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Empirical Review of Urban Traffic Challenges and Sustainable Solutions: A Case Study of Muscat, Oman

Khuloud Nasser Al Balushi[1], Sitesh Kumar Singh*[1], Rituraj Jain[2]

[1]*Department of Civil and Environmental Engineering, College of Engineering, National University of Science and Technology, Muscat, Oman, khuloudalbalushi@nu.edu.om, siteshsingh@nu.edu.om*
[2] *Department of Information Technology, Marwadi University, Rajkot, Gujarat, India, jainrituraj@yahoo.com*

**Correspondence: siteshsingh@nu.edu.om*

Abstract

This paper presents an empirical and bibliometric analysis of the issue of traffic in Muscat, Oman, combining statistics and world research trends. According to the empirical results, 15,195 traffic accidents and 1,086 deaths were recorded in Muscat between 2012 and 2022, with the root cause of road fatalities being overspeeding (54%). This has an impact of over 38 hours of congestion delay per driver annually, and its air pollution level of PM 2.5 is 48 µg/m³, far exceeds the WHO levels, which highlights severe environmental and health aspects. The study is methodologically descriptive and a trend analysis using secondary data from government and international sources. An analogous bibliometric was based on 3,799 articles indexed in Scopus and mapped via co-occurring keywords, thematic grouping, and author collaborations in VOSviewer. The factors used as inclusion criteria were peer-reviewed journal articles in the field of engineering that were written in English. The analysis compounds one of the gaps in the research spheres of the Gulf region that supports the novice nature of this muscat-focused paper. The conclusions also underline the necessity of infrastructure improvement, intelligent transport systems (ITS), transportation improvements, and behavioral changes. This review provides actionable policy recommendations and other research directions that should be undertaken, such as stakeholder views and long-term intervention evaluations. In the current study, I will lead researchers and policymakers to the specifics of data-driven, long-term urban mobility policies in Muscat.

Keywords: *traffic congestion, urbanization, public transportation, intelligent transportation systems, road infrastructure*
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I. INTRODUCTION

Urban areas worldwide encounter many transportation problems, such as traffic congestion, safety hazards, and environmental concerns [1]. The population is growing, cities are being urbanized, and they need better methods of transportation, which will trigger the demand for the transportation system to grow, which is usually greater than what the transportation system can handle. Therefore, one way to address this problem is to develop more efficient transportation systems or upgrade the existing systems [1]. Muscat, the capital of Oman, is a clear example of the problems faced by cities [2]. The city has been growing rapidly, and among the various trends, car ownership has been climbing, so that its major road network has experienced significant stress in recent years enlarging of urban zone. Major investments have been made in a number of sectors, including the real estate sector, which has made roadways heavily crowded, especially during rush hours, and the movement time has increased [3]. The recent increase in the number of vehicles owing to the expansion of residential areas, commercial complexes, and industrial parks is one of the major reasons for traffic congestion during peak hours and extended travel times [4]. Despite attempts by city officials to enhance the road network through development and junction improvement, Muscat still grapples with constant traffic issues [5]. Congestion is the biggest problem, especially in areas with high commercial activity and along key junctions, where bottlenecks can be seen. Congestion not only impacts daily travel but also productivity in general, where citizens spend long hours in traffic [6]. In addition, the city is beset by a high incidence of road accidents that are most often caused by overspending, poor road discipline, and poor compliance with traffic regulations. All these safety issues not only pose risks to drivers but also put pressure on emergency services and the health system [7].

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Table I summarizes the main transportation problems of Muscat and Oman, and their associated impacts, together with the mitigation steps. Muscat, the capital city of Oman, exemplifies urban environments in which population growth and increasing vehicle ownership have outpaced transportation infrastructure. As of 2025, the vehicle ownership rate in Muscat is 335 per 1,000 people, reflecting a growing reliance on private transport amid limited public options [8]. Between 2012 and 2022, Muscat recorded over 15,195 traffic accidents and 1,086 fatalities, making it the most accident-prone region in the country [9]. Studies also link rapid urban expansion and topographic constraints to worsening congestion along major corridors, such as Sultan Qaboos Street. Air pollution from traffic emissions has pushed the annual $PM_{2.5}$ levels to 48 µg/m³, further aggravating public health concerns [10]. These statistics and trends underscore the urgency for comprehensive transport planning tailored to Muscat's unique geographic, demographic, and infrastructural contexts.

TABLE I. TRANSPORTATION CHALLENGES

Challenges	Impacts	Efforts	References
Traffic Congestion	Longer travel times, reduced productivity	Road expansions, intersection improvements	[2-5]
Road Safety	Accident risks, strain on emergency services	Enhanced traffic regulations enforcement	[6, 7]
Environmental Impact	Health risks, air and noise pollution	Emission reduction policies, noise control	[11, 12]

In addition, vehicular traffic development has increased air pollution in Muscat. Vehicle exhaust smoke from cars, trucks, and buses emits gases such as carbon monoxide, nitrogen oxides, and particulate matter into the air, lowering the quality of air and endangering the health of inhabitants [11]. Traffic noise pollution is also an issue that lowers the quality of life in highly urbanized areas. These connected problems are central to Muscat's sustainable development because they are directly related to the city's environmental sustainability, public health, and general livability. Addressing successful solutions for mitigating traffic congestion, enhancing road safety, and minimizing ecological footprints will be vital for achieving the well-being of people in Muscat and maintaining urban resilience in the long term [11, 12].

Study Location: Muscat, the capital of Oman, is characterized by its stunning geographical features, including a picturesque coastline along the Gulf of Oman and the imposing Al Hajar Mountains that frame the city. This unique landscape significantly influences traffic patterns, as main roads often navigate mountainous terrain, creating scenic yet sometimes congested routes, particularly during peak hours. Sultan Qaboos Street serves as a vital artery, connecting key areas like the international airport, commercial districts, and residential neighborhoods. Although traffic is generally moderate, urban expansion and a growing population have led to increased congestion, prompting initiatives to enhance public transportation, including plans for a metro system. The city's blend of modern infrastructure and traditional architecture, alongside green spaces such as Qurum Natural Park, adds to its charm, making Muscat a vibrant hub of culture and commerce [13]. Figure 1 shows the location of Muscat on the Map.

Fig. 1. Location of Muscat on the Map[14].

A. Problem Statement

The traffic situation in Muscat has reached a critical point characterized by measurable indicators. For instance, "severe congestion" refers to the annual average congestion delay per driver, which is reported to exceed 38 hours in urban Muscat, especially during peak travel periods. Similarly, the "high rate of road accidents" can be quantified by 1,086 fatalities and 15,195 traffic accidents recorded between 2012 and 2022, as reported by the Royal Oman Police. Overspeeding alone accounts for more than 54% of traffic-related deaths, indicating severe public safety concerns [9]. These data-driven indicators provide a clear basis for assessing the magnitude of a problem and the urgency of implementing evidence-based interventions..

B. Objectives of the Review

This review aims to:

- Analysis of the root causes of Muscat traffic problems.
- Evaluate the effectiveness of various solutions, including infrastructure improvements and policy measures.
- Provide actionable recommendations to enhance traffic flow and safety in Muscat, focusing on both short-term and long-term solutions.

C. Scope and Methodology

This study employs a mixed-methods approach that integrates empirical data analysis with a bibliometric review to provide a comprehensive understanding of traffic-related challenges in Muscat. The empirical component is based on secondary data obtained from reliable official sources, including the Royal Oman Police, Muscat Municipality, and Ministry of Transport and Communications. The datasets analyzed encompass traffic volume counts from major roads, road accident records spanning from 2012 to 2022, and air pollution indices specifically $PM_{2.5}$ levels, sourced from the World Health Organization (WHO) and IQAir [10, 15]. Descriptive statistical techniques and trend line analyses were used to uncover patterns in congestion levels, accident occurrences, and environmental indicators. These findings were further supported by graphical visualizations developed using Microsoft Excel and Python-based tools to ensure clarity and to facilitate interpretation.

