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Machine Learning: A way forward in Transportation Strategies for Smart Cities

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Abstract: The increase in urban drift has led to an unprecedented surge in the urban population in Bihar. Patna, the state's capital and on the list of the Smart City, is having a massive rise in population which has brought in many challenges for the transportation industry, including the development of efficient strategies to utilize available infrastructures and minimize traffic congestion. Thus efficient transportation strategies need to be formulated to tackle the issues affecting the Smart City transportation industry. This study has been taken as a pilot project. This paper gives a comprehensive review and discussion focusing on emerging Machine Learning approaches. It is aimed to provide a valuable pathway to researchers regarding the roles that data-driven strategies can be utilized for Smart Cities (SCs) transportation. An objective of this paper was to acquaint researchers with the use of Machine Learning (ML) approaches for SC transportation applications and to give helpful insight to researchers on how it can be explored for SC transportation strategies. This paper also examines the impacts of Machine Learning as a technological driving force.

Keywords: *Smart Cities, Transportation Strategies, Machine Learning (ML).*

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Introduction:

Smart City (SC) is a framework equipped with information and communication technology advancements (ICT) and addresses various urbanization challenges. People are increasingly acquainting themselves with SC platforms in multiple ways (e.g., smart homes, mobile devices, connected cars, etc.). However, the development of frameworks for SCs has not matured and, therefore, cannot take advantage of new and emerging data-driven technologies. The advancement of Machine Learning and related new technologies will help shape the SC framework and bring a revolution in different SC sectors in SCs [2, 3].

The framework of SCs is based on various ICTs and advanced technologies, which can become one of the reasons for bringing changes in many socio-economic aspects of society, including health, energy, education, and transportation, thus enabling smart technologies to a new techno-based society. With the surge in the urban population in Patna, the transportation industry is facing many challenges due to human mobility and huge traffic congestion. Due to the unprecedented urban migration, the SC transportation industry faces many technological challenges. Hence, there is the need to devise efficient strategies to utilize the available infrastructure and minimize traffic congestion. Accordingly, managing transportation systems by making them smart will play an important role in urban areas to address issues such as traffic control and urban congestion. Smart transportation systems can provide services to improve road safety, give on-time information to drivers and users and thus reduce accidents.

Machine Learning plays a vital role in SC technology-focused research. Several research areas in smart transportation and its applications, which are significant components of SC, are today's prime concern of technology-focused SC research. SC requires an innovative monitoring system, intelligent instrumentations, and interconnections between various components, including driver experience, autonomous vehicles, traffic flow prediction, collaborative traffic control, and management. The researchers are creating new Machine Learning models and re-training the existing models for better performance and results since enormous computing resources are readily available to researchers.

In recent years the design and planning of intelligent transportation, control systems, and communities have been done using the support of big data analytics. While making transportation smart, data is obtained from multiple heterogeneous sources such as transportation logistics, video data, GPS data, social media data, sensors, and systems data. Examples include vehicle-sensing data (VSD), vehicular mobile service data (VMS), advanced driver-assistance data, connected car data, etc. A generic architecture of deploying and utilizing big data analytics in intelligent transportation systems is shown below in Figure 1. The architecture has three layers: The data sensing and collection layer, the Data analytics layer, and the Application layer.

SMART TRANSPORTATION
APPLICATION LAYER
Route Planning
Traffic flow prediction
Accident Detection and Emergency Response
DATA ANALYTICS LAYER
Geo-spatial and Geo-Information
Machine and Deep Learning
AI and Other Techniques
DATA SENSING AND COLLECTION LAYER
GPS and Location data
Vehicle and Roadside station data
Social networks and mobile device data

Figure 1. Generic architecture for big data analytics for smart transportation.

