ENHANCING SAFE MOBILITY USING INCLUSIVE INTELLIGENT INFRASTRUCTURE MANAGEMENT SYSTEM

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ABSTRACT

In the dynamic realm of urbanization, smart city development, particularly in relation to transportation infrastructure, is gaining momentum. This study addresses a gap in the current strategies by emphasizing effective management over mere expansion. Managing infrastructure systems is essential given the increasing trend of tech-driven transportation and the vehicle-to-capacity ratio. To maximize the current infrastructure in East London, South Africa, the Inclusive Intelligent Infrastructure Management System (IIIMS) is the suggested solution. For more sophisticated transportation system design, the project combines data-driven approaches with intelligent transportation systems (ITS). Demand management, predictive maintenance, route optimization, and real-time data collection are important components of this approach. By offering information on traffic patterns, hotspots for congestion, and possible conflicts, these initiatives support well-informed decision-making for capacity expansion. Focusing on Oxford Street, a congested area in East London, this research employs the smart city wheel and the 15-minute smart city concept. The IIIMS loop incorporates adaptive hypotheses for safe mobility principles in a specific spatial and temporal context. By examining the elements of an inclusive intelligent transportation system, this study considers telematic technologies, data-driven traffic management, and safe mobility principles. Hypotheses related to private vehicle access, worker safety, citizen well-being, and urbanized infrastructure management are discussed, offering solutions for safe mobility. The proposed framework includes an operational level-of-service (LOS) lane change modification for Oxford Street, promoting flow and reducing congestion. Recommendations should focus on competitive measures for delay-time management, congestion patterns, and hotspot identification, contributing to smart city discourse and emphasizing inclusive intelligent infrastructure management for safe mobility and urban transportation competitiveness.

Keywords: Driver safety, Inclusive intelligent infrastructure management system, Intelligent systems, Road markings, Safe mobility.

1. INTRODUCTION

In the past decade, the development of smart cities through innovative transportation infrastructure modes and elements has gained popularity. Although numerous systems management strategies primarily focus on infrastructure upgrades and development, there is little focus on managing the infrastructure system. Additionally, the vehicle-to-capacity ratio has been increasing following recent technology trends and improved standards of living, resulting in an increasing number of vehicles. This aligns with a statement made by Zhang *et al*. (2011): "*transportation systems make up most of human activity, with an* *average of 40% of the human race spending at least 1 hr on the road each day moving from origin to destination in one way or another.*” Therefore, there is a need to focus on managing infrastructure rather than merely developing and expanding transportation infrastructure. This implies that lane widening and increasing the number of lanes can be mitigated by proper infrastructure management systems. This can be achieved by deploying inclusive intelligent infrastructure management systems (IIIMSs), which will be outlined in detail in this study.

In recent years, there has been a shift toward improving transportation systems through intelligent transportation systems (ITS). This study envisages that safe mobility using ITS plays a significant role in enhancing travel security and providing road users with diverse multimodal travel options. These options include various inclusive movement network systems (Malta *et al.*, 2009; Zhang *et al.*, 2011; Western *et al.*, 2024). With the adoption of ITS, it has become possible to create multifunctional data-driven concepts that refine transportation system design and efficiency, thereby optimizing performance and ensuring safe mobility.

1.1 Data-Driven Traffic Management

In transportation system management, multifunctional data-driven initiatives play an important role in refining the concept of transportation systems and aid in the design and/or redesign of methods for improving efficiency (Zillner, 2021). By harnessing the power of data management concepts, transportation planners and traffic engineers can access valuable insights into various aspects of system management, enabling them to make informed decisions and implement effective strategies for improving the capacity and efficiency of traffic routes.