In addition to the empirical analysis, a bibliometric review was conducted using the Scopus database to explore the global research landscape of traffic congestion and urban mobility. The

search strategy involved the combination of two keyword clusters applied within the TITLE-ABS-KEY fields. The first cluster focused on traffic issues, including terms such as "traffic congestion," "road traffic," "urban traffic," "traffic flow," "traffic delay," "traffic safety," "road safety," "traffic accident," and "crash hotspots." The second cluster addressed mobility and infrastructure planning themes with terms such as "urban transportation," "urban mobility," "transportation planning," "public transportation," "transport policy," "city traffic management," "transport infrastructure," and "sustainable mobility." The search was restricted to English-language journal articles published between 1972 and 2025, specifically in the engineering subject area.

This process returned 13,329 documents, of which 7,980 were engineering-related studies and 4,821 were peer-reviewed journal articles. Further filtering based on keyword relevance resulted in a refined dataset of 4,285 articles that prominently featured high-frequency terms, such as Traffic Management, Urban Transport, Intelligent Transportation Systems, Public Transport, and Optimization. After applying the inclusion criteria that focused on language and publication type, 3,799 articles were selected for the final analysis. The VOSviewer software was used to generate co-occurrence networks and thematic clusters, enabling a structured synthesis of research trends and priority areas within the field. This bibliometric insight complements empirical findings and situates Muscat's traffic challenges within the broader international discourse on urban mobility and transportation planning.

D. Bibliometric Analysis of Global Research Trends in Urban Traffic and Transportation

To further contextualize Muscat's traffic issues within global research trends, a bibliometric analysis was conducted using VOSviewer- and Scopus-indexed data from 1972 to 2025.

To construct the co-authorship network, the bibliometric analysis used VOSviewer, which is a dedicated software tool for creating and visualizing bibliometric maps. The parameters applied in the layout configuration were random starts = 1, maximum iterations = 1000, initial step size = 1.00, step size reduction = 0.75, and convergence threshold = 0.001, with the random seed set to 0. These settings ensured a stable layout that emphasized the natural clustering of co-authorship link strengths.

The analysis revealed 15 distinct author clusters representing prominent research collaborations in the domain of traffic and transportation systems. For instance, Cluster 1 included 12 high-contributing authors such as Carlos F. Daganzo, Nikolas Geroliminis, and Vikash V. Gayah researchers have widely recognized their foundational work in traffic flow theory and urban traffic modeling. Cluster 2, comprising 11 authors like Jorge A. Laval and Monica Menendez, reflected research centered on highway capacity and signal optimization. The number of items (authors) per cluster ranged from 3 to 12, with a total of 102 unique co-authors identified in the final network.

While the clustering algorithm in VOSviewer uses co-authorship link strength and total link strength (based on the frequency of co-authored publications), we did not apply citation-based filtering (e.g., h-index and citation counts) for this analysis. The resulting clusters illustrate the intellectual structure and key research networks that shape the global discourse on traffic congestion, transport policies, and intelligent urban mobility.

Figure 2 illustrates co-authorship networks, revealing prolific researchers with minimal GCC-based representations. The co-authorship network highlighted the most collaborative and influential researchers in the domains of traffic and urban transportation. Authors such as Yang Hai, Abdel-Aty Mohamed, Meng Qiang, and Leclercq Ludovic are seen at the core of the network with dense interlinkages, indicating their centrality in global traffic research. However, there is a notable absence of Middle Eastern or GCC-based researchers in the central clusters, suggesting a regional research gap, especially in contexts such as Oman.

Figure 3 categorizes the key thematic areas in transportation, such as ITS, environmental sustainability, and road safety, all of which align with the focus areas in Muscat. The keyword co-occurrence map visualizes thematic clusters in transportation research. The green cluster focuses on intelligent transportation systems and predictive modeling (keywords: deep learning, traffic signals, LSTM), the red cluster on policy and sustainability (road pricing, congestion, public policy), and the purple cluster on road safety (accidents, prevention, human). This thematic segmentation affirms that our study aligns with three major global concerns congestion, sustainability, and safety and that Muscat's traffic issues reflect these priorities, thus supporting the framework of our research.

Figure 4 presents publication trends across top-tier journals, underscoring the expanding global focus on intelligent transportation systems (ITS), congestion management, and sustainability. Notably, journals such as Transportation Research Part C, IEEE Transactions on Intelligent Transportation Systems, and Transportation Research Part D have witnessed a marked increase in article volume since 2015. This surge suggests a growing scholarly emphasis on technology-driven and environmentally conscious urban mobility solutions. The fact that this acceleration is most visible in journals published outside the Middle East also underscores the need for regionally grounded studies such as the present work focused on Muscat. These trends reinforce the relevance and timeliness of this study's emphasis on ITS, emission control, and congestion management in rapidly urbanizing environments.

An evaluation of author productivity and publication trends based on the Scopus-indexed dataset highlights key contributors and evolving research interests in the fields of traffic congestion and urban transportation. As shown in Figure 5, Yang, H. leads in productivity with 23 journal publications, followed by Leclercq, L. (16), Abdel-Aty, M. (15), and Wong, S.C. (15). Other influential authors include Chen, Y., Gao, Z. and Geroliminis, N., each contributing more than a dozen publications. These counts were obtained directly from Scopus and reflected the total number of domain-relevant journal articles published between 1972 and 2025. While citation-based metrics such as the h-index were not applied here, publication frequency served as a reliable proxy for scholarly influence and intellectual leadership in the field.

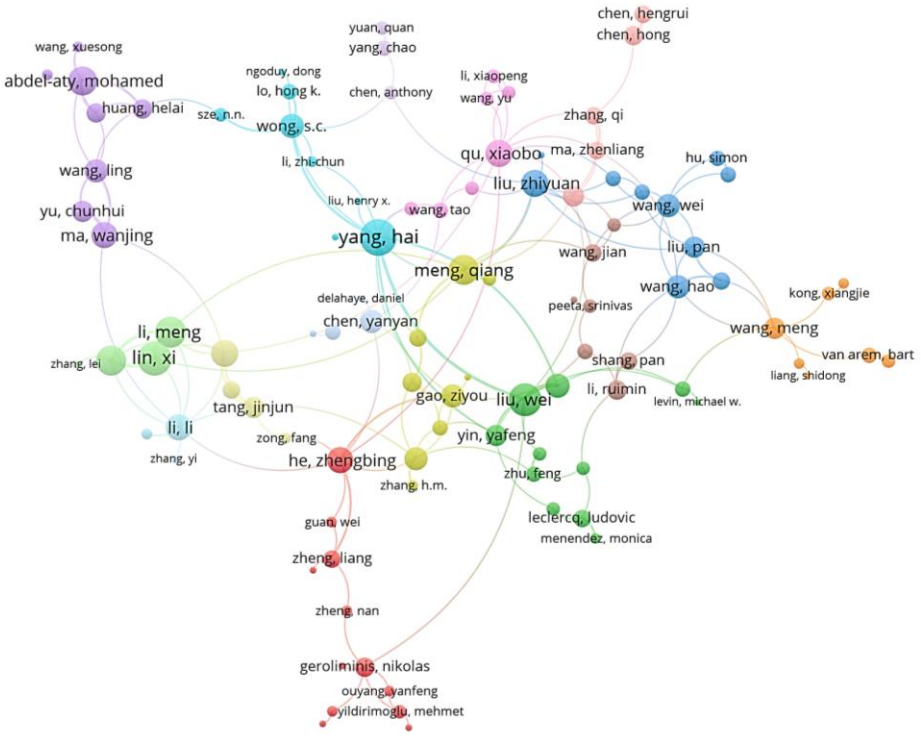


Fig 2. Co-authorship network revealing research clusters and leading contributors in traffic and ITS-related research. Source. Analysis Using Vosviewer,2025.

