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Research Article

Applying Mathematical Models in Reducing Road Traffic Congestion: A Case of Kamwala (Lusaka) District, Zambia

[a]Emmanuel Malichi and *[b]Patricia Tombi Muyunda
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[a&b]Rockview University, 10 Miles Lusaka, P.O. Box 31108, Zambia
*Corresponding Author Email: muyundapatricia@gmail.com

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Abstract
The study aimed to assess application of mathematical models in reducing traffic congestion in Lusaka district of Lusaka province. The study will seeks to: examine the factors contributing to traffic congestion in Lusaka district, identify mathematical models suitable for analysing and mitigating traffic congestion, assess the effectiveness of the proposed mathematical models in reducing traffic congestion, and provide recommendations for implementing mathematical models in traffic management practices in Kamwala Lusaka.
Keywords: Mathematical Models, Road Traffic, Traffic Management.

1. Introduction
Traffic congestion is a significant issue affecting urban areas worldwide, and Lusaka, the capital city of Zambia, is no exception. Lusaka has experienced rapid urbanization and population growth, leading to increased vehicular traffic and subsequent congestion. This congestion not only affects the daily lives of residents but also hampers economic productivity, environmental sustainability, and overall quality of life. Addressing traffic congestion in Lusaka requires a multi-faceted approach, with one promising avenue being the application of mathematical models. This research proposal aimed to investigate the application of mathematical models in reducing traffic congestion in Lusaka district, Zambia. The introduction chapter provided an overview of the proposed study, including the background, problem statement, research objectives, questions, rationale, limitations, delimitations, and definition of terms.

Lusaka has seen substantial urban growth over the past few decades. According to the Central Statistical Office of Zambia (2020), Lusaka's population grew from approximately 1.7 million in 2010 to over 2.5 million in 2020. This rapid growth has outpaced the development of the city's infrastructure, leading to severe traffic congestion. Major roads and intersections in Lusaka, such as the Great East Road, Cairo Road, and the Kafue Roundabout, are frequently clogged, particularly during peak hours. The impact of traffic congestion extends beyond mere inconvenience.

1.1. Statement Problem
Traffic congestion is a pervasive issue in urban areas worldwide, leading to numerous economic, social, and environmental challenges. Lusaka district, the capital of Zambia, is no exception. As the urban population grows and vehicle ownership increases, the existing infrastructure struggles to accommodate the rising demand, resulting in frequent traffic jams, prolonged travel times, and heightened levels of pollution. Despite various interventions aimed at addressing traffic congestion in Lusaka district, Zambia, the problem persists, adversely affecting the economy, environment, and quality of life for residents.

1.2. Objectives of the Study
The research objectives were as follows:
1) To identify mathematical models suitable for analysing and mitigating traffic congestion.
2) To examine the factors contributing to traffic congestion in Lusaka district.
3) To assess the effectiveness of the proposed mathematical models in reducing traffic congestion.
4) To provide recommendations for implementing mathematical models in traffic management practices in Lusaka.

1.3. Research Questions

The research questions guiding this study were:

1) What were the main factors contributing to traffic congestion in Lusaka district?
2) Which mathematical models were most appropriate for analysing and mitigating traffic congestion in Lusaka?
3) What was the effectiveness of the proposed mathematical models in reducing traffic congestion?
4) What were the recommendations for implementing mathematical models in traffic management practices in Lusaka?

1.4. Significance of the Study

The significance of this study lied in its potential to address a critical and persistent issue affecting the daily lives of residents and businesses in Lusaka district, Zambia. Traffic congestion not only leads to economic losses due to increased travel times and fuel consumption but also contributes to environmental degradation and public health concerns. By exploring innovative solutions through the application of mathematical models, this research offered several noteworthy contributions. Firstly, this study would contribute to the advancement of knowledge by exploring alternative approaches to traditional traffic management methods. Furthermore, the findings of this study would have significant implications for policy-making and urban planning decisions. By providing insights into the effectiveness of mathematical model-based solutions, policymakers could make informed decisions regarding the allocation of resources and the implementation of traffic management policies.

