Glasgow Low Emission Zone: Simulating the Change in Traffic Flow and the Following Health Outcomes*

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Abstract. Glasgow, a major city in the UK, faces significant traffic congestion and high levels of air pollution. To address these issues, the Glasgow City Council plans to implement a low emission zone (LEZ) from June 2023. This article discusses the challenges and potential benefits associated with the introduction of the LEZ. While previous studies have focused on air quality changes, this research aims to bridge the gap by simulating traffic flow and individual health outcomes using an agent-based model. The work-in-progress study investigates the present traffic and emission levels in Glasgow City Centre, explores the impact of the LEZ on traffic patterns, mobility patterns, and exposure levels, and examines the potential health benefits resulting from reduced air pollution exposure and increased physical activity. The simulation framework utilizes the SUMO traffic simulator and incorporates human agents (pedestrians) and vehicular agents (passenger cars, trucks, buses) to capture the complexity of traffic dynamics and individual behaviours. The model's initial stage seeks feedback to develop a comprehensive and open-source traffic simulation framework. Additionally, the study aims to establish a case study linking traffic patterns to human health, considering the implications for policy scenarios. The findings from this research can inform effective LEZ policy design and implementation, aiding in the reduction of air pollution and improvement of public health in Glasgow and potentially other cities. As we are currently in the developing stage, We would like to reach out to the ESSA@Work experts for advice on how to determine the level of granularity for the traffic simulation (seconds, minutes, or hours), as well as the best simulation documentation framework (ODD+D is one option, but are there any others?). We'd also like to know the best practises for developing a mesoscale traffic simulation. Finally, we'd like to talk about what we should keep in mind when implementing policy scenarios.

Keywords: Low Emission Zone (LEZ) · Glasgow · Traffic Simulation · SUMO · Air Pollution · Health · ESSA@Work.

* This work has been supported is funded by the UK Medical Research Council (MRC) Places and Health Programme, Grant/Award Number: MCUU00022/4; Chief Scientist Office (CSO), Grant/Award Number: SPHSU19

1 Introduction

Glasgow is a major city in the UK that has a high traffic volume from private vehicles to Heavy Goods Vehicles (HGVs) [1]. According to the Scottish Transport Statistics 2022 [2], Glasgow had the most licenced vehicles among Scottish cities in 2021, with nearly 3 million. As the city struggles to keep up with the increasing number of cars and lorries on its streets, the accompanying congestion has resulted in extraordinary quantities of nitrogen oxides from tailpipes and particulates from brake wear, tyre wear, and road abrasion [2, 3]. The situation is further complicated by the fact that the majority of traffic congestion and leading emissions occur in the city centre, where the zone intersects with the busiest pedestrian area in Glasgow with a population of over 60,000 people [2, 4]. Therefore, urgent action is required to address the issue of congestion in Glasgow to reduce its impact on air pollution and protect the health of its residents as well as to encourage people to use active transport.

In response to traffic congestion and a leading health risk, Glasgow will be the first city to enforce a low emission zone (LEZ) from the 1st of June 2023, restricting entry only to vehicles that meet the emission standards. The Glasgow city council predicts that the introduction of the LEZ will lead to an overall reduction in emissions, following successful precedents such as London's city-wide Ultra-Low Emission Zone (ULEZ) [5–10]. However, some studies have raised concerns that the LEZ enforcement may displace air pollution to neighbouring areas due to the possibility of increased traffic congestion from vehicles bypassing the zone or parking for short periods and then restarting engines, leading to further idling [9, 11, 12]. Further, the limited geographical coverage of the LEZ boundaries, such as in the case of Madrid where the zone was 4.7km^2 which accounted for 1% of the municipality's total area [13], raises concerns that the LEZ's effectiveness in reducing air pollution may be limited. As such, the implementation of LEZ is a complex and multifaceted process that requires careful consideration of several factors, including city traffic patterns, spatial coverage, and the economic impact on local businesses and drivers who may not have the financial resources to upgrade their vehicles to meet LEZ standards.