A key concept is data-driven traffic management, which involves real-time data collected from sensors, cameras, and connected vehicles along the traffic stream (Qi, Shi & Abdel-Aty, 2015). These data can be analysed to identify traffic patterns, congestion hotspots, and bottlenecks, and further predict potential conflicts and generate future expansion plans. This information allows for dynamic traffic signal optimization, where signal timings can be adjusted in real-time based on current traffic conditions, leading to improved traffic flow and reduced congestion (Lv *et al.*, 2014; Ghosh *et al.*, 2005; Liu *et al.*, 2018). The signals can be accessed with magnetic sensor devices installed in close proximity to the traffic signals/robots. This helps to manage priority measures to improve flow and reduce congestion at intersections.

Another multifunctional concept is the predictive maintenance of infrastructure along the traffic route. This is achieved by continuously monitoring and regulating the performance of transportation infrastructure such as bridges, tunnels, and roads. Furthermore, data-driven models can predict potential failures or maintenance needs. The adoption of an inclusive proactive approach helps optimize maintenance schedules, minimize disruptions, enhance the longevity of the infrastructure, and improve efficiency during peak operation times.

Data-driven route optimization (DD-RO) is another valuable concept (Tak *et al.*, 2014). By analysing historical traffic data, real-time conditions, and other relevant factors, algorithms can calculate the most efficient routes for vehicles while considering factors such as travel time, fuel consumption, and environmental impact. This not only improves individual travel experiences but also contributes to overall traffic flow efficiency. The use of DD-RO aims to provide the most efficient paths for vehicles to counter congestion, reduce fuel consumption, minimize environmental impact, and improve travel time efficiency. The purpose of data collection is to collect, analyze, and predict travel patterns as well as identify congestion-prone areas. This eventually has the potential to train models using Artificial Intelligence to adapt to differential routes dynamically in real-time. Although weather conditions vary, an inclusive sophisticated algorithm using AI and machine learning, which considers regression models, heuristic and metaheuristic models in the form of genetic algorithms and ant colony methods, will seamlessly provide scalability and, most importantly, interoperability of systems to enhance transportation.

Moreover, data-driven concepts can be utilized in demand management strategies. By analysing travel demand patterns and understanding the preferences of travellers, transportation planners can develop targeted interventions such as dynamic pricing, incentives for off-peak travel, or promoting alternative modes of transportation (Zillner, 2021). These strategies help reduce peak-hour congestion and balance the load on transportation networks. This can be done by providing a ratio for trip distribution as informed by the traffic patterns within the given area (Kumar, 2017; Calabrese *et al*., 2013), which is coordinated using adaptive response sensor devices in the form of permanent traffic counting devices installed within major network links or nodes. The adaptive response device (traffic counting devices, magnetic sensors) aims to collect multiple alternate travel patterns that exist along the traffic route and, by inference, simulation trip assignment logic models and patterns are developed to help in distributing trips across the area based on three major categories: primary trips, diverted trips, passed-by trips, and reroute/reassigned trips resulting from bypass routes, temporary malfunctions, conflicts from adjacent trips, or adjacent network links (Chu, 2016; Li *et al*., 2013). To ensure an inclusive intelligent infrastructure management system, multifunctional data-driven concepts in transportation system design and efficiency, as highlighted, need to take into consideration several factors such as real-time traffic management initiatives, predictive maintenance, route optimization, and demand management. Furthermore, by leveraging data and employing advanced analytical techniques, these concepts enable transportation systems to operate more smoothly, reduce congestion, enhance safety, and ultimately provide more efficient and sustainable mobility solutions for users.

