Research Statement

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The recent availability of data and advancements in computational tools have opened up new possibilities and challenges in urban planning and city management. Data-driven spatiotemporal models are continuously being developed to study complex activities within cities, such as urban mobility (the flow of people) and supply chain (the flow of goods). While these models offer valuable insights towards achieving theoretical objectives, there remains a need to understand how to effectively incorporate these models into practical decision-making processes. In light of this, **my research aims to develop methodologies that combine spatiotemporal analysis with practical implementations to effectively manage the flow of people, goods, and services in space and through time, with the overarching goal of establishing a safe, efficient, and inclusive urban societal system.**

In my doctoral research, I specifically focus on facilitating the decision-making process in two application domains related to smart urban systems: **(1) pedestrian mobility, and (2) manufacturing operations**, with the help of **advanced machine learning and data analytics methods**. From a practical perspective, I identify and formulate real-world motivated problems. Furthermore, I implement simulators and algorithms, collaborating with industry professionals and public security experts to validate my solutions for robustness and reliability. From a theoretical standpoint, I draw upon expertise in data science, particularly employing machine learning models that analyze spatiotemporal graph-based data, image and video data, and simulations. Through the application of these methodologies, I aim to generate effective solutions to address practical challenges faced in our urban environments. I describe my work below.

Crowd Flow Monitoring and Forecasting for People Safety

Understanding and predicting the movement of individuals in crowded scenes is crucial for advanced crowding alert and control, aiding in evacuation planning, preventing congestion, and even avoiding stampedes. However, crowd flow forecasting is a complex task as both spatial and temporal factors can influence people's movement in a physical space. While existing works often consider temporal dependencies and inter-personal interactions of pedestrians, the spatial information of the surrounding space, such as the locations of entrances and exits, is rarely taken into account.

In our research sponsored by Stanford Center at the Incheon Global Campus (SCIGC), a center focusing on smart and sustainable city research, I proposed a graph formulation that fuses the **spatial** connectivity, i.e., the routing between entrances and exits, into **temporal** crowd flow data. Deploying a graph neural network (GNN) model and subsequently validating the model with a public train station dataset, I found that incorporating spatial information improved forecasting accuracy compared to relying solely on temporal data [1].

Performing crowd flow forecasting requires annotated crowd movement data and floor plan information. Manual annotation, which involves tracking each individual, can be labor-intensive, particularly in dense crowds with long time horizons. Additionally, existing public datasets often lack floor plan information. Recognizing these challenges, I identified the need to apply forecasting methods directly to raw, unannotated surveillance videos, which provide a cost-effective and efficient means of crowd monitoring. In a concurrent work [2], I utilize geometric transformations and object detection networks to automatically generate annotations and spatial connectivity data. Collaboration with the Stanford public security officials allowed us to collect real-world crowded videos, of which analysis yielded valuable insights for space planners. This included the identification of frequently congested areas, such as narrow tunnels and female bathroom entrances (Fig. 1).

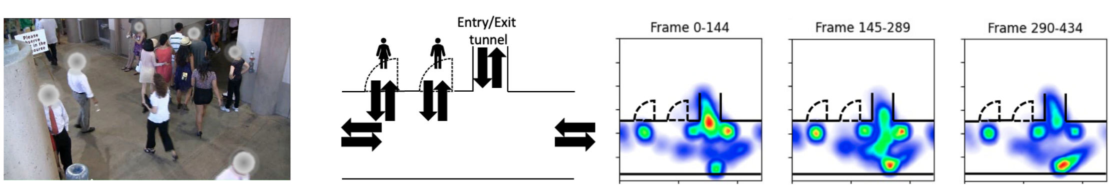

Figure 1: Heatmap highlighting commonly congested locations at a stadium.

The fundamental contribution of this work is that it provides a practical data-processing pipeline and forecasting technique that can assist facility managers and event planners in improving crowd management at large public venues such as stadiums, theaters, train stations, and other crowded, gathering places. Moreover, it is crucial that my research methodology proves adaptable across diverse domains. In pursuit of this objective, I have identified that my GNN approach can be extended to formulate scheduling strategies for manufacturing processes.

Production Scheduling and Event Detection for Manufacturing Efficiency

This line of research has greatly benefited from interaction with a number of industry professionals. In manufacturing systems, there exists a rich body of previous work developing scheduling strategies of future production operations to enhance production efficiency. Through collaboration with an engineer at Samsung Electronics, I learned that the industry often relies on simple dispatching rules for production scheduling due to the potential dynamic changes in production, such as machine shutdowns. Consequently, there is a need to generate real-time dispatching rules to cope with such interruptions.

