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THE ECODRIVE PROJECT: TRAFFIC MANAGEMENT AND CONTROL MEASURES TO MITIGATE ROAD TRAFFIC NOISE

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ABSTRACT

In the last decades, huge investments in road infrastructures and the spread of private cars have been necessary to meet the mobility needs of the population, whose well-being, work and personal needs have led to an ever-increasing travel demand. This ever more prevalent use of private road transport, in addition to its benefits, has also given rise to well-known consequences, including congestion, accidents, pollution and, notably, traffic noise. Over the years, different solutions have been proposed to reduce the effects of long exposure in areas close to road infrastructures, involving cars technology and road pavements characteristics. The ECODRIVE Project tries to address these issues, providing traffic management and control schemes and combining different policies affecting flow variables and traffic dynamics, with the aim of reducing the environmental impact of road transport. Even though the project, based on a simulative approach, is focused on the simultaneous reduction of atmospheric and acoustic emissions, it produced significant and interesting results in terms of noise reduction. In this paper a summary of the main aspects and the most interesting outcomes of the ECODRIVE project is provided.

Keywords: *noise pollution, road traffic, noise mitigation*

1. INTRODUCTION

The economic development that has occurred in recent years, combined with general prosperity and technological improvements, has significantly changed the needs of the population. This, coupled with the growth of urban centers and the spread of services [1], has led to an increase in demand for mobility of population, which has been met, over the years, with huge investments in the field of road infrastructures and the purchase of cars by users. For all these reasons, private road transport has become the most widespread mode of transport, almost in the European context [2], with all the consequences that such massive diffusion of private road transport brings. The negative externalities associated with the increased traffic are not only those that directly affect users' comfort, such as congestion and road accidents, with the resulting inconveniences and delays, but also those affecting the environment, such as gaseous emissions and noise from motor vehicles. As reported in [3], after air pollution, noise, also defined as the "unseen pollutant" [4], is the second most impacting disease factor in the European Union and its long-term effects can severely affect human health, environment, and ecosystems. To address the problem, the relevant authorities have issued a series of National and European regulations [5], [6] with the aim of curbing the problems related to noise levels exceeding the permitted thresholds. However, the European Green Deal's goal of a 30% reduction in the number of people exposed to traffic noise by 2030 [7] is still a long way off and new and specific measures need to be taken. In this context, the ECODRIVE project takes place, providing traffic management and control strategies to improve air quality and reduce the overall emissions from road transport. It should be noted that the project has been developed with the aim of simultaneously reducing gaseous and noise emissions, however, only noise-related results will be analyzed in this paper. The paper is organized in section: in the next one (Section 2) a literature review is provided, while Section 3 provides an overview of the project, with the methodology followed, the description of the case study, and the main results. In the last paragraph (section 4) some conclusions are drawn.

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2. LITERATURE REVIEW

Noise pollution is defined as the introduction of any unwanted, unintentional and disturbing sound that produces annoyance in humans, their activities, and ecosystems [4]. The main sources of noise are due to human presence in the environment [8], such as industrial, commercial and craft activities, domestic life, and transportation systems. The latter, according to the European Environmental Agency's data [9] is the major cause of noise pollution in urban areas and three main transportation-related noise sources can be identified: roads, railways and aircrafts. However, if noise generated by railways and aircrafts is discontinuous in space and in time, road traffic noise affects the whole territory, both in urban and in suburban areas, due to the ever-increasing number of cars on the road network and the capillary presence of roads. Traffic noise generation and its impact on receivers is influenced by several factors which involve all the components of a road transport system [10]. For example, among traffic-related factors can be counted traffic volumes, speeds, vehicle compositions, and the share of heavy vehicles within the fleet, while road-related factors include all the characteristics of the infrastructure, such as the type of pavement, the geometry or the presence of intersections. Vehicle characteristics, such as fuel type, engine type, and state of maintenance also play a key role in noise generation, but drivers' behavior, habits, and driving style can also contribute. Traffic noise assessment has been the subject of different previous studies, and, over the years, different models have been developed [11], taking into account some of the just mentioned parameters. Until a few years ago, each European country had its own standard calculation model, but, in order to harmonize all the methodologies and to follow common procedures for all Member States, the European Commission released a standard methodology: the CNOSSOS-EU model [12], [13]. The model, that proposes to calculate vehicle noise as the energy sum of propulsion noise – originating from the engine of the vehicle – and rolling noise – due to the interaction between tire and pavement – is constantly updated and is the method currently used. For addressing the problem of noise levels that exceed the admitted values, the European Commission released, over the years, several regulations to urge all the Member States to adopt proper actions. Among them, the Environmental Noise Directive 2002/49/EC [14] set several rules to be followed by Member States, including the strategic noise mapping and the drafting of the Action Plans. Within these plans, the mitigation measures to be considered can be divided into three categories [15]:

