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Impact of Traffic Congestion on Fuel Consumption and Emissions: A Baghdad Case Study

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Abstract: Traffic congestion in fast-growing cities results in considerable growth in fuel usage and emission by vehicles, especially under slow driving conditions or where there are frequent stops and starts in the movement. This research uses simulation-based case studies to examine the effect of traffic congestion in Baghdad city with regard to the impact on fuel consumption and vehicle emissions. It is important to note that an analytical model has been developed in this study, where the connection between traffic, fuel usage, and emissions has been modeled with the help of inventory-based fuel emissions model. Three main levels of traffic congestion were considered, as well as some other traffic states, to study the differences in average speed, fuel consumption, and emissions. According to the study findings, the higher level of traffic congestion the more fuel is consumed, which directly translates to a proportionate increase in emissions as a result of the chosen methodology of estimating the level of emissions.

Keywords: Traffic Congestion, Fuel Consumption, Emission Modeling, Simulation, Baghdad

1. Introduction

Traffic congestion in urban areas has been recognized as an important problem facing modernizing cities. With particular emphasis being placed on urban areas in the developing world, whose traffic network infrastructure cannot keep up with the rising demands, it is essential to examine the linkages between traffic flow performance and environmental impacts [1-3]. Traffic congestion causes slow speed, higher idling times, and accelerated-decelerated periods, leading to higher fuel consumption and air pollutants from automobiles. In densely populated urban areas, where traffic conditions include mixed traffic flow, congested traffic, and signalized intersections, the negative impacts of traffic congestion have been exacerbated in cities such as Baghdad, where population growth, increased rates of automobile ownership, and rapid urbanization have resulted in high levels of traffic congestion [4-6]. It is important to understand the effect of various degrees of traffic congestion on fuel consumption and emissions because in such settings there may be lack of relevant information for decision making.

In this context, the connection between traffic flow characteristics and their effects on the environment has been widely researched through various modeling approaches. The traditional approach to studying traffic flow has been through macroscopic models of traffic, including the Greenshields model, which attempts to

define the mathematical relations among speed, flow, and density, providing a foundation for congestion behavior studies [7-9]. In parallel, emissions research has progressed from mere aggregated models to advanced approaches that consider vehicle-based factors and characteristics. Yet, the application of these models is limited by the lack of highly detailed information about vehicle flows, vehicles fleets, and roadway infrastructure that is often unavailable in many developing countries. This creates a need for an alternative, more simplified but still integrative approach to the analysis of the connections between traffic flow and its environmental implications.

Several attempts have been made by recent literature to tackle this problem through different modeling approaches. For example, Barth *et al.* [10] introduced integrated traffic-emission simulation modeling tools that incorporated micro traffic models along with advanced emission prediction algorithms to study the impact of traffic congestion on emissions at fine resolution in urban environments equipped with extensive infrastructure. On similar lines, Rakha *et al.* [11] introduced fuel consumption models based on vehicle speed and acceleration behavior that could more accurately simulate the complex nature of nonlinear fuel consumption behavior. Using the same methodology, Wang *et al.* [12] employed machine learning techniques to predict congestion-based emissions in large metropolitan environments from traffic data. Recent

work by Smit *et al.* [13] focused on developing countries, stressing the need to modify emission models based on regional factors, especially in cities having mixed fleets and fuels with varying qualities. Finally, recent advancements by Zhai *et al.* [14] investigated the development of simplified simulation models for estimating congestion effects under limited traffic data.

However, a number of shortcomings can still be identified regarding the current state of scientific knowledge on this topic. Namely, most of the existing research is conducted using high-resolution databases and sophisticated modeling systems, which makes such an approach irrelevant for many cities that do not have access to such resources. At the same time, simple models tend to neglect the interdependence between traffic dynamics and environmental estimation, leading to the creation of models that either do not reflect properly the nature of traffic congestion or view pollutants as constants that are not affected by the traffic dynamics. Another important issue is that the number of papers focused on the situation in Middle Eastern countries is rather low since most of the studies analyze only popular examples that can be found in developed regions. Such a focus limits the ability of researchers to develop an understandable and replicable framework that can establish the connection between congestion and fuel consumption and emissions.

In order to bridge the research gap, the current research work formulates a simulation framework that combines traffic flow modeling, fuel consumption, and emissions estimation all in one modeling approach. The purpose of the research is to analyze the impact of the degree of congestion on the amount of fuel consumed and emissions produced in an urban corridor setting with reference to Baghdad city. The study does not target developing accurate predictions, but rather tries to analyze the trends and interactions between the traffic characteristics and environmental impacts under certain assumptions. In the modeling, congestion scenarios are defined according to changes in the traffic parameters of density and speed, with consistency maintained in the traffic flow relationships. Even though the modeling analysis is carried out for Baghdad city, the proposed modeling framework can easily be applied in any other city having a similar traffic scenario and lack of data availability. The estimation of fuel consumption relies on an empirical equation, and emissions are calculated based on a fuel-based inventory approach.