Several Multi-Agent Systems (MAS) studies have examined the possible effects of LEZs on air quality and public health, which could provide useful insights into effective LEZ policy design and implementation [14, 15]. De Bok et al. [16] utilised MAS to investigate the effects of implementing a zero-emission zone (ZEZ) on truck logistics and emission levels in Rotterdam, Netherlands. Their results showed a 0.25% increase in logistical distance, but a significant 90% reduction in CO_2 emissions within the city zone. Meanwhile, Gurram et al. [17] employed Daysim as a scheduler, MATSim as a traffic simulator, and R-LINE as a pollution generator to examine the mobility patterns of individuals.

However, while these studies have provided a meticulous analysis of traffic mobility and emissions, they have primarily focused on changes in air quality levels and have not explored the positive health outcomes associated with such changes, such as increased life expectancy and reduced rates of low-weight full-term births [14]. To address this gap, Shin and Bithell [15] compared the exposure levels of non-exhaust emissions among pedestrians and vehicle drivers after the introduction of a low-emission zone (LEZ) in central Seoul. However, as with Gurram et al. [17], their analysis only considered private vehicles and overlooked LGVs and HGVs, which are major sources of toxic air pollution [14]. Also, the model did not indicate which roads were prohibited for the vehicles that did not meet the standard and how the traffic lights should be redirected [18].

This study aims to bridge research gaps by developing an agent-based traffic simulation that takes into account changes in traffic flows, emission levels, and pedestrians' exposure levels after Glasgow's low emission zone (LEZ) is implemented. Specific research questions include:

- What is the present status of traffic flow and emission levels in the vicinity of Glasgow City Centre?
- To what extent can agent-based modelling be utilised to simulate changes in traffic flow resulting from the implementation of the new LEZ scheme?
- How will individuals' mobility patterns and exposure levels differ once commercial and private vehicle traffic is reduced?
- How does individual health change as a result of less frequent exposure to air pollution and an increase in physical activity after the LEZ implementation?

2 GlasgowLEZSim: The agent-based model for simulating traffic flow and individual health outcomes in Glasgow

2.1 What is the environment?

The LEZ covers the city centre, which is bordered to the north and west by the M8 motorway, to the south by the River Clyde, and to the east by High St and Saltmarket (see Fig 1 left). This area is approximately 4km^2. To simulate inbound and outbound traffic to the city centre, we included road networks from the M8, M77, and M74 motorways, as well as the A74, using the SUMO traffic simulator [18]. SUMO (Simulation of Urban MObility) allows vehicle agents to operate precisely on the road, rather than relying on rules at each junction, making it more accurate than other simulators such as NetLogo [19]. We will explain more about SUMO in the Appendix.

2.2 Who are the agents?

This study classifies agents as either human or vehicular. For **human agents**, their attribute table includes age, educational attainment, employment status, place of origin and destination, as well as walking speed. To realistically model individual-level data, this study collected area-aggregated determinants from census data and survey questionnaires [20]. The maximum speed of an agent may vary based on age, pregnancy, and physical disability. Notably, the agent's nominal health can serve as a proxy for measuring their exposure to traffic emissions [15].

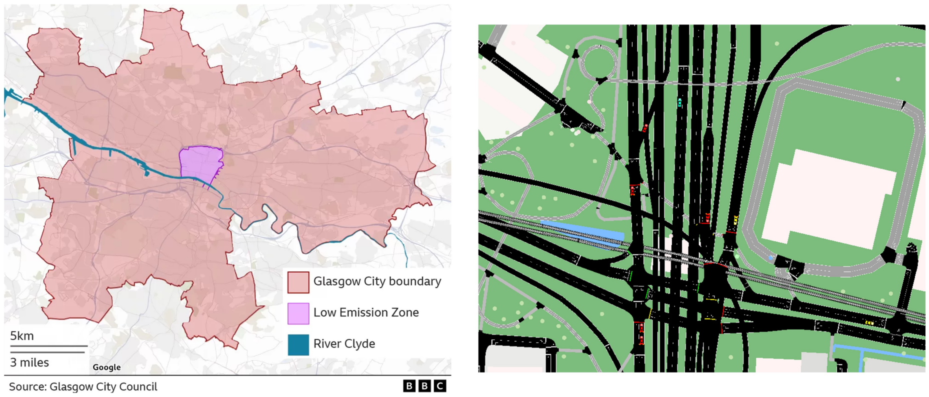

Fig. 1. Glasgow LEZ (left) and A snapshot of SUMO zoomed in Glasgow M8 motorway (right)

