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Nambua Ladslaus Mnyone and [Noor Ul Amin](#)*

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Article

Applications of Big Data in Smart Transportation

Nambua Ladslaus Mnyone and Noor Ul Amin *

Taylor's University Subang Jaya, Malaysia

* Correspondence: nooraminnawab@gmail.com

Abstract

Because of the recent urbanization and exponential population growth there has come significant pressure on urban transportation systems. Therefore, people encounter many traffic challenges now a days like traffic congestion, environmental pollution, inefficient public transport, and safety concerns. Smart transportation has been talked about recently in this regard which has emerged as a promising solution for addressing all the mentioned challenges. It integrates advanced technologies such as machine learning, internet of things (IoT) and big data analytics into transportation infrastructure. In this research we aim to explore the role of big data in enhancing smart transportation systems and improving urban mobility. In this research we discuss key challenges that are associated with urban mobility and introduce the concept of smart transportation as solution which is technology driven and automated. We also examine later in this research the characteristics and applications of big data in transportation optimization, including traffic congestion management, public transport route optimization, accident prevention, environmental sustainability, ride-sharing services, and multimodal transportation systems. We also discuss in detail a case study of data-driven ride-sharing platforms such as Uber to show how real-time data analytics can improve mobility efficiency and service reliability.

Keywords: data analytics; smart traffic; IoT; big data analytics

1. Introduction

Mobility is often defined by the potential for movement and the ability to get from one place to another, through single or multiple modes of transportation [1]. It has also been defined as the ability to participate in society [2]. Mobility isn't just about having access to one mode of transportation, but it is having the ability to access these services and obtain the quality of those options. Mobility is what makes getting to important places possible such as workplaces, education, healthcare, government facilities, community centers, parks and leisure-related destinations. In simple terms mobility is the ability to move freely[3].

1.1. Concept of Urban Mobility:

Urban mobility is the movements of both people and goods from one place to another that occur in a city either through public or private transportation. Walking, cycling, public transit, private vehicles and new technologies such as electric scooters and ride-sharing are modes of transportation that can be seen in urban mobility[4].

Urban mobility is faced by different challenges globally, but its main aim is to ensure sustainable, efficient, and balanced transportation systems that meet the needs of urban populations while ensuring that there is minimal impact socially and environmentally.

Since the urban population is expected to reach 68% of the world's population by 2050, new cities and new infrastructure, including buildings and transport systems, need to be made to meet the needs of increasing population [5].

1.2. Challenges Facing Urban Mobility

1. Pollution and Emission

Urban mobility is faced by challenges such as pollution and emissions where transportation is the major contributor of greenhouse gas emissions and air pollution. Gas emissions from urban transport systems are estimated at about 60% of the total greenhouse gas emission [6]. It has also been written that transport emissions contribute to 27% of greenhouse gas emissions in Europe (European Environment Agency, 2021), which is a threat to the environment, especially in cities [7]. In the transport sector, road transport is a leading emitter, which is responsible for 72.9% emissions. On the other hand, the marine and aviation industries make up 12.8% and 13.3% of the total emission, respectively stated by [8]. The excessive dependence on private vehicles in places like Jeddah is a transportation challenge that is brought on by a number of factors such as the ineffective public transportation system, cultural preferences for private automobiles, and urban planning that has traditionally prioritised road expansion over sustainable mobility options. Due to all this the transportation system is environmentally damaging and inefficient, which raises energy consumption and degrades the environment [9,10].