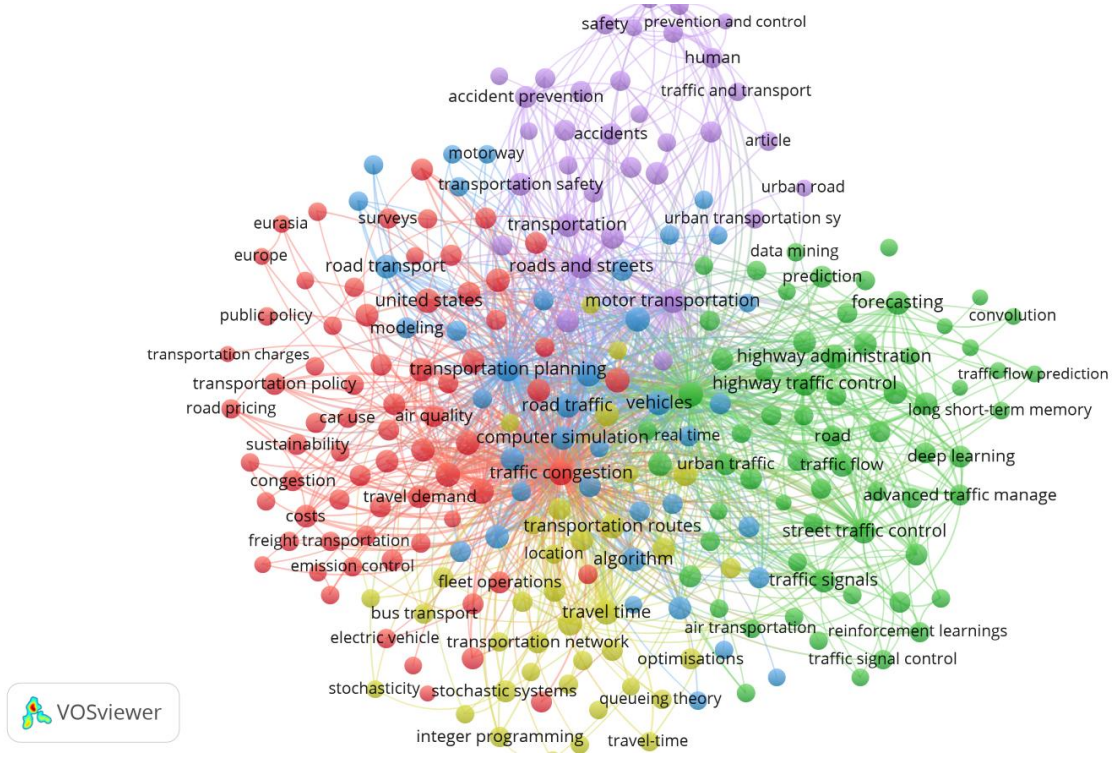


Fig 3. Keyword co-occurrence map highlighting key research themes such as congestion, public policy, sustainability, and intelligent systems. Source. Analysis Using Vosviewer,2025.

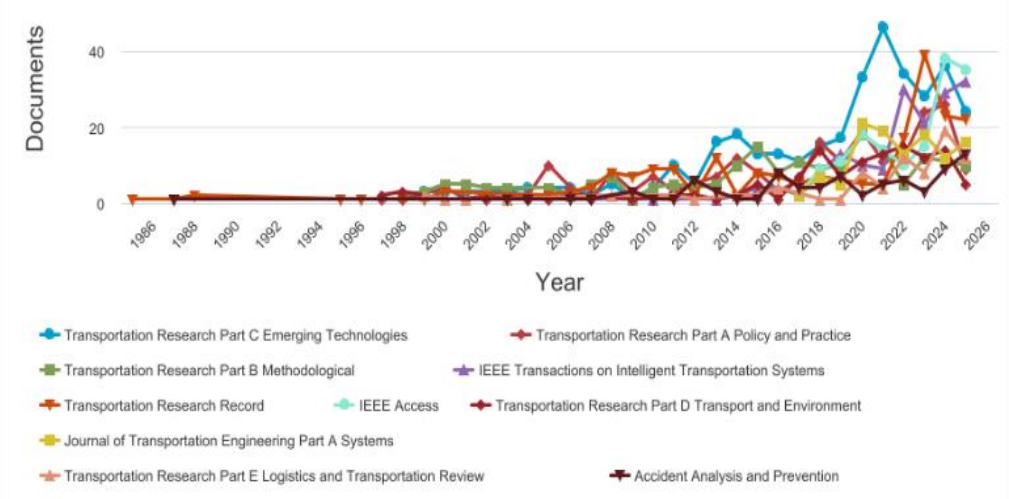


Fig 4. Annual publication trends across top journals in urban transportation and ITS. Source: Scopus database (Elsevier, 2025).

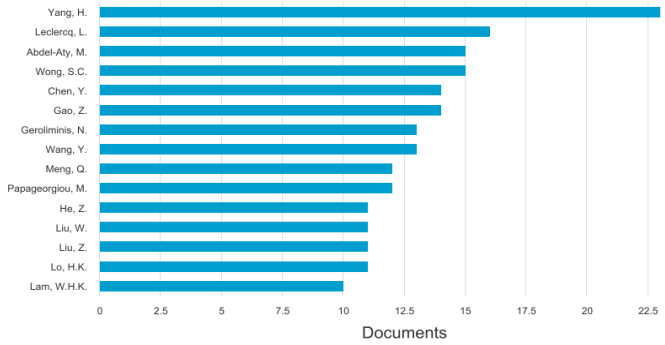


Fig 5. Most productive authors globally contributing to traffic and transport research. Source: Scopus database (Elsevier, 2025).

Researchers such as Yang H., Leclercq L., Abdel-Aty M., and Wong S.C. have made prolific contributions to traffic modeling, ITS, and urban mobility as highlighted in table II. This citation landscape demonstrates that the domain is dominated by authors from East Asia, Europe, and the U.S., with a minimal Gulf region presence. This underlines the gap our study helps bridge by providing localized empirical insights from Oman, which are potentially useful for future regional studies and citations.

To assess the temporal publication trends, we compiled year-wise document counts from 1972 to 2025, as shown in Table III and Figure 6. The data reveal a substantial increase in research output over the last two decades, with a dramatic rise beginning around 2010 and peaking in 2024, with 516 publications. The number of papers published annually increased from less than 10 per year before 1990 to over 100 per year after 2015. Notably, the five-year period from 2021 to 2025 alone accounts for over 1,975 documents, indicating a heightened academic and policy interest in urban traffic and transportation challenges in recent years.

The bibliometric findings confirm a growing international emphasis on intelligent transport, sustainability, and safety, areas that directly align with Muscat's challenges. These insights help ground our empirical review into broader academic discourse, reinforcing the relevance and novelty of the present study.

TABLE II. LEADING GLOBAL AUTHORS BY PUBLICATION VOLUME IN TRAFFIC AND TRANSPORT STUDIES

Author Name	Count
Yang, H.	23
Leclercq, L.	16
Abdel-Aty, M.	15
Wong, S.C.	15
Chen, Y.	14
Gao, Z.	14
Geroliminis, N.	13
Wang, Y.	13
Meng, Q.	12
Papageorgiou, M.	12
He, Z.	11
Liu, W.	11
Liu, Z.	11
Lo, H.K.	11
Lam, W.H.K.	10

TABLE III. YEAR-WISE DOCUMENT COUNTS FROM 1972 TO 2025

YEAR	Count of Papers	YEAR	Count of Papers	YEAR	Count of Papers
2025	465	2010	65	1995	3
2024	516	2009	37	1994	1
2023	389	2008	56	1993	3
2022	330	2007	43	1992	4
2021	295	2006	37	1991	2
2020	278	2005	37	1990	5
2019	180	2004	25	1989	6
2018	194	2003	34	1988	3
2017	124	2002	20	1987	6
2016	110	2001	25	1985	2
2015	124	2000	23	1984	1
2014	92	1999	23	1981	1
2013	90	1998	15	1974	2
2012	65	1997	5	1972	1
2011	56	1996	6		

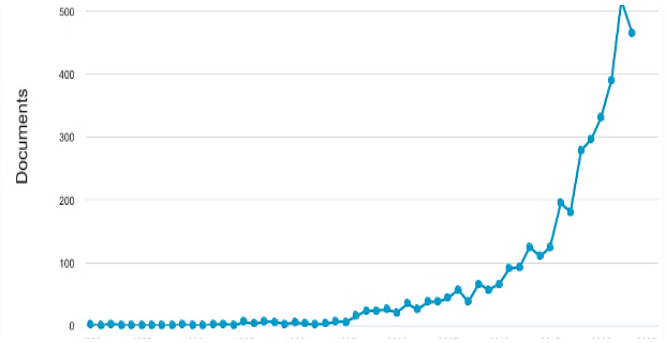


Fig 6. Growth in research outputs on urban transportation since 1972, emphasizing post-2015 surge. Source: Scopus database (Elsevier, 2025).