Moreover, this research would have the potential to enhance urban liveability and quality of life for residents of Lusaka. By reducing traffic congestion, not only were travel times and fuel costs minimized, but there would also associate benefits such as improved air quality, reduced noise pollution, and enhanced road safety. Additionally, this study would provide a framework for future research and application of mathematical models in other urban contexts facing similar challenges. The methodologies and findings generated from this research could serve as a valuable reference for researchers, practitioners, and policymakers working in other cities grappling with traffic congestion issues.

2. Literature Review

This chapter provided a comprehensive review of existing literature related to traffic congestion and the application of mathematical models in traffic management. It examined theoretical frameworks, global perspectives, regional insights, local contexts, related studies, research gaps, and concludes with a summary of the chapter. There are numerous uses for traffic models. They can be applied, for instance, when making infrastructural changes or attempting to address the present traffic issues. Research on traffic models receives a lot of attention since they are employed in many applications. In the 1950s, the first models of traffic flow were created. After these traffic models and other models have been built, additions are made (Hoogendoorn and Bovy, 2001). The Macroscopic Traffic Flow Model provides a high-level representation of traffic flow dynamics, focusing on aggregated variables such as flow, density, and speed. This model is particularly useful for analysing traffic patterns and congestion on a network-wide scale, allowing for the evaluation of system-level impacts of various interventions, such as road expansions or signal timing adjustments (Daganzo, 1995).

3. Methodology

This study was descriptive aiming at collecting first-hand information through administering of 120 questionnaires and interview guides to research participants. The questionnaires and interview guides were employed as tools for data collection in this study. This study followed mixed research design where both quantitative and qualitative approaches were employed. The collected data was analysed using SPSS 20 to produce outputs such as frequencies tables, distribution tables, pie charts and bar charts while qualitative outputs were analysed thematically.

4. Data Presentation and Data Analysis

This chapter presents the findings of the study which sought to assess the application of mathematical models can be used in reducing traffic congestion in Lusaka district. The presentation of the findings has taken into consideration attitudes, views, suggestions, and assumptions of the various categories of respondents that participated in the research. This study engaged commuters, drivers, RTSA officials and urban planners selected from Lusaka district. Below is the data that was collected from respondents. In order to gather data for research, the researcher made use of questionnaires. A total number of 120 questionnaires for commuters, drivers, RTSA officials and urban planners selected from Lusaka district.

4.1. Data Analysis

The study was conducted in Lusaka district, Zambia. The respondents were randomly selected from Lusaka district where transporters and RTSA officials who face traffic congestion issues were located. Figure 1 below illustrates the map of Lusaka district.

