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Assessment of the Traffic Enforcement Strategies Impact on Emission Reduction and Air Quality

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Abstract

The World Health Organization (WHO) reported that globally 3.7 million deaths were attributable to ambient air pollution (AAP) in 2012. Traffic congestion is one of the significant sources of air pollutants Intelligent Transportation Systems (ITS) are advanced technologies that have been used widely in large cities. They have a potential impact on reducing traffic congestion and then improving environmental quality. Many countries have targeted urban policy traffic enforcement strategies that are ITS-based on improving traffic emission and air quality. Because each strategy has a different impact level, the strategy that positively impacts location and traffic conditions might negatively impact under different conditions. Also, the authorities that take the decision which strategies could be implemented. Therefore, this paper aims to evaluate the potential impact of traffic enforcement strategies on reducing traffic emissions and improving air quality. In our study, three typical traffic enforcement strategies were evaluated: a traffic management regulation for speed limit changes, route changing, and fleet composition changes. The impact of these strategies on air quality was evaluated through evaluating the traffic air quality changes brought by these strategies against a baseline (Base Case) scenario. The results indicate that the impact of these strategies on increasing environmental quality is not always positive. The reduction of CO was the highest in the speed restriction scenario (25.6%) than other scenarios. While reducing the reduction of PM10 was less in speed restriction scenario (25.6%) than other scenarios. The findings can help the decision makers implement the best strategy to reduce traffic emission under different situations.

Keywords: *Intelligent Transportation Systems; Traffic Congestion; Environmental Quality; Large Cities*

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1. Introduction

The world population living in urban areas has increased from 33% in the 60s to 55% in 2017 (according to the United Nations (2018) and is estimated to increase by 68% by 2050[1]. Rapid urbanization has resulted in a large increase in the number of vehicles and car ownership. The growth has led to serious traffic congestion problems. Traffic congestion is a global problem that has a negative impact on safety, the economy, and the environment [2]. The World Health Organization (WHO) reported that "globally 3.7 million deaths were attributable to ambient air pollution (AAP) in 2012[3]. Approximately 88% of these deaths occur in low- and middle-income (LMI) countries, representing 82% of the world population. Deaths also occurred in large numbers in high-income countries of Europe, the Americas, and the Eastern Mediterranean [3]. Traffic is one of the primary sources of outdoor air pollution in urban areas [4].

Urban transportation is responsible for 40% of CO_2 emissions, and about 70 % of other pollutants come from road transport in the European Union [5]. CO_2 from the transportation sector in developing countries was estimated to double in the next two decades by an increased rate of 3.5% per year [6]. Out of all transportation modes, vehicles only are responsible for 25% of the carbon dioxide (CO_2) emissions, as well as 90% of the carbon oxide (CO) and 50% of the nitrogen oxides (NO_x) emissions generated worldwide [6]. Another report in the United States in 2013 estimate that traffic contributed to 14% of all volatile organic compound (VOC) emissions, 38% of all nitrogen oxide (NO_x) emissions, and 34% of all carbon monoxide (CO) emissions [7].

Several traffic management strategies have been proposed and introduced in many cities as an essential part of urban management to improve the environment. Governments worldwide are taking action to reduce traffic emissions and build sustainable urban transport systems [8]. These strategies include (1) improved road infrastructure; (2) encouragements for road-based public transport; (3) operating restrictions and pricing; (4) technological solutions; (5) awareness-raising campaigns; (6) speed management; (7) traffic flow control/ fleet composition control, and (8) control of land-uses [8]. Traffic management strategies that are introduced to reduce air pollution emissions are complex. They vary in many ways, having different impact levels, effect ranges, and costs. For example, diesel engines were reported to be more efficient than petrol engines and consume less fuel, and emit less CO_2, which is the major contributor to global warming. But diesel vehicles emit more NOX than petrol vehicles, which is harmful to human health [9].

Traffic Enforcement is considered an integral part of traffic management strategies. As traffic management is logically applied and consistently enforced, it will not be sufficient [10]. On the other hand, some traffic enforcement strategies that reduced air pollutants and GHGs emissions at one location may have an opposite impact at another connected location. For example, the policy of setting low emission zones (LEZ), which restrict vehicles entering certain areas, may reduce the emissions within the LEZ, but also may force some vehicles to choose alternative longer routes and thus increase the traffic volume at other areas [9].