- *At-source measures* directly act on the sources of noise, through interventions on vehicles, tires, road surface and traffic dynamics.
- *Measures on the propagation paths* are needed when the at-source interventions are not sufficient or too expensive. The typical intervention belonging to this category of measures is the installation of noise barriers.
- *Measures at the receivers* include modifications and improvements to buildings and façades. These are the last type of mitigation measures to be used, only when the first two categories are not sufficient or too complicated to adopt.

The ECODRIVE project, whose purpose is to optimally combine the most well-known traffic management and control strategies, by acting on flow parameters, traffic dynamics, and travel demand, applies several source-related measures to reduce both noise and air pollution.

3. THE ECODRIVE PROJECT

The idea behind the ECODRIVE project stems from the need to respond to the European Community's pressure on the Member States to reduce the environmental impact of human activities on the territory. ECODRIVE's activity focuses on emissions originating from transportation systems and, particularly, from private road transport, which is the most harmful to the environment and air quality in general. The approach used during the development of the project is an "integrated" one, which aim is to simultaneously reduce air and noise pollution. The project, following a simulation-based approach, has combined several well-known traffic management and control policies. The purpose was to find the best combinations of these policies capable of reducing the environmental impact, without unduly worsening the level of service of the road infrastructure. To this end, three indicators were identified among the outcomes of simulations that could provide an estimate of the performances: travel time has been chosen as a parameter for the level of service, while noise and energy consumption have been identified for assessing the environmental performances of the system. This paper focuses solely on the noise outcomes, with only a brief mention of the other indicators.

3.1 Methodological Approach

As already mentioned before, the study is based on the combination of different traffic management and control policies and their application to a road transport system, to identify the best strategies to improve its environmental impact. Such transportation system consists of a network and all the vehicles running on it. The first step of the research was, therefore, to build the vehicle fleet. Cross-referencing the two datasets provided by the Italian companies operating in the field of road infrastructures – ANAS [16] – and of fleet management – ACI [17] – it was possible to reconstruct a vehicle fleet that mirrors that circulating in the city of Rome, in Italy, composed of the following vehicle classes:

- *19.94%* of High-Emitting Cars – *HE Cars* – encompassing all vehicles belonging to a range of emission standards from EURO 0 to EURO 3.
- *33.45%* of Medium-Emitting Cars – *ME Cars* – which includes all the EURO 4 and EURO 5 vehicles.
- *25.55%* of Low-Emitting Cars – *LE Cars* – entirely composed of EURO 6 cars.
- *20.86%* of Heavy Vehicles – *HV*.
- *0.20%* of two-wheeled vehicles – *Moto*.

The selection of the policies to be applied was carried out considering the geometric and functional characteristics of the infrastructure analyzed in the case study, namely a motorway with three lanes in each direction, flanked by an emergency lane (further details in sub-section 3.2).
“Speed Policies” are the first set of policies applied to the network and provide for a gradual reduction in speed limits, differentiated according to the different vehicle classes, with values ranging from 130 km/h – the maximum speed admitted by Italian regulations – to 70 km/h – the minimum speed limit compatible with a motorway driving. In Table 1, how the limit varies for each class is reported:

Table 1. Speed Policies. The columns report the speed limit applied to each vehicle class.