However, addressing issues such as accidents, traffic congestion, delays, and poor road markings caused by inefficient traffic management systems and inadequate infrastructure management is crucial (Li *et al*., 2013). To achieve this goal, an efficient smart system incorporating an intelligent safe mobility system is necessary. Therefore, the main research questions for this study are as follows: Can the implementation of an inclusive intelligent system enhance safe mobility and improve the competitiveness of infrastructure management systems in the East London Oxford Street Road area? Zhang *et al*. (2011) developed a Data-Driven Intelligent Transportation System (D2-ITS) to optimize mobility using visual sequences and learning algorithms to optimize the performance and efficiency of traffic. Further studies by Malta *et al*. (2009) and Hamza-Lup *et al*. (2008) identified potential vulnerabilities that impair the resilience of transportation infrastructure performance and the behaviour of vehicular traffic. These vulnerabilities are often identified as difficulties in implementing public transport solutions and the increasing demand for transport resulting from urban sprawl. It is important to note that developing a framework that integrates inclusive intelligent infrastructure transportation systems (IITS) with competitive transport infrastructure to achieve smart mobility using space-time design in East London cannot be overemphasized.

1.2 Study Area

East London is a small city around the Indian Ocean in Eastern Cape South Africa. The city is known for its warm beach spots in various locations, such as Nahoon and Cove Rock shown as Figure 1.

LEGEND

Road Layout	Description
Purple	Secondary Road
Red	Secondary Road
Black	Fleet Street
Green	Station Street
Yellow	Oxford Street
Beige	Cambridge Street
Blue	Beaconfield Road
White	Buffalo Street

Figure 1: Layout showing the East London CBD and Oxford Street (Source: Google Earth Image 2023)

Oxford Street, represented by the yellow line, spans approximately 2.8 km from the fleet street which collects and distributes traffic from the N-2. The black line represents fleet street which connects with R-72 further South-West ward, the Green line represents Station Street, the Beige line represents Cambridge street, the white line represents buffalo street while the red and purple lines represents intermediate secondary streets within the CBD. The most critical which is the Oxford Street (congested – N-2 collector and distributor with high traffic volumes at peak times, also associated with on street parking) area of study spans approximately 780 m of the total length from the fleet street. This makes Oxford Street the most highly congested network link in East London. The traffic volume is usually most critical on Fridays with increasing density and reduced flow along the entire Oxford Street. An inclusive intelligent infrastructure management system is proposed to improve the capacity and efficiency of vehicles via a developed framework which is presented in this study.

2. INVESTIGATION OF SAFE MOBILITY IN EAST LONDON

The ideas and principles underpinning the 15-minute smart city concept are not new. Bruno *et al*. (2023), in a study to optimize efficiency of urban networks concluded that futuristic smart infrastructure system and management is a key material element to enhance and optimize safe mobility. Thus, the 15-minute smart city concept revolves around the idea of creating urban environments where residents can access essential services and amenities within a 15-minute walk or bike ride from their homes. This concept aims to promote sustainability, improve quality of life, and reduce reliance on cars for everyday tasks. Furthermore, the core principle of the 15-minute smart city is to design neighbourhoods and urban spaces in a way that minimizes travel times for residents. This is achieved by concentrating essential services such as grocery stores, schools, healthcare facilities, parks, and public transit hubs within a short distance from residential areas, cities can create more walkable and bike-friendly communities in nuclei forms dispersed within a city or community. This radically redefines the planning, and functionality of a city towards sustainable smart mobility. Thus, implementing the 15-minute smart city concept to be adopted in the East London CBD will involve careful urban planning, zoning regulations, and investment in infrastructure and route management. This will also require collaboration between city planners, architects, transportation experts, and transport stakeholders to redesign the entire CBD that prioritize pedestrian and cyclist safety, connectivity, and accessibility.

One example of a city that has embraced the 15-minute smart city concept is Paris, France. In 2020, Paris Mayor Anne Hidalgo announced plans to transform the city into a "15-minute city," where residents can find everything, they need within a 15-minute walk or bike ride from their homes. This initiative created more pedestrian-friendly streets, expanding bike lanes, and increasing access to public transportation. Later on, many cities around the world began to align with the 15-minute smart city principles, either accidentally or by design. Thou some of the cities already have longer-standing urban development plans that strive for the very outcomes sought by the 15-minute smart city model, extending its benefits across the whole city. The smart city wheel (Figure 2) developed by Cohen 2012 was considered as one of the foundations for smart infrastructure management system. Elements of this model is adopted in this study to improve the efficiency of Oxford Street in this study.