Road authorities have now recognized that building additional road capacity alone does not help to solve traffic congestion due to the cost of new infrastructure and a long time to construct; the intelligent transport-based solution is accepted recently [6].

Intelligent Transportation Systems (ITS) are advanced technologies that have been used in large cities to reduce the impact of traffic congestion. These systems involve applying advanced technologies, including computers, information processing, communications and control systems to improve the efficiency and capacity of existing road infrastructure [6]. Numerous reports have been published in order to determine the extent of the problem, and in particular, this has led to the development of a new area of study, Intelligent Transportation Systems (ITS) [11]. with the primary objective of optimizing road traffic by managing the capacity of the roads, improving driver safety, reducing energy consumption, and improving the quality of the environment, among many others things [12]. Because each strategy has a different impact level, which means the strategy that has a positive impact at location and traffic conditions might negatively impact under different conditions. Also, the authorities take the decision which strategies could be implemented. For example, the speed restrictions strategy may not always decrease emissions; some vehicles and some pollutants can decrease with speed for lower speeds and increase again at higher speeds [13].

Consequently, the analysis of traffic enforcement strategies concerning their potential impact can help the public and policymakers be aware of these strategies' effectiveness when and where they should use. Therefore, the paper's objective is to evaluate the potential impact of traffic enforcement strategies on reducing traffic emissions and improving air quality.

In our study, three typical traffic enforcement strategies were evaluated: a traffic management regulation for speed limit changes, route changing, and fleet composition changes. The impact of these strategies on air quality was evaluated through evaluating the traffic air quality changes brought by these strategies against a baseline (Base Case) scenario. Therefore, this study's findings might help the decision-makers identify the best strategy that can be implemented to reduce traffic emissions under different conditions (traffic conditions and location).

To estimate the vehicle emission, the emission models are classified as microscopic models, which estimate vehicle emissions based on second-by-second vehicle performance characteristics, and macroscopic models, which are based on the aggregated variables. Microscopic emission models take instantaneous driving modes (e.g., cruise, acceleration), vehicle loadings, road slopes, and vehicle characteristics such as weight and size into account [8]. Many software was used to estimate the emissions include PHEM and MOVES, COPERT and EMIT [8]. For the purpose of our, study EMIT is used EMIT, a comprehensive tool for compiling and editing emissions inventories, which allows simple, fast calculation and analysis of emissions [13].

2. Background

Several broad-scale scenario studies have been conducted to evaluate the potential emissions effects of implementing traffic enforcement and other transportation strategies [14]. Cambridge Systematics (2009) estimates that a full set of operations and ITS improvements could achieve less than 1% GHG emissions reduction in the U.S., while lower speed limits, eco-driving, and road pricing combined could achieve 1–4% reductions [15]. Hodges and Potter (2010) assess several traffic enforcement strategies, including congestion pricing and a national 55 miles/hour speed limit on U.S. highways, with estimated U.S. GHG emissions reductions of 1–3% [16].

A report for ERTICO - ITS Europe concludes that traffic signal improvements, variable speed limits, and parking guidance systems could generate GHG emissions reductions [17].

The State-of-the-Art of traffic enforcement strategies' impact can be classified into (a) Schemes affecting vehicle/driver behavior, e.g., speed limits, road humps (b) Schemes affecting traffic numbers, routes and patterns, e.g., new routes, new roads, car' sharing, and (c) Schemes affecting traffic composition, modes and technology, e.g., Low Emission Zones (LEZ), restriction of HGVs [13]

Other measures that affect vehicle/driver behavior include parking availability, the introduction of speed cameras, and coordinated signaling [13]. A Low Emission Zone (LEZ) can force certain vehicles to change their routes, affecting traffic numbers and patterns and changing the traffic composition inside and outside the LEZ [13]. Moreover, Car-sharing, congestion charging, and freight management similarly affect both traffic numbers and traffic composition. In practice, many measures have a combination of these effects [13]. A study by Porter et al. (2010) reports good cost-effectiveness of speed limit reductions, traffic signal improvements, and incident management programs for multi-pollutant emissions reductions [18].