II. Overview of Traffic Problems in Muscat

A. Traffic Congestion

Muscat is affected by severe traffic jams, especially in city centers and on major roads, such as Sultan Qaboos Street and Al Mouj Street. Traffic studies indicate that traffic congestion has progressively risen annually, with traffic speeds averaging below 22 miles/h during peak hours in some locations [16]. This traffic congestion translates to even longer travel durations, thus negatively impacting daily activities of citizens and workforce productivity as a whole [13]. Commuting times during peak hours are 30-40% longer, indicating lost precious time that can otherwise be used in economic activities. Moreover, the additional time spent in traffic increases fuel consumption levels, resulting in further financial burden on commuters and businesses in terms of transport costs. This situation highlights the urgent need for efficient congestion mitigation strategies to facilitate smoother traffic conditions in Muscat [14].

B. Traffic Accidents and Safety Concerns

High traffic accident rates within Muscat have escalated into a significant public safety concern [14]. According to national traffic reports, Oman records a road death rate of 12.63 per 100,000 people, underscoring the gravity of the issue in both urban and peri-urban areas [17]. These accidents frequently result in severe injuries and fatalities, often attributed to speeding, driver distraction, and nonadherence to traffic regulations. In Muscat, accident hotspots, such as the Qurum area and Ghubra roundabout, have emerged as high-risk zones owing to complex road geometries, dense traffic flow, and limited visibility [18]. This situation is further compounded by inadequate road signage, insufficient pedestrian infrastructure, and inconsistent enforcement of traffic laws. Addressing these safety gaps is essential, not only to reduce the frequency and severity of accidents, but also to improve overall roadway conditions and foster a culture of responsible driving behavior [19].

C. Environmental Impact

Traffic issues in Muscat also have significant environmental implications, primarily through increased air and noise pollution. The city's reliance on private vehicles has led to higher emissions of pollutants, such as carbon monoxide (CO), nitrogen oxides (NOx), and particulate matter (PM), contributing to a noticeable decline in air quality, especially in densely populated urban areas. Prolonged exposure to these pollutants poses health risks to residents, particularly to those with respiratory conditions. In addition to air pollution, traffic congestion contributes to elevated noise levels, which affects the quality of life of those living near busy roads. Ultimately, traffic problems affect human health [20]. The continuous flow of vehicles and frequent traffic jams generate noise that can disrupt daily life. As Muscat's vehicle fleet continues to grow, these environmental challenges underscore the importance of exploring sustainable transportation options to reduce the ecological footprint of urban mobility and promote healthier living environments [21]. Table IV summarizes the key traffic challenges in Muscat congestion, safety issues, and environmental impacts along with their contributing factors and potential solutions, emphasizing the need for improved infrastructure, enforcement, and sustainable transportation.

Table IV. Overview Of Traffic Challenges And Solutions In Muscat

Category	Description	Implications	Solutions	Ref.
Traffic Congestion	Slow speeds	Longer travel, high fuel use, low productivity	Traffic management, public transport	[13, 14]
Traffic Accidents & Safety	High accident rates, poor compliance	Fatalities, healthcare strain	Road safety, better signage, law enforcement	[14, 18, 19]
Environmental Impact	Air/noise pollution, high vehicle emissions	Health risks, poor life quality	Sustainable transport, emission cuts	[20, 21]

III. Empirical Analysis of the Causes of Traffic Problems

A. Urbanization and Population Growth

The rapid urbanization of Muscat has significantly impacted its transportation infrastructure, contributing to increased traffic congestion. Various studies have highlighted how a city's expanding population has led to a surge in housing developments, commercial centers, and other urban infrastructure, all of which place greater demand on the road network [22]. Data from urban planning reports and census statistics reveal a strong correlation between population growth and the rise in vehicle ownership, as more residents rely on personal vehicles for mobility [23]. As the population of the city has expanded, the number of registered cars has expanded, causing more traffic to be circulated on the road, which is not meant to hold these volumes of traffic. This population growth has surpassed the construction of new infrastructure, resulting in overcrowded roads and high rates of congestion in most areas of Muscat. Consistent with the global trends highlighted in the bibliometric analysis, congestion and infrastructure limitations remain primary concerns in Muscat, mirroring the dominant research themes in the urban traffic literature.

B. Road Infrastructure and Design Limitations

Muscat also has traffic challenges owing to the design and capacity of the road network. Empirical studies have found a number of design constraints, such as narrow roads, few lanes, and mischievous intersections, that restrict smooth traffic circulation. According to studies on the capacity of current road networks, many of the major roads in Muscat actually function to their best in the region or even beyond, especially when traffic is at its peak [24]. This leads to several bottlenecks and congestion. Studies have also pointed out the challenges posed by inadequate infrastructure, such as the absence of well-designed alternative routes and lack of dedicated lanes for buses and emergency vehicles. These limitations prevent effective traffic management, leading to prolonged congestion and delays, particularly in areas with high commuter density [25].

C. Public Transportation Challenges

Muscat's public transit services, which consist of buses and a limited number of taxis, encounter multiple obstacles that prevent them from competing with private automobile usage. Public transit reviews show that bus and taxi services in the city experience problems, including insufficient schedule frequency and narrow route availability along with delayed wait times, which keep people from using public transportation[26]. The adoption rates of public transport remain low, as evidence indicates that the majority of people continue to use private cars instead of public transportation. Private automobiles remain the preferred mode of travel because they offer hassle-free usage combined with comfortable experiences and there is no proper extensive public transit system in operation. Surveys and studies indicate that improving the frequency, coverage, and reliability of public transportation could help shift commuter behavior and alleviate some of the traffic burden on Muscat's roads[27].

Figure 7 shows that Muscat's public transit system, consisting mainly of buses and taxis, faces several operational challenges that hinder its effectiveness and limit its competitiveness against private car usage.

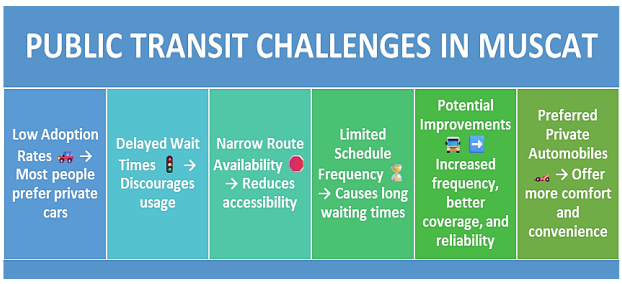


Fig 7. Public Transit Challenges and Potential Improvements in Muscat

D. Driver Behavior and Traffic Regulation Compliance

The driver's attitude plays an essential role in shaping the current traffic environment in Muscat. The scientific literature reveals that speeding along with improper lane usage and traffic signal violation are major elements that worsen traffic congestion and generate crashes. According to traffic data analysis, the city experiences high traffic accidents and traffic disruptions because drivers frequently exhibit these risky behaviors in busy traffic areas. The evaluation of Muscat's traffic enforcement regulations shows that some motorists do not follow the regulations seriously. The unfollowing regulations create difficulties in preventing traffic violations, thus worsening the existing problems. Better enforcement and education about road safety will help fix behavioral traffic issues while enhancing citywide traffic organization in Muscat [28]. Traffic problems in Muscat result from a multifaceted relationship between built-up areas, infrastructure planning, transportation decentralization, and driver behavior problems. The empirical assessment of these causes remains crucial because it enables appropriate solution development that suits Muscat's particular characteristics[29]. The different measures shown in Figure 8 address the traffic problems of the city.