Policy	LE Cars	ME Cars	HE Cars	HV
01	130 km/h	130 km/h	130 km/h	80 km/h
02	130 km/h	130 km/h	120 km/h	80 km/h
03	130 km/h	120 km/h	120 km/h	80 km/h
04	120 km/h	120 km/h	120 km/h	80 km/h
05	120 km/h	120 km/h	110 km/h	80 km/h
06	120 km/h	110 km/h	110 km/h	80 km/h
07	110 km/h	110 km/h	110 km/h	80 km/h
08	110 km/h	110 km/h	100 km/h	80 km/h
09	110 km/h	100 km/h	100 km/h	80 km/h
10	100 km/h	100 km/h	100 km/h	80 km/h
11	100 km/h	100 km/h	90 km/h	80 km/h
12	100 km/h	90 km/h	90 km/h	80 km/h
13	90 km/h	90 km/h	90 km/h	80 km/h
14	90 km/h	90 km/h	80 km/h	80 km/h
15	90 km/h	80 km/h	80 km/h	80 km/h
16	80 km/h	80 km/h	80 km/h	80 km/h
17	80 km/h	80 km/h	70 km/h	80 km/h
18	80 km/h	70 km/h	70 km/h	80 km/h
19	70 km/h	70 km/h	70 km/h	70 km/h

From the values in Table 1 it can be seen that limits reduction only involves cars, without affecting Heavy Vehicles that are already forced to travel at lower speeds by Italian regulations, except for policy 19, where all vehicles are forced to take a speed equal to 70 km/h. The gradual reduction of the limits has been chosen with the aim of penalizing the most polluting vehicles.
All the just described policies have been combined with the “Closure Policies”, that prevents one or more vehicle classes from using one or more lanes of the road. Even in this case, the intent is to reduce the circulation of older vehicles, in order to encourage the use of newer cars. Closure schemes are reported in Table 2.

Table 2. Closure Policies. Each column reports the list of the vehicles prevented from travelling on each lane.

Policy	Emergency Lane	Right Lane	Central Lane	Left Lane
CH1	All	None	None	HV
CH2	All	None	None	HV, HE
CH3	All	None	None	HV, HE, ME
CH4	All	None	HV	HV, HE, ME
CH5	All	None	HV, HE	HV, HE, ME
CH6	All	None	HV, HE, ME	HV, HE, ME
CH7	None	None	None	HV
CH8	None	None	None	HV, HE
CH9	None	None	None	HV, HE, ME
CH10	None	None	HV	HV, HE, ME
CH11	None	None	HV, HE	HV, HE, ME
CH12	None	None	HV, HE, ME	HV, HE, ME

Table 2 can be ideally divided into two parts: policies identified with the acronym CH and a number from 1 to 6 do not allow any vehicle to use the emergency lane. Policies from CH7 to CH12 repeat the same closure schemes but opening the emergency lane, that becomes available to all the vehicles.
During the simulation process, each scenario has been built combining one-to-one alle the policies just described.
The methodology followed in the study is reported in the flowchart shown in Figure 1. This methodology can be ideally divided into two parts: the Simulation Process, that focuses on scenarios simulation and the assessment of the main indicators and the Optimization Procedure, that helps the modeler to identify the best combination of policies for the system. The upper part of Figure 1 shows how the Simulation Process works: starting from an initial setup,

consisting of a supply system (a road network), the demand matrix and a vehicles fleet with its specific composition, all the scenarios are simulated with the microsimulation software PTV Vissim™ [18], that outputs the values of travel times, traffic volumes, and speeds. The latter two are then used to feed the emission models in order to obtain the environmental indicators: COPERT [19] methodology is used for estimating energy consumption, while CNOSSOS-EU [13] model is used for calculating noise. Energy consumption is assessed as a proxy variable for emissions, since the vehicle fleet is composed of a wide range of vehicles produced in different periods. Using consumption rather than emissions helps to take into account the different technologies that equip the cars, in order to make the outcomes from the different vehicle class comparable.