Today, Machine Learning plays a vital role in data science and is used for modelling and analytics to derive trends and patterns from data. The categories for Machine Learning algorithms are given in figure 2 below:

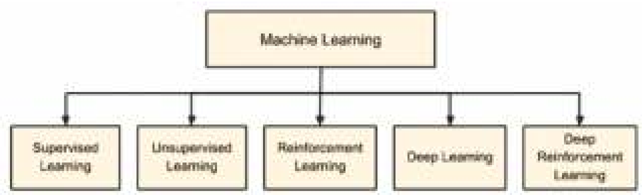

Figure 2: Categories of Machine Learning

Supervised learning algorithms use labelled data for their process of classification and regression. Artificial Neural networks (ANN) are a popular supervised learning technique for both classification and regression [16], whereas, Unsupervised learning algorithms do not use labelled data. Unsupervised learning has been used for different smart transportation applications, such as traffic flow prediction [26, 27], transportation travel route evaluation [30], parking spaces forecasting [32], bus arrival time prediction [5], etc.

Deep Learning (DL) models are another emerging trend in modern Machine Learning algorithms is Deep Learning (DL) models. DL models include the deep reinforcement learning models, Convolutional Neural Network (CNN), stacked auto-encoders, deep restricted Boltzmann machine, recurrent neural network, etc. A survey of deep reinforcement learning for intelligent transportation can be found in [9]. DL models can be used for vehicle detection [6], traffic data imputation [7], and prediction of traffic flow density [20, 11]. This paper focuses on Machine Learning techniques for transportation and mobility, traffic modelling and prediction, traffic management and control, public transportation, and other applications for SCs.

This study aimed to investigate the impact of Machine Learning in the context of SC transportation strategies. Due to the vast real-time data being generated daily due to a rapid and unprecedented surge in urban migration, the existing conventional data processing tools are deficient in effectively realizing the critical targets of an SC transportation ecosystem. As a result, enormous challenges have emerged for the SC transportation sector, including traffic congestion, route planning issues, fleet management problems, parking request modelling problems, and short-term forecasting problems. Challenges have even cropped up in developing efficient strategies to utilize available infrastructures to minimize traffic/accidents and improve road safety. This paper presents a comprehensive review and representative studies focusing on the Machine Learning approaches.

Research Method

The objective of this paper was to present a comprehensive study on SC transportation techniques and approaches, focusing on Machine Learning models used for data analytics. The literature review was conducted as a necessary step in structuring a research field and thus constitutes an integral part of the research. The study has been divided into a four-step research method used for collecting and analyzing the literature, namely, (1) defining the unit of analysis, (2) selecting the classification context, (3) collecting relevant publications and delineating the field, (4) analyzing or evaluating the collected materials. Thus, within the parameters of this objective, the literature is categorized into two parts: (1) an overview of smart city transportation and comparison, and (2) Machine Learning for SC transportation. A complete search using Google Scholar, IEEE Explore, and Scopus databases has been done for relevant papers and other references.

In recent years Machine Learning has paved its way in various fields; therefore, a wide range of publications was found between 2017 and 2020. Thus the search was refined and analyzed under two primary contexts, namely: (1) the problem context and (2) the solution/methodology context, to sufficiently cover both studies on smart city transportation strategies, as well as methods utilizing Machine Learning technology for smart city transportation applications, to address problems.

SC Transportation and Machine Learning

Machine Learning, tools of artificial intelligence, provides machines and autonomous systems with the ability to learn and improve on previous experiences. It focuses on developing computer programs that can autonomously access data and use it for learning and self-improvement. Machine Learning offers a solution for SC transportation, considering its capability to exploit the power of data that has become increasingly available to SC transportation researchers and administrators. With massive data generated by SC transportation data sources (e.g., smart cards, sensors, videos, etc.) that cannot be examined individually, it is necessary to have a system with optimizing capability that learns on its own, based on previous experience. The issues in transportation are becoming a challenge in Patna due to population growth, expansion of the city in the west and south, safety concerns, and environmental degradation. Due to urban migration and the increasing volume of traffic, urban development often reaches a bottleneck.