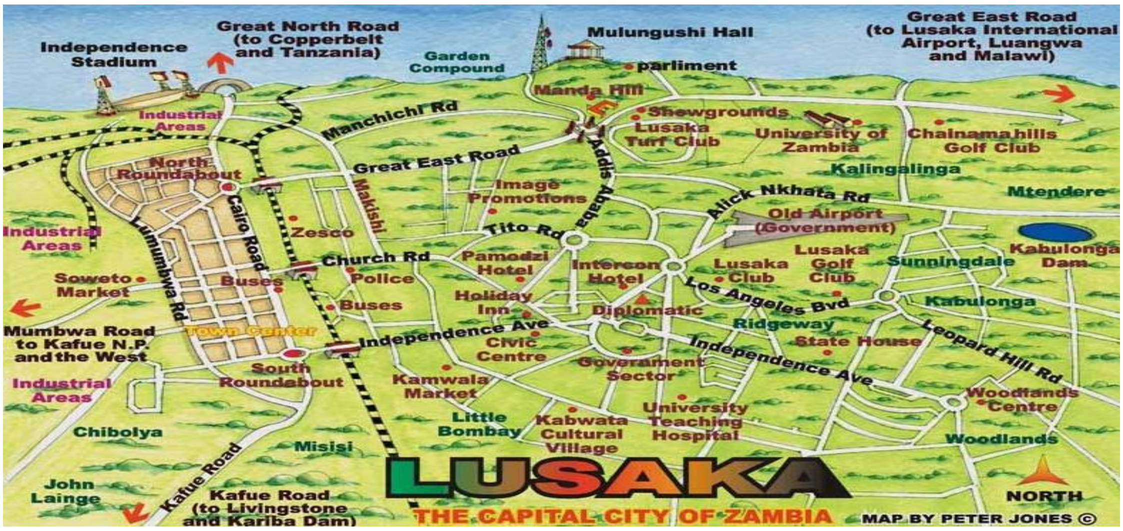

Figure 1. Map of Lusaka district.

4.2. Target Population

Holliday (2005) states that a target population is that population which the researcher wants to generalize results from. The target population for this study includes all road users in Lusaka. The target population was 600 people which comprised drivers, commuters and officials from RTSA for these were assumed to have the first hand that would necessitate the study implementation.

4.3. Population and Sample Size

According to Lohr (2022), the sample size is a number of individual samples measured or observed in a survey. The sample size which is 20% of target population was used in this study which was determined as follows: 20% of 600 gives 120, therefore, the sample of this study was 120 people which encompassed drivers, commuters and RTSA officials. The researcher used the combination of purposive and random sampling techniques in the selection of the sample size.

4.4. Sampling Procedure/Techniques

Sampling is a technique of choosing a sub-group from a population to participate in the study. The study therefore used probability and purposive sampling procedures. Kombo and Tromp (2013) stated that the probability random sampling ensures that every element in the sampling frame has an equal chance of being included in the sample. This part encompasses the demographic features of the road users and agents interviewed. The features include; gender, occupation and age.

4.5. Gender

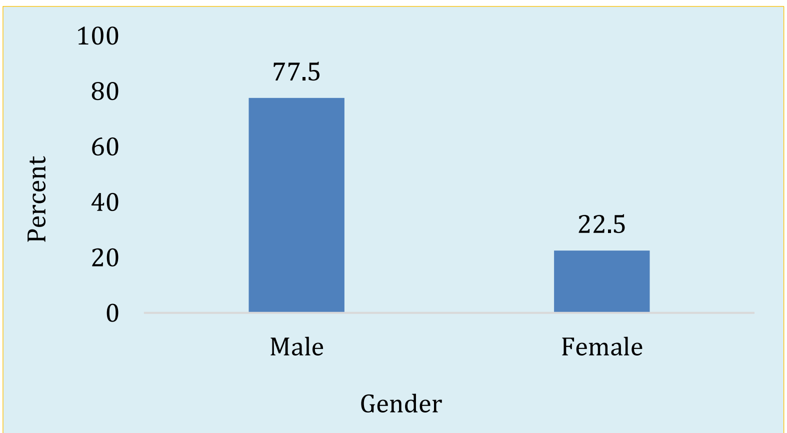

Figure 2. Gender.

4.6. Age of Respondents

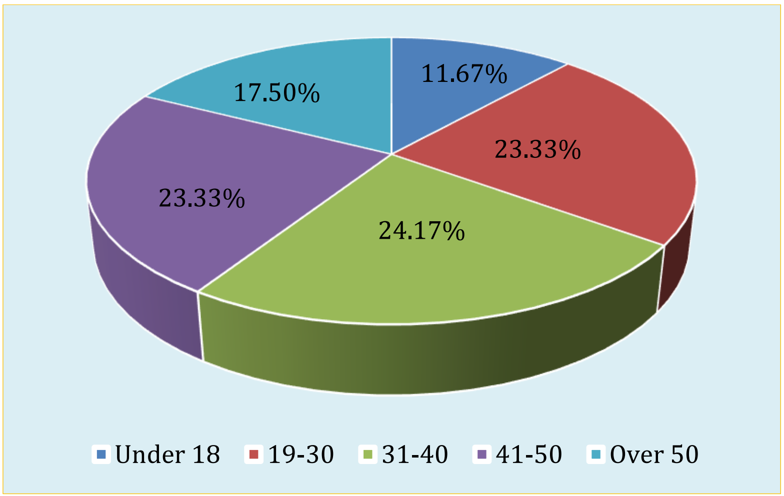

Figure 3. Age of respondents.