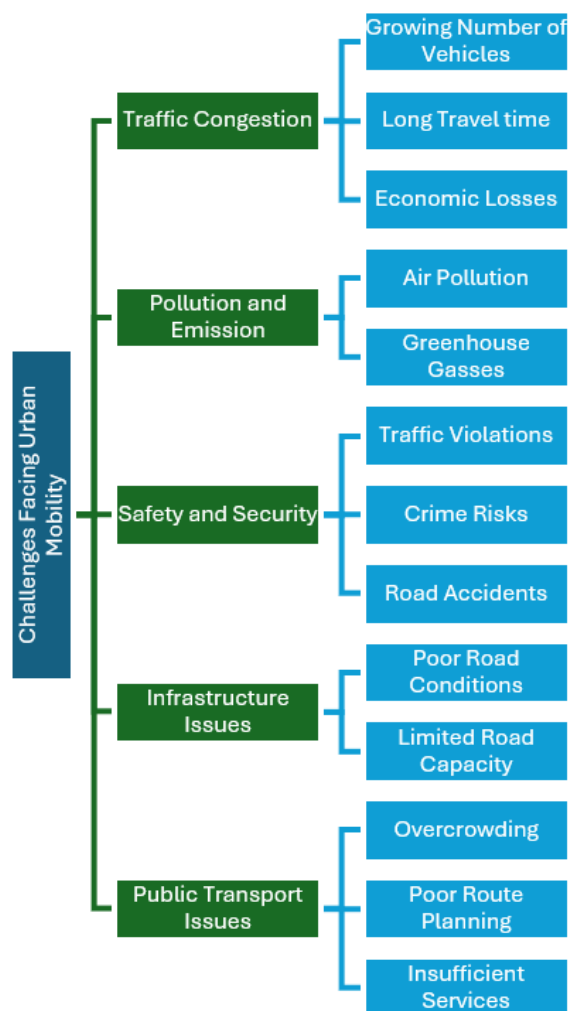


Figure 1. Challenges Facing Urban Mobility.

2. Traffic Conges-on

Traffic congestion is also another challenge facing urban mobility whereas as cities and population grow roadways become overcrowded leading to delays, increased fuel consumption, and pollution. Cities around the world are dramatically expanded, urban population growth is reaching

around 2.5 billion people in urban areas and exceeds 1.2 billion cars up to 2050 N [11]. The growth of population in the world has led to an increase in the dependence of the transport system. It is believed that an average of 40% of the population has spent at least one hour daily on the road, so the congestion has increased. In various developed countries such as the United States, the cost of traffic congestion costs more than \$ 101 billion annually, and the European Union economy is more than 2% of GDP.

3. Inadequate public transportation system

Another challenge is insufficient public transport system where by public transport systems in many cities are overburdened or undeveloped for various reasons. The causes of this include the lack funds to improve or enhance the transport systems, lack of political support and different parking issues. This was stated by [12]. The lack of investment in public transport, lack of adequate transport scheme, congestion and parking problems [13] have also been stated in different publications as a causative of ineffective public transportation system . Another author also mentioned that he global transport system is currently characterized by insufficient and disabled public transport systems [14,15].

4. Poor Infrastructure and road conditions

Poor infrastructure and road conditions, a challenge in urban mobility caused due to rapid urbanization. In many areas the roads and other transportation infrastructures were built to accommodate a smaller population and have not been developed to cater the growing population. In addition, it was mentioned in a publication that the cost of operation and maintenance of permanent transport systems and infrastructure may exceed the traditional systems thus leading to the creation of challenges for governments when prioritizing permanent transport investment [16]. Also, it was stated that poorly developed and disable transport system brings a huge obstacle to the development of urban mobility [17]. The poor infrastructure leads to road accidents, congestion and the overall inefficiency of the transport system. In addition to that, the essential transport infrastructure and lack of plan promote high traffic congestion which makes it difficult to design infrastructure that can meet current requirements [18].

5. Limited access to sustainable transport

Limited or no access to sustainable transport, there are different sustainable modes of transport such as walking, cycling and public transit that are often not prioritized, hence lack of or insufficient infrastructures such as bike lanes, pedestrian zones, and metro systems.

This can be witnessed in many developing countries. Infrastructure and management challenges in developing countries often lead to inefficient governance and environmental management, making it extremely challenging for them to pursue sustainable transportation [19].

The lack of different sustainable transportation options leads to car dependency, which increases the problems of congestion, air pollution, and traffic accidents. It also reduces the quality of life for people who do not or may not own cars. Therefore, the way to bring about potential development and sustainable transport in different developing areas is by improving their public transportation and improving infrastructure such as bus stations , roads, using advanced street lights also focusing on the paths of bicycles and pedestrians ,diversifying transport options such as encouraging people to use bicycles or walking, also using innovative technologies for efficient traffic management and promoting the culture of stability among the residents through educating them.

6. Safety and security concerns

Another challenge, safety and security concerns, whereby major issues such as traffic accidents, pedestrian injuries, theft and robbery, and destruction of property occur in areas with high number of vehicles and inefficient or inadequate road safety measures. The objective of urban mobility is to ensure that people and goods are transported in a safe and secure way but due to several challenges this objective hasn't been met. According to the World Health Organization, 1.35 million on the roads of the annual world are fatal[20]. Several studies have found that high population density areas, increase in traffic, and more urbanization displays high rates of traffic accidents. Globally, pedestrians

and cyclists' deadly forms a significant part, while 26% of all deaths, while users of motorized two and three-wheeler accounts for additional 28% [21].