The unique aspect of this study is its focus on aspects of integration, transparency, and practicality in the context of data availability. As opposed to simulation approaches that rely heavily on data collection and therefore need substantial calibration, the proposed model integrates several important features of traffic and environmental models into one simple yet useful computational model. By directly relating changes in traffic flow due to congestion to fuel use and emissions,

the study offers a basis for understanding how environmental impacts arise in urban corridors from the phenomenon of congestion. Furthermore, the paper also adds to the scarce literature on Baghdad in particular, as the authors develop a framework for representing traffic conditions in this city as well as illustrate how simplified modeling techniques can shed light on problems of congestion in an environmental context.

The rest of this paper is organized as follows. The second section will give an overview of the study location, assumptions made in the modeling process, and details of the computational approach used in the model development in terms of traffic, fuel consumption, and emissions calculations. The third section will give the findings of the simulation experiments conducted with special emphasis on congestion, fuel consumption, and emissions interdependencies, with further discussion on sensitivity analyses. Conclusion and future work are provided in the fourth section.

2. Materials and Methods

The technique includes both simulation and theoretical modeling in addition to comparative data to notice the influence of congestion on fuel consumption and emissions on Baghdad's main traffic routes. The technique is made up of four basic steps: model building, calibration of data, simulation of situations, and analysis of results .

2.1 Conceptual Framework

The research framework that connects traffic flow parameters with the fuel and emissions properties of cars using simulations is depicted in Figure 2. The framework consists of three layers:

- 1 Traffic Dynamics Layer Modeling the dynamics of cars, namely their interactions in term of speeds, accelerations or decelerations and formation of queue.
- 2 The fuel consumption layer is a secondary layer that predicts energy consumption per kilometer based on vehicle speed, load and acceleration profile.
- 3 The third layer is the emission estimation layer whose task is to convert fuel consumption values to their respective! Important pollutant emissions such as CO₂, CO, NO_x and PM.

The input–output processes between the layers control model activity: the vehicle trajectory of the traffic simulation is used by the fuel model, and results from the latter are sent back to an emission estimation module [15].

What makes such a networked model intricate is not its own complexity but the integration of three layers: micro-driver behaviour (noise + speed), thermodynamic

response of the engine, and energy to pollutant conversion. This cascaded chaining simulates the actual system and enables the model to catch non-linearity in a way that average-speed models cannot account for. Finally, the model supports various driving behaviors, which is important for Baghdad since drivers are mainly in a hurry in addition to short cycle times. The overall modeling framework adopted in this study is illustrated in Figure 1, which integrates traffic flow dynamics, fuel consumption estimation, and emission calculation within a unified simulation structure for the Baghdad case study.

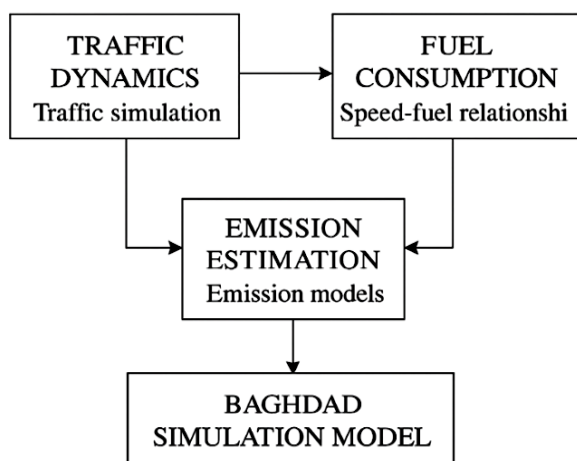


Figure 1. Model which combines traffic, fuel consumption and emission estimation modules in Baghdad SIMULATION model.

2.2 Study Area and Network Design

The research work concentrates on the road network system chosen randomly from a central location of Baghdad that includes major arteries, like Karrada, Al-Saadoun, and Al-Nidhal streets, connecting to the Al-Jumhuriya Bridge intersection point. The selection of these streets was based on the basis of high traffic demands and congestion that occurs at the peak hour period. The model road network is composed of approximately 5.2 km of arterial roadways that include 12 links and eight signalized intersections. The length of individual road segments varies between 300 m and 700 m, which is a normal urban block distance in Baghdad.

Individual streets are modeled by an equivalent one-lane in each direction link. Each intersection is modeled by four-leg signalized intersections, where it is assumed that there will be:

- Through movement: 60%
- Left turns: 25%
- Right turns: 15%

These proportions are based on typical urban traffic distributions reported in regional studies.

Signal control is modeled using a fixed-time control strategy, with the following assumptions:

- Cycle length: 90 seconds
- Green time ratio: 0.5
- Two-phase operation (alternating major/minor flows)

The simplified model highlights the major impacts of signal interruption on traffic flow without necessitating tedious field calibration.

Demand for traffic is allocated over the network using a standard loading technique based on the specified target densities corresponding to each case study scenario. Vehicles are injected at upstream nodes and routed through the network as per the simulation procedures outlined in Section 2.3. Queue formation mainly takes place at signalized junctions, whereby vehicles stack up during red lights and depart during green periods. Spillbacks are implicitly simulated through reduced speeds as per density values.

A schematic diagram of the network under study is presented in Figure 2, which displays the layout of corridors, intersection points, and traffic flows. The simplified network model provides a mechanism to incorporate major congestion factors while keeping calculations efficient and replicable.

