RESEARCH STATEMENT

My research is primarily focused on two areas: (1) data-driven management of supply chain and logistics, encompassing both foundational and emerging business models such as the last-mile problem; and (2) analytics for social good, which addresses critical issues related to system robustness, social well-being, and sustainability. In the sections that follow, I will detail these themes, highlighting my contributions and outlining the implications of my work on the field.

1 Data-driven Management of Supply Chain and Logistics

In this section, I delve into the critical role of data-driven strategies in improving supply chain and logistics systems. Tackling both fundamental and emerging challenges within this domain, my research utilizes predictive and prescriptive analytics to streamline operations and solve the last-mile problem effectively. By integrating the advanced methods in robust analytics, my work furnishes actionable insights that significantly improve decision-making processes in supply chain and logistics management.

Predictive and Prescriptive Analytics for the Last-mile Problem

The rapid expansion of e-commerce has compelled e-retailers and local businesses to enhance their logistics operations, striving to deliver goods promptly, reliably, and cost-effectively. This imperative has significantly heightened the importance of optimizing last-mile delivery systems, where improving both cost-effectiveness and service quality is crucial. My research contributes directly to these challenges through two key papers — the first tackles strategic-level workforce management issues, while the second addresses operational challenges in delivery routing decisions.

- Robust Workforce Management with Crowdsourced Delivery. With Chun Cheng and Melvyn Sim. Forthcoming in ***Operations Research***.
- Service Oriented Considerate Routing: Data, Predictions and Robust Decisions. With Zhixing Luo, Stanley Frederick W. T. Lim, Caihua Chen, and Melvyn Sim. Major revision in ***Management Science***.

In the first study, we address workforce management challenges in crowdsourced delivery platforms, balancing the use of contracted and ad-hoc couriers amidst uncertainties. We introduce a reduced information model to estimate and optimize crowdsourcing costs under uncertainty, developing a robust satisficing model that is efficiently solved using a binary search algorithm applied to a series of convex optimization problems. The second research focuses on enhancing service-oriented routing by incorporating punctuality into delivery logistics. By analyzing a comprehensive dataset from a cold chain logistics company, we highlight the limitations of using travel distance alone for predicting delivery times. Our model integrates couriers' individual attributes and location familiarity into a novel metric, the Courier Assigned Location Mismatch (CALM), optimizing route assignments to improve punctuality and reduce stress. We employ both exact and heuristic algorithms to solve this model, demonstrating superior performance and providing a robust satisficing strategy that effectively addresses predictive inaccuracies and model misspecifications.

Implications. The first study illustrates the application of our novel reduced information approach which bypasses the complex human decision-making process employed by couriers, achieving robust strategic decisions with streamlined data requirements. The second study introduces an axiomatic metric to quantify couriers' familiarity with locations, seamlessly integrating this metric into the downstream prediction and routing model to improve the decisions. Collectively, these studies provide profound policy implications for enhancing operational effectiveness and service quality to a broad array of urban logistics platforms, including delivery companies, ride-sharing services, and taxi applications.

Data-driven Supply Chain and Logistics Systems

In the increasingly complex field of supply chain and logistics, the advent of big data and advanced analytics offers transformative opportunities to enhance decision-making and operational efficiency. My co-authors and I have explored this potential through the following papers, each addressing unique challenges within this domain. These studies leverage data analytics and robust optimization to tackle pervasive uncertainties in supply chain and logistics networks, demonstrating how data-driven approaches can significantly refine classic models and improve the efficiency and resilience of supply chain and logistics systems.

- Supply Chain Resilience Management with Moment-dispersion Ambiguity. With Chun Cheng, Melvyn Sim, and Taozeng Zhu. Work in Progress.
- Vessel Deployment with Limited Information: Distributionally Robust Chance Constrained Models. With Zhi Chen, Zhenzhen Zhang and Andrew Lim. ***Transportation Research Part B: Methodological*** **161 (2022): 197-217**.
- Distributionally Robust Chance Constrained p-Hub Center Problem. With Zhi Chen and Zhenzhen Zhang. ***Informs Journal on Computing*** **35(6) (2023): 1361-1382**.