Literature Review

The incorporation of data analytics, advanced technologies, and different management strategies into the transportation system to improve or develop sustainability, increase safety, enhance user experience and to make transportation more cost effective is known as smart transportation. It is also defined as, the use of advanced sensor, computer electronics, and communication technologies, and management strategies in an integrated or combined manner so as to improve the safety and efficiency of the surface transportation system" [22]. Smart transportation has so many definitions, some complex, some simple. Smart transportation in simple terms means the integration of application modern technology and management strategies into the transportation systems (Michel, n.d.). Smart transportation is primarily being facilitated by the growth of IoT devices and 5G communication technology [23,24]. IoT devices provide sensors and collectors that can be inserted in almost any physical machine and can be controlled and managed remotely while 5G communication provides high speed communication that is needed for controlling the transportation systems and managing them in real time without wasting a lot of time. Different technologies are used to enhance smart transportation and they include Ground-Penetrating Radar(GPR) which improves detection of subsurface defects, Mobile Mapping Systems(MMS) which combines multiple sensors for broad road condition monitoring, Machine learning which improves efficiency , Light Detection and Ranging (LiDAR) which improve detailed digital road surface feature , and Computer Vision and photogrammetry technologies which enables real-time data collection across extensive road networks. The aim of smart transportation is to improve the safety, sustainability and efficiency of transportation system. Four major concepts, stability, integration, safety and accountability, are preferred when adopting and implementing emerging technologies in the transport system, these principles are important in achieving the main goals of transport that are access and dynamics, environmental stability and economic growth.

Applications of Smart Transportation

Smart transportation can be seen in different basic management systems such as car navigation a GPS system that uses satellites to figure out where one is and directs them to the best route , traffic signal control system that change based on how many cars are on the road, automatic number plate recognition that reads the license plates on cars using cameras, speed cameras which catch cars moving too fast by using sensors to detect the speeding vehicles and take a picture of the car to warn the speeding driver , and so many others. As technology has advanced there even more systems that are used in smart transportation and more are being discovered, this advancement integrates live data and feedback to multiple sources. According to (*What Is Smart Transportation?* | IBM, 2024) Many smart transport solutions exist for some time, for example, a city transport department, provides real-time arrival data of buses and trains, electronic toll collections, bike sharing, dynamic pricing on cars entering the city and public transport smart cards.

Hence smart transportation is not just an idea that is to be done in the future, it is being implemented today in different cities and their failures and successes are being used to improve systems in new areas and for the future. Smart transportation is used in different countries and cities globally such as Dublin, Ireland where a city- wide sensor is implemented, which works by collecting data from bus timetables, traffic detectors, closed circuit cameras and GPS updates transmitted by city buses every 20 seconds [25]. In London oyster card is in use while in Hon Kong, Sydney and Malaysia octopus card, opal card and touch n' go card are used respectively [26]. These cards work on the basis of being preloaded with funds and the money is deducted each time a user scans it at a ticket date, hence alleviating the need to wait in line for a ticket. Other different areas such as Seoul

South Korea, Atlanta USA, London, Paris, Amsterdam, Rio De Janeiro have invested in smart transportation as a key component of their smart- city initiatives[27].

Role of Smart Transportation in Addressing Urban Mobility challenges

Smart transportation helps in the better allocation of resources so cities can do more with less and avoid unnecessary energy consumption and resource costs. The development of smart transport is based on existing intelligent transportation by incorporating human intelligence and more advanced information technology, communication technology, sensor technology, computer technology, and system integration technology [28]. Smart transportation systems can address the challenges facing urban mobility such as spiraling travel demand, increasing number of personalized vehicles, declining share of public transport, severe traffic congestion, fast deterioration in the quality of city environment due to rising air pollution, heightened risks to pedestrians and cyclists due to increase in road accidents and deaths, lack of integration between transportation and land use planning, and decades of under-investment in transportation infrastructure are amongst the key challenges of urban mobility [29]. The field of smart transportation has captivated different researchers due to its potential to develop or revolutionize the way people and goods are moved from one place to another, hence many researches have been made on how smart transportation can make transportation easily accessible and efficient. It is said that the Internet of Things (IOT) provides many benefits in a smart city such as traffic management, better logistics, smart parking systems, enhanced security measures and so much more which enhances transportation in general. Smart transportation is the combination of all these benefits into the applications for transportation systems. However, as a way to further improve the benefits provided by smart transportation, other techniques have been used, such as machine learning, big data and many others. Some examples of their application are the enhancement of routes, better parking, street lighting, prevention of accident, detection of abnormal traffic conditions, and maintenance of roads. The following is a detailed understanding of how these benefits are met;

1. Reduced Congestion

Reduced congestion through use of real-time data from various sources such as sensors example lidar sensors, inductive loop sensors, magnetic sensors, traffic cameras such as CCTV cameras, Automatic number plate recognition cameras, surveillance drones, and GPS data such as vehicle GPS trackers , Mobile GPS , Public transport GPS from vehicles. Smart transportation system can provide real-time traffic information to drivers through apps or navigation when the data collected from the different sources is analyzed. The real-time information provided to the drivers helps them choose alternative routes, reducing congestion on busy roads. Simply put, real-time monitoring, predictive analytics, signal control, dynamic route recommendations, and improved accessibility to public transportation are all ways that smart transportation improves traffic management. (*How Smart Transportation Improves Traffic Management* | Seagate US, 2024).

