Research Statement

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December 2023

Background

Today, around 55 percent of the world's population lives in an urban area or city, and that figure is expected to rise to 70 percent over the coming decades. Novel challenges and opportunities arise in modern urban systems as shown in Figure 1. First, the rapid development of infrastructures and technologies—including autonomous and connected vehicles, robotics with artificial intelligence, information and communications technologies, and wearable devices and smart appliances—is creating numerous possibilities and inspiring unconstrained imagination. Second, many innovative urban services and business models, such as shared mobility, on-demand transportation, food delivery and homecare, real-time health monitoring and healthcare, automated and secured home systems, and smart e-commence and city logistics, are booming and changing everyday life for urban residents. Third, advances in big data analytics and computing methodologies are being developed and implemented to leverage the large volumes of data to uncover patterns in and insights regarding urban systems, understand the behavior and preferences of urban residents, and improve the design and operation of smart city infrastructure and services.

Framework and Summary

My research focuses on addressing challenges in the broad context of smart cities, using methodologies in data analytics, data-driven optimization, advanced computing, and machine learning. The theme of my research is to leverage new infrastructure and technology, innovative urban services and business models, as well as advanced data analytics and computing methods to improve the livability, intelligence, efficiency, connectivity, safety, equity, sustainability, and resilience of cities.