Regarding the age of the respondents who participated in this study of road traffic congestion, the research revealed that 24.17% of the total respondents asserted that there were in the age range of 31-40 years old, 23.33% of the total respondents stressed that they were in the age range of 19-30 years old, another 23.33% of the total respondents accentuated that they were in the age range of 41-50 years old, 17.50% of the total respondents asserted that they were in the age range of over 50 years old. 11.67% of the total respondents accentuated that they were in the range of 18 years and below.

4.7. Occupation of Respondents

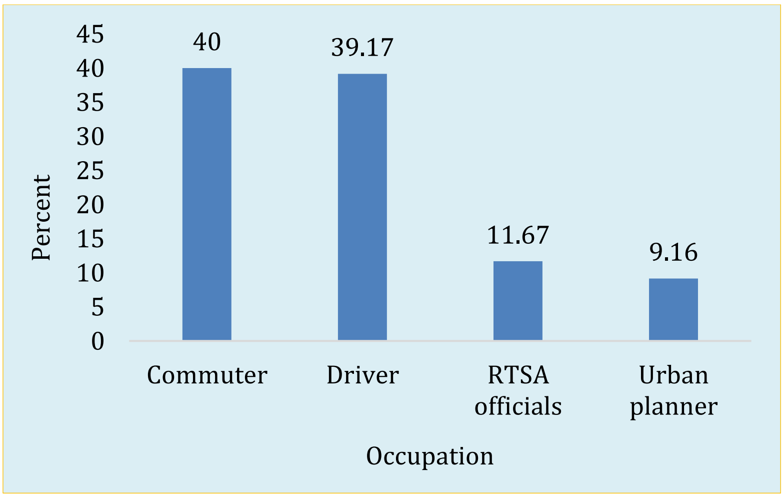

Figure 4. Occupation.

From the figure above, the study revealed that 40% of the total respondents asserted that they are just commuters, 39.17% of the total respondents revealed that they are just drivers, 11.67% answered that they are RTSA officials, lastly but not the least 9.16% of the total respondent accentuated that they are urban planners.

4.8. Driving Permit

Table 1. Illustrates the driving permit.

		Number of respondents	Percent
Valid	Driving license	42	35.0
	Provision	22	18.3
	None	56	46.7
	Total	120	100.0

Regarding the results obtained from the study indicates that 35% of the total respondents asserted that they have driving license, 18.3% of the total respondents stressed that they possess driving provision, but 46.7% of the total respondents opined that they do not either a driving license or driving provision. This indicates how weird the situation is in that the percentage of those without any driving permit but they drive vehicles in the highway is just too bad, which calls for something to done so quickly to curb the situation.