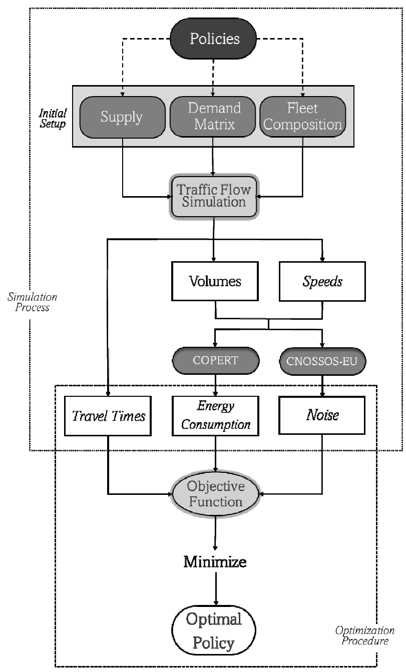

Figure 1. Flowchart of the methodology followed in the study.

For assessing noise, the equations provided in [13] are used: this formulation allows to calculate the value of noise as the combination of propulsion and rolling noise.

Once all the parameters have been assessed, traffic management and control policies are applied on the initial setup, modifying one or more of its components and then simulations are repeated. The simulation process ends with the analysis of travel times, chosen as indicator for the level of service of the infrastructure, and energy consumption and noise, indicators for the environmental impact, in order to identify how the system evolves after the application of policies. The three indicators serve as inputs to the Optimization Procedure, which combines them within an objective function that is minimized using a purpose-built algorithm. The aim is to identify the best combination of policies to apply to the network, for minimizing the environmental impacts without compromising the quality of the infrastructure service.

3.2 The Case Study

The network chosen for testing the policies is the South-Eastern quadrant of motorway A90, a ring-shaped highway located in Rome, in Italy, commonly known as Grande Raccordo Anulare, that is reported in Figure 2.

Figure 2. The case study: the South-Eastern quadrant of motorway A90 in Rome.

The network is made of two main trunks running in two opposite travel directions. The total length of the network is about 19 km, with junctions occurring each 2 km. Since the road is the main travel corridor in the city of Rome, high traffic volumes are recorded, especially during the morning rush hour. The ascending direction, corresponding to the internal carriageway that runs in a clockwise direction, although quite busy, is less congested than the descending direction – the external carriageway that runs in a counterclockwise direction – which is often affected by stop-and-go phenomena. After importing the network, with its characteristics within the simulation tool, the system underwent a calibration process using two different databases. Traffic simulations have been calibrated using data from ANAS detectors [16], while noise levels were calibrated using data collected from sensors installed during the DYNAMAP project [20] have been used.

3.3 Results from simulations

Simulation results are presented below, separately for the two travel directions. As an example, two adjacent sections have been considered, one in the internal carriageway (ascending direction) and one in the external carriageway (descending direction), both located between the junction with the motorway A1 and the junction with Via Tuscolana. This section is particularly critical due to the important junctions it connects and the high traffic volumes it carries. Noise results are shown, but information on speed variations is provided as they help to understand how the system responds to the application of policies. Moreover, in order to isolate the effects of each policy, the aggregated results for speed policies and road closure policies are shown separately.

In the ascending direction, values of traffic mean speeds with ever more restrictive speed policies are reported in Table 3.

Table 3. Values of traffic mean speeds recorded for the ascending direction in the reference section, with ever more restrictive speed policies.