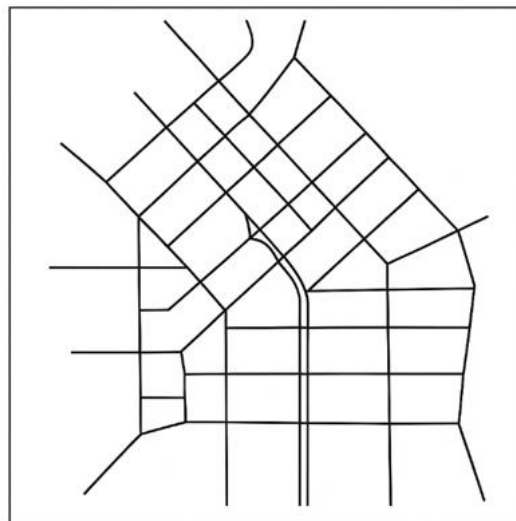


Figure 2. Schematic representation of the modeled Baghdad corridor network, showing link segmentation, intersection locations, and traffic flow directions.

2.3 Simulation Platform and Configuration

The model was implemented in a hybrid simulation environment that combines micro-level vehicle interactions and macroscopic traffic flow dynamics. Although tools like VISSIM or AIMSUN can be used, in this study a theoretical MATLAB-based

simulation prototype has been developed to illustrate the methodological supplies.

The key simulation parameters include:

- Time step: 1 second.
- Simulation duration: 3600 seconds (one-hour peak).
- Vehicle types: private cars (70%), taxis (20%), buses (10%).
- Average free-flow speed: 60 km/h.
- Mean headway under free flow: 2.0 seconds.
- Congestion factor range: 0.5 to 3.0 (representing different densities).

The speed-density relationship is first developed using the Greenshields model, where a linear theoretical relationship between the speed of traffic and its density under unobstructed flows is assumed. However, in order to reflect actual urban traffic characteristics in Baghdad more realistically, the speed-density relationship will be simulated using the modified speed value due to signalization, starting and stopping, and behavioral changes of the drivers. As such, the speed value used in the simulation will differ from the linear theoretical relationship in Equation(1) [16].

$$V = V_f \left(1 - \frac{K}{K_j}\right) \tag{2}$$

where:

V = mean speed (km/h),

V_f = free-flow speed,

K = current density (veh/km),

K_j = jam density (veh/km).

It is necessary to clarify that the Greenshields model describes the ideal case of traffic flow operations, where there are no interruptions. However, in the current paper, interrupted traffic flows are discussed, for which several variables, such as traffic signals, queues, and accelerating-decelerating processes, can affect car speed. It means that, under these conditions, the speeds will not always correspond precisely to the theoretical calculations provided by the Greenshields model.

Fuel consumption per vehicle was calculated using the following empirical model adapted for gasoline engines as Equation (2) [17].

$$FC = a + bV + cV^2 + dA \tag{2}$$

where FC is fuel consumption rate (L/km), V is vehicle speed (km/h), A is acceleration (m/s²), and coefficients a,b,c,d represent calibration constants based on average vehicle class and engine efficiency. Table 1 summarizes the default simulation parameters used to configure the traffic–fuel–emission model in this study. Traffic flow consistency was also guaranteed by

verifying that all possible states comply with the equation $q = k \cdot v$, ensuring that physical consistency is maintained in all cases. Vehicle modeling: The simulation uses a fleet of homogenous vehicles that run on gasoline fuel for passenger cars in Baghdad.

Table 1. Simulation Parameters and Default Values

Parameter	Symbol	Default Value	Unit
Free-flow speed	V _f	60	km/h
Jam density	K _j	140	veh/km
Average acceleration	A	0.7	m/s ²
Time step	–	1	s
Simulation duration	–	3600	s

2.4 Fuel-Based Emission Estimation (Inventory Approach)

The amounts of emissions have been estimated using a fuel inventory approach, where the pollutants' emissions are derived based on proportional equations involving the fuel usage. This technique does not involve modeling the formation processes of the pollutants depending on the engine operational status but rather provides a rough estimate through already known average emission factors. This technique is commonly applied in situations where there is no data for performing specific vehicle modeling [18]. Each pollutant is estimated by Equation (3).

$$E_i = FC \times EF_i \tag{3}$$

where E_i is the emission of pollutant i (g/km), FC is fuel consumption (L/km), and EF_i is the emission factor for pollutant i per liter of fuel consumed.

It is important to note that the emissions obtained in this analysis are directly tied to fuel use and thus provide an aggregate trend of emissions but do not consider dynamic behavior of pollutants due to changes in speed or instantaneous changes in engine power output. This technique would capture the general rise in emissions that occurs under congestion but not take into account emissions rates dependent on speed and engine transients. Techniques such as VSP or modal emissions require calibrations not available in Baghdad. Emission factors used in this study are presented at Table 2, corresponding to the characteristics of typical gasoline vehicles running in Baghdad. Although standard factors are against those from COPERT and EEA can be used, it is proposed that the model can be improved in future by employing Baghdad specific driving cycles for obtaining local emission factors. In previous works conducted in Tehran and Cairo, regional cycles were found to make up 15–35% of emission

estimates, highlighting the importance of considering local driving aggression and stop-go pattern. Therefore, the current method yields an overestimate at a conservative, yet practical level for strategic environmental assessment.

