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HOW LOWERING SPEED LIMITS IN AN URBAN HIGHWAY AFFECTS TRAFFIC PERFORMANCE AND EMISSIONS: THE CASE OF MADRID M-30 RING-ROAD

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ABSTRACT

The city of Madrid keeps not meeting the GHG and air pollutant limits set by the European legislation. A broad range of strategies have being taken into account to reduce both types of emissions; however traffic management measures are usually consigned to the sidelines. In 2004, Madrid City Council launched a plan to re-design its inner ring-road **s**upported by a socioeconomic study that evaluated the environmental and operational benefits of the project. For safety reasons the planned speed limit for the tunnel section was finally reduced from 90km/h to 70km/h. Using a Macroscopic Traffic Model and the European Air Pollutant and Emissions Inventory Guidebook (EMEP/EEA), this paper examines the environmental and traffic performance consequences of this decision. Results support the thesis that reduced speed limits leads to GHG and air pollution reductions in the area affected by the measure without substantially altering traffic performance. The implementation of the new speed limit policy brings about a 15% and 16% reduction in both CO_2 and NOx emissions respectively. Emissions' reduction during off-peak hours is larger than during peak hours.

1. INTRODUCTION

In the past years, some important efforts have been made worldwide to study the effects of different strategies to reduce greenhouse gasses and air pollutant emissions from road transport.

Transport is the second-largest sector in the world regarding CO2 emissions. Although they have minimal local impact, global cumulative CO2 emissions are important because they contribute to global warming (Health Effect Institue 2010).CO2 emissions accounted for 22% of word CO2 emissions in 2010, 75% of these emissions are attributable to road transport (OECD/IEA 2012). In Spain figures are similar to other European countries; 36.4% of total emissions CO2 are due to transport and 76.2% of these are caused by road

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transport. If the scope continues to be reduced, transport in Madrid City accounts for 47.3% of total CO_2 emissions of which 85% comes from road transport (Madrid 2011).

On the other hand, road transport is a major source of air pollutant emissions in EU cities which have major local impacts: they can be relatively short-lived and usually only impact the area or the street where they are emitted (Health Effect Institue 2010). In 2009, road transport accounted for 65.4% of NOx, of the total air pollutant emissions in Madrid (Madrid 2011).

A broad range of strategies have been taken into account to reduce both types of emissions: promote the use of less polluting technologies and fuels, foster the use of public transportation, encourage the use of alternative modes of transportation or restrict the use of private vehicles (Madrid 2011). However, traffic operations strategies such as signal optimization and coordination, real-time travel information or speed management have been consigned to the sidelines as far as emissions are concerned. These kinds of measures could help reduce both air pollutant and CO_2 direct emissions from vehicle operations, at the same time that they reduce travel times and traffic congestion. Different studies analyze the efficiency, cost-effectiveness and/or feasibility of these traffic management measures (TRB 2012, Cambridge Systematics 2009,OECD/IEA 2005). Besides some specific cases studies can be found in transport related literature e.g. in Belgium a study have shown that reductions of about 10% in NOx and CO_2 can be expected from the implementation of a green wave signal coordination scheme along an urban arterial road (Madireddy et al. 2011). In Barcelona, model calculations indicated that the