Chapter 5
Machine Learning and Robotics in Urban Traffic Flow Optimization With Graph Neural Networks and Reinforcement Learning

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ABSTRACT

Increased congestion, inefficiency, and accidents in cities are major issues for urban traffic systems. However, rapid urbanization and increasing numbers of cars exacerbate problems that have created an environment too dynamic and sophisticated for traditional solutions like static traffic signals or road expansion. The chapter discusses the use of machine learning and robotics with graph neural networks and reinforcement learning for optimizing traffic flow. Traffic networks pose intricate relationships that GNNs model under the form of nodes and edges representing roads, intersections, and vehicles. RL allows for continuous real-time interaction through which autonomous agents learn optimal strategies; thus, better decision-making takes place in dynamic traffic conditions and the system can proactively adjust signal

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timings, reroute vehicles, and manage congestion. Integration of these technologies will indeed be transformative to traffic management; hence, more effective, flexible, safest transportation systems will be expected in the future.

1. INTRODUCTION

The complexity of the urban traffic system Urban traffic systems have undergone significant changes with the expansion of cities and the increase in population density. The speedy urbanization of cities has put much pressure on the transportation infrastructure, which usually cannot keep up with the growing demands of this fast-urbanizing population. Challenges in traffic systems are mainly congestion, accidents, environmental pollution, and bad use of resources. Urban traffic congestion results in significant loss of economic productivity and considerable time loss while considerable quantities of fuel get wasted by vehicles queuing up over long distances (Akram et al., 2024). Cities have to innovate new models that combine efficiency, sustainability, and security while managing traffic.

Traditional methods like traffic signals and road widening techniques have exhausted all their potential in most urban centers. With this increasing complexity of urban traffic, these methods have proven to be inadequate in ways to avert congestion and ensure smooth flow. They cannot accommodate real-time conditions and hence create bottlenecks and inefficiencies in the system. Dynamic and intelligent systems now become fundamental solutions for those complexities. Technologies in the forms of machine learning, artificial intelligence, and autonomous systems have emerged as fertile grounds for making traffic management smarter and more responsive.

Technology use in transport has led to an overall focus on intelligent transportation systems. ITS refers to merging data from a wide variety of places to monitor, manage, and optimize traffic flow in real time. Some of the technologies include sensors, cameras, and connected vehicles gathering data from every point in the traffic network. This data gathered can be analyzed to determine patterns and predict congestion points, so that real-time adjustments can be made to traffic signals, rerouting of vehicles, and giving suggestions for navigation to drivers. ITS reduces the complexity of city traffic systems and aims to improve transportation infrastructure's functionality (Almalawi et al., 2024).

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