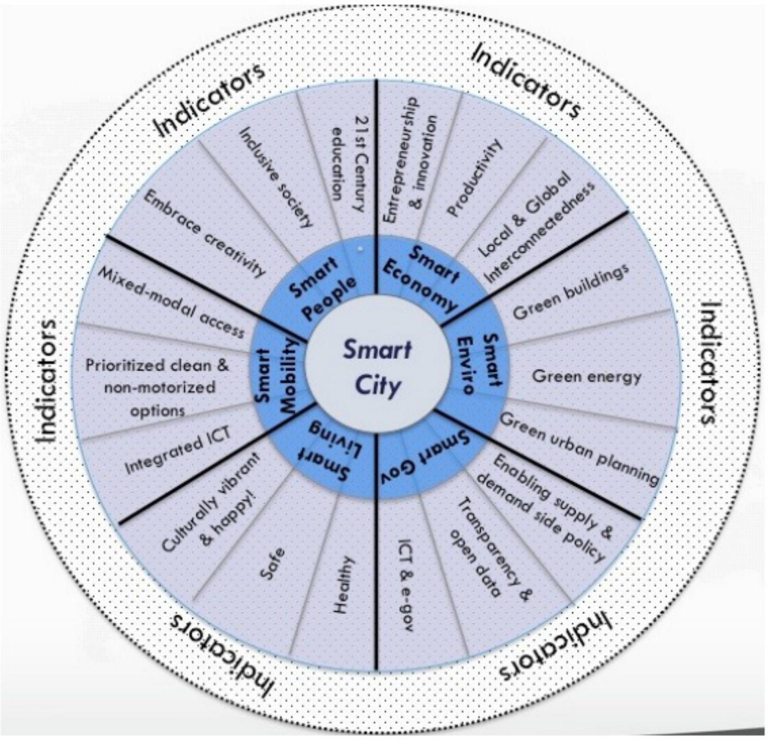

Figure 2: Smart city wheels. Source: Cohen, 2012

2.1 Elements of the Inclusive Intelligent Transportation Systems Model in East London

The foregoing elements of the Intelligent Transportation System (ITS) include various tools relating to information technology, wireless communication and vehicle electronics (Brzozowska *et al*., 2019). This approach will harmonize with the smart city wheel. Consequently, models and indicators from Zhang (2011) and Malta *et al*. (2009) concept will be adopted to develop an inclusive intelligent infrastructure management system for Oxford Street, East London CBD. Telematic technologies (a process that properly interprets information and transmits data in an efficient and cost-effective way, all in real time using devices such as inductive loops and video cameras connected with controllers and computers to enable more effective use of road infrastructure) are embedded in the elements of transportation infrastructure system management to be considered in this study.

