Emission Calibrated Traffic Model for Environment-Sensitive Decision Making in Sri Lanka: Review

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***Abstract*— Air pollution from road transportation is a growing concern in urban areas, particularly in Sri Lanka, where vehicle emissions account for a significant portion of air pollutants. The increase in the number of vehicles on the road and the resulting traffic congestion exacerbate this problem. Therefore, accurate prediction of emissions and air quality related to road traffic is essential for informed decision-making in traffic planning and management. While Sri Lanka has made progress in developing driving cycles and traffic flow simulations tailored to its unique context, there remains a gap in calibrating these models with local emission values, which are influenced by specific driver behaviours and operational modes. An emission-calibrated traffic model specific to the Sri Lankan context can integrate both traffic-related and environmental factors, providing a comprehensive tool for analyzing the impact of traffic management strategies on emissions and air quality. By addressing the discrepancies between global manufacturer data and local conditions, this model can enable more environmentally friendly decisions in urban transportation planning, contributing to the reduction of air pollution. The study identifies, through a comprehensive review, the need for an emission-calibrated traffic model to address the unique challenges posed by Sri Lanka's evolving traffic landscape. While traffic modelling has made strides in Sri Lanka, this study identifies a significant research gap in modelling the emissions generated by these traffic models, especially considering the unique characteristics of the region's roads and vehicles. Further, the paper concludes that an emission-calibrated traffic model specifically tailored to the Sri Lankan context is essential to guide environmentally friendly traffic planning decisions and bridge the gap between traffic data and its environmental consequences.**

Keywords*— Emission-calibrated traffic model, Traffic Management, Sri Lanka, Air pollution, Urban transportation.

I. Introduction

Globally, increased air pollution has become a major threat to public health, particularly among urban populations [1]. Road transportation plays an important role in this regard [2], [3], [4], [5]. Among the contributors to this air pollution, motor vehicle emissions play a major role in the Sri Lankan context, as 55-60% of air pollutants are due to vehicle emissions [6]. The increased number of vehicles on the road, which has led to increased levels of congestion, produces more air pollutants [6]. Furthermore, aggressive driving behaviour patterns in heterogeneous traffic environments increase air pollution [1],[7]. Increased traffic congestion has been identified as a major contributor to increased air pollution in the Colombo area. Therefore, at the policy level decision-making regarding traffic planning, it is required to consider the impact on air quality [8].

Improving the accuracy of predicting emissions and air quality related to road traffic is crucial for controlling air pollution caused by transportation on roads [9]. Emissions generated by road traffic significantly contribute to air pollution in urban areas. When road traffic is considered, emissions can be quantified based on the principle of average emission factor for the average speed during a trip. This may vary according to the average speed of the trip [9]. To address this, the complexities of traffic conditions should be addressed.

To address the complexities of Sri Lanka's evolving traffic landscape, significant steps have been taken in the development of driving cycles, particularly tailored to the dynamics of the Colombo area and the expressway network [10], [11]. These driving cycles serve as critical benchmarks to assess vehicle performance, fuel consumption, and emissions within the unique context of Sri Lanka's unique context. However, for a more reliable understanding of traffic flow, traffic flow simulations have been developed [12], [13].

Even though these advancements have brought Sri Lanka's traffic planning and management efforts forward, these models have not been calibrated with the emission values of the vehicles with respect to the Sri Lankan context. Vehicle emissions have been identified to be strongly dependent on vehicle operating modes [14]. Thalgaskotuwa et al. have identified in their research that, to optimize the condition, improving the traffic management strategy as well as reducing traffic emissions should be considered as the optimum solution for traffic management may not necessarily be the optimum one from an environmental perspective. [14]. Even if data is available on emissions from vehicle manufacturers, this information falls short of capturing the actual conditions of Sri Lankan roads as emissions can vary on driver behaviours and operation modes [1], [14], [15], [16].

II. 2 Research Methodology

This study focuses primarily on a literature review aimed at identifying the need for an emission-calibrated traffic model. A thorough examination of existing literature was carried out using Google Scholar's database, specifically focusing on research papers published from 2009 to 2023. Google Scholar was chosen for its ability to access a wide range of databases, given the limited availability of relevant literature. Only peer-reviewed journal papers and conference papers were included, while other sources such as theses, textbooks, book chapters, unpublished research articles, and internet data were excluded from the study.

The initial search used the keywords "traffic simulation models", "vehicle emissions," "calibration," and "modelling," resulting in 270 retrieved articles. Subsequently, a second search was conducted using the keywords "traffic simulation models" and "Sri Lanka," yielding 36 results.

However, not all the articles initially identified were relevant to the goal of identifying the need for an emission-calibrated traffic model. Some articles merely contained the keywords in their title, abstract, or content. To ensure relevance, a preliminary review of abstracts and, where necessary, the content of these articles was conducted. After this filtering process, 43 articles were considered relevant and suitable for further analysis.