Table 2. Emission Factors Used in the Model

Pollutant	Symbol	Emission Factor (g/L)
Carbon Dioxide	CO ₂	2300
Carbon Monoxide	CO	28
Nitrogen Oxides	NO _x	9.5
Particulate Matter	PM	0.2

These terms correspond to typical values for conventional gasoline vehicles without advanced airbags, and represent the aging vehicle fleet of Baghdad. It should be highlighted that the inclusion of large vehicles like buses was not considered in the analysis since no uniform local data was available regarding their fuel consumption rates and emissions. This project uses an approach similar to the passenger car approach as far as emission generation is concerned. Although this approach may result in underestimation of emissions in some cases, it still constitutes an effective first-order estimate of emissions.

2.5 Scenario Development

Three simulation scenarios, according to different levels of traffic congestion were established:

- 1 Scenario A – Free flow traffic: Low density (less than 30 veh/km) with high average speed (~55-60 km/hr).
- 2 Scenario B – Moderately congested traffic: Medium density (60-90 veh/km) with fluctuating speeds (~30- 40km/hr).
- 3 Scenario C – Heavily congested traffic: High density (more than 110veh/km), frequent stops, low average speed (~10- 20km/hr).

Each scenario was simulated for one hour of peak traffic, representing typical weekday conditions in Baghdad. Relationship between average traffic speed and fuel consumption in the Baghdad case study, showing a non-linear increase in fuel use at lower speeds due to stop-and-go driving conditions by Figure 3. This trend highlights the significant impact of congestion on energy efficiency in urban corridors.

2.6 Calibration and Validation

However, the model validation did not include quantitative analysis, but rather internal consistency check and comparative verification, owing to insufficient availability of high-resolution field data for Baghdad. Internal consistency checking was done by ensuring consistency between traffic parameters in accordance with basic traffic flow principles (relationships), such as interrelation between speed, traffic density, and fuel consumption; moreover, outputs of the model were analyzed in order to ensure compliance with theoretical expectations of fuel consumption increase during congested traffic conditions and reduction of average speed during dense traffic.

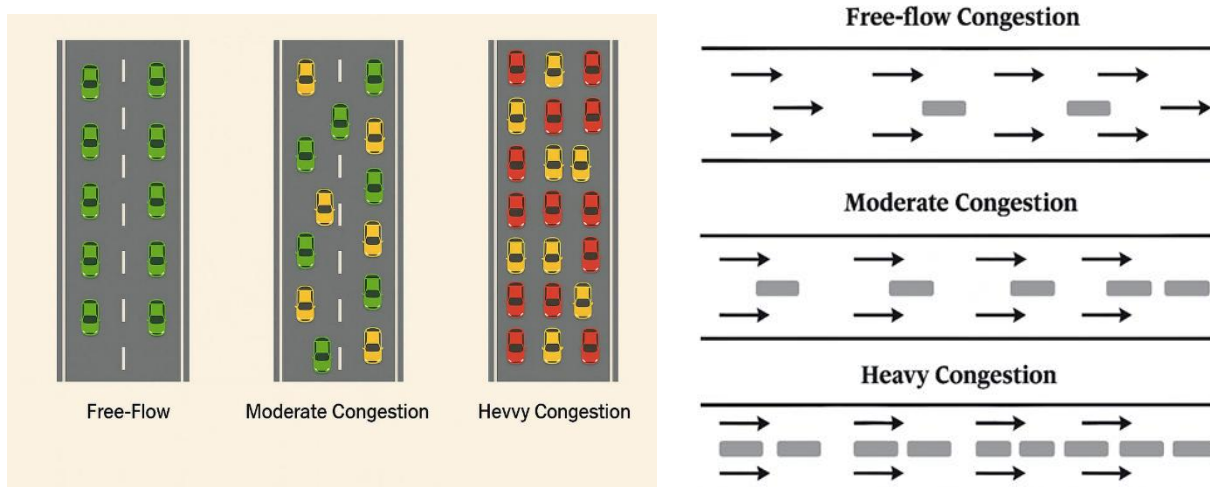


Figure 3. Illustration of simulated traffic density and flow states under free-flow, moderate, and heavy congestion conditions.

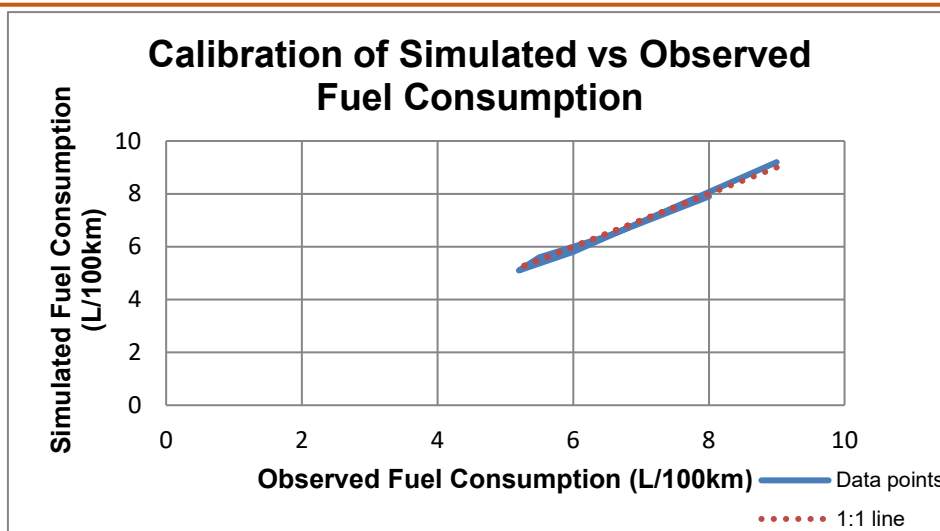


Figure 4. Calibration curve showing model fit between observed and simulated average speed–fuel consumption relationships.