Policy	**LE Cars** *[km/h]*	**ME Cars** *[km/h]*	**HE Cars** *[km/h]*	**HV** *[km/h]*	**Mean** *[km/h]*
01	100.45	93.93	89.13	69.97	88.37
02	100.88	93.20	87.41	69.68	87.79
03	100.25	91.94	87.55	69.74	87.37
04	98.12	91.95	87.72	69.79	86.90
05	97.98	91.53	85.45	69.75	86.18
06	96.73	88.56	85.11	69.60	85.00
07	93.81	88.74	85.26	69.87	84.42
08	93.62	88.29	81.96	69.82	83.42
09	92.45	84.48	82.28	69.99	82.30
10	88.74	84.37	82.02	69.79	81.23
11	88.23	83.43	77.33	69.80	79.70
12	87.11	78.34	77.28	69.85	78.15
13	81.91	78.24	77.14	69.71	76.75
14	81.41	77.66	71.17	69.85	75.02
15	80.72	71.16	70.92	69.74	73.14
16	74.03	71.02	70.74	69.72	71.38
17	72.82	69.60	62.52	67.05	68.00
18	72.29	62.43	62.30	65.50	65.63
19	65.49	62.37	62.36	51.50	62.93

According to the values of Table 3, speed values decrease in proportion to the restrictions applied on speed limits. The only exception is heavy vehicles which, having from the baseline scenario a strong constraint on speed, are not affected by speed policies. The system's response to the implementation of policies, as just described, is also evident in the noise values, whose trends are shown in Figure 3.

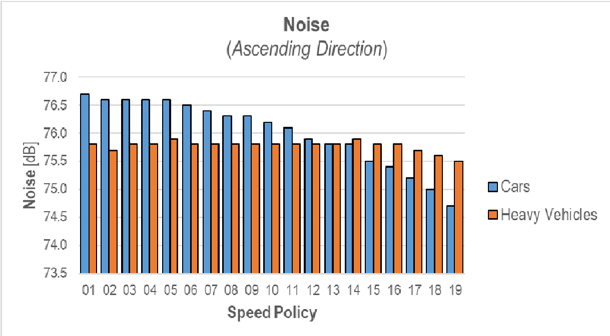

Figure 3. Noise values recorded in the ascending direction for ever more restrictive speed policies.

According to the histogram reported in Figure 3, it is evident that noise generated by cars tends to decrease as speed limits become more stringent, In fact, in some cases, a reduction of up to 2 dB compared to the baseline scenario can be observed. In contrast, heavy trucks are not significantly affected by changes in speed and, consequently, show no meaningful reduction in the noise they generate.
As regards the application of closure policies, the values of traffic mean speeds recorded are shown in Table 4.

Table 4. Values of traffic mean speeds recorded for the ascending direction in the reference section, with even more restrictive closure policies.

Policy	**LE Cars** *[km/h]*	**ME Cars** *[km/h]*	**HE Cars** *[km/h]*	**HV** *[km/h]*	**Mean** *[km/h]*
CH1	94.66	93.78	92.01	78.65	89.78
CH2	94.64	93.80	88.58	78.70	88.93
CH3	94.47	89.37	88.50	78.76	87.78
CH4	95.86	91.90	90.88	78.74	89.35
CH5	97.13	93.99	79.43	78.58	87.28
CH6	39.72	16.60	16.89	16.44	22.41
CH7	96.04	95.32	93.15	78.95	90.87
CH8	96.17	95.42	90.74	78.95	90.32

CH9	96.62	92.47	91.09	79.06	89.81
CH10	98.13	94.26	92.70	78.71	90.95
CH11	98.96	95.69	87.60	78.31	90.14
CH12	50.19	27.02	26.68	23.93	31.96

According to what is reported in Table 4, reducing road capacity for some vehicle classes leads to different speeds reductions for each vehicle type. Again, heavy vehicles are the exception, and they even affect the travel of all the vehicles that are forced to share the lane with them. Moreover, there does not seem to be any significant difference whether the emergency lane is open or closed. Noise values corresponding to speed values reported in Table 4 are reported in Figure 4.