Real-time traffic monitoring is one of the important parts of of smart transportation, this technique enables smart cities to get immediate traffic conditions, thus it allows for the prepared management and timely measures or actions to be taken. In general, real -time data is necessary to improve traffic flows, increase road safety and respond quickly to events. Authorities are able to respond quickly to different incidents by immediately recording and analysing the traffic conditions which then allows them to reroute traffic in order to reduce congestion and stop additional problems. Hence due to this there is a creation of a continuously evolving traffic management system that enhances and prioritises the safety of those who commute on the roads and bike paths. (*How Smart Transportation Improves Traffic Management* | Seagate US, 2024).

Predictive Analytics uses historical data, statistical algorithms, and machine learning techniques to identify future traffic patterns. Predictive analysis predicts congestion by understanding where and when the traffic jams are likely to occur then the transportation authorities can take measures to alleviate congestion, such as adjusting traffic signal timings or setting up additional resources. By

predicting and reducing congestion before it happens, predictive analysis is transforming traffic management apart from that it also minimizes congestion, reduces commute times, and also enhances efficiency in traffic management.

Dynamic route guidance is also a method in smart transportation that is used to reduce congestion using real-time data to analyze current traffic conditions, road closures, and other factors and share alternative routes with drivers. Dynamic route guidance continuously updates recommended paths hence avoiding congestions, lower fuel consumption, reduce travel times and delays. Lowered traffic congestion reduces roadways idle periods which lowers the possibility of traffic jams. These combined results create a congestion-free urban transportation system with improved traffic conditions and faster commute times.

In simple terms, smart transportation changes urban transportation practices and creates a traffic-management system that predicts congested highways based on historical and current traffic jams and recommends alternative paths or routes[30].

2. Enhancing public transport efficiency.

The smart transport system expands beyond individual vehicles to include public transport. Smart transport uses technologies such as IOT, Big Data, AI and real-time communication to improve the general performance and reliability of public transport. Real-time tracking and passenger information systems is one of the applications, where public transport buses, trains and trams are supplied with GPS and IoT sensors to provide real-time location data. This ensures that passengers get live updates of the vehicle arrival times hence reducing waiting times and improves customers confidence in public transport.

A smart public transport system can dynamically adjust the service frequency based on real-time calculations of passenger flow and road conditions, automatically detect and process different abnormalities, such as early and late departures and missing crew attendance, and conduct trip statistics, mileage, fuel and electricity consumption, and other vehicle operating data reports to reduce operating costs.

Passengers can know vehicle arrival times and the number of in-vehicle passengers based on the smart public transport management platform in real-time to choose boarding vehicles and reduce waiting time reasonably. It can also realize convenient passenger ticket payment [31]. While some research results also show that the coordinated operation of buses and subways can help reduce passenger transfer waiting time, reduce the total travel time and total operating costs, and improve the operational coordination of multi-modal public transport. It is also pointed out that the application of IC cards, GPS, and other related technologies in the public transport field has improved the service level of public transport operations and generated a large amount of data on public transport operations, which provides the primary data source for bus passenger flow analysis while accelerating the development process of intelligent public transport.

3. Minimization of environmental impact

Smart transportation solutions not only improve public transportation and reduce traffic congestion it also contributes to reduced environmental footprint. Smart transport technologies contribute to more environmentally friendly areas by optimizing traffic flows, reducing congestion and promoting efficient public transport and parking management (*How Smart Transportation Improves Traffic Management* | Seagate US, 2024). Apart from that, smart transportation initiatives often encourage or support biking and walking, through creation of bike lanes and pedestrian friendly infrastructure which in turn reduces the dependency on motor vehicles hence decreases emissions. As smart transportation is data-driven it ensures that city planners make informed decisions with the analyzed data, hence creation of efficient transportation networks, reducing unnecessary travel and minimizing the environmental impact. Smart transportation also encourages and facilitates carpooling and ride-sharing services, thus reducing the number of vehicles on the road, leading to a decrease in fuel consumption and emissions. In addition, it can accelerate the penetration of more environmentally friendly transport modes, such as electric vehicle (EV) and high-speed rail (HSR).