A generic, dynamic and continuous learning technique is required due to operational changes in the context of SC transportation applications. Therefore, it is critical to investigate the potential of Machine Learning in developing individualized services in SC transportation to increase efficiency. Machine Learning techniques are evolving rapidly due to enhanced data collection methods, improved algorithms, improved communication networks, new sensor/IO units, and interest in self-customization in response to user activity. The goal of Machine Learning in this research is to effectively interpret new data and make predictions beyond the training sample, similar to real-time data. In general, machine-learning-based methods can offer predictive (predict the future state and values of a system), descriptive (describe the current state of a system), or prescriptive (recommend actions to maintain or improve system functionality) analyses. The researchers have proposed Machine Learning techniques and approaches to addressing real-world problems for SC transportation. The authors in [1] presented a study on intelligent transportation using Machine Learning. Their study focused on traffic management approaches for detection and prediction analyses by exploring Machine Learning in the research and transportation industry. In recent years, many machine-learning-based studies have emerged in the literature, notably with a diverse use of multiple Machine Learning methods to investigate various challenges in SC transportation. Firstly, we will discuss Machine Learning techniques for transportation applications in SCs. To do the writing within control, some selected transportation applications have been presented in three critical areas—transportation and human mobility for SCs; traffic flow and density prediction; routing, planning, and route recommendation.

Transportation and Human Mobility for SCs

Human mobility data plays a vital role in urban dynamics, planning, and development as the data has been used to analyze a city. Community structures of cities can be extracted from human mobility data. The authors proposed an approach that utilizes network clustering methods using geographical cohesiveness and regularity from extracted clusters in [14]. The results showed that the predictive information about the community structures of cities could be best obtained directly from the functional relations between city areas.

Traffic Flow and Density Prediction

Traffic flow data can play an essential role in density predictions. Various approaches have been proposed for the prediction of a traffic parameter. The authors considered using GPS tracking systems in public transportation to analyze and predict passenger flow in Real-Time [31]. In contrast, a short-term traffic flow prediction approach that utilizes wavelets and an Extreme Learning Machine (ELM) was proposed by authors in [8]. In [28], the authors proposed an ERS-ELM (Ensemble Real-Time Sequential Extreme Learning Machine) prediction approach for highway peak and nonstationary states. The results from the experiments showed a high prediction accuracy of ERS-ELM, with an optimized training time. A method was proposed for estimating user demand in the public transportation network typified in the Origin-Destination Matrix (ODM) from buses by the authors in [19]. The authors validated the model using data from the city of Quito. The authors proposed a hybrid forecasting model for short-term passenger flow prediction in [12]. Their approach utilized a combination of a Kernel Extreme Learning Machine (KELM) and Wavelet Transformation (WT). The authors validated the model by using data from the city of Beijing. Their experimental results showed that the KELM-WT approach could give accurate information for early warning and monitoring urban rail transit. In [21], the authors presented a study on Machine Learning algorithms for green context-aware transportation systems. The study's objective was to recommend the best transportation routes to reach a destination based on user parameters by different means of transportation (bus, metro, and train). A comparative analysis of four neural networks— two deep learning models on recurrent neural networks (RNN) and two Machine Learning models based on back propagation neural networks (BPNN) was carried on by the authors in [10]. It was observed from the experimental results that models implemented on BPNN showed high performance in comparison to those models implemented on RNN. Today Internet data from social networks (e.g., Twitter) have become new sources for traffic flow prediction besides traditional approaches such as traffic sensors and devices. In [4], the authors proposed a framework that retrieves and uses data from heterogeneous sources, including social networks, to detect traffic flows or patterns. Figure 3 shows the proposed framework. Data utilization in the application is done from various sources, such as entities extraction in tweets, event classifications, and classification of traffic states from image sources. Other research works on data analytics from heterogeneous sources or multimodalities, e.g., text, image, video, and speech, can be found in [22, 23, 24]. The authors proposed a neural network-based model for public transportation prediction using the traffic density matrix (Figure 4) in [18]. Their objective was to consider the local traffic conditions and offer solutions to the bus arrival times at bus stations. Stochastic Gradient Descent (SGD) was used for network training. A traffic density matrix was used to represent the traffic conditions. The authors in [19] proposed a real-time public transportation prediction with Machine Learning algorithms, including optimal least square (OLS) linear regression and Support Vector Regression (SVR). Their work was validated on the SUMO (Simulation of Urban Mobility) simulator [17]. The results experimentally showed that the proposed approach could outperform other approaches and reduce the mean absolute prediction error.

