., social welfare and revenue, to multiple time-sensitive operational objectives, e.g., feasibility and ‘quality’ of multi-modal trips. The ability of the market to facilitate efficient multi-modal solutions for commuters, thereby injecting complementarity into otherwise purely substitute services, can be exploited to possibly overcome limitations of traditional mechanism design. In order to test the analytical insights in a real city transportation network, I am concurrently leading the design and development of a data-driven, multi-modal mobility simulator that can support various market models and economic control policies.

My recent work on Sequential Individual Rationality and Fairness [6] with Koyel Mukherjee and Theda Tulabandhula focuses on pricing (by a commercial service provider) or cost sharing (among users who independently share service) in dynamic service systems that incentivize the choice of shared (over exclusive) service. In the commercial setting, recent empirical work in ridesharing [1] suggests that ex-post Individual Rationality (IR) of customers is an important Quality-of-Service (QoS) guarantee for providers to offer. However, a risky matching policy could impose inconveniences that damage the customers’ utility during their time in service, leading to a potential ex-post IR-violation penalty to the provider. (Note that this risk is usually unbalanced: providers do not benefit as much ex-post from increased retention by exceeding expectations.) On the other hand, in community carpooling, fair group formation and cost sharing are the most important concerns. We prescribe a utilitarian approach to modeling QoS, by introducing novel sequential notions of IR (i.e., SIR) and fairness that favorably regulate fluctuations in customers’ utilities during service at decision epochs, in order to optimally manage revenue to a commercial provider (or delay/fairness in a nonprofit setting) on a myopic, per-server basis. In the ridesharing scenario, imposing
SIR induces natural limits on the incremental detours permissible, resulting in sublinear bounds on the fractional delays. Interestingly, our characterization of sequentially fair cost sharing schemes implies a strong requirement that passengers must compensate each other for the detour inconveniences that they cause. Our research guided the implementation of the core cost sharing method (patent pending) of Xerox/Conduent’s ridesharing subsystem. I am currently working with Theja on investigating how these myopic policies impact system-wide operations through simulations based on New York City’s taxi data. My doctoral work on Cost Sharing Games [5] with Jason Marden and Adam Wierman, published in Mathematics of Operations Research, characterized cost sharing rules that guarantee stability in a broad class of resource allocation games, as being weighted Shapley values. It has a current citation count of 58.

RESEARCH PLANS

Much of my research in pricing and revenue management, in particular, the most recent piece on sustainable market design for urban mobility, includes natural extensions that I intend to pursue, e.g., investigating the environmental footprint of market mechanisms, impact on personal vehicle ownership, etc. Given the economic promise of multi-modal travel, another important problem is to identify meaningful structural characteristics of scheduled services and on-demand services (in relation to the underlying network and demand characteristics) that benefit the most from multi-modal trips. For example, multi-modal trips are unlikely to matter much in cities where public transit is either too bad (because they are infeasible) or too good (because they are unnecessary). Such results would not only help identify existing cities for potential pilots, but also provide valuable inputs to long-term urban planning and smart city projects.

I am also keen to continue contributing to the growing literature on queueing systems with strategic servers. Several problems, well-studied in the traditional queueing literature, are still open when servers are strategic, e.g., analysis of queueing systems with strategic customers, optimal system configuration (pooled, dedicated, or hybrid) when servers are heterogenous, analysis of the popular “Join the Shortest Queue” policy. Another promising direction is to explore applying “SIR-like” concepts to strategic queueing systems, and the optimal system policies (routing/staffing) that emerge under such dynamic utilitarian constraints.

In summary, I intend to sharpen my focus on the transportation domain, where my interdisciplinary technical background in academia, coupled with the industrial experience in developing MaaS solutions, is best suited to tackle the emerging complex, multi-faceted problems in building the next generation of transportation systems and mobility solutions. While industry has undoubtedly had a heavy hand in shaping my maturity in formulating impactful problems, I sense a more effective path to impactful solutions in an academic career unfettered by corporate obstacles to the scope of investigation and collaboration. In executing my research agenda, I envision establishing active collaborations with fellow researchers in my area as well as from companion areas such as behavioral operations management, machine learning and data science, and strategic partnerships with interested government and business stakeholders in transportation.

REFERENCES