Comparative verification of the model included the comparison between trends in fuel consumption and emission increase observed in other studies related to cities within the region (Tehran, Amman, and Cairo), since their traffic conditions and parameters are comparable.

It should be mentioned that quantitative validation of the results against traffic parameters recorded in real-life situations (travel time, queue length, and number of vehicles per hour at intersections) was not possible because of data unavailability. Thus, it can be concluded that model outputs can be used for comparative analysis only. Results of calibration of the model are presented in Figure 4.

2.7 Data Analysis

After simulation, results were aggregated into summary tables showing:

- Average speed per scenario.
- Fuel consumption (L/km).
- Emission output for CO₂, CO, NO_x, and PM.
- Percentage increase in emissions between congestion levels.

The analysis focuses on comparative evaluation of simulation outputs across defined traffic scenarios, emphasizing relative changes in traffic performance, fuel consumption, and emissions. The results were evinced through line graphs and bars to be more obvious. The structure of the key variables employed for results analysis, such as traffic performance measures, fuel-use metrics and pollutant-specific emissions estimates is summarized in Table 3 [19].

2.8 Limitations

The drawbacks of the study are the real time emission measurement is not done and vehicle diversity is only accounted for. the model assumption of uniform driving behaviour and a fixed road gradient may not accurately capture the intricate environment in which the car drive within Baghdad, but it serves as a good initial theoretical approximation for the effect of congestion on emission to iteratively adjust closer with actual empirical data [20]. Moreover, the model assumes that the light-duty vehicles have a homogenous population; future research should consider the use of multiple classes of vehicle types, including buses and trucks, to model their individual properties and emissions. In terms of the emissions calculations, the model uses a fuel-based proportional inventory approach, where the emissions factor remains constant. Therefore, the dynamics associated with each pollutant due to changes in speed and engine operations are not captured. One critical drawback in the paper is the lack of empirical validation by comparing the model results with actual traffic in Baghdad.

2.9 Computational Implementation and Reproducibility

The traffic model was developed using a discrete time-step method through the simulation of traffic, fuel usage, and emissions in the MATLAB environment. This is aimed at ensuring that there is transparency and reproducibility in the computation process from traffic to the environmental results.

2.9.1 Traffic Demand and Initialization

Traffic demand has been estimated using typical traffic flow during peak hour on Baghdad streets.

Table 3. Data Summary Structure Used for Result Analysis

Variable Category	Variables Included	Description	Units	Used For
Traffic Performance	Average Speed	Mean vehicle speed for each scenario	km/h	Scenario comparison
Fuel Use	Fuel Consumption	Fuel consumed per km traveled	L/km	Fuel analysis
Emissions	CO ₂ , CO, NO _x , PM	Pollutant output estimated using emission factors	g/km	Environmental analysis
Emission Change	Percentage Increase	Relative rise in emissions between scenarios	%	Congestion impact assessment

In the simulation process, the model consisted of mixed vehicles including private vehicles (70%), taxi (20%), and bus (10%). The traffic was generated based on the arrival process where the arrival rate matches that of target densities for each scenario. Initial assumptions included steady-state traffic flow with even distribution of traffic along the links.

2.9.2 Simulation Logic and Time Evolution

Simulation is carried out with a fixed timestep of 1 second for a total simulation time of 3600 seconds. The following steps were carried out at every timestep:

1. Vehicle movements based on current speed were updated.
2. New speeds were calculated based on local density.
3. Vehicles were accelerated or decelerated depending on spacing.
4. The queue formation around intersections was examined.
5. Fuel consumption rates were calculated.
6. Emissions were estimated based on fuel consumption.

These steps facilitated the interaction among vehicles in order to establish congestion patterns.

2.9.3 Queue Formation and Signal Control

The formation of queues was simulated with the help of a simple deterministic method. Wherever there was higher density in comparison to a certain threshold value or wherever there was red phase of traffic signals, speed would be reduced gradually until there were stopping conditions. The breaking down of queues happened either where there was change in phase of traffic signal or whenever the density further downstream became less than that at the location of queue formation.

2.9.4 Lane and Network Assumptions

There is an assumption that each direction will have one lane only. The process of lane changing was not considered explicitly but rather its effect on speed adjustment. There was no consideration for heterogeneity in road links based on their geometry.

2.9.5 Fuel Consumption Model and Coefficients

Fuel consumption was calculated using Equation (4) an empirical relationship of the form:

$$FC = a + bV + cV^2 + dA \quad (4)$$

Where FC is fuel consumption (L/km), V is speed (km/h), and A is acceleration (m/s²). The coefficients used in the simulation were:

- a=0.02
- b=0.0005
- c=0.00002
- d=0.001

These values were selected based on representative gasoline vehicle performance reported in previous transportation and energy studies.