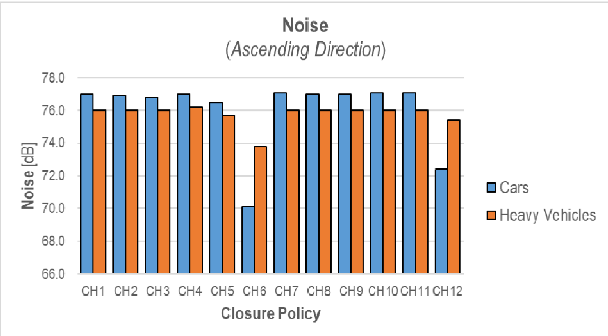

Figure 4. Noise values recorded in the ascending direction for even more restrictive closure policies.

With reference to the graph in Figure 4, it can be observed that restricting certain vehicle classes from using specific lanes can lead to a noise reduction of more than 4–5 dB. Moreover, in this case, slower vehicles—which emit less noise—are confined to the rightmost lane, which is closest to the receivers.

In the descending direction, values recorded for traffic mean speeds with restricted limits are reported in Table 5.

Table 5. Values of traffic mean speeds recorded for the descending direction in the reference section, with even more restrictive speed policies.

Policy	**LE Cars** *[km/h]*	**ME Cars** *[km/h]*	**HE Cars** *[km/h]*	**HV** *[km/h]*	**Mean** *[km/h]*
01	70.13	61.94	58.95	51.71	60.68
02	71.26	63.49	60.31	52.89	61.99
03	69.89	61.88	58.98	51.58	60.58
04	69.04	61.48	58.78	51.38	60.17
05	69.46	62.08	59.03	51.90	60.62
06	69.46	61.98	59.29	52.47	60.80
07	68.94	62.02	59.60	52.84	60.85
08	68.40	61.48	58.46	51.81	60.04
09	68.15	60.97	58.64	52.02	59.95
10	66.87	61.00	58.52	51.95	59.59
11	66.92	60.95	57.92	51.97	59.44
12	66.81	60.17	58.14	52.25	59.34
13	64.99	60.09	58.04	52.09	58.80
14	64.85	60.11	56.79	52.50	58.56
15	65.30	58.82	57.28	52.98	58.60
16	62.02	58.74	57.05	52.76	57.64
17	60.87	56.68	52.84	51.29	55.42
18	60.85	54.44	53.20	51.21	54.93
19	57.35	54.51	53.44	50.22	53.88

It is evident how the situation of increased congestion that occurs in the descending direction significantly reduces traffic mean speeds. This makes the implementation of the closure policies less effective, as can be seen in Figure 5.

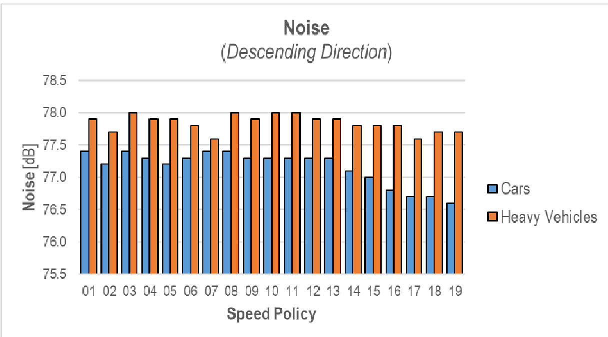

Figure 5. Noise values recorded in the descending direction for even more restrictive speed policies.

In Figure 5 emerges how noise reduction is halved compared to the other travel direction, settling at around 1 dB.

Mean speeds recorded when closure policies are applied are shown in Table 6.

Table 6. Values of traffic mean speeds recorded for the ascending direction in the reference section, with even more restrictive closure policies.