Table 1. An example of attributes of a pedestrian agent

Type	Value (example)
Origin	Glasgow Central
Destination	John Lewis
Current Road	Cathedral Street
Speed (mph)	1.8
Nominal Health	75

Vehicle agents are automatically generated in SUMO. This study considers three types of vehicles: passenger cars, trucks, and buses, as well as electric vehicles. For more information, please follow the link provided. Vehicles that are registered as resident vehicles or belong to local businesses can travel to and from the LEZ boundary without issues. However, if the driver of a non-resident vehicle wishes to enter the LEZ, they must comply with the emissions standards, such as Euro 4 for petrol vehicles and Euro 6 for diesel vehicles. The table below provides an example of a passenger vehicle attribute. The number of imported vehicles is determined based on vehicle status statistics from Scottish Transport and CCTV data from the Urban Big Data Centre.

2.3 What do they do? Why?

Pedestrians Pedestrian agent behaviours can be broadly classified into three situations: 1) walking or running outdoors, where they may be exposed to ambient air pollutants; 2) in buildings, including indoor subway platforms, where pollutant concentrations may be brought in from outside; and 3) in vehicles, where road dust can enter through the vehicle filter [21]. In terms of mobility, the software's shortest path algorithm determines the agent's route to their destination, but they will pause and wait if crowd density is too high in certain

Table 2. An example of attributes of a vehicle agent

Type	Value (example)
Vehicle Type	Private Car
Make Year	2017
Fuel	Petrol
Euro	5
NOx	50
PMx	30
Origin	M8 northeast
Destination	Finneston
Current Road	Cathedral Street
Speed (mph)	18
Speed: Max	70
Arrive Time	"13:24 22/07/2023"
Counter (mins)	37

areas. To estimate indoor air pollution rates, this study uses indoor/outdoor (I/O) ratios [22]. For in-vehicle exposure, an equation that takes into account the air exchange rate from windows and the ventilation system, filtration rate, and vehicle volume is strongly considered [21]. The agents' health is assumed to deteriorate if their NO_x exposure exceeds the WHO threshold and improves if they walk or wheel instead.

Vehicles To model non-resident vehicles, we use buses, private vehicles, LGVs, and HGVs to assess traffic in and out of the city centre. Accurately calibrating the volume of vehicles based on factors such as time of day, day of the week, and holidays is critical to the success of the model. We will compare traffic and pollution levels before and after enforcement to determine how pollution changes hourly on each road and rank areas of potential pedestrian risk.

2.4 Are agents reactive or deliberative?

Since atmospheric pollutants are invisible, pedestrians would be unaware unless there was a noxious odour associated with them. Thus, pedestrians are mostly reactive. On the other hand, vehicles have more deliberative behaviour as they must make rational route choices depending on the congested areas and the alternative roads after the LEZ enforcement.

2.5 Do agents learn or adapt behaviours?

Vehicle agents that do not meet the Euro 4 unleaded or Euro 6 diesel standard will adapt to a new behaviour by assigning a new route as a destination. Once the new direction is assigned to these vehicles, the drivers must learn where to park for short periods of time and restart engines once they have re-entered the vehicle. This will obviously be determined by the time of day as well as traffic.

2.6 What is a time step? How long is each model run?

Our model will run continuously, synchronized with the clock time, to simulate traffic patterns. To ensure comprehensive data collection, we plan to run the simulation for two weeks prior to enforcement and two weeks after enforcement. This time frame allows us to observe the daily patterns of commuting traffic and pedestrian movement. Additionally, the two-week period is ideal as it avoids national holidays and pre-school breaks, enabling us to obtain accurate and representative data.

3 The Traffic Simulation Framework using SUMO

3.1 What is SUMO?

This project is using Simulation of Urban Mobility (SUMO), an open-source simulation platform which handles large road networks in a continuous geographic space [18]. This section explains the basics of SUMO and why we try to answer our questions using the platform.

SUMO was developed by the German Aerospace Center in 2002 under a General Public License, with the goal of promoting transportation innovation across various sectors and communities. SUMO's primary function is to simulate traffic flows in cities or identify the routes of individual vehicles. However, what makes this model special is its ability to incorporate code from different libraries into its own model. In our study, we focused on two models for pollution emissions: HBEFA and PHEM. HBEFA, or The Handbook Emission Factors for Road Transport (3rd edition), provides pollution factors such as CO2, CO, HC, NOx, and PMx by vehicle category and fuel type. PHEM (Passenger Car and Heavy Duty Emission Model), on the other hand, determines vehicle emissions according to European emission standards.