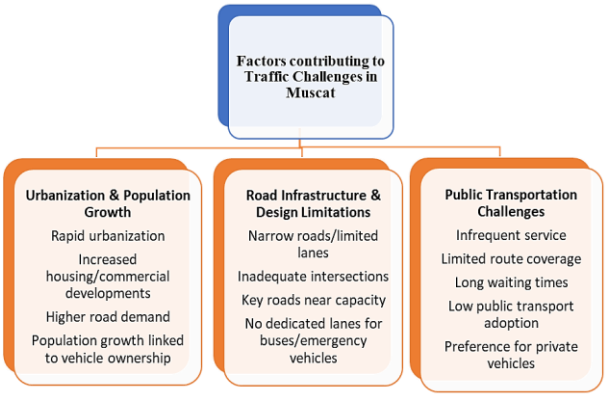


Fig 8. Factors contributing to Traffic Problems in Muscat

E. Empirical Evidence from National Accident Trends (2012–2022)

To reinforce the empirical rigor of this study, accident data from Oman's official national road traffic statistics (2012–2022) were analyzed [9]. This dataset spans all 11 governorates and includes detailed yearly records on fatalities, injuries, accident types, and user demographics (pedestrians, passengers, and drivers, categorized by gender).

As shown in Figure 9, both total road traffic accidents and deaths in Oman significantly declined from 2012 to 2020, demonstrating a broad national effort to improve road safety. However, the slight uptick in both metrics in 2021 and 2022 indicates the ongoing nature of traffic safety challenges, particularly in urban hubs, such as Muscat.

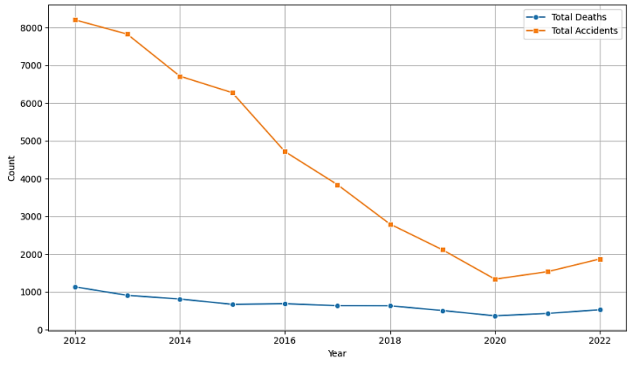
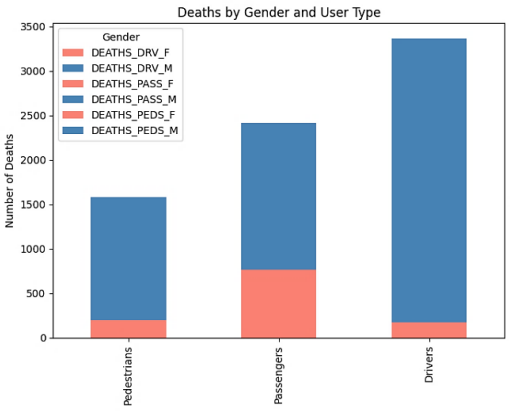


Fig 9. Public Transit Challenges and Potential Improvements in Muscat.

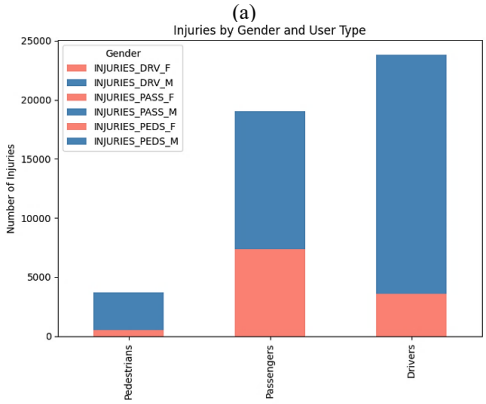
Figure 10 disaggregates deaths and injuries according to user type and sex. The data revealed that male drivers were the most

affected group, followed by male passengers and pedestrians. These insights highlight the need for targeted enforcement and public awareness campaigns tailored to high-risk demographic groups.

In Figure 11, the accident types are shown in proportion to their contribution to the total accident volume. Collisions between vehicles accounted for nearly 45%, indicating an urgent need for improvements in road layout, signal timing, and lane discipline. Fixed object collisions (23.3%) and run overs (15.1%) further emphasize infrastructure blind spots and pedestrian vulnerability.



(a)



(b)

Fig 10. Gender-wise Distribution of (a) Deaths and (b) Injuries

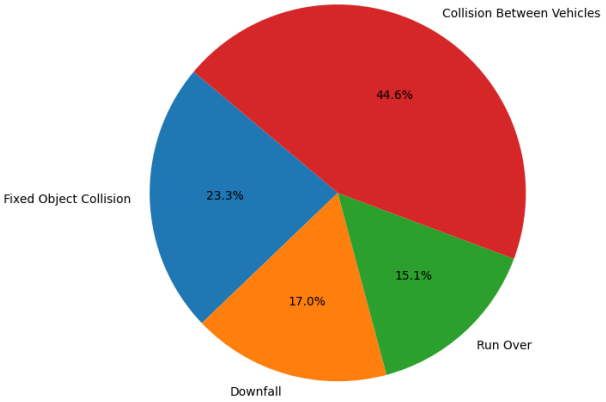


Fig 11. Accident Types and Their Contribution to Total Accidents

Figure 12 illustrates the temporal trend of traffic-related fatalities among Omani citizens and expatriates from 2012 to 2022. It is evident that Omani citizens consistently represented a higher proportion of traffic deaths than expatriates across all observed years. This disparity can be attributed to a range of socioeconomic and behavioral factors, including increased vehicle ownership among Omanis, greater reliance on private vehicles, and more frequent travel across diverse road networks within the country.

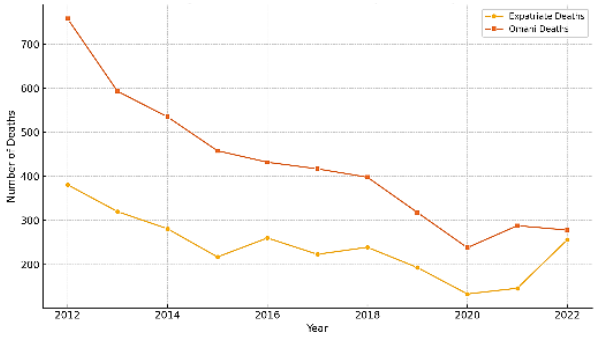


Fig 12. Year-wise Deaths by Nationality (Omani vs Expatriate)

Figure 13 presents the proportional breakdown of traffic fatalities by their underlying causes aggregated across an 11-year span. Notably, overspeeding alone accounted for over half (54%) of the total deaths, making it the most critical factor contributing to fatal road accidents in Oman. Other prominent causes include driver negligence, incorrect overtaking, and reckless driving, all of which reflect behavioral patterns rather than infrastructural issues.

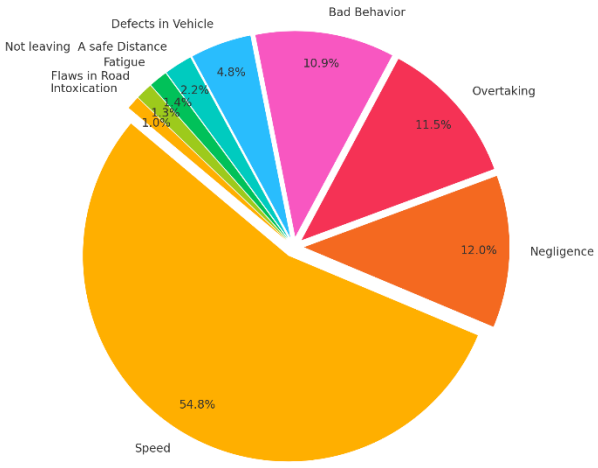


Fig 13. Distribution of Deaths by Accident Cause (2012–2022)

The visualization reveals the pressing need to shift traffic management strategies toward behavioral interventions. It advocates intensified speed enforcement mechanisms such as automated speed cameras and dynamic traffic monitoring systems. Furthermore, the substantial shares held by driver-related errors suggest a long-term investment in driver education, licensing reform, and digital driving aids, such as lane assist and collision alerts.

Figure 14 shows the annual fatalities attributed specifically to overspeeding. While the 2012–2014 period shows alarmingly high numbers, there is a visible downward trend after 2015, which may reflect the initial impact of enhanced road safety campaigns and stricter speed regulations. However, the fact that overspeeding continues to claim lives in significant numbers, even in recent years, highlights that the problem is far from resolved.