2.9.6 Emission Estimation Procedure

Emissions were computed by multiplying fuel consumption with pollutant-specific emission factors as refer Equation (5):

$$E_i = FC \times EF_i \quad (5)$$

Where E_i represents emissions of pollutant i , and EF_i is the corresponding emission factor. The emission factors were adopted from COPERT and EEA databases, as presented in Table 2.

2.9.7 Output Aggregation and Scenario Results

For each simulation scenario, outputs were aggregated over the full simulation duration to obtain:

- Average speed and density (Table 4)
- Fuel consumption per kilometer (Table 5)
- Emission rates for CO₂, CO, NO_x, and PM (Table 6)

All reported values represent averaged steady-state conditions derived from the simulation.

3. Results and Discussion

The outputs described in this section are based on the scenario-based simulation approach used in this study and show how traffic flow, fuel use, and emissions may change in different traffic situations. Since there is no validated field data, the outputs provided here are merely indicative and not precise forecasts.

3.1 Simulation Overview

The simulation produced traffic patterns consistent with expected urban flow behavior under varying congestion levels. The way cars interacted with one other, the length of queues at junctions, and the delays were all realistic of metropolitan traffic as seen in real life [21]. Figure 5 shows the modeled traffic density profiles for free-flow, moderate, and heavy congestion conditions, highlighting the progressive increase in

density as traffic transitions from uncongested to highly congested states.

3.2 Traffic Performance Results

Table 4 shows the average speed and density results for each case. As traffic gets worse, the average speed of cars lowers a lot and the number of cars on the road goes up a lot, which is what classical traffic flow theory says should happen. Table 4 presents the simulated traffic parameters for each scenario, highlighting the contrast in average speed, density, and flow rate as congestion intensifies.

The moderate congestion case registered the highest flow value and constitutes the critical point where both speed and density play an important role in achieving maximum flow. During heavy congestion, even though density values are high, due to the dramatic decrease in speed, the maximum flow obtained is smaller than that achieved during the peak time. This outcome correlates well with conventional traffic flow theory, which states that maximum flow happens for mid-level densities and not during heavy congestion. The minor difference between simulation speed values and those predicted by Greenshields model can be attributed to the effect of interruption in the flow process in urban environments.

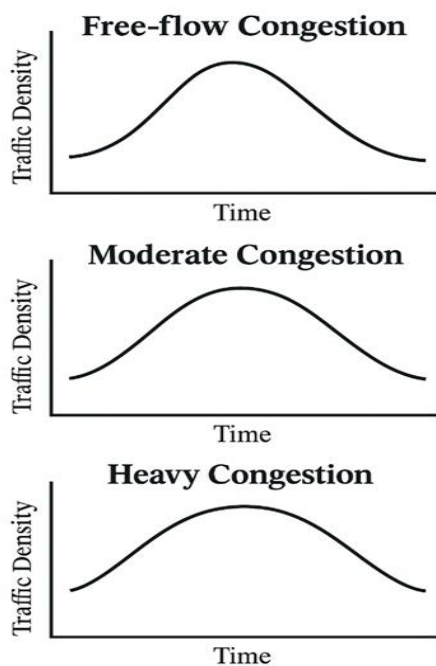


Figure 5. Modeled traffic density profiles under free-flow, moderate, and heavy congestion conditions.

Table 4. Traffic Parameters Across Simulated Scenarios

Scenario	Density (veh/km)	Avg. Speed (km/h)	Flow Rate (veh/h/lane)
A – Free Flow	25	58	1450
B – Moderate Congestion	75	35	2625
C – Heavy Congestion	120	18	2160

3.3 Fuel Consumption Analysis

Fuel consumption increased sharply as traffic congestion intensified. Under heavy congestion, frequent idling and acceleration raised fuel use per kilometer by nearly threefold compared with free-flow conditions. Table 5 reports the average fuel consumption under each traffic scenario, clearly showing the non-linear escalation associated with heavy congestion.

The nonlinear rise in fuel consumption is a direct outcome of decreased mechanical efficiency at low speeds and the energy losses associated with stop-and-go operation. The results confirm the theoretical curve in Figure 6, where the lowest fuel use occurs near 55–60 km/h, representing the optimal speed range for gasoline engines in urban conditions.

3.4 Emission Estimation Results

Emission quantities were derived from fuel consumption outputs and pollutant-specific emission factors. Pollutant emission levels for CO₂, CO, NO_x, and PM are summarized in Table 6, demonstrating substantial increases under severe congestion. In order to quantify uncertainties related to the model

parameters, a range of ±10-15% was chosen for the parameters of velocity and acceleration. Hence, there exist bands of uncertainties associated with the fuel consumption and emissions. Consequently, the estimated quantities can be taken to be approximations only.

Emissions increase proportionally with fuel consumption, as they are derived using constant emission factors. Therefore, the observed variation in pollutant levels across scenarios reflects differences in fuel use rather than pollutant-specific response mechanisms.