Integration of hybrid and electric vehicles due to smart transportation has also made a great impact in the reduction of the overall environmental footprint. It supports the use of electric and hybrid vehicles such as tesla model 3, ford escape hybrid, lucid air and many others by providing necessary infrastructure, such as charging stations. These electric and hybrid vehicles produce fewer emissions compared to other vehicles that use fuel.

4. Enhanced Safety

Smart transportation systems enhance safety and security in several ways. Real-time traffic monitoring and management is one of the ways through which smart transportation enhances safety, through use of sensors, cameras, and other technologies. Through the real-time data collected there is quick identification of accidents, congestion, and many other issues, hence enabling prompt responses to improve safety. Information, communications, and technology (ICT) advancements in the transportation industry have led to a major improvement in traffic efficiency and a further strengthening of traffic safety, while the number of traffic accidents has also decreased[32].

Smart transportation technology such as advanced driver-assistance systems (ADAS) in smart vehicles include different features such as automatic emergency braking, lane departure warnings, and adaptive cruise control which provide safety to drivers by helping them prevent accidents through alerting them from potential hazards and, in other cases taking the corrective actions to avoid collisions.

Improved road infrastructure and installation of intelligent traffic signals comes with the development of smart transportation. Features such as better lighting, road markings and signage are provided through smart transportation which enhance visibility and reduce the risk of accidents. The smart traffic signals are made to be adjustable based on real-time traffic data which reduces the likelihood of accidents at intersections, they also prioritize emergency vehicles ensuring that they reach their destinations quickly and safely.

Lastly, smart transportation enhances public safety through interacting with public safety services such as emergency medical services and police by providing real-time information about incidents.

Apart from public safety, smart transportation technology is also said to protect the infrastructure made for transportation. Transportation infrastructures and systems are protected from various dangers by intelligent transportation systems like dynamic route guidance, security cameras, and traffic management software [33].

Apart from the above explained solutions there are several other approaches or ways that smart transportation address urban mobility challenges such as enhancing user experience, improves accessibility to transportation system , promotes multimodal transportation and smart parking solutions [34].

Big Data in Smart Transportation

Big Data refers to the enormous amount of structured and unstructured data generated at high speed or velocity from a multiple of sources. Large and complicated data sets that are difficult to handle or analyze using spreadsheets or other traditional data processing tools are also referred to as big data. Big data includes unstructured data like emails, movies, audio files, and web pages; structured data like relational databases or financial transaction records; and mixed data like medical records and e-commerce data. It is also believed that there is semi-structured data such as xml files, JSON files and HTML pages.

Big Data has three core characteristics which are known as the 'three Vs' which are volume, velocity and variety but as of now they are five in addition to veracity and value.

Volume

This refers to the amount of data that is present. Data volume is also referred to as the size of data in terms of standard information matrices which are bits and bytes. Volume or amount of data

to be processed is the biggest factor for determining storage and processing requirements. Storage of data has become easier due to new storage technologies and the ability to store non - sensitive data on external cloud providers while more resources have been directed toward increasing a system's processing power, the acceleration of data growth continues to exceed the rate at which computation capacity is improved, which poses challenges for processing systems.

Velocity

Velocity is the speed or fast rate at which data is received and acted on. Velocity is about the speed at which the data is processed, generated and also analyzed. Data is being created and processed at exceptional speeds which requires real-time or near real time analysis.

Variety

Variety in big data stands for the different types and formats of data that are generated. Data can be structured where it has a predefined format such as in tabular form, it could be semi-structured such as xml files or it could be in an unstructured format with no predefined organization such as videos, images and so much more. These different kinds of data require different methods of processing and analysis. The article "Veracity in big data: How good is good enough" [35] discusses the importance of data veracity and the methods to ensure data quality and reliability

Veracity

Veracity means the quality or the reliability of data. There is a large amount of data generated, processed and analyzed, it is essential to ensure that the data is accurate and trustworthy. If the data is not of good quality and it is not reliable wrong insights can be derived from the data hence incorrect conclusions and decisions can be made. This characteristic highlights the importance of data governance and management practices.

Value

Value is the usefulness of the data and the insights that can be obtained from it. One can have vast amount of data but without meaningful information. Meaningful information is required to make good decisions and create value. The article "What counts: Making sense of metrics of research value" [36] examines the different ways to measure the value of data and research.