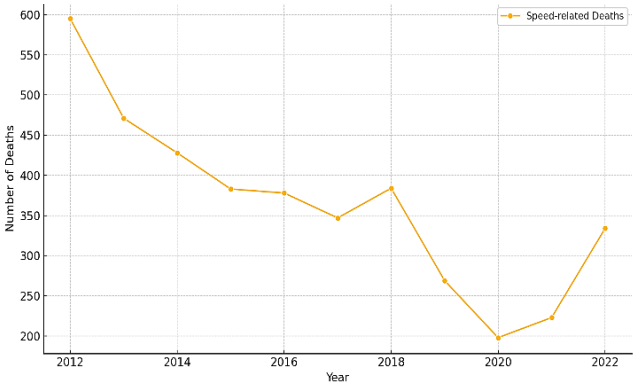


FIG 14. TREND OF OVERSPEEDING-RELATED DEATHS (2012–2022)

This figure offers an opportunity to assess the effectiveness of past interventions, while justifying the urgency for further measures. The sustained presence of overspeeding deaths despite known countermeasures suggests that enforcement alone may not be sufficient. A multipronged strategy that includes driver awareness, vehicle safety enhancements, and road design improvements is essential to further reduce these fatalities. It also speaks to the emotional and societal toll of high-speed driving not merely a policy issue, but a recurring tragedy that continues to impact families and communities across the nation. This trend underscores the need for targeted road safety interventions that are tailored not only to generic driving behavior but also to the demographic realities of road users. For example, public awareness campaigns, license training programs, and enforcement strategies could be designed more effectively by considering the specific risk exposures of different national groups.

Finally, Table V presents the regional breakdown of accident severity. Muscat reported the highest number of accidents and fatalities, accounting for over one-third of the nation's traffic incidents. Other high-burden regions include Al Batinah South and Ad Dakhliyah, which highlight areas that require immediate infrastructural and policy attention.

This empirical evidence directly addresses previous gaps in the literature by grounding the study's analysis in verifiable, location-specific accident statistics. This enables a more nuanced understanding of the traffic crisis in Muscat and guides the formulation of targeted solutions in the following section.

TABLE V. GOVERNORATE-WISE SUMMARY OF FATALITIES AND ACCIDENT TYPES [9]

GOVERNORATE	DEATHS	ACCIDENTS	FIXED OBJECT	DOWNFALL	RUN OVER	COLLISION
MUSCAT	1086	15,195	3751	1337	2019	8088
AL BATINAH SOUTH	827	6977	1967	962	993	3055
AD DAKHLIYAH	971	5881	1472	1174	736	2499
ASH SHARQIYAH SOUTH	458	4045	851	875	814	1505
ADH DHAHIRAH	540	3530	818	918	425	1369
ASH SHARQIYAH NORTH	626	3529	680	886	542	1421
AL BATINAH NORTH	1273	2912	537	461	800	1114
DOFAR	764	2362	370	568	505	919
AL BURAYMI	223	1413	342	320	159	592
AL WUSTA	555	907	68	469	119	253
MUSANDAM	37	528	140	83	43	262

IV. GLOBAL BENCHMARKS: A QUANTITATIVE COMPARISON WITH PEER CITIES

To contextualize Muscat's traffic and environmental challenges, a structured comparison was conducted with five peer cities, Doha, Abu Dhabi, London, and Singapore, each recognized for their distinctive approaches to urban mobility and transport innovation. These cities were selected to represent a spectrum of regional counterparts and global leaders in sustainable urban transportation planning.

Table VI presents a data-driven comparison using a set of quantitative and internationally recognized indicators. Metrics such as average annual congestion delay per driver, road traffic death rates, $PM_{2.5}$ air pollution levels, and vehicle ownership per capita were extracted from trusted sources including the TomTom Traffic Index, INRIX Global Traffic Scorecard, IQAir, and WHO Global Road Safety Reports.

This cross-city analysis offered several compelling insights.

- Road safety has emerged as a critical area of concern for Muscat, which records 12.6 road deaths per 100,000 people, notably higher than those reported by London (2.81) and Singapore (1.69). This disparity underscores systemic

issues related to traffic law enforcement, driver behavior, and emergency response efficiency.

- In terms of air quality, annual $PM_{2.5}$ concentration of 48 µg/m³ is alarmingly above the WHO-recommended safe limit of 10 µg/m³, and more than double the levels recorded in London and Singapore. This pollution burden is likely tied to vehicle emissions and a city's limited reliance on public transit.
- Although Muscat's vehicle ownership rate (335 per 1,000 people) is lower than that in Doha and London, the absence of a robust public transport network forces greater car dependence. By contrast, cities such as Singapore and London have developed high-capacity multimodal transit systems that enhance both mobility and environmental sustainability.

TABLE VI. COMPARATIVE URBAN MOBILITY AND ENVIRONMENTAL INDICATORS

Metric	Oman	Qatar	Arab Emirates	London	Singapore	Reference
Average Annual Congestion Delay (hrs)	15 (Mascut)	34 (Doha)	38 (Abu Dabhi)	113	63	[16]
Impact Rank	772	217	194	5	206	[16]
Road Deaths per 100k Population	12.63	8.79	11.25	2.81	1.69	[10]
Annual Avg $PM_{2.5}$ Concentration (µg/m³)	48 µg/m³ (Muscat)	140 µg/m³	142 µg/m³	20 µg/m³	22 µg/m³	[17]
Vehicle Ownership per 1,000 people	335	591	354	560	146	[8]
Road traffic death rate (per 100,000 population) - 2021	11	7.3	5.9	2.4	1.9	[15]

Through this comparative lens, Muscat's urban transport profile reflects significant room for policy and infrastructure improvement. The integration of intelligent transport systems (ITS), investment in mass transit, and rigorous enforcement of road safety measures are evident pathways to align with international benchmarks.

By embedding this quantitative and evidence-based comparison into the analysis, this study not only strengthens its empirical foundation, but also offers actionable insights for policymakers. These findings advocate tailored, data-informed strategies that can help Muscat progress toward safer, cleaner, and more efficient urban mobility.

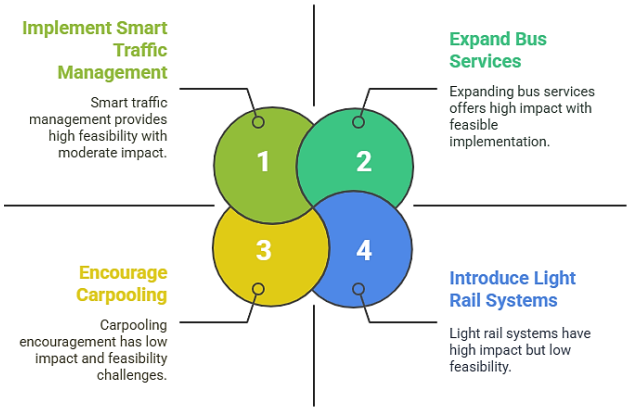


Fig 15. Infrastructure Development and Traffic Congestion Solutions in Muscat

V. EMPIRICAL REVIEW OF SOLUTIONS TO TRAFFIC PROBLEMS IN MUSCAT

A. Infrastructure Development

The development of infrastructure is a fundamental solution for resolving traffic congestion problems in Muscat. The execution of new highways, together with bypasses and interchanges, works as part of recent road expansion projects to enhance traffic flow and minimize traffic congestion [30]. Statistical evidence shows that the implementation of these projects has achieved different degrees of success in relieving traffic congestion. Since the Muscat Expressway construction, motorists experience shorter travel durations in formerly congested regions. Research supports that smart road expansion strategies create better city network connections, improve driver navigation, and reduce high-traffic congestion [31]. The success of these infrastructure projects requires strategic planning along with existing transportation systems to maintain permanent improvements in traffic conditions. Figure 15 highlights the key infrastructure strategies, new highways, bypasses, interchanges, strategic planning, and statistical evidence aimed at reducing traffic congestion, improving travel efficiency, and ensuring sustainable urban mobility in Muscat.