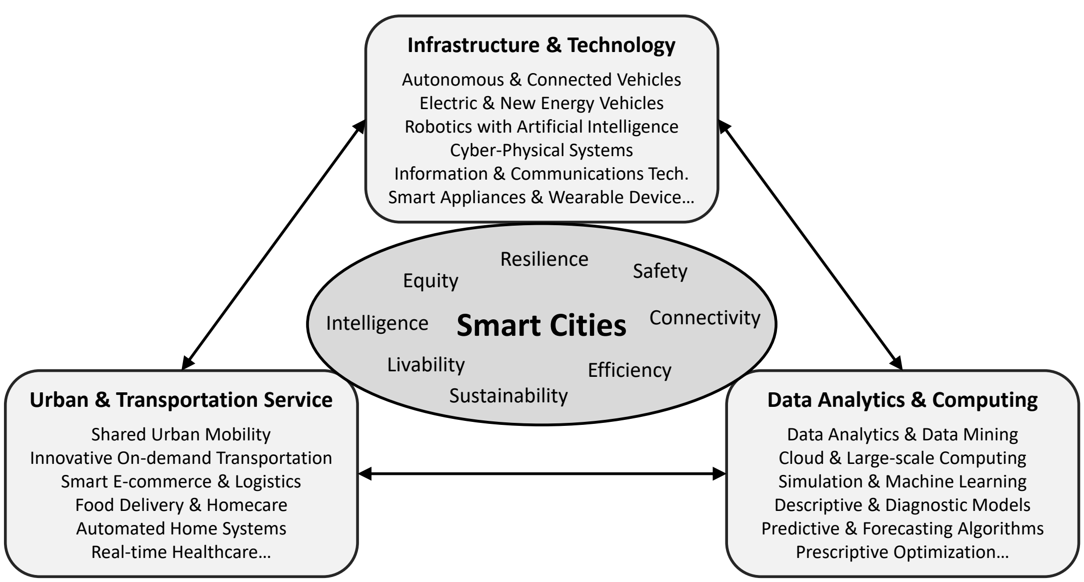

Figure 1: Development and Challenges in Smart Cities

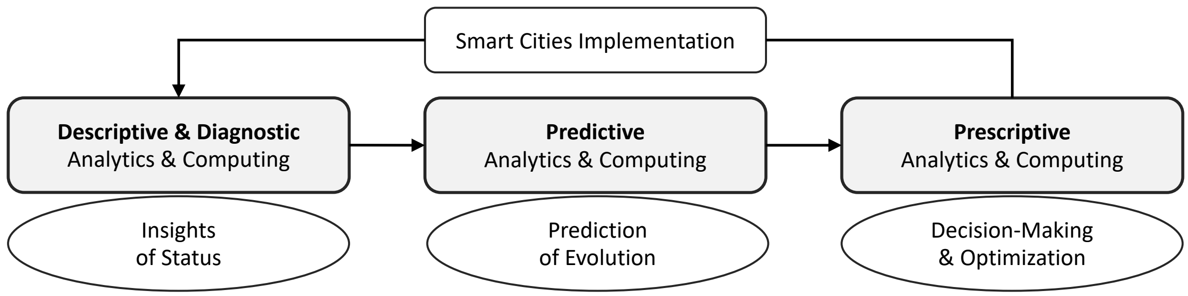

Figure 2: Research Roadmap and Framework

My research roadmap is aligned in a three-step analytics and computing framework as in Figure 2. First, in the descriptive and diagnostic step of analytics and computing, the key is to understand and explain what happens in the urban systems. Specifically, I am developing analytical models and conduct empirical analysis to better understand the patterns and characteristics of urban systems, the behavior and reasonings of urban residents, and how they might influence the design and operations of general smart cities. Using analytical models synergized with advanced data aggregating and data mining techniques, in this step, my research focuses on gaining insights of status into current urban systems. Examples include what is the dynamics of demand and supply equilibrium in on-demand transportation, and how and why wage and incentive affect the working patterns of freelance drivers in shared mobility.

Second, in the predictive step, the key is to predict what would happen in the urban systems and urban services for the residents. Specifically, I am using analytical and forecasting techniques, such as probabilistic and simulation models of stochastic systems and emerging machine learning models to predict the status, evolution, and performance of various urban services and systems and their impacts on urban residents. Examples include service quality prediction and evaluation in last-mile transportation, and predictive health status monitoring and readmission prediction for ICU patients in intelligent healthcare.

Third, in the critical prescriptive step, I am deeply engaged in developing data-driven decision-making models and optimization algorithms, particularly involving online information, stochasticity, and uncertainty, to solve decision problems in the design and operations of various components in urban services and urban systems. Specifically, my methodological work study how to improve online decision with offline information and how to improve decision adaptivity with prediction in a nonstationary dynamic environment, which are common in smart city challenges. Application examples include pricing and matching drivers and passengers in shared mobility, fleet routing and scheduling in on-demand transportation, testing and treatment decisions for ICU patients in intelligent healthcare, and various operations for urban, rail, port, and maritime logistics.

The three steps are also deeply interactive with real implementations in the broad context of smart cities. In terms of application areas, I am particularly interested in on-demand transportation, shared urban mobility, transportation-enabled services, advanced logistics, and intelligent healthcare. I summarize my research projects as follows.

Specific Research Areas

A. On-Demand Transportation

On-demand transportation systems provide flexible and demand-responsive transportation services. In my continuing research dating to my Ph.D. thesis, I study the design and operations of diverse on-demand transportation services from various perspectives.

Design of Last-Mile Service (TRISTAN[13], TS[16]). Last-mile problem refers to the provision of travel services from the public transportation node to a final destination. We study last-mile systems serving batch demands. Closed-form approximations are derived for the system performance such as passenger waiting time, which can support the design of on-demand transportation system.

Pricing of Last-Mile Service (TRB[18]). We study the pricing problem of last-mile system serving multi-type passengers, such as adults, seniors, children, and students. We propose a constrained nonlinear optimization model to determine the price with the objective of maximizing social welfare.

Routing and Scheduling of Last-Mile Service (TS[19]). I optimize the routing and scheduling of a multi-vehicle last-mile fleet, with the objective of minimizing passenger waiting time and riding time. An exact mixed-integer programming model is presented, and computationally feasible heuristic approaches based on column-generation are developed and evaluated.

Service Prioritization and Fairness (WP[a]). We study the service prioritization and fairness in last-mile systems considering multi-type passengers. We conduct both theoretical analysis and numerical experiments to show that it is critical to enforce fairness guarantees.

Fleet Sizing and Allocation (TRC[21]). We propose a two-stage stochastic programming model and a distributionally robust optimization model for the vehicle fleet sizing and allocation problem in last-mile systems, assuming known and unknown distribution of the demand, respectively.

Express Urban Metro Systems (ISRERM[18], NTS[23]). Considering demand distribution, train headway, frequency, and capacity, we develop models to optimize station-skipping patterns for express urban metro systems with cyclic station-skip to reduce passenger travel time and serve more passengers.

B. Shared Urban Mobility

Shared urban mobility systems are growing exponentially, driven largely by the rapid advances in internet and communication technologies and the advent of smartphone applications. Since the start of my faculty career after Ph.D. graduation, I have been focusing on the planning, design, and operational challenges of shared urban mobility from diverse perspectives.

Framework and Review of Ride-Sourcing (TRB[19a]). This is one of the most important and comprehensive survey papers on ride-sourcing systems. We propose a framework to describe the interactions between system variables, platform strategies and decisions, system objectives, and market equilibrium. We also summarize and review relevant research problems and methodologies.