Table 1. Simplified explanation on big data characteristics.

| Big Data Characteristic | Description |
|-------------------------|---|
| Volume | The large amount of data generated and stored, requiring efficient storage and processing solutions. |
| Velocity | The speed at which data is created, processed, and analyzed, often in real-time. |
| Variety | Different types of data, including structured (tables), semi-structured (XML, JSON), and unstructured (videos, images, text). |
| Veracity | The accuracy and reliability of data, ensuring it is trustworthy for analysis and decision-making. |
| Value | The usefulness of data in generating insights and making informed decisions. |

Roles of Big Data in Transportation Optimization

Big Data is defined by its variety (data available in multiple formats including emails, documents, photos, and videos), velocity (the quick creation of new data), and volume (such as the massive volumes of data produced by social media, mobile devices, and e-commerce).

Dynamic Data Driven Application Systems (DDDAS) are applications that leverage Big Data sources and integrate real-time data into their calculations to direct the application systems' measurement procedures. By integrating many infrastructure systems that exchange data through portals, DDDAS play a critical role in putting smart city concepts into practice [37]. Big data is used in many areas in such as designing and planning the systems to be used in smart transportation, smart control systems, smart cities, smart communities and so much more. Using big data has become really important for managing smart city issues in a sustainable way.

1. Traffic Management and Congestion Reduction

Big data is crucial in traffic management and congestion reduction through analyzing real time traffic patterns through different data that is collected through different sources such as GPS systems, surveillance cameras, and road sensors. The data collected helps in adjusting traffic lights dynamically based on traffic flow, reducing unnecessary waiting times at intersections, it also enables efficient rerouting through suggesting alternate routes, helping drivers avoid congestion. This is done through applications such as Google Maps and Waze. Prediction and prevention of bottlenecks can also be witnessed whereby different artificial intelligence driven models analyze the present and past traffic data to pin point high risk congestion areas which allows the authorities to take preventative measures. For example, a study that was published by [38] demonstrated how analyzing vehicle trajectory data can reveal urban traffic patterns, aiding in traffic management strategies. Also, in a study of transportation research highlighted the effectiveness of deep learning models in forecasting traffic congestion with high accuracy, enabling timely interventions [39].

2. Optimizing Public Transportation Routes

Transportation companies use big data to find the most efficient routes for their vehicles so as to efficiently accommodate demand while minimizing unnecessary trips. Through analyzing different historical data, current transport conditions and weather patterns using big data, best paths are determined hence minimizing travel time and fuel consumption. Big data does all this through predicting passenger demand by analyzing travel patterns to adjust bus, train and subway schedules based on peak hours, holidays and other major events. According to research by [40] utilizing big data from smart card transactions has led to improved route planning and increased passengers' satisfaction in metropolitan areas. For example, New York City Metropolitan Transportation Authority (MTA) uses predictive analytics to determine the most efficient train frequencies, reducing overcrowding and improving reliability.

3. Enhancing Road Safety and Accident Prevention

Big data can help in understanding the different causes of accidents in transportation and help develop strategies on how to mitigate them. Transportation authorities use big data to analyze accident data and identify different patterns and implement safety measures in high-risk areas accordingly. Smart transportation systems detect accidents and immediately alert respective emergency services such as medical, fire and rescue, and police services, hence reducing response times. Monitoring driver behavior is also done through use of fleet managers which use real-time tracking to check drivers' actions such as speeding, aggressive driving or harsh braking. For example, in Los Angeles data-driven approach to road safety is used by using accident analytics to place resources more effectively, reducing traffic-related incidents. In a study done by [41] they presented how data-driven allocation led to a 20% improvement in fleet utilization.

4. Promoting Sustainability and Reducing Emissions

Big data also plays a role in minimizing the environmental impact or consequences of transportation such as air pollution, greenhouse gas emissions and many others through analyzing

emission data and traffic patterns. The insights extracted from the analyzation help cities develop different strategies to promote eco-friendly or greener transportation options such as electric vehicles or improved public transit systems. [42] Garcia wrote an article which showed how implementing big data analytics in traffic management reduced carbon emission by 12% in urban areas. Since big data also supports eco-friendly traffic management strategies such as optimized traffic flow and reduced congestion, less fuel consumption and emission is witnessed. For example in London, London's Ultra Low Emission Zone(ULEZ) uses big data to monitor vehicle emissions, hence improving air quality and limiting high-pollution vehicles.

5. Enhancing Ride-Sharing, Mobility-as-a-service (MaaS)

Enhancing ride-sharing and mobility-as-a-service (MaaS) through big data involves the use of data-driven understandings to improve different aspects of these services. Big data allows the analyzation of a large amount of past travel data which predicts when and where demand for rides will be highest. By improving the effectiveness of matching drivers and passengers, artificial intelligence (AI) is essential to ride-sharing. AI is able to identify the closest driver to a passenger's location by analyzing real-time data. In addition to cutting down on passenger wait times, this increases a driver's profits and improves passenger service by maximizing the number of rides a driver can finish in a given amount of time. In an article written by Williams [43] it reported that real time big data analytics has reduced the average travel times by 15% in smart city projects. Big data real life application is used in Uber and Lyft to predict peak hours, improve driver-passenger matching, and flexibly modify prices based on demand.