4.9. Education Background

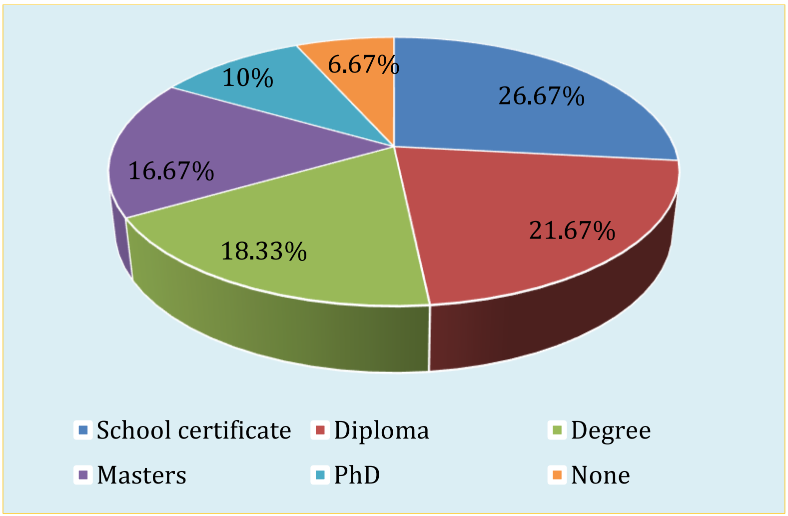

Figure 5. Education background.

The figure above indicates the results from the study which shows that 26.67% of the total respondents said they have school certificate, 21.67% of the total respondents asserted that they possess Diploma, 18.33% stressed that they have Degree, 16.67% of the total respondents answered that they have masters, 10% of the total respondents pinpointed that they possess PhD. Lastly, but the least, 6.67% of the total respondents they do not possess any qualification. From the results obtained from the study, it can be deduced that better education has nothing much do with the reduction of traffic congestion in Lusaka.

5. Related Studies (or) Related Study Findings

Related studies have extensively explored the factors contributing to traffic congestion in urban areas, providing valuable insights for the current research. For instance, a study by Wang *et al.,* (2018) identified various factors such as population density, road network design, land use patterns, and traffic demand fluctuations as significant contributors to congestion. By analyzing these factors, researchers can gain a better understanding of the underlying causes of congestion in Lusaka district, Zambia, and develop targeted strategies for mitigation.

Several mathematical models have been proposed for analyzing and mitigating traffic congestion, offering diverse approaches to address this complex problem. Simulation-based models, such as the Cellular Automata Model (CAM), have been widely used for traffic flow analysis and prediction (Zhao and Zhao, 2016). These models simulate individual vehicle movements and interactions within a network, allowing researchers to evaluate the impacts of different scenarios and interventions on congestion levels. Additionally, optimization models, such as the Traffic Assignment Model (TAM), optimize traffic flow by assigning vehicles to routes based on criteria such as travel time, cost, and network capacity (Wang and Nie, 2019). By leveraging these mathematical models, researchers can develop comprehensive strategies for congestion management tailored to the specific conditions of Lusaka.

To develop and validate mathematical models tailored to the traffic conditions in Lusaka, researchers can draw insights from previous studies that have applied similar methodologies in other urban contexts. For example, a study by Zhang *et al.,* (2020) developed a hybrid simulation-optimization model to optimize signal timings and reduce congestion in a Chinese city. By adapting and calibrating such models to the unique characteristics of Lusaka's transportation system, researchers can ensure their effectiveness in accurately representing local traffic dynamics and informing decision-making processes. Assessing the effectiveness of proposed mathematical models in reducing traffic congestion requires rigorous evaluation through empirical validation and scenario analysis. Studies such as that by Li and Chen (2017) have employed field data collection and simulation experiments to validate the performance of traffic flow models in real-world conditions. By comparing model predictions with observed traffic patterns and conducting sensitivity analyses, researchers can assess the accuracy and reliability of the proposed models in capturing and mitigating congestion dynamics in Lusaka.

Finally, providing recommendations for implementing mathematical models in traffic management practices requires a comprehensive understanding of the institutional, technical, and socio-economic factors influencing policy adoption and implementation. Studies such as that by Li *et al.,* (2018) have highlighted the importance of stakeholder engagement, capacity building, and policy coordination in effectively utilizing mathematical models for congestion management. By integrating insights from these studies into the research findings, policymakers and transportation authorities in Lusaka can develop and implement evidence-based strategies for leveraging mathematical models to improve traffic management and alleviate congestion.