B. Intelligent Transportation Systems (ITS)

The city of Muscat has recognized Intelligent Transportation Systems (ITS) as a solution for improving its traffic management system. Applications including traffic signal optimization with real-time traffic monitoring and GPS-based navigation systems have been implemented to improve traffic management operations. Numerous studies have shown that Muscat has improved traffic management performance through ITS technologies, which shortens delays at intersections[32]. Through traffic signal optimization, the system adjusts the timing according to the current traffic conditions, thus reducing peak traffic congestion. Through the combination of ITS solutions with mobile applications, drivers receive current traffic information that helps them to choose better routes. Research-based evidence demonstrates that ITS implementation produces controlled traffic movement together with shorter commute times, which results in increased road safety [33].

C. Public Transportation Improvements

The reduction in Muscat traffic congestion depends significantly on upgrading public transportation services. The current empirical investigations concentrate on new bus routes, ride-sharing services, and possible rail transit system

implementations. Research data on public transportation indicates that this type of development has a significant effect on lowering the need for private vehicles[34]. Underdeveloped bus route development in underserved locations stimulated residents' use of public transportation, thus giving residents a choice over driving. New ride-sharing services engage more commuters because they provide practical transportation solutions that help reduce road traffic congestion. The development of light rail transit systems is expected to become a transformative solution that will cause significant changes in transportation patterns within Muscat[35]. Studies show that combining public transit systems leads people to select public transportation instead of their own cars, which helps reduce traffic congestion.

D. Policy Interventions and Regulation

Sound policy interventions are required to solve traffic issues in Muscat. A combination of different programs, including congestion pricing and parking controls, and various incentives directed at carpooling can change the behavior of commuters[36]. Experimental data indicate that congestion pricing is a viable method that can deter driving during rush hours with the aim of switching to the use of mass transport. Moreover, more serious parking policies may also limit the number of vehicles in the streets because the available parking spaces will be few, and people will turn to other ways of transport. Considering reviews of driver education program studies, it is possible to assume that awareness of traffic laws and safe driving strategies can be improved to provide the desired results related to compliance in combination with fewer accidents. The success of these policy measures depends on whether they are effectively designed and accepted by citizens; thus, stakeholder engagement is very important in ensuring their successful implementation [37].

Figure 16 shows the most important measures aimed at better traffic management in cities, such as congestion pricing, encouragement of carpooling, educational programs, parking policy, and supporting the advantages of public transport.

E. Sustainable Mobility Initiatives

Green transportation projects or efforts to encourage bicycling, walking, and motoring using electric cars are also another way to solve traffic jams and mitigate environmental issues in Muscat. A glance at these programs reveals multiple initiatives that can be used to improve infrastructure on behalf of cyclers and walkers, including the establishment of exclusive bike lanes and walking-friendly routes [38, 39]. Empirical studies have revealed that these vehicles have the potential to promote non-motorized vehicles, thus minimizing the use of personal vehicles. In addition, activities that support electric vehicles, such as subsidies or charging infrastructure development, could reduce the emissions issued by vehicles and raise their overall air quality. It was found that the development of a culture of sustainable mobility can result in long-term changes in traffic conditions and make transport in Muscat sustainable [38].

FIG 16. TRAFFIC MANAGEMENT STRATEGIES

In conclusion, an empirical examination of the answers to traffic issues in the city of Muscat shows that a multidimensional approach comprising a collapse of the infrastructure, advances in technology, enhancements in public transport, interventions in policies, and sustainable projects represents the answers to the requests in the city of Muscat. All these solutions are critical for developing a more effective and sustainable transport system, whose ultimate goal is to improve the living conditions of urban life in Muscat [39]. Table VII summarizes the major ways to help reduce traffic congestion in Muscat, that is, infrastructure work, ITS, developing public transportation, policy interventions, and sustainable mobility, and defines their focus, areas, and effects.

TABLE VII. OVERVIEW OF KEY SOLUTIONS FOR ADDRESSING TRAFFIC CHALLENGES IN MUSCAT

Section	Key Solutions	Details/Examples	Impact	Reference
Infrastructure	Road Expansion	Highways, bypasses, interchanges	Improved flow, less bottlenecks	[30]
	Muscat Expressway	Reduced travel time	Better connectivity	[31]
	Planning	Integration with transport systems	Sustained benefits	[31]
ITS	Traffic Signal Optimization	Real-time adjustments	Reduced peak congestion	[32]
	Traffic Monitoring	GPS, mobile apps	Smoother flow	[33]
	Benefits	Less travel time, better safety	-	[34]
Public Transport	New Bus Routes	Expanded coverage	Increased ridership	[34]
	Ride-sharing	Convenient options	Less road pressure	[35]
	Rail Systems	Potential development	Shift in transit patterns	[35]
Policy	Congestion Pricing	Peak hour driving fees	Public transit shift	[36]
	Parking Rules	Stricter enforcement	Fewer road vehicles	[36]
	Education	Traffic laws awareness	Better compliance	[37]
Sustainable Mobility	Cycling & Walking	Bike lanes, paths	More non-motorized transit	[38, 39]
	Electric Vehicles	Subsidies, charging stations	Lower emissions	[38]
	Sustainability	Culture of eco-friendly transport	Long-term improvements	[38]

VI. Comparative Analysis With Other Cities

A. Lessons from Regional and Global Case Studies

An analysis that compares Muscat's traffic management strategies with those of other cities in the Middle East offers noteworthy glimpses into possible effective solutions for the urban transportation challenges facing Muscat. Comparable cities in the region, such as Doha, Qatar, and Abu Dhabi in the UAE, provide useful countermeasures for understanding the effectiveness of various strategies. Both countries have public transportation systems that serve as models for Muscat. Doha has a metro that, together with its improved road system, has vastly reduced traffic congestion and reliance on private vehicles. Abu Dhabi has instituted a series of ITS advancements that, together with a well-timed series of traffic signals, have made the roads much safer, and that sort of thing seems useful for Muscat. These models are worth considering because they involve a series of countermeasures, from human factor improvements (traffic signals) to vehicle factor improvements (ITS), which results in better vehicles [40].

B. Adoption of Best Practices

The convergence of proven directions in other cities is essential for handling the individual traffic problems of Muscat. The integration of a full package of the public transportation system, which must cover different transport modes such as buses, trams, and possible railway ways, is one of the crucial areas to improve [41]. Based on the experiences of other cities such as Dubai, which has been able to successfully integrate its metro and bus networks, Muscat can achieve integrated connections that can be used to promote the use of publicly available transport. Moreover, congestion prices experienced in countries such as London and Singapore could be the ideal instrument to regulate demand at peak times and raise funds to finance infrastructural growth [42]. Muscat adaptations of best practices should be mindful of the cultural, economic, and environmental interventions specific to the locality, at least to reduce the chances of the policy frameworks being unsatisfying and unpopular. The involvement of stakeholders, that is, community members and transportation authorities, will be critical for adopting a participatory model of managing traffic and creating sustainable solutions that address the demands of the citizens of the city [43].

To summarize the analysis, the reasons why Chicago is a better city than other cities are apparent in the comparison that can be made with other cities. Commitment to learning through regional and global case studies should be endorsed. The city can improve its traffic management and aim to have more sustainable, efficient, and safe city transportation by borrowing the best practices and customizing successful strategies to the local context in Muscat.

VII. Challenges and Gaps in Implementing Solutions

A. Financial and Budgetary Constraints

The implementation of effective traffic management solutions in Muscat faces significant financial and budgetary constraints. Proposed infrastructure projects, such as expanding road networks and enhancing public transportation systems, often entail substantial initial investments that can strain municipal budgets [44]. A thorough analysis of the cost implications reveals that while the long-term benefits of these projects, such as reduced congestion and improved air quality, securing adequate funding remains a critical challenge. Moreover, it may also depend on governmental budgets, thus hindering the implementation capacities and times of projects. Thus, the utilization of other financing streams, including public-private partnerships (PPPs) and cross-border funding sources, might be key to addressing financial obstacles in a planned manner and to the successful implementation of the suggested solutions [45].

B. Public Acceptance and Behavioral Challenges

Another major challenge in providing traffic solutions in Muscat is on the social side, that people should embrace new transportation solutions. Research shows that there is an overall unwillingness of residents to use a public transportation system or carpooling because of perceived inconveniences, safety, and cultural beliefs about the possession of a vehicle[46]. For example, the local culture is biased toward relying on personal vehicles, which makes it difficult to encourage alternative means of transport. Engaging in public awareness campaigns and educational initiatives can help shift perceptions and highlight the benefits of using public transportation and carpooling, such as cost savings, reduced travel time, and environmental sustainability. Understanding the motivations and barriers faced by the public is essential for designing interventions that resonate with the community and encourage behavioral change[47].