In the first paper, we introduce a novel risk index to model supply chain resilience under the uncertainty of correlated disaster events. This research offers a robust framework for understanding and enhancing the resilience of supply chains, providing critical insights for strategic decision-making in the face of disruptions. Additionally, the last two paper address the optimization of logistic networks under uncertainty. These studies develop advanced distributionally robust models to effectively manage and optimize maritime and hub-and-spoke transportation systems, respectively. The methodologies employed provide a more accurate assessment of risks and resource allocation, ensuring operational efficiency and robustness across various logistics networks.

Implications. The research across these studies significantly enhances supply chain and logistics management by offering data analytics and robust optimization tools that improve operational resilience and efficiency. The first study equips supply chain managers with strategies to anticipate and mitigate disruptions, ensuring stability in volatile conditions. Subsequent papers enhance service reliability and operational efficiency, critical in industries dependent on timely delivery. Advanced algorithm acceleration techniques developed in these works enable real-time decision-making, allowing businesses to quickly adapt to changes. Collectively, these insights empower businesses to optimize resource allocation, reduce risks, and maintain a competitive edge in diverse supply chain and logistics environments.

2 Analytics for Social Good

This section highlights my research on utilizing advanced analytical techniques to tackle pressing societal challenges and foster solutions for social good. It delves into three critical areas related to my past and ongoing research: optimizing resource allocation for enhanced social well-being, designing sustainable network for net-zero data centers, and developing trustworthy machine learning models. Each subsection illustrates how data analytics and optimization can significantly advance social benefits, adapting to the needs of a rapidly evolving world.

Resource Allocation for Social Well-being

Resource allocation in the public domain is critical for enhancing social well-being and ensuring equitable access to essential services. This encompasses a wide range of activities, from deploying policing resources to prevent crime to distributing food to those in need. Effective allocation of these resources not only addresses immediate needs but also builds long-term resilience in communities. In the realm of law enforcement, strategic resource allocation can deter criminal activities and promote safer neighborhoods. Similarly, in the context of food security, efficient logistics and distribution strategies are vital for food banks, contributing to community resilience and sustainability by reducing food waste and ensuring that surplus food reaches those who need it most instead of going to landfills.

- Proactive Policing: A Resource Allocation Model for Crime Prevention with Deterrence Effect. With Long He and Xiaobo Li. Major revision in ***Operations Research***.

- Joint Routing and Resource Allocation for Nonprofit Operations under Uncertainty. With Sheng Liu and Mengling Zhang. Work in progress.

The first paper redefines police resource allocation by introducing a proactive model that minimizes the impact and costs of potential crimes across multiple locations. Utilizing a multinomial logit model, we enhance the understanding of how police presence influences crime distribution, incorporating crime control diffusion and displacement strategies that address modern crime patterns effectively. This model is formulated to be compatible with standard optimization software, and we validate our approach through a case study in New York City that demonstrates significant advancements in crime prevention. The second paper focuses on optimizing resource distribution for food banks. We develop a multistage robust optimization model aimed at maximizing the minimum fill rate across food banks, ensuring equitable resource distribution. By establishing an optimal policy based on a fixed fill rate and implementing an adaptive robust linear decision rule, our findings show substantial improvements over traditional methods. A practical application using data from London food banks illustrates the effectiveness of our model in enhancing food bank logistics.

Implications. The first paper introduces a proactive policing model that employs deterrence and preemptive strategies, significantly improving public safety and advancing social well-being by preventing crimes before they happen. This innovative approach demonstrates how data analytics and optimization can transform traditional practices, offering a new paradigm for resource allocation in law enforcement. The second paper enhances the efficiency of food banks through an robust resource allocation model that ensures equitable distribution. By applying data-driven strategies to address logistical challenges, this work highlights the vast potential of analytics to improve social welfare.