2.1.1 Smart City Wheel Concept

The smart city wheel in Figure 2 serves as a platform for highlighting the major elements of an inclusive smart city. The purpose of using ITSs and D2-ITS models in smart cities is to provide intelligent solutions in road traffic management systems. These elements serve to create scalable solutions (McDonald *et al*., 2017). However, different ITS architecture developments do not indicate specific technologies, which are becoming open systems and increasing the competitiveness of implemented solutions (Brzozowska *et al*., 2019). To foster inclusive ITS toward enhancing safe mobility, four major factors regarding safe mobility along Oxford Street as a 15-minute smart city are proposed. First, access to private vehicles, either as a driver, for as long as it is safe to drive or as a passenger (commuter) for easy access to other forms of transport, is essential in the management of health, well-being and safe mobility of older road users. Second, safe mobility, specifically for workers, will mean a reduced risk of work-related ill health as well as fewer days lost due to injury. Third, the improved well-being of citizens, as a smart form of urban transport, prevents traffic accidents. Finally, safe and urbanized city infrastructure management can improve city security, reliability, transportation speed, road capacity and energy efficiency. The elements of the abovementioned factors for improving efficiency through the use of an inclusive intelligent infrastructure transportation system aim to provide a solution to the four hypotheses presented. Considering the current design of corridors in the study area, the issue of safe mobility might not be directly achieved; resulting from the increasing traffic volumes and demand which exceeds the capacity to which the lanes can manage as all the streets are two-way streets with informal trading activities as well as uncontrolled on-street parking from taxi and bus drivers. It is necessary to develop a framework that can enhance safe mobility considering the constraints (inefficiency and shortcomings) of Oxford Street transportation infrastructure. This is presented in the next section of this study. A proposal to reconsider the capacity management of Oxford Street (Yellow line), Station Street (Green Line), Buffalo Street and Cambridge Street (Beige lines respectively) is needed by alternating either of these streets one way to efficiently maximize the capacity of the traffic route since impending constraints such as zoning and proximity of traffic route to service buildings, offices, banks and community halls will not permit lane widening or additional lanes.

2.2 Development of Framework for Inclusive Intelligent Infrastructure Transportation Systems Management in Oxford Street, East London CBD

The proposed map shown in Figure 3 provides a layout plan of the study area with the most problematic section. The proposed network layout (Figure 1) adopts the four previously highlighted factors to address the four major concepts developed for this study: adaptive travel, safe mobility, indicators and essentials. These four concepts have been linked using a smart art chart.

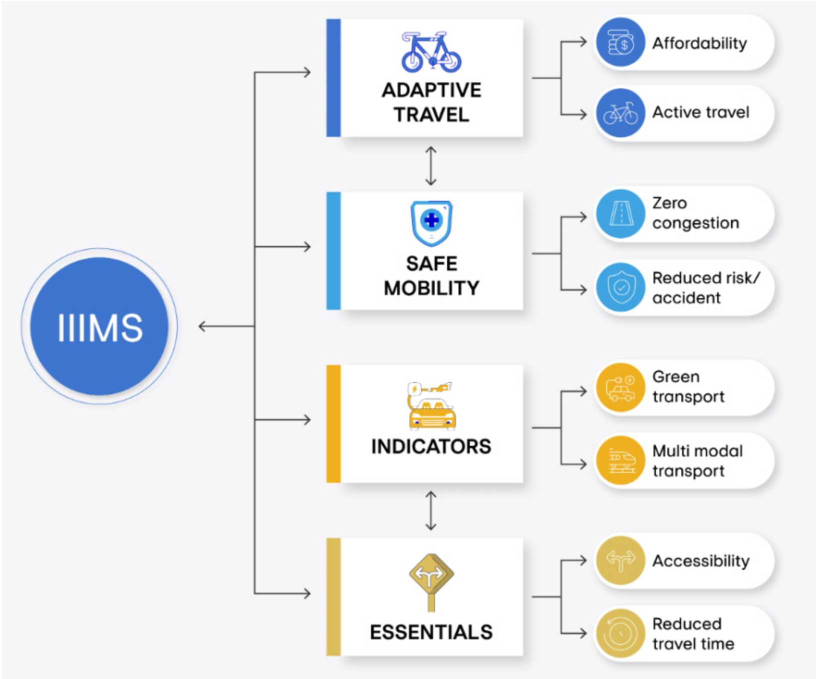

Figure 3: Inclusive intelligent transportation hypothesis framework

This study further makes use of the four factors to develop an inclusive intelligent infrastructure management system for CBD road network links in an urban-semi or urban area. Furthermore, this creates and opportunity towards proposing an operational LOS lane change modification to be implemented to improve the traffic flow and capacity of the East London, Oxford Street, and CBD. The layout from the (Figure 1) makes use of the IIMS hypothesis to improve flow and reduce congestion. This is shown in Figure 4.