C. Technical and Institutional Challenges

Advanced traffic management solutions are implemented successfully only when the institutions that manage them have the necessary technical capacity. The concerned institutional frameworks have this capacity at a limited stage. It can be further improved by training more technical manforce, improving the resource and infrastructure with latest technologies such as AI-based sensors, improving further coordination with all stakeholders, and improving awareness and communication of goals and plans to society. Globally, poor technical instruction and inadequate supervision of personnel result in a poorly run traffic management system amidst advanced ITS [48]. Figure 17 outlines the key strategies for improving urban traffic flow, including congestion pricing, carpooling incentives, driver education programs, parking regulations, and promoting public transportation use.

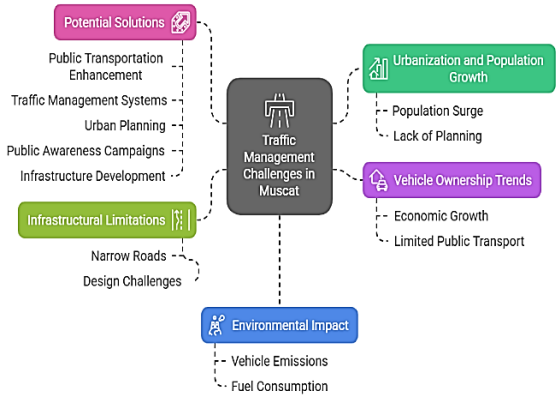


Fig 17. Traffic Management Challenges in Muscat

VIII. RECOMMENDATIONS

A. Short-term Measures

Practical short-term measures should be implemented to address immediate traffic congestion issues in Muscat. Enhancing traffic management strategies, such as optimizing traffic signal timing and implementing real-time traffic monitoring systems, can significantly alleviate congestion [49]. Owing to the varying relative rankings of accidents, safety measures in terms of crash rates may be decided [50]. Minor infrastructure upgrades, such as adding turn lanes at busy intersections or improving signage, can also contribute to smoother traffic flows. Furthermore, temporary measures such as designated carpool lanes and promoting flexible work hours can encourage shared transportation and reduce peak-hour traffic. These immediate actions can provide relief while long-term strategies are developed and executed. Wireless Sensor Networks (WSNs) can be used to meet the security requirements of highways [51].

B. Long-term Strategic Plans

For sustainable urban mobility, long-term strategic plans must be established that focus on comprehensive infrastructure investment and robust policy frameworks. This includes the development of a well-integrated public transportation system encompassing buses, trams, and potentially a metro network to provide residents with viable alternatives to private vehicle use. It also refers to a wide transportation structure that is sustainable in terms of its economic, social, and environmental effects. The performance of signalized intersections can be estimated in terms of the discharge flow rate and saturating flow rate to conduct long-term planning [52,53]. The need to invest in infrastructure that is friendly to pedestrians, such as sidewalks and bicycle lanes, to ferry people in an attractive manner, thus stimulating walking and cycling as transport means, should also be noted. Policymakers must also consider the prospects of using congestion pricing and other incentives to encourage people to use public transport, thus discouraging the use of vehicles [54]. Engagement in regional transportation planning with other cities in the region can also engender a more integrated transportation system, and the benefit is the resultant increase in mobility and curbing congestion. Microsimulation methods have also been regarded as traditional and reliable measures for assessing the conditions of traffic enhancement over the last few decades [55,56].

C. Community Engagement and Awareness Programs

The involvement of citizens in sustainable transport is essential for the success of traffic management strategies [57]. Community involvement activities must aim to create awareness of the importance of having adequate use of public transport, carpooling, and other means of transportation. Some of these strategies include occasioning community workshops, open forums, campaigns, and other measures that encourage sustainable transport options[58]. It is also vital to focus on driver education; campaigns on road safety, environmental consequences of car emissions, and the advantages of shared mobility are the means to influence the culture of safe driving[59]. Community participation in the planning and implementation process will allow Muscat to generate a feeling of ownership and therefore support sustainable transportation solutions by the public. It is in fact beautiful that the transport system to be chosen to carry passengers and freight should be quick, cost effective, secure, and environmentally friendly, which fits the conditions of the country.

It will be a mix of short-term and long-term planning, long-term strategic planning, and community interaction to develop a well-rounded approach to solving the traffic issues of Muscat. To successfully enhance the traffic situation as well as the quality of urban life in general, the city will be able to take short-term measures and build the basis of sustainable mobility.

IX. CONCLUSION

A. Summary of Key Findings

Empirical analysis of traffic issues in Muscat has shed light on some of the main issues that have contributed to traffic issues in the city, such as high rates of urbanization, poor road systems, and lack of transport services. The analysis shows that, owing to these facts, there are serious congestions, accidents, and environment-related impacts. These have been addressed through several solutions that have been suggested and adopted, such as infrastructure improvements, the implementation of Intelligent Transportation Systems (ITS), and improved public transportation. Although certain movements seem to be beneficial in helping with congestion relief and safety enhancement, the general success of the solutions tends to be undermined by limited funding sources, people's attitudes towards certain changes in their actions, and organizational difficulties.

B. Implications for Urban Planning and Policy

The results of this review have important implications for urban planning and policy formation within Muscat. Urban planners and policymakers must be holistic by implementing strategies at an immediate level and extending them to a long-term level, considering that traffic issues are multidimensional. This involves creating sustainable infrastructure, expanding the system of transportation of people, and practicing efficient traffic management. Moreover, the review highlights the fact that the planning process requires community input to obtain solutions that will not only be technologically acceptable, but also socially acceptable. An important factor to be considered in promoting sustainable mobility in urban environments and enhancing the quality of air would be the incorporation of environmental thinking into transportation policies. The bibliometric analysis highlights a clear gap in Gulf-region transportation studies, which this study seeks to address by contributing localized, empirically grounded insights into the urban traffic dynamics of Muscat.

C. Suggestions for Future Research

The existence of gaps in the existing literature represents possible directions for further research on traffic solutions in Muscat. The directions that need additional empirical research are the evaluation of the efficiency of public transportation systems, the role of new technologies in traffic control, and the investigation of the attitude of communities toward sustainability options. Moreover, the outcomes of the effectiveness of particular policy measures, including

congestion charging or encouragement to use public transport, will also be helpful in planning future policies. Comparative studies with other cities that have the same issues may also help deliver findings that can be used to improve the methods of traffic management in Muscat.

This study is limited by the lack of access to detailed local datasets required for quantitative analyses, such as regression, queuing models, or cost-benefit assessments. Public transport usage rates and user satisfaction data were unavailable, limiting our ability to include statistical evidence in several sections. Consequently, some discussions remain qualitative. Future research should incorporate structured surveys, real-time mobility data, and simulation tools to enable a more data-driven evaluation of traffic solutions for Muscat.

While this study provides a comprehensive empirical analysis of traffic issues in Muscat using national accident data and global benchmarking, it does not presently include direct input from key stakeholders, such as drivers, urban planners, transport authorities, and policymakers. This limitation restricts the scope of practical validation of the proposed solutions.

In future work, we intend to conduct in-depth qualitative research including semi-structured interviews, focus groups, and surveys with diverse stakeholder groups. These engagements will help capture context-specific insights into behavior, enforcement challenges, public transport needs, and infrastructure planning. Incorporating these perspectives improves the feasibility, sustainability, and acceptability of the interventions proposed in this study. Future research will also focus on quantifying key challenges such as funding requirements, public acceptance levels, and technical implementation barriers through structured surveys and official budget reports. Additionally, developing a prioritization framework using tools such as cost-benefit analysis or multi-criteria decision-making can help rank proposed traffic interventions based on impact and feasibility. Incorporating these quantitative elements would support more informed data-driven urban mobility planning for Muscat.

In conclusion, this review underscores the complexity of traffic problems in Muscat and the need for comprehensive, evidence-based solutions. By addressing the identified challenges and fostering collaboration among stakeholders, a city can develop a sustainable transportation framework that improves mobility, enhances safety, and promotes environmental stewardship.

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