It is essential to emphasize that this study exclusively focuses on reviewing and drawing conclusions from the relevant articles obtained through the specific literature search approach. It does not encompass a comprehensive review of all articles on the topic. The selected relevant articles will be reviewed, presented, and discussed in the following section of this paper.

Fig. 1 illustrates the entire research process as previously described. The literature review process adheres to a systematic and logical sequence, commencing with the selection of an appropriate search engine. This is followed by an initial desktop search to retrieve relevant articles, a brief review of the articles to identify related articles and a critical analysis of these selected articles. The goal is to identify, present, and discuss the need for an emission-calibrated traffic model.

III. Results and Discussion

Urban areas require more consideration to address climate change and lower harmful air pollution levels. To integrate policies that address climate and air quality into traffic planning decisions, it is crucial to consider methods to reduce

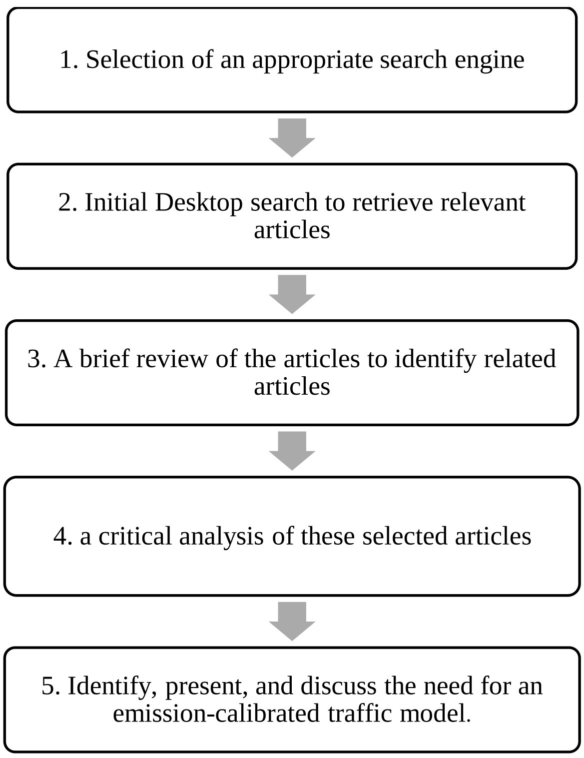

Fig. 1. Overall research process.

emissions [17]. The creation of an inventory of emissions from the transportation sector is required, as understanding the emissions related to traffic is a fundamental step in this process [18], [19].

A. Air Pollution and Urban Traffic Congestion

In Sri Lanka, motor vehicles are a major source of air pollution, accounting for 55-60% of it [6]. The transportation sector contributes significantly to air pollution due to the growing number of vehicles on the road, despite limited improvements in the road infrastructure. Currently, there are about 3 million registered motorcycles, which is almost five times more than in 2000. Additionally, there are approximately 600,000 cars, marking a 300% increase since 2000 [6]. The rise in the number of vehicles has led to more traffic congestion and hence more air pollution. Vehicles caught in traffic jams emit higher levels of soot, carbon monoxide, and unburnt hydrocarbons compared to vehicles travelling smoothly at a steady speed of about 40 km/h [6]. Heavy traffic often causes many vehicles to move slowly within a confined space. Behaviours of drivers such as buses racing on first gear at all bus stops for a long time have also contributed to increased air pollution [1], [7]. Rathnayake et al. have identified massive traffic congestion due to limited road capacity, poorly maintained timeworn vehicle usage, and using poor fuel as factors that cause high emissions from traffic that decrease the outdoor air quality [8].

B. Driving Cycle Development and Traffic Flow Simulations

As emissions from transportation represent the largest single cause of air pollution researchers and practitioners have put a lot of work into trying to quantify the emissions because of the harmful effects that transportation-related emissions have on the social and the economic environment. For the planning and implementation of any efficient emissions control initiatives, accurate modelling of transportation emissions is essential. The driving cycle is an important idea in models for estimating emissions [20].

In the process of creating driving cycles for analysis, a common approach involves examining and choosing a set of micro-trips that most accurately reflect the speed-time data collected [20]. Driving cycles have been developed for the Sri Lankan context considering the Colombo area and the southern Expressway [10], [11]. However, the resulting driving cycle is often not rigorously evaluated to determine if it accurately represents real-world driving behaviours and traffic conditions. Additionally, it remains unclear which specific parameter related to driving activity provides the most accurate explanation for mobile emissions [20]. Various research studies have demonstrated that contemporary techniques used to develop driving cycles maintain overall features, like the average speed, but fail to capture specific local attributes, such as brief accelerations and decelerations. These short-term events are of significance, as they are likely to influence the quantification of emissions [21], [22].