Network Design of Net-Zero Data Centers

Data centers are major electricity consumers, underscoring the urgent need for sustainable operations. Tech giants like AWS, Google, Meta, and Microsoft are pursuing net-zero emissions, challenging due to the variability and intermittency of renewable energy sources. My recent research addresses these issues, aiming to develop resilient and sustainable network solutions that align with these environmental targets.

- Network Design of Net-Zero Data Centers for Sustainable and Efficient Operations. With Sheng Liu, Ho-Yin Mak, and Shixuan Zhang. Work in progression.

Our research introduces the first comprehensive network design model for data centers aiming for net-zero emissions, specifically crafted to meet the significant energy demands of modern computational technologies. This model addresses key challenges in the rapidly evolving field of sustainable data centers, including optimal setup, strategic job allocation, and the incorporation of renewable energy sources. The fluctuating nature of green energy sources like solar and wind introduces complexity, especially in matching energy supply with the variable computational loads of data centers. At the core of our approach is the Stochastic Dual Dynamic Programming method, which excels in managing the uncertainties associated with renewable energy production and the demands of data processing. Our strategy not only helps control the carbon emissions of data centers but also guarantees their ability to consistently fulfill extensive computational needs.

Implications. The implications of our work are particularly significant for data centers involved in processing large language models, which require immense computational resources and can cost millions of dollars per training session. By implementing our net-zero emission model, these data centers can drastically reduce their environmental impact while managing costs more effectively. This strategic approach not only supports the technological advancement of AI but also aligns with global environmental goals, demonstrating a scalable solution for energy-intensive industries worldwide.

Trustable Machine Learning

Trustable machine learning involves creating robust and safe systems that users and stakeholders can rely on, particularly in critical applications such as autonomous vehicles and healthcare systems. This aspect of machine learning is crucial in operations research, as it ensures the security and integrity of models that are essential for promoting social good and harnessing the power of AI in operations management. In this vein, my research includes two notable publications. Both papers specifically tackle the vulnerabilities in deep learning models that process 3D data — an area of growing importance in machine learning research.

- On Isometry Robustness of Deep 3D Point Cloud Models under Adversarial Attacks. With Yuwei Wu, Caihua Chen, and Andrew Lim. ***CVPR2020*** (AI conference).
- PointBA: Towards Backdoor Attacks in 3D Point Cloud. With Xinke Li, Zhirui Chen, Zekun Tong, Yabang Zhao, Andrew Lim and Joey Tianyi Zhou. ***ICCV2021*** (AI conference).

My first study delves into the robustness of 3D deep neural networks during the testing phase, highlighting a critical issue unique to 3D models — the isometric robustness. We are the first to discover that minor rotational manipulations can drastically compromise model integrity, achieving an attack success rate exceeding 95%. This vulnerability demonstrates strong transferability across various 3D network architectures. The second paper pioneers the exploration of backdoor attacks during the training phase. We have developed a comprehensive framework for introducing data-poisoned backdoor attacks in 3D deep learning environments. The triggers for these attacks are ingeniously mundane, incorporating everyday objects such as small balls or subtly altered point clouds, making them highly effective and challenging to detect. These two works not only advance our understanding of robustness and security in 3D neural networks but also contribute to broader discussions in machine learning security, including the generative adversarial networks and transformers.

Implications. As operations research increasingly integrates with artificial intelligence, particularly large language models, the implications of our research become crucial. Our studies highlight significant robustness and integrity challenges in deep learning models, emphasizing the need for enhanced security measures as these technologies merge. Addressing these vulnerabilities is essential for ensuring the reliability of AI systems in critical applications, safeguarding the trust and effectiveness of AI-related operations research as it evolves.