Policy	**LE Cars** *[km/h]*	**ME Cars** *[km/h]*	**HE Cars** *[km/h]*	**HV** *[km/h]*	**Mean** *[km/h]*
CH1	58.57	58.06	58.12	50.13	56.22
CH2	57.48	57.10	52.05	48.41	53.76
CH3	56.29	49.42	49.69	46.17	50.39
CH4	63.72	57.67	57.69	45.20	56.07
CH5	64.07	57.06	45.96	45.03	53.03
CH6	67.53	49.93	49.76	49.25	54.12
CH7	64.35	63.81	63.96	54.17	61.57
CH8	66.57	66.12	61.51	56.57	62.69
CH9	68.63	63.42	63.42	57.80	63.32
CH10	71.89	65.35	65.20	54.30	64.19
CH11	78.48	71.63	62.31	58.73	67.79
CH12	79.04	62.21	62.02	58.31	65.40

Speed values show that, in the event of congestion, opening the emergency lane improves flow conditions. This is also reflected in the noise levels, which inevitably tend to increase, as shown in Figure 6 below.

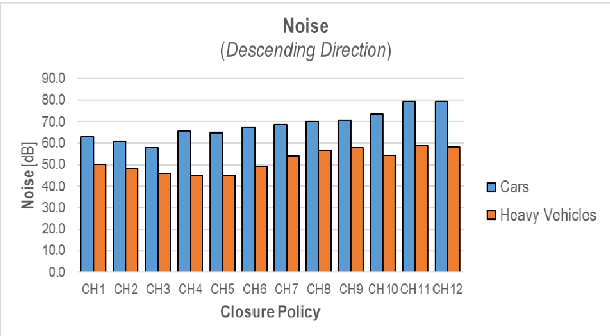

Figure 6. Values of traffic mean speeds recorded for the descending direction in the reference section, with even more restrictive speed policies.

Given the nature of the ECODRIVE project, additional considerations are necessary: for traffic conditions that tend to improve the acoustic impact of the system, as in the case of the ascending direction, travel times, inevitably, tend to be longer. However, if the increase is kept below a certain threshold, it is considered acceptable in light of environmental benefits that do occur, both in terms of noise and energy consumption. Conversely, in the descendant direction, reductions in congestion bring benefits in terms of energy consumption and travel time, but not as many acoustic benefits. The aspects concerning air pollution and the level of service are beyond the scope of this discussion. What is important is that the need to balance the three effects is clear and highly significant. This balance among the effects is possible in the optimization phase, which will not be discussed here, as this paper only aims to identify the effect of traffic management and control on the acoustic performance of road infrastructure.

4. CONCLUSIONS AND OUTLOOKS

This study demonstrates that traffic management and control strategies are crucial for facing air and noise pollution from private road transport. For less-congested situations, the application of policies that affect traffic flow variables, such as speed limits or road capacity, is effective and allows noise reduction even higher than 4 dB. Conversely, for heavily congested road sections, traffic fluidifications that occur when the usage of lanes is limited to certain vehicle classes may even worsen the acoustic impact of the whole system, if no other action (for example, speed limits reduction) is taken. What emerges from the analysis of two small road sections is that combining different kinds of policies is crucial for achieving the goal of reducing noise generation from traffic. This 'optimal' combination must be identified by taking into account the entire system, including other key elements such as the level of service—which should not be unduly worsened by the implementation of environmentally driven policies—and vehicle energy consumption..

In this paper, the effect of supply policies (speed and closure) has been analyzed. Such policies should not only be seen as tools to penalize the most emissive vehicular classes, but also as strategies to improve traffic conditions on particularly busy roads or to push toward a fleet renewal, with newer and more environmentally sustainable vehicles. However, intervening in transportation demand, such as changing the demand matrix, or changing the vehicular composition may also be aspects to consider. Finally, it is important to note that all policies tested during ECODRIVE act indiscriminately on any part of the network. In the future, it would be of interest to evaluate the overall effects of targeted policies applied only to small, particularly critical road sections.

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