Compared to driving cycles, the traffic flow simulations done by software such as VISSIM, provide high-detail visualizations of complex traffic circumstances [13]. To meet the local conditions in Sri Lanka, a calibration technique and representative values for parameters have been established for the VISSIM microsimulation software. Parameters have been successfully validated using signalised intersections in the Colombo and Gampaha districts [12]. Furthermore, even though Thalgaskotuwa et al. have identified in their research that there is a need to consider improving the traffic management strategy as well as reducing traffic emissions to optimise the condition, due to the limitation of data availability, they have used the secondary data published on emissions which was conducted in Beijing by Kun & Lei in 2007. The VISSIM simulation model was created afterwards only considering the traffic-related parameters [14].

C. Emission models

Efforts to minimize emissions from road traffic can be achieved through the optimization of traffic management strategies [16], [23], [24], [25]. Evaluating the impact of these strategies on vehicle emissions involves extensive research and applications focused on integrating traffic microsimulation models with vehicle emission models which can create accurate estimations of pollutant emissions [24], [26]. Further, vehicle emissions are dependent on the vehicle operation modes, speed-acceleration profiles, number of stops, duration of the trip, climate, vehicle characteristics such as mass and age, engine temperature, fuel type used, and driver behaviour patterns [1], [14], [15], [16], [27], [28], [29], [30]. Vehicle performance measures, including engine power and engine speed, are also closely connected to the level of emissions produced and the road gradient is a main factor influencing these vehicle performance measures [27], [28], [30], [31]. Intersections and roundabouts, due to their unique traffic flow characteristics which have a high concentration of vehicles, leading to frequent stops and repetitive acceleration and braking cycles, directly affect vehicle emissions [16], [32]. Hence, taking these factors into account is necessary for emission models. Directly using the emission models developed for developing nations can lead to inaccuracies in emission estimates due to significant differences in technology, infrastructure, traffic conditions, driving habits, and emission factors between developed and developing countries [25], [28], [33].

Emission rates are created by testing the vehicles on dynamometers using driving cycles, or speed-time traces [21]. The availability of accurate local data, such as the number of on-road cars, fleet characteristics, vehicle utilization, and driving habits, is essential for the accuracy of emission inventories [34]. Also, the current approaches for predicting actual vehicle emissions use uniform emission parameters and ignore critical elements that may change depending on the purpose of the journey, such as load status, empty-load rate, driving style, etc. [35], [36]. Further, it has been recognized that when calibrating traffic simulation models for specific applications, it is essential to configure the simulation tool to align with each actual initial trajectory and compare the simulated positions with the real ones [37], [38]. In the context of emerging applications concerning emissions and fuel consumption, there is a need for proficient representations of both microscopic and macroscopic traffic streams to represent the real-world scenario [39], [40]. Furthermore, it should be noted that uncertainties in the input data of pollutant emission models have a consequential impact on the resultant traffic-related pollutant emissions, and therefore proper calibration is required [41], [42], [43].

These vehicle emissions are considered in two categories, Direct and Indirect. Top-down and bottom-up methods can be used to develop these vehicle emission inventories [44]. Both approaches depend on emissions factors (EFs) to establish the relationship between activity data (traffic) and the associated emissions. The emission models developed with EFs can be categorized as either static or dynamic (modal) based on the variables utilized, such as speed and acceleration, and their method of integration [44]. The production and composition of emissions change notably depending on the time of day and local factors like wind patterns, traffic composition, and traffic flow [45]. A need has been identified to investigate the significant disparities in emissions measurements between car manufacturers and research labs considering developing countries. This requires creating a comprehensive local emission factor dataset for all vehicle types and standardizing traffic emission assessment methods. Additionally, the impact of fuel quality, different fuels, and alternative technologies on emissions from various types of vehicles, including passenger cars, commercial vehicles, buses, and motorcycles should be studied [44].

Considering the world, the utilization of traffic microsimulation to estimate emissions and analyze traffic has grown in the past decade [46], highlighting the growing necessity for a more detailed calibration [47]. Creating an emission-calibrated model enables decision-makers to assess how traffic management strategies affect urban emissions and air quality [17], [46], [48]. It also helps estimate the emissions resulting from various mobility policies [49], [50]. However, as identified earlier, only secondary data was used for traffic modelling in Sri Lanka due to the limitation of data availability [14].

IV. CONCLUSION

It has been observed that, while traffic modelling has been carried out in Sri Lanka, there is insufficient research focused on modelling the emissions generated by these traffic models, which could aid in making environmentally friendly decisions. Furthermore, it was observed, that while emissions data from vehicle manufacturers is accessible, it inadequately represents the specific circumstances on Sri Lankan roads due to variations influenced by driver behaviours and operational modes. The conditions in which Sri Lankan vehicles operate, the types of vehicles that dominate local roads, and the driving habits unique to the nation, all contribute to emissions profiles that deviate significantly from the global averages upon which manufacturer data is typically based. Hence, it can be identified that there is a need to develop an emission-calibrated traffic model specifically tailored to the Sri Lankan context. The emission-calibrated traffic model, capable of analyzing both traffic-related factors and environmental factors in one single model, will serve as a powerful tool that will bridge the disconnect between traffic flow data and the environmental consequences of traffic planning decisions.

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