3.2 Why is SUMO selected?

We chose this model for both technical and financial reasons. Firstly, the graphical user interface (GUI) makes it easy to import roads in shapefile (.shp) format, allowing us to quickly check for any issues like disconnection points (as shown in Fig 2). Typically, we obtain street data from OpenStreetMap, which includes nodes, links, and turn signals.

Secondly, SUMO has the ability to collaborate with various models, including an emission model. iTETRIS, a model developed by the German government to reduce emissions from vehicles [23, 24], is one such example. Additionally, since SUMO is written in C++ and Python, vehicle emissions can be calculated on a High-Performance Computing such as the cluster located in our unit at the University of Glasgow. Lastly, it's important to note that both SUMO and iTETRIS are freely available software packages that can be downloaded and used on Windows, Linux, or Macintosh operating systems. Alternatively, we are also considering using GRAL (Graz Lagrangian Model), which takes into account the city's meteorological conditions and morphology.

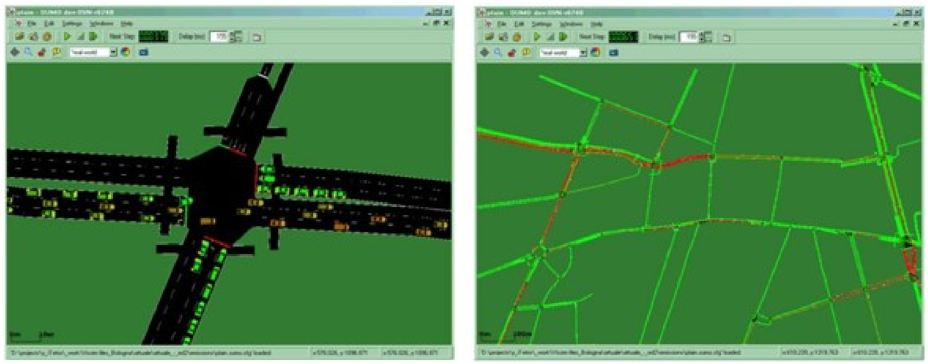

Fig. 2. Example of SUMO GUI (Left), and a map of CO2 emission (Right). Adapted from Krajzewicz et al. [25]

3.3 How does SUMO work?

The overall process involves three main steps: network generation, demand generation, and simulation (as shown in Fig 3). The first step is network generation, where the digital road map is imported and checked for completeness. The netconvert function can read codes from other traffic simulators, such as Visum, Vissim, or MATSim. OpenStreetMap is now the most commonly used format in SUMO [25].

The second step is demand generation, which involves creating vehicles and defining their routes through the network. Each vehicle is given a unique identifier, departure time, and route. SUMO has built-in route functions, allowing it to run simulations with a large number of vehicles without the need for manual traffic demand control. Origin-Destination matrices are commonly used in city-scale analyses, providing estimates of the number of vehicles moving between specific origins and destinations per hour.

There are two versions of SUMO for simulation: a pure command line version and a command line version with a graphical user interface (GUI). The GUI allows for customization of the visualization, such as adjusting car speeds and signal waiting times or tracking individual vehicles. In the simulation stage, SUMO uses a time-discrete simulation, with a default length of 1 second that can be scaled down to 1 microsecond. The maximum duration of one simulation run is about 49 days.

During the simulation, each vehicle's speed is controlled by considering various factors, such as the distance to the leading vehicle, junctions, and lane changes. These car-following models were first created by Brockfeld et al. [26] and have since been expanded to more sophisticated models, including the intelligent driver model (IDM), Wiedemann model, and three-phase model. Results are exported in XML format as time steps, single vehicles, or aggregated measures of all streets.