A few researchers [19-20] studied the impact of speed limit changes, reducing traffic emissions. For example, studies in the Netherlands and Barcelona, Spain found that speed limit change from 120 or 100 km/h to 80 km/h could reduce NOX and PM10 in the range of 5% - 30% [19-20]. The impact of different intersection control approaches on traffic emissions has attracted a lot of attention [7,21-22]. in Stockholm, Sweden, the implementation of a congestion tax has reduced the concentrations of PM10 by 15%-20%, NOX by 10%, and CO by 15% on average were observed after [23].

EMIT has been specifically designed to help local authorities to develop air quality action plans by estimating the emissions consequences of traffic management schemes. Fig 1 is a schematic diagram showing an approach for investigating the effectiveness of traffic management schemes. EMIT users can rapidly assess different schemes by modeling a range of scenarios and hence obtain an indication of air quality's likely impact in the current year and the future. The emissions totals with traffic management may be greater or smaller than those for the Base Case. If the aim is to improve air quality, we will be looking to reduce the total emissions or at least a spatial redistribution of emissions.

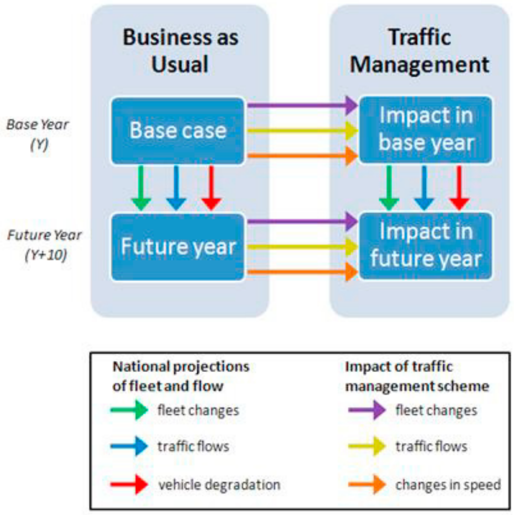


Fig. 1. approach for investigating the effectiveness of traffic management schemes (EMIT 2015).

Firstly, EMIT is used to set up emissions from road traffic inventory for a specific year (the Base Case year: is the current year of study). This inventory may contain emissions due to a variety of sources: industrial, commercial and domestic, road or rail, but in this section, we are only going to be concerned with changes in the emissions from road traffic. Next, an inventory can look at the emissions totals for future years in the absence of any traffic management schemes (future scenario). In the third step, the effect of traffic management schemes on the current situation (Base Case) can be examined, for that further inventories are set up containing copies of the sources for the Base Case year, and then the sources edited to represent changes due to the schemes. Finally, the longer-term impact of traffic management schemes can be assessed by creating additional EMIT scenarios to calculate future emissions with the schemes in place.

Hence, we can distinguish between specific emissions reductions due to the traffic management schemes and the general reduction due to the increased presence of newer, cleaner vehicles in the future years

3. Implementation

EMIT contains 50 pollutant species. Different pollutants were considered in our study, the regulated pollutants NOx, VOC, CO, and CO2; also, PM10, PM2.5, and the unregulated pollutants Benzene, Butadiene, and Methane (EMIT,2015). In our study, we modelled a range of scenarios and indicated the likely impact on air quality. To achieve the purpose, we plan to compare two scenarios:

- Scenario-1: The Base Case: we will use EMIT to calculate emissions from road traffic without implementing any traffic restrictions.

- Scenario-2: Traffic Enforcement strategies scenarios A1, A2, and A3. In these scenarios, we will consider traffic management schemes' effect on the current situation (Base Case).

3.1. Step 1 A: Base Case.

The example database contains scenarios, ‘A: Base Case.’ We identified the road attributes such as road type and width, traffic attributes such as traffic volume(vehicle/day), traffic composition, speed. In our study, the traffic volume was classified into two vehicle classes: cars, heavy vehicles

The base case and scenarios cases' total emissions are calculated and viewed using the View—totals button. Total emissions for the Base Case scenario are given in Table 1.

Table 1. Total emissions for the Base Case scenario.