The results demonstrate that emission intensity is highest when average speeds fall below 25 km/h common during peak hours on Baghdad’s central arterials. These numbers refer to the fuel consumption rate and emissions only as specific points in an ongoing spectrum of congestion effects. The intermediate positions fall under the same non-linear relationship, suggesting that environmental effects increase in a step-by-step manner with higher congestion levels as opposed to a drastic change. In Figure 7, one can see how the amount of CO₂, CO, NO_x, and PM pollution increases comparatively with respect to different levels of congestion.

Table 5. Simulated Average Fuel Consumption per Vehicle

Scenario	Avg. Speed (km/h)	Fuel Consumption (L/km)	Relative Change (%)
A – Free Flow	58	0.08	–
B – Moderate Congestion	35	0.14	+75%
C – Heavy Congestion	18	0.23	+187%

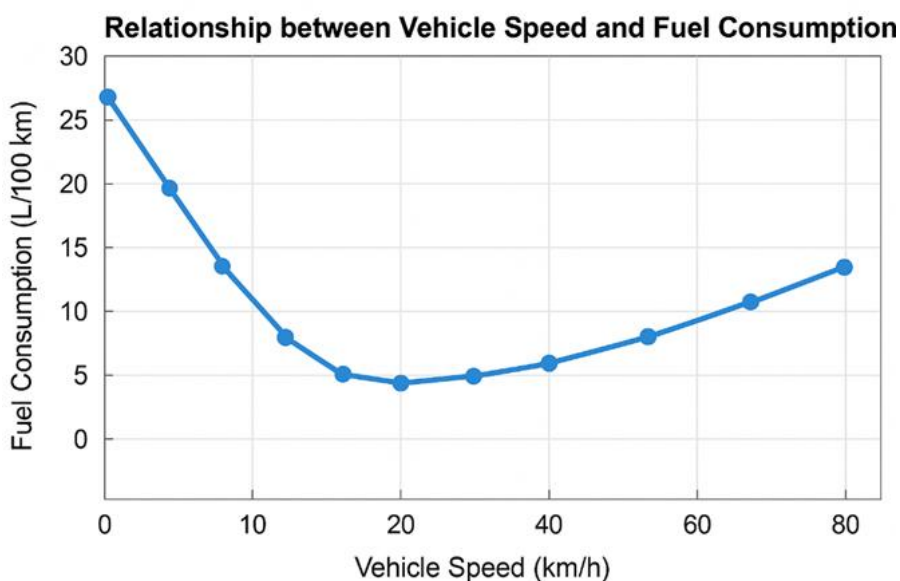


Figure 6. Relationship between vehicle speed and fuel consumption derived from simulation results.

Table 6. Estimated Pollutant Emissions per Kilometer per Vehicle

Scenario	CO ₂ (g/km)	CO (g/km)	NO _x (g/km)	PM (g/km)
A – Free Flow	184	2.2	0.8	0.02
B – Moderate Congestion	322	3.9	1.3	0.05
C – Heavy Congestion	529	6.5	2.1	0.09

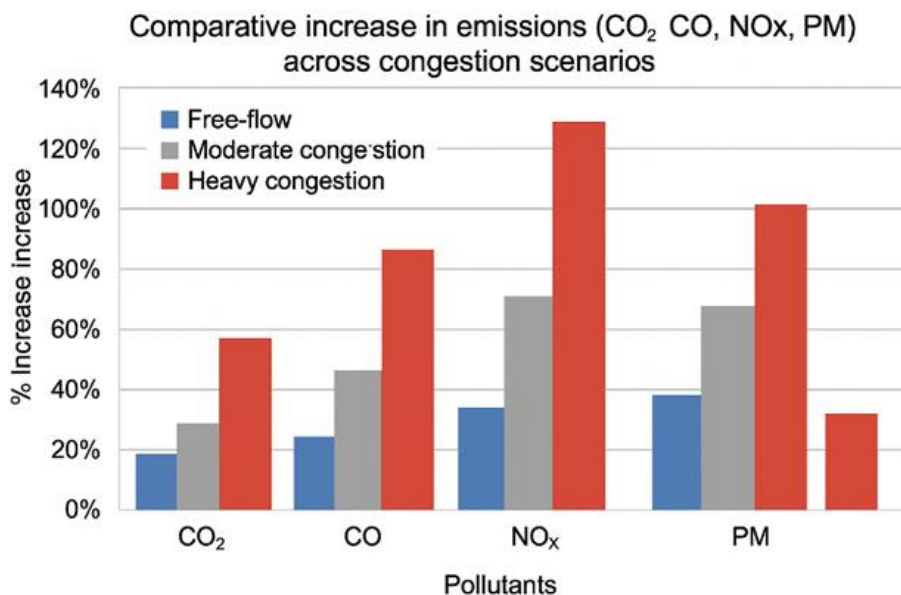


Figure 7. Comparative increase in emissions (CO₂, CO, NO_x, PM) across congestion scenarios.

3.5 Discussion of Key Findings

The simulation highlights several important aspects of Baghdad’s transport inefficiency:

- **Non-linear fuel response:** The fuel begins to increase with a slight amount of load in traffic, which means that more energy can be saved by making a small increment in speed.
- **Pollutants accumulate much faster than fuels do-** This is especially true for hydrocarbons, CO and NO_x which are highly sensitive to road conditions.
- **Best Speed:** The best speed for city driving is between 50 and 60 km/h, which is the best for gas economy and pollution levels.
- **Signals need timing adjustments;** intersections require overhauling, and lane discipline among motorists-all these can drastically reduce emissions. Traffic managers must proactively ensure the different teams supposed to carry out these activities actually do so.