6. Promoting Multimodal Transportation

Big data encourages multimodal transportation by combining several forms of transportation to give users a smooth travel experience. Big Data assists users in making properly informed travel decisions by offering real-time information about a variety of transportation options, including buses, trains, bike-sharing programs, and walking routes. The advantages of choosing different forms of transport, like less expensive travel expenses, less of an impact on the environment, and better health through walking or cycling, are brought out by big data analytics. Transportation platforms may additionally customize suggestions to encourage a more economical and environmentally friendly choice of travel options by looking at trends in user behavior. It promotes a more environmentally friendly approach to urban mobility and reduces traffic on the roads, which eventually results in a more effective transport system. [44] discussed in their article how data-driven applications promote sustainable mobility choices, leading to decreased traffic congestion and environmental impact.

Discussion (Case Study)

In this section we use a case study approach to examine how data-driven technologies are implemented in real world smart mobility systems. This helps us better understand the practical impact of big data in transportation. Modern cities generate massive volumes of transportation-related data from a variety of sources such as GPS-enabled devices, IoT sensors, and traffic monitoring systems. Once able to analyze this data using advanced analytics and machine learning techniques can help the transportation authorities and service providers optimize traffic flow, improve route planning, enhance safety, and provide better mobility services. Ride-sharing platforms such as Uber represent one of the most widely adopted real-world implementations of big data analytics in transportation systems. Figure 2 shows the layered architecture. It shows the big data analytics pipeline for smart transportation systems showing how data from GPS devices, IoT sensors, traffic cameras, and mobile applications is collected, processed using machine learning algorithms, and used to optimize ride-sharing services, traffic prediction, and route planning.

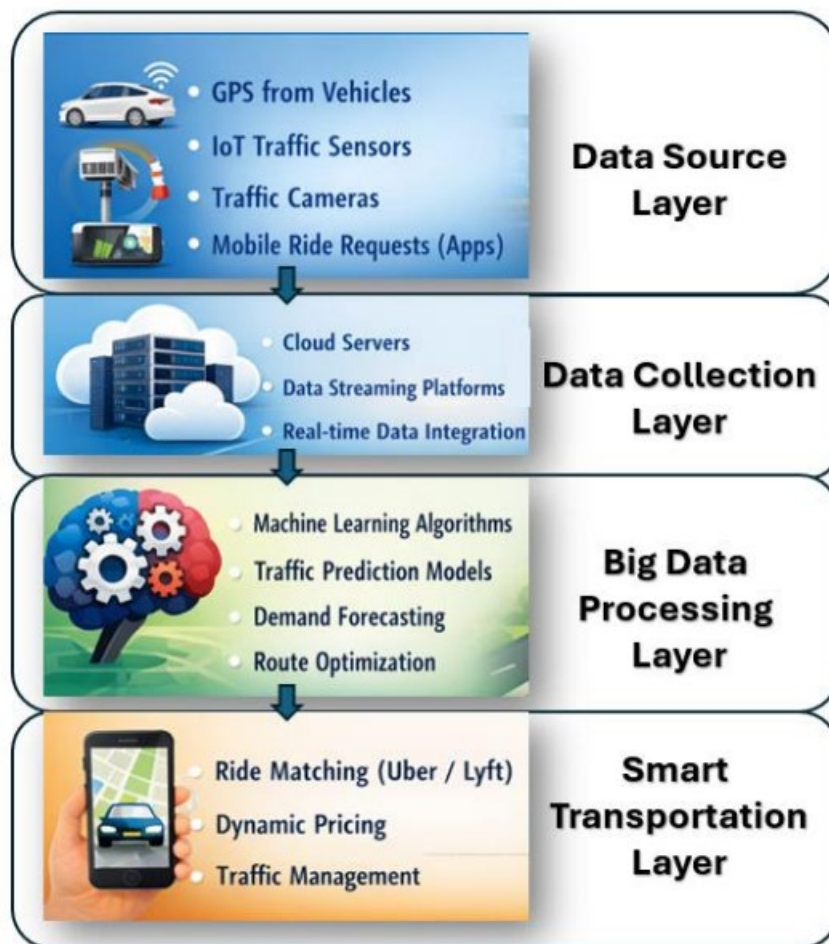


Figure 2. Big Data Pipeline for Smart Transportation (Ride-Sharing Example).