To address this challenge, I introduced a problem formulation, the interrupting swap-allowed blocking job shop problem (ISBJSSP), which models both unforeseen production interruptions and the lack of storage capacity. When a machine is shut down, it effectively detaches from the job shop floor, causing a change in the **spatial** layout of the floor. Simultaneously, real-time production progress introduces changes in the **temporal** aspects of scheduling. To capture these spatial and temporal dependencies, I formulated the problem as a dynamic disjunctive graph. Subsequently, I developed a simulator and employed GNN in conjunction with a reinforcement learning (RL) based framework to iteratively learn dispatching rules through simulations. Validating with simulated examples, I show that the ISBJSSP can be scheduled efficiently with the proposed method when production interruptions occur with random machine shutdowns [3].

Furthermore, in collaboration with engineers and scientists at the National Institute of Standards and Technology, our earlier work proposed a machine learning framework that utilizes computer vision techniques to automatically detect and segment manufacturing defects in additive manufacturing parts [4].

Future Research and Potential Projects for People-Centric Cities

I hope to investigate whether decision-making processes in our society adequately consider not only safety and efficiency but also the diverse needs of all individuals. My experience developing research methodologies on spatiotemporal analysis makes me well-equipped for researching both methodological frameworks and applications to advance equity and sustainability of our urban society. There are two initial research projects that I would like to embark on.

The first project, titled "**Accessible and Empathetic Urban Environment System**," aims to improve the design of spaces to enhance accessibility and inclusiveness for disabled individuals in crowded public areas. Our methodology of integrating spatial and temporal information from the built environment can be used towards developing smarter designs that facilitate the navigation of disabled persons through crowded public spaces. During my in-field research in public venues, I observed first-hand that wheelchair users face challenges and potential discomforts when squeezing through heavy crowds. This research, with a focus on the well-being and safety of wheelchair users, seeks to identify potential hazards, high-risk areas, and proactive measures during crowded events. The immediate steps for this project include:

1. Developing solutions to improve the design of spaces for enhanced accessibility and inclusiveness.
2. Utilizing wheelchair-mounted sensors to detect metrics related to occupant comfort, such as vertical acceleration, and carbon dioxide and particulate matter concentrations, in order to quantify the impact of crowd flow distributions on well-being.
3. Devising implementable guidelines for efficiently facilitating the entry and exit of wheelchair users during large events in public venues.

The primary objective of this project is to promote inclusive and accessible urban environments while also contributing to the broader goal of building systems that prioritize human needs and promote empathetic designs.

While I have previously researched production efficiency, I now raise the question of how these produced goods and services are allocated towards the end of the supply chain — in the hands of consumer citizens. The second project, titled "**Data-driven Allocation of Public Resources and Services**," aims to leverage our RL-based framework, previously deployed in the job shop scheduling domain [3], to automatically generate allocation strategies for public resources, such as medical drugs and healthcare services. Subsequently, causal inference models will be deployed for evaluating whether the allocation strategies are equitable. Equitable distribution of such resources play a crucial role in the functioning of a resilient community. As a first step, I aim to apply this framework to optimize post-disaster events (such as earthquakes, hurricanes) healthcare delivery systems, such as patient flow and the dispatching of manufactured medical devices and drugs. By minimizing response times and enhancing healthcare service quality and equity, the overall healthcare experience for individuals can be improved. The planned steps for this project are:

1. Collaborate with biomedical professionals to identify cutting-edge research opportunities to develop theory for healthcare operations and public resource management.
2. Develop simulator and use causal inference to quantitatively validate the allocation of resources based on (1) efficiency, (2) equity, and (3) robustness.
3. Implement existing research to improve the equity and efficiency healthcare delivery.

As a future faculty member who values the education of the next generation, I am committed to integrating innovative research with inspiring students and researchers to collectively improve the safety, inclusiveness, and sustainability of our society. Additionally, I am particularly keen on interdisciplinary collaborations with other faculty members and researchers from various programs, as well as industry professionals to explore influential problems at the intersection of data-driven engineering and urban systems applications.

References

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[2] V. W. H. Wong and K. H. Law, "Fusion of CCTV video and spatial information for automated crowd congestion monitoring in public urban spaces," *Algorithms*, vol. 16, no. 3, p. 154, 2023.

[3] V. W. H. Wong, S. H. Kim, J. Park, J. Park, and K. H. Law, "Generating Dispatching Rules for the Interrupting Swap-Allowed Blocking Job Shop Problem Using Graph Neural Network and Reinforcement Learning," *ASME Journal of Manufacturing Science and Engineering*, vol. 146, no. 1, p. 011009, 2023.

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