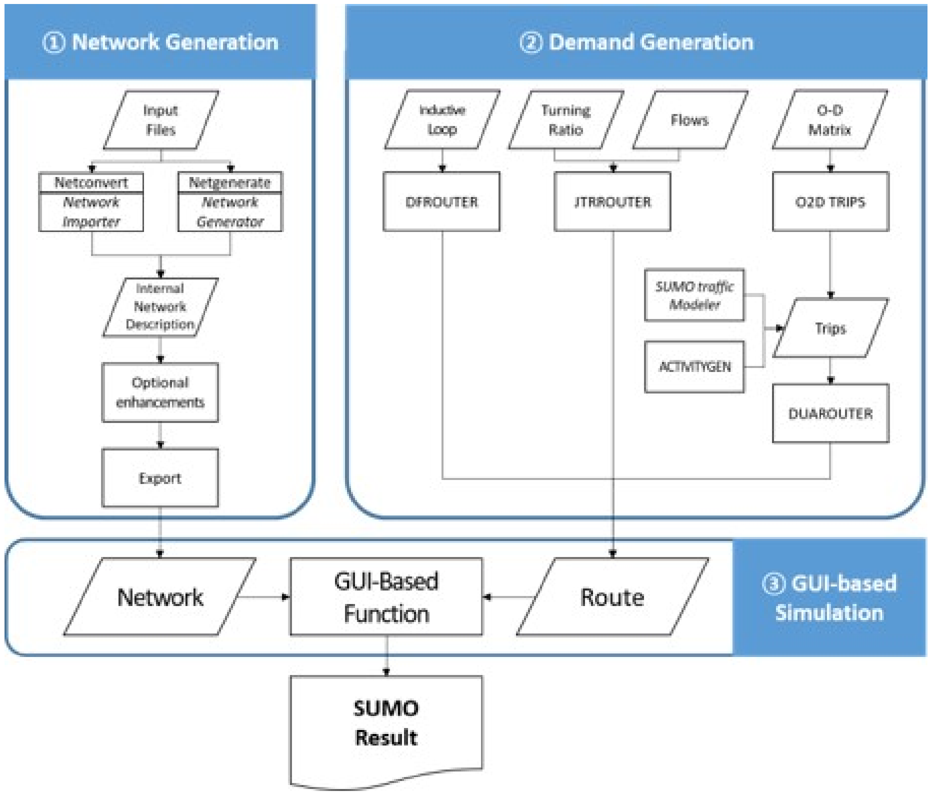

Fig. 3. Overall procedure of SUMO modelling

3.4 Plans to mount SUMO with dispersion models

To ensure accurate results, this project will first verify that the road network is properly connected, as fragmented nodes can lead to traffic congestion and introduce errors in the simulation. Once the road network is verified, each vehicle will be assigned an emissions function based on its fuel type and engine displacement. SUMO provides a built-in emissions function called PHEM-lite (or PHEM for the paid version).

After setting up the emissions model, we will integrate it with a dispersion model. We will use a dispersion model called R-Line, which was developed by the Community Modelling Analysis System (CMAS) team at the University of North Carolina at Chapel Hill and is available for free. R-Line is a steady-state plume dispersion model that integrates point sources along roads [27], and accounts for vertical wind effects and low-wind situations based on the Monin-Okukhov equation. We note that R-Line is a research model and not a regulatory model [27].

4 At the current stage: What do we need for help?

The GlasgowLEZSim project began in April 2023, thereby the model is still in its early stages. As a result, we have three major plans for which we welcome feedback in various forms.

First, we are seeking to develop an open-source and realistic traffic simulation framework for Glasgow, with the possibility of expanding to other Scottish cities. As we embark on this project, we would greatly appreciate empirical advice from the experts at ESSA@Work on how to define the project's scope.

Specifically, we are seeking guidance on how to determine the level of granularity for the traffic simulation (seconds, minutes, or hours), as well as the best simulation documentation framework(ODD+D is one option, but are there any others?). Additionally, we would like to know the best practices for creating a meso-scale traffic simulation. Additionally, we would like to know the best practices for creating a meso-scale traffic simulation. Should we start with a crude yet testable model or gather all the necessary information before beginning the building process? Lastly, what are the best practices for sharing code? Your insights would be greatly appreciated.

Second, we are attempting to develop a case study that associates traffic with human health, particularly trying to answer the question: "Can reducing car use and using more active travel and public transport benefit health?". This research question bears a resemblance to a previous study, entitled "Can air pollution negate the health benefits of cycling and walking?" [28]. Despite its difficulty, what should we keep in mind when implementing policy scenarios?

Data and Models for Reproducibility

As we are attempting open-source research, all data and codes are available to the public in the following URL: https://github.com/dataandcrowd/GlasgowLEZ

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