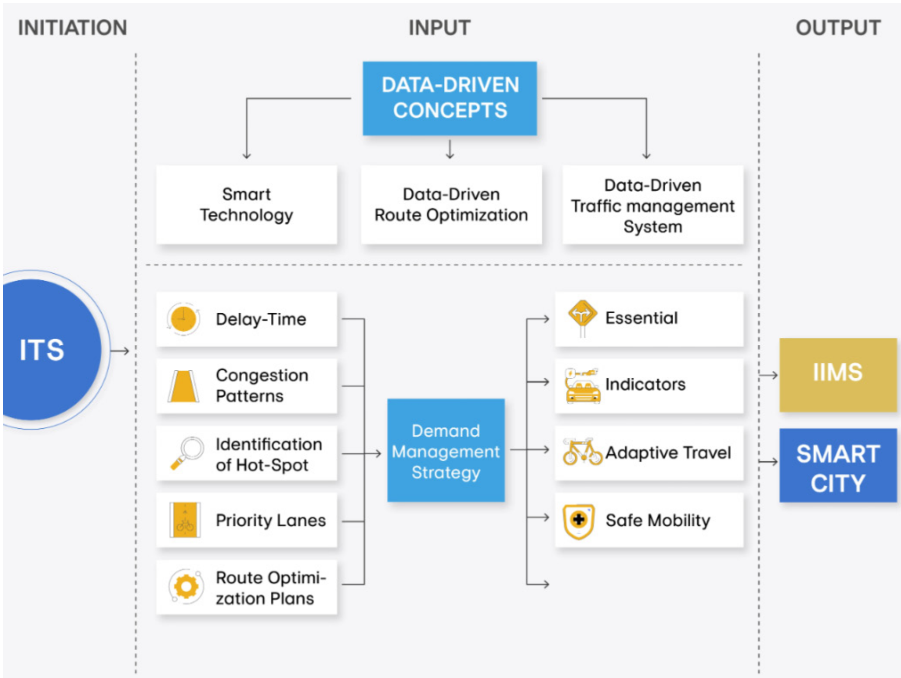

Figure 4: Inclusive Intelligent transportation system Model

Figure 4 considers enhancing competitiveness and efficiency of the East London CBD by proposing an optimized route with selective functionality adopting one-way and two-way lanes to improve efficiency and reduce congestion. This is provided in Table 1.

Table 1: Optimized route operation plan to improve efficiency along the East London CBD

Proposed Corridor Plan	Description
Purple	One Way Route East (Secondary Road)
Red	One Way Route West (Secondary Road)
Black	Two-way Route North and South (Fleet Street)
Green	One Way Route South (Station Street)
Yellow	One Way Route South (Oxford Street)
Beige	One way Route North (Cambridge Street)
Blue	Two-way route (Beaconfield Road)
White	One Way Route North (Buffalo Street)

3. CONCLUSION AND RECOMMENDATION

In conclusion, this study highlights the importance of inclusive intelligent transportation systems when they incorporate intelligent transportation system models such as data-driven traffic management systems. This further delves into facility management of infrastructure along the traffic route. Several other important models for ensuring inclusive infrastructure management will adopt data-driven concepts and smart technology systems. These various aspects drive the competitiveness of achieving safe mobility toward the efficiency and performance of transport infrastructure. The key measures to which competitiveness will be addressed along the CBD Oxford-street are optimum delay-time management within the CBD regarding essential travel, identification and remodelling of congestion patterns at the various intersections and corridors to accommodate increasing traffic growth from R72 and N2, identifying Hotspots (High collision or accident zones). Once the competitive measures are addressed and accounted for, the IIIMS model proposes the development of a dynamic traffic operation schedule, which can be cascaded into traffic signal operation schedules and the provision of priority lanes (BRT, Toll-lanes) to accommodate congestion and increase flow. This model is anticipated to improve competitiveness and efficiency of the road network infrastructure within the East London CBD.

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