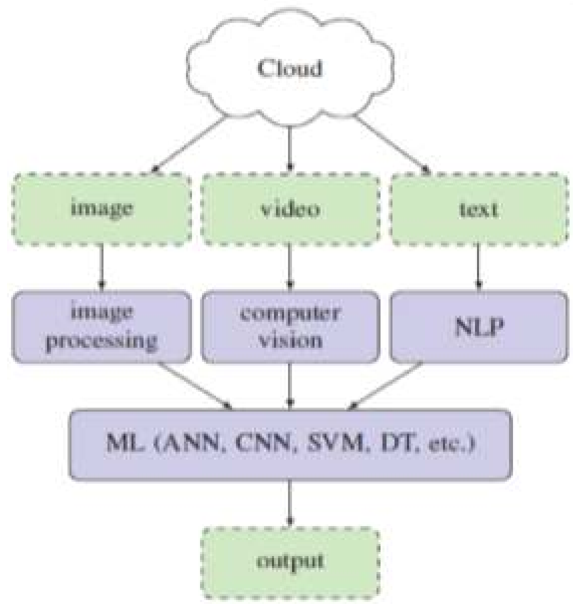

Figure 3. A framework of heterogeneous sources in intelligent transportation [4].

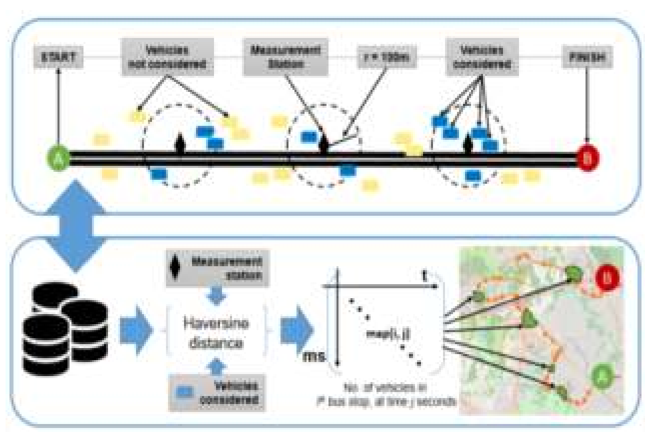

Figure 4. Public transportation prediction using the Neural Network approach [18].

Routing, Planning, and Route Recommendation

Route planning is essential in SC transportation. Machine Learning can play a vital role in real-time route planning and assist users in planning their travel trips and routes. The authors in [13] proposed a bus routing model that identifies and optimizes region pairs with flawed bus routes to improve the utilization efficiency of public transportation services. The authors used taxi traces and bus transactions to generate human mobility patterns among regions. Their experimental results used real-world data collected in the city of Beijing. The authors in [25] proposed trip purpose prediction and a hybrid solution for real-time travel mode detection, which considered using a single preprocessing algorithm (using location traces obtained through smartphone sensors) for both problems. The accuracies obtained by the experiment were 81% for trip purpose prediction and 88% for travel mode detection. The authors proposed a formal approach for public transport anonymous data collection in [15].

Conclusions

Due to an unprecedented surge in the urban population due to population migration from small towns to Patna, the capital of Bihar, large volumes of real-time data are being generated daily. It has become difficult to process this massive volume of data using the existing conventional data-processing tools as they are deficient in effectively realizing the critical targets of an SC transportation ecosystem. As a result, the SC transportation sector is facing challenges in fleet management/route planning problems and traffic congestion. Reducing traffic congestion and developing effective and efficient strategies to utilize the available infrastructures has become more challenging. To address these challenges, a study has been carried out for SC transportation applications focusing on Machine Learning from several data-driven perspectives and information. A comprehensive survey of the research area of SC transportation systems and Machine Learning approaches has been presented in this paper. The paper contains core discussions on Machine Learning approaches for SC transportation and recent trends using integrated deep learning for SC transportation. Researchers can gain insight from the findings in this survey paper and demonstrate that data-driven approaches can be utilized for the transportation architecture of SC.

The paper is presented with the hope that researchers will get acquainted with Machine Learning approaches and recent trends in SC transportation applications. It is up to the researchers to gain helpful insight and consider how SC transportation strategies can be explored and improved. Several use cases have been examined that can be exploited for SC transportation strategies in future work.

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