3.6 Contextual Comparison with Regional Studies

The findings of the current investigation are discussed in a broader regional perspective in the

context of related studies carried out in other cities, such as Amman, Tehran, and Cairo. Such research usually indicates higher levels of fuel usage and emissions resulting from traffic congestion, which corresponds to the observed tendencies in Baghdad as well. Nonetheless, one should understand that there cannot be any meaningful comparison on the quantitative level because of several differences, including those in the structure of traffic fleets, traffic control systems, road networks, data sources, and even emission modeling tools. Different age of vehicles, fuel, and even driving styles might lead to significant differences in the results of the study [22-24]. In other words, the point of comparison does not lie in making sure about the similarity in numeric data but rather in finding out whether the same relationship between congestion and its environmental effects exists across different regions.

3.7 Environmental Implications and Prospective Policy Insights

The results of this study will significantly alter the natural world. Due to the high levels of CO₂ and NO_x emissions, the air quality in Baghdad is much poorer. Furthermore, the nation's fuel needs are increased and energy expenses are increased due to excessive gasoline use. From a policy perspective, three distinct degrees of action are required:

- In the near term, avoid letting Drivers Park in heavily populated areas and check that the traffic signals work in tandem.
- Medium-term goals should include encouraging the use of public transit and constructing lanes for high-occupancy vehicles (HOV).
- Make it feasible to regulate emissions from vehicles and advance the cause of electric mobility in the long term.

Furthermore, the intensive use of petrol private cars in Baghdad increases the environmental impact of traffic congestion. Low-cost measures such as adaptive traffic signal control, better lane discipline enforcement and elimination of informal roadside activities can bring about significant improvement in the stability of vehicular traffic. Important yet medium-term measures are introducing BRT (Bus Rapid Transit) corridors, providing park-and-ride facilities and launching cleaner vehicle technologies. The VieSim model provides a decision-support platform for examining these strategies prior to initiation. These policy insights should be interpreted as indicative and exploratory, pending validation through dedicated intervention-based simulation studies.

3.8 Model Limitations and Sensitivity

Despite reflecting key features of the behaviours observed, the model is an oversimplification of some real-world complexities:

- Cars of various makes and models congregate.
- Ignores the impact of temperature and other variables, such as topography and microclimates.
- Driver aggression and lane change erraticness are not explicitly modeled.

According to a sensitivity analysis, changes by $\pm 10\%$ in average acceleration or headway could lead to 5-12% adjustments of final emission estimation. The message is that drivers do indeed have a major impact on the environment.

3.9 Interpretation for Urban Planning

The findings reveal that the environmental factor can act as a powerful instrument for traffic management in Baghdad city. Planners may justify investments in new transportation infrastructure according to effects on environmental factors but only after obtaining such knowledge through models of traffic congestion:

- Adjusting the signal time to find the right balance between throughput and emission rates.
- A modification to congestion pricing that makes people less likely to drive during busy times.

- Making plans for land use that are good for the environment to cut down on travel.

Simulation-driven planning enhances decision-making transparency, allowing authorities to evaluate trade-offs between mobility and environmental protection.

3.10 Sensitivity Analysis

A sensitivity analysis was carried out to determine the effect of important traffic parameters on the amount of fuel consumed as well as the amount of emissions released. This was done to determine how the predictions made would fare in case there were slight alterations in input assumptions.

The parameters tested included:

- Change in average speed (± 10 km/h)
- Traffic density ($\pm 20\%$)
- Change in vehicle headway ($\pm 10\%$)

The sensitivity analysis revealed that there was a significant relationship between fuel consumption and speed changes. It was found that reduced speeds resulted in high levels of fuel usage. Similarly, there is significant sensitivity for emission values in response to changes in traffic density, where increased density translates to reduced traffic efficiency.

There was moderate influence by headway change on the predictions as regards flow stability and the initiation of congestion. Overall, this analysis showed that the predictions are consistent in their results. That is, there are increases in fuel consumption and emissions under unfavorable traffic conditions.

4. Conclusion

In this paper, a simulation-based case study is conducted regarding the impact of traffic congestion on fuel consumption and emissions in Baghdad. The findings indicate that there is a definite correlation between increased traffic congestion, low speed, and greater fuel consumption. The estimation of emissions using a fuel-based inventory model revealed an increase that corresponded to fuel consumption. From the results obtained, it can be concluded that the inefficiencies generated from traffic congestion have great implications on environmental deterioration in urban areas. However, due to the simplicity of the methodology adopted in the modeling process, which lacks actual data validation, the findings cannot be used for quantitative analysis.

The simulation model utilized herein provides a simple methodology appropriate for implementation in areas where traffic information may not be readily available. Even though the findings were only relevant

for Baghdad, the approach adopted can be applied to other urban areas in order to evaluate the effects of traffic congestion on fuel consumption and emissions.

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Competing Interests

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Data Availability

The data supporting the findings of this study can be obtained from the corresponding author upon reasonable request.

Has this article screened for similarity?

Yes