Data Sources in Smart Transportation

Smart transportation systems rely on the integration of multiple data sources that continuously generate real-time information about traffic conditions, vehicle movements, and passenger demand. One of the most important sources of transportation data is Global Positioning System (GPS) technology, which is embedded in vehicles, smartphones, and public transport systems. GPS allow transportation systems to monitor traffic patterns and estimate travel times accurately as the data provides real-time information about vehicle location, speed, and travel routes.

Another key source of transportation data is Internet of Things (IoT) sensors. These sensors are deployed across road networks, traffic lights, parking systems, and public transportation infrastructure. IoT devices collect information such as vehicle counts, road conditions, environmental conditions, and parking availability. This data helps authorities monitor urban mobility conditions and detect anomalies such as accidents or traffic congestion.

Apart from the above two technologies, traffic cameras and surveillance systems also contribute significant data to smart transportation systems. Cameras installed at intersections and highways capture visual data that can be analyzed using computer vision techniques to detect traffic density, monitor vehicle behavior, and identify incidents. The integration of these multiple data sources enables transportation systems to obtain a comprehensive understanding of urban mobility patterns.

Data Analytics for Traffic Prediction

The large volumes of data collected from transportation infrastructure require advanced data analytics techniques to extract meaningful insights, in this regard big data analytics enables

transportation systems to analyze both historical and real-time traffic data to identify patterns and predict future traffic conditions. While, machine learning algorithms are commonly used for traffic prediction and congestion forecasting. These algorithms have infinite power to analyze historical traffic data along with real-time sensor information and identify trends such as peak travel hours, accident-prone locations, and recurring congestion points. These ML based predictive models can then forecast future traffic conditions and support proactive traffic management strategies.

For example, predictive analytics can help transportation adjust traffic signal timings dynamically, reroute vehicles to alternative routes, and allocate emergency response resources more efficiently. These capabilities significantly improve traffic flow and reduce delays in urban environments.

Example: Uber and Smart Ridesharing

Ride-sharing platforms such as Uber provide a clear example of how big data analytics can transform urban transportation systems. Uber collects massive amounts of data from its platform, including GPS data from drivers, passenger ride requests, traffic conditions, and historical demand patterns. Using this data, Uber applies advanced machine learning algorithms to perform demand prediction, driver-passenger matching, and dynamic pricing optimization. The platform analyzes historical travel patterns to predict where ride demand will increase and strategically position drivers in high-demand areas. Doing these measures reduces passenger waiting times and improves the efficiency of ride allocation.

Optimal routes for drivers are determined using the real-time traffic data, helping reduce travel time and fuel consumption. Uber's dynamic pricing model also uses big data analytics to adjust fares during periods of high demand, encouraging more drivers to operate in busy areas and ensuring service availability.

Impact on Urban Mobility

The integration of big data technologies by analyzing large volumes of transportation data, cities can develop smarter traffic management systems that improve mobility efficiency and reduce congestion. The major role played by big data is for transportation authorities to make informed decisions regarding infrastructure development, public transportation scheduling, and traffic management strategies. Real-time data also allows rapid responses to traffic incidents, reducing delays and improving road safety.

Furthermore, data-driven transportation systems support the development of sustainable mobility solutions by encouraging the use of public transportation, ride-sharing services, and multimodal transportation options. These improvements not only enhance the overall efficiency of transportation networks but also contribute to reducing environmental impacts such as air pollution and greenhouse gas emissions.

Discussion

The integration of big data technologies has become a fundamental component in the development of smart transportation systems. By leveraging large-scale transportation data, cities can gain valuable insights into traffic behavior, passenger demand, and mobility patterns. These insights support better decision-making and enable the development of efficient transportation policies and infrastructure planning strategies.

One of the major advantages of big data in transportation is scalability. Modern transportation systems generate continuously increasing amounts of data from millions of connected devices, vehicles, and infrastructure sensors. Big data platforms allow this information to be processed and analyzed efficiently, enabling transportation systems to scale and adapt to growing urban populations and mobility demands.

However, despite its benefits, the use of big data in transportation also presents several challenges. One of the primary concerns is data privacy and security, as transportation data often includes sensitive location information about users. Another challenge is data integration, as transportation data is collected from multiple heterogeneous sources such as sensors, cameras, GPS devices, and mobile applications.

Conclusion

In conclusion, to make transport systems smarter, more effective, and sustainable networks, big data is essential. Cities may plan and reduce traffic, improve public transportation, make wise decisions in real time, and efficiently distribute resources by evaluating enormous volumes of data. By reducing emissions and encouraging more environmentally friendly modes of transport, these improvements not only increase mobility and shorten travel times but also make an important addition to environmental sustainability.

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