Coordinating Demand and Supply (MSOM[19]). Both supply and demand in shared mobility depend on the price and wage set by the platform. We propose a queueing model with endogenous supply and demand to characterize the system performance at equilibrium and determine the optimal price and wage that maximize the platform's profit or social welfare.

Matching Drivers and Passengers (TRISTAN[19], MSOM[23]). We develop an online optimization algorithm with theoretical performance guarantees to match drivers and passengers. We consider multiple objectives, such as pick-up time, platform revenue, and service quality. Using real data, we demonstrate the advantages of the proposed adaptive matching algorithm.

Supply Model and Elasticity (TRB[19b], WP[c]). Considering the flexible contracts and weak constraints between shared mobility platforms and drivers, we propose models to describe drivers' working decisions and supply patterns, and develop an econometric framework to estimate the participation and working-hour elasticity of ride-sourcing drivers using real data.

Reward Scheme with Surge Pricing (TRB[20a]). We analyze a novel reward scheme integrated with surge pricing: Passengers pay an additional amount on top of regular surge price to a reward account during peak hours, then use the balance to compensate for trips during off-peak hours. We find that in some situations, all stakeholders will be better off under the reward scheme.

Pricing and Equilibrium in Ride-Pooling (TRB[20b]). Ride-pooling services offer benefits for both individual passengers in the form of cost savings and society in the form of traffic alleviation and emission reduction. We develop models to describe platform pooling decisions on price discount, vehicle fleet size, and allowed detours, and characterize the system equilibrium with ride-pooling.

Short-Term Fleet Repositioning (TSL[20]). Due to the imbalance between stochastic demand and supply in shared mobility systems, the repositioning for empty fleet is critical to improve passenger service level, driver income, and platform revenues. We propose a two-stage framework to optimize the short-term fleet repositioning with theoretical performance bounds.

Spatial-Temporal Subsidies for Drivers (TRB[21a]). We propose a mean-field Markov decision process model to describe the dynamics in shared mobility with mixed agents, where the platform optimizes system objectives using spatial-temporal subsidies for self-relocation drivers.

Third-Party Ride-Sourcing Integrator (TRB[22a]). Third-party service providers integrate ride services offered by multiple independent platforms. We propose models to describe the market with multiple competing platforms and evaluate the system performance with platform-integration.

Regulation of Service Quality (TRB[22b]). We propose a model to describe and analyze the market equilibrium when platform excludes low-quality service providers/drivers from the ride-sourcing market by setting a quality threshold of admission, which serves as both quality management and supply regulation strategy.

Multi-Homing of Platform Drivers (TRC[23a]). Freelance drivers in the shared mobility market frequently switch or work for multiple platforms, affecting driver labor supply. We taxonomize and estimate perceived switching and multi-homing frictions on mobility platforms using public and limited high-level survey data.

C. Transportation-Enabled Services

Transportation-enabled services is a service model that uses transportation systems to enable and enhance the delivery, accessibility, and effectiveness of non-transportation services. As a pioneer in this field, I first formally define the concept and highlight crucial research outlooks in this field. I believe that the emergence, widespread adoption, and popularity of transportation-enabled services will significantly enhance and reshape future mobility in the broader context of smart cities.

Concept and Framework (MulT[22], WP[24]). We introduce the concept of transportation-enabled services and establish a general framework, in which the services involve four stakeholders: customers, suppliers, TRENS providers, and transportation carriers. We present five service models: a one-sided market, three variants of two-sided markets, and a three-sided market, each characterized by the interaction dynamics among stakeholders. We highlight crucial research outlooks to enhance understanding of service planning, operations, evaluation, and regulation.

Three-Sided Delivery Market (TRE[23]). On-demand delivery services are three-sided markets that enable interactions between customers and suppliers with the help of crowd-sourced drivers. We characterize the properties of markets and propose pricing strategies that enable the platform to manipulate the market towards profit or social welfare maximizing outcomes.

Food Delivery Demand Prediction (ITS[23]). We develop a Poisson-based distribution prediction framework equipped with a double-hurdle mechanism to forecast the range and distribution of potential customer demand in the on-demand food delivery market. A multi-objective function is designed to learn the likelihood of zero demand and approximate true demand and label distribution.

D. Advanced Logistics and Intelligent Healthcare

Advanced infrastructure and technologies are also transforming modern logistics and healthcare, which are critical pillars of the smart city. I am also exploring research in these areas.