6. Conclusion

In conclusion, the research findings indicate that the major or rather primary factors leading to traffic congestion in Lusaka city are inadequate road infrastructures which always make it hard to accommodate the increased number of vehicles, high volume of vehicles which increases each and every day which has been attributed by another factor called high population density in the city, poor traffic management in that sometimes where the traffic officers position themselves just increases the preference of traffic congestion in Lusaka, and lack pedestrian facilities also contribute to lots of traffic congestion such that most pedestrian happen not to have facilities where they can be passing free leaving the main roads free so that only vehicles can possibly pass there, instead, both pedestrian and vehicles pass through the main roads causing the said unbearable traffic congestion. On the other hand, the results obtained from the regression analysis indicated that age and drivers experience were positively related to traffic congestion.

Regarding the application of mathematical model to reduce traffic, the study indicated that indeed employing the proposed mathematical models namely Macroscopic Traffic model, Payne's model, LM model and Agent based model) in the quest to analyse and mitigate the unbearable traffic congestion in some areas of Lusaka could be of good help and likely to bring the most lucrative results because some spots call for special attention for they bear uncontrolled traffic congestion as Lusaka is not the capital city.

In relation to effectiveness of the proposed mathematical models in the quest to reduce traffic congestion in Lusaka, the study alluded that the proposed traffic congestion could be very effective in the bid to reduce the unbearable traffic congestion in Lusaka in that they could bring efficiency in public transportation, reduce delays and fuel consumption, and also facilitate in increase in the pedestrian facilities in Lusaka city.

Lastly but not the least, the revealed that with the proper implementation of the proposed mathematical model; the road network infrastructure is likely to be enhanced, the implementation of the advanced traffic control system is likely to be into effect, promotion of the traffic alternative routes is also likely to be observed, and the implementation of some regulations in terms of the importation of vehicles is likely to be in place. With these recommendations, there is no reasonable doubt that proposed mathematical models in the quest to reduce the lethal traffic congestion in Lusaka should be applied so as to test their efficiency and effectiveness in relation to traffic congestion reduction in Lusaka district.

7. Recommendations

Here are some recommendations for the research on the application of mathematical models in reducing traffic congestion in Lusaka town:

7.1. Engage with Stakeholders

The success of any traffic management strategy depends on the buy-in from stakeholders, including government agencies, public transport operators, and the general public. Regularly engage with stakeholders to gather input and ensure that your recommendations are practical and aligned with their needs. Consider forming a collaborative task force to oversee the implementation of your proposed solutions.

7.2. Optimize Public Transport Networks

Mathematical models can be used to optimize the routes, schedules, and capacities of public transport systems to reduce congestion. Analyse the current public transport network in Lusaka using optimization models to identify inefficiencies and propose improvements.

7.3. Incorporate Behavioural Models

Traffic congestion is influenced by the behaviour of drivers. Incorporating behavioural models into your mathematical framework can help understand and predict how drivers' choices affect traffic flow.

7.4. Use Geographic Information Systems (GIS)

GIS can be used to analyse spatial data and visualize traffic patterns, making it easier to identify congestion hotspots and plan interventions. Integrate GIS with your mathematical models to map out traffic flow in Lusaka. Use this tool to identify areas where infrastructure improvements are most needed and to monitor the impact of implemented solutions.

7.5. Develop a Congestion Pricing Model

Congestion pricing models charge drivers for using certain roads during peak hours, encouraging the use of alternative routes or modes of transport. Create a congestion pricing model for Lusaka, tailored to the city's specific economic and social context. Simulate the potential impact on traffic flow and evaluate the feasibility of implementing such a system.

7.6. Monitor and Evaluate Implementation

Continuous monitoring and evaluation are essential to ensure that the implemented solutions are effective and to make necessary adjustments. Propose a framework for monitoring and evaluating the impact of your recommended strategies in Lusaka. This could involve setting up a data collection system, establishing performance indicators, and conducting regular assessments.

Declarations

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