Base Case (Scenario A)										
Group	BENZENE	BUTADIENE	CO	NO2	NOx	PM10	PM2.5	VOC	CO2	METHANE
TOTAL	1.34E-02	6.34E-03	4.42E+00	1.42E+00	5.07E+00	7.66E-02	7.28E-02	2.13E-01	3.14E+03	2.86E-02

3.2. Step 2 Traffic Enforcement strategies scenarios.

- Scenario A1

The next step is to consider the effect of the speed restrictions on the Base Case scenario totals. We will create a new inventory, 'A1: Base Case + speed restrictions. In the EMIT interface, the new inventory was created. The values were copied from those for Scenario A. a new group is set up in the database: 'A1: Go slow (major roads)', and then the sources edited to represent changes due to the schemes. Then, apply the speed restrictions. We changed the speeds on the major roads to be reduced to 50km/hr. Once the speed restrictions have been applied, the inventory totals are recalculated. The new totals are shown below, in table 2.

Table 2. Total emissions for Low Emission Zone (LEZ) scenario A2.

Speed restrictions (Scenario A1)										
Group	BENZENE	BUTADIENE	CO	NO2	NOx	PM10	PM2.5	VOC	CO2	METHANE
TOTAL	1.19E-02	7.74E-03	3.29E+00	1.15E+00	5.25E+00	5.19E-02	4.93E-02	2.53E-01	3.02E+03	3.43E-02

- Scenario A2: The effect of an LEZ on the Base Case

Low Emission Zone (LEZ) will change the traffic composition by excluding vehicles that do not conform to specific emissions standards from the LEZ area. Therefore, the total number of cars will not change, but heavy vehicles will not be allowed. This scenario (LEZ) can be applied by two schemes. First, traffic numbers, routes, and patterns where the total number of traffic is reduced by traffic route for all heavy vehicles. Second, the total number will not increase, but only heavy vehicles will not be allowed. In our study, we used the second scheme.

Table 3. Total emissions for Low Emission Zone (LEZ) scenario A2.

LEZ (Scenario A2)										
Group	BENZENE	BUTADIENE	CO	NO2	NOx	PM10	PM2.5	VOC	CO2	METHANE
TOTAL	4.35E-03	6.15E-03	4.25E+00	1.10E+00	3.18E+00	2.98E-02	2.83E-02	1.89E-01	1.71E+03	2.68E-02

- Scenario A3: The effect of an LEZ on the Base Case

To investigate the effect of an LEZ on the Base Case emissions, a new inventory is created. The major source from the Base Case scenario, A, is copied across to groups 'A2: Major roads' and A3: Major roads'

For A2 case, we set up an LEZ: exclude all heavy vehicles in the Base Case from a particular area. Therefore, the percentage of heavy vehicles within the LEZ was set to be zero, while the total traffic volume did not change. Table 3 shows the new inventory totals for scenario A2

For the A3 case, we set up an LEZ: excluding all heavy vehicles in the Base Case from a particular area route. Therefore, the percentage of heavy vehicles within the LEZ was set to be zero and only the traffic volume of light vehicles. The new inventory totals for scenario A3 are given in Table 4.

Table 4. Total emissions for Low Emission Zone (LEZ) scenario A3.

LEZ (Scenario A3)										
Group	BENZENE	BUTADIENE	CO	NO2	NOx	PM10	PM2.5	VOC	CO2	METHANE
TOTAL	3.48E-03	4.92E-03	4.52E+00	8.76E-01	2.54E+00	2.39E-02	2.27E-02	1.51E-01	1.37E+03	2.15E-02

4. Discussion

We evaluated the impact of identified traffic management strategies, namely, traffic management regulation for speed limit changes, route changes, and fleet composition changes on emission reduction. The overall results showed that the implementation of traffic management restrictions positively impacts reducing the emissions from traffic and improving air quality. Table 5 shows the reduction percentage of implementation of different scenarios. Fig 2 a, and b shows a comparison of different pollutants between a Base Case and other scenarios.