Freight Rail Consolidation (RAS[13]). In the rail freight service networks, railcars and shipments are classified and consolidated in transshipment nodes to benefit from economies of scale in logistics costs. We propose optimization approaches with computational advantages to minimize the total waiting time of railcars and maximize the total number of railcars processed in the consolidation.

Logistics Gate Operations (WSC[17], WSC[18]). In the context of seaports that connect urban- and sea-side operations in an ocean-to-cities value chain, we develop simulation tools to characterize the performance of gate operations and propose optimization models for efficient lane-management.

On-Orbit Satellite Systems (JSR[20]). Robotic on-orbit servicing provides responsive services to the random failures of satellites distributed in space. By leveraging queueing theory and inventory management methods, we develop a semi-analytical model for the system design and analysis.

Feeder Vessel Synchronization (TRB[21b]). We study the feeder vessel routing and synchronization at a congested transshipment port. We propose optimization models to coordinate feeder vessel traffic to avoid schedule conflicts and congestion, thus improve transshipment efficiency.

Airport Slot Allocation (TRC[23b]). Multiple-airport systems consist of multiple airports and scheduled flights at different airports may have conflicts regarding shared fixes or routes, thus causing airspace congestion and flight delays. We develop a chance-constrained slot allocation model to optimize slot allocation in multiple airports while considering fixed capacity constraints and uncertainty of flying times.

ICU Medical Scores Validation (JCS[20]). We validate the prognostic accuracy of several important medical scores for patients admitted to a cardiothoracic intensive care unit using real data. We evaluate the sequential organ failure assessment (SOFA) score, systemic inflammatory response syndrome (SIRS) criteria, and quick SOFA (qSOFA) score.

Patients Health Transition Estimation (WP[d]). We propose a structural model to estimate the true patients health transitions from censored data observations under the treatment-effect-based policies, which are increasingly used in healthcare decisions but may distort observed transitions.

Diagnostic Testing with Monitoring (WP[e]). To address the overuse of medical tests and resources, we propose a finite-horizon, partially observable Markov decision process model to capture real-time health monitoring information to enable better diagnostic testing decisions.

E. Decision and Inference Models

Aside from the research in specific domains, I also have some continuing methodological work, which mainly focuses on online decisions and large-scale inference models.

Cause and Outcome Inference (AER.PP[17], WP[f]). We study how to infer probability measures of unobservable events from observed outcome frequency in a bipartite event-outcome graph. We propose an algorithm to construct the minimum set of inequalities to describe the probability measures of the unobservable events, and prove its good statistical properties.

Online Planning with Offline Simulation (WP[g]). We study a class of online planning problems with concave objective functions and global feasibility constraints under nonstationary decision environments. We develop an offline-to-online mechanism leveraging the offline simulation information and show the theoretical performance guarantee with either perfect or imperfect information.

Dynamic Decision Adaptivity (WP[h]). Classic decision models derived for a static environment may fail in a dynamic environment with possible structural breaks and regime shifts. We propose a framework to leverage multiple models to improve decision adaptivity in the dynamic environment.

Future Perspective

The combination of rapid development of infrastructure and technologies, various innovations in urban services, and advances in analytics, computing, and artificial intelligence will result in a steady stream of dramatic changes in the urban environment and in reshaping of modern cities. This process and evolution will have major and long-lasting impacts on everyday life around the globe. In the long run, I see myself as a researcher who combines solid methodological skills and tools with practical insights to address various fundamental smart city challenges.

Specifically, following the research roadmap, in the descriptive and diagnostic step, I aim to develop more advanced econometric methods combined with structural causal models to gain more insights and implications into various aspects in urban systems, leveraging the multi-source data; in the predictive step, I am interested in applying cutting-edge machine learning techniques to predict performance of emerging urban services and evolution of urban systems; in the prescriptive step, I am enthusiastically interested in the combination and integration of classic structural optimization models with online learning and inference methods, which are increasingly important in solving complicated decision problems with a strongly dynamic and stochastic environment in smart cities.

In terms of application domains, I will continue and expand my research on on-demand transportation and shared urban mobility to encompass additional transportation- and mobility-enabled urban services. I also aim to broaden and deepen my research to include other important pillars of smart cities, such as advanced logistics, intelligent healthcare, and innovative e-commerce, as an unlimited set of novel opportunities and challenges will arise from the availability of more and more autonomous and information-connected devices in the city. The path to smarter cities is difficult, yet extremely exciting. It is what I am eager and proud to work on now and in the future.

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