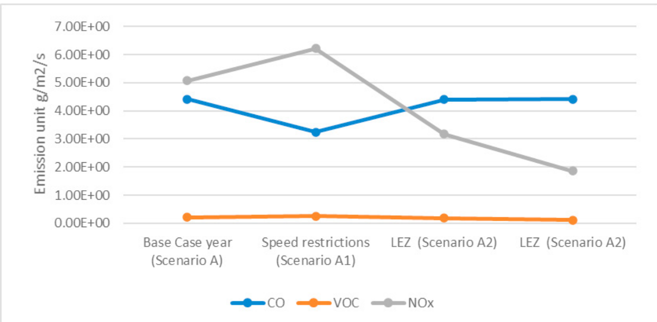
Table 5. Percentage Reduction in traffic emission for traffic management strategies .

Base Case (Scenario A)	BENZENE	BUTADIENE	CO	NO2	NOx	PM10	PM2.5	VOC	CO2	METHANE
Speed restrictions (Scenario A1)	-11.26%	22.12%	-25.6%	-18.8%	3.51%	-32.2%	-32.2%	18.8%	-3.86%	19.67%
LEZ (Scenario A2)	-67.5%	-3.0%	-0.48%	-22.8%	-37.3%	-61.0%	-61.0%	-11.1%	-45.5%	-6.2%
LEZ (Scenario A2)	-74.1%	-22.4%	-0.25%	-38.2%	-49.8%	-68.8%	-68.8%	-28.9%	-56.4%	-24.9%

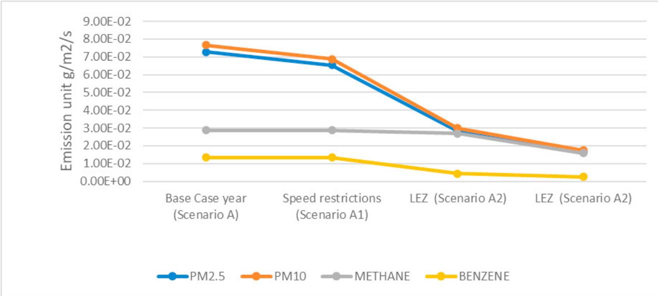
In table 5 and Fig 2, we found that emission totals have been slightly reduced by introducing a peed restriction scenario A 1 compared to the LEZ strategies scenarios A2 and A3. The general results were as follows:

1. The reduction of CO was the highest in the speed restriction scenario (25.6%) compare to LEZ strategies scenarios A2 (0.4%) and A3 (0.25%).
2. An increase of 3.5% is achieved for NOx in scenario A1. While there is a reduction of -37.3% and -49.8% for scenarios A2 and A3, respectively. Also, the increase of 18.7% is achieved for VOC in scenario A1 and, while a reduction of -11.1% and -28.9% for scenario A2 and A3 respectively
3. The reduction of PM10 was (-10.3%) in scenario A1 and, -61.0% and -68.8% for scenario A2 and A3 respectively.

The emissions totals with traffic management may be greater or smaller than those for the Base Case. If the aim is to improve air quality, we will be looking to reduce the total emissions or at least a spatial redistribution of emissions.



(a)



(b)

Fig. 2. (a) The inventory total for the base scenario and management scenarios for emissions (co,voc,and nox); (b) The inventory total for the base scenario and management scenarios for emissions (Pm2.5,10, Methane, and Benzene).

5. Conclusion and future work

Assessing the consequences of traffic management schemes has been carried out as recently by many countries. In general, the traffic enforcement schemes were classified into three categories: (a) Schemes affecting vehicle/driver behavior, (b) Schemes affecting traffic numbers, routes, and patterns, and (3) Schemes affecting traffic composition, modes, and technology. Our study used EMIT to evaluate different traffic enforcement strategies by modeling a range of scenarios that include the three schemes and hence obtain an indication of the likely impact on air quality. We compared the Base Case with different scenarios to distinguish between specific emissions reductions due to traffic management schemes. Seven regulated pollutants are NOx, NO2, VOC, CO, and CO2; also, PM10, PM2.5, including the unregulated pollutants Benzene, Butadiene, and Methane

Generally, the implementation of traffic management restrictions has a positive impact on reducing traffic emissions and improving air quality. We found the speed restrictions may not always decrease emissions; for some pollutants, they can decrease, and other pollutants can increase. This may be due to the vehicle's decrease their speed and then increase again at higher speeds.

In the future, we plan to investigate the implementation of such strategies due to the increased presence of newer, cleaner vehicles in the future years, such as autonomous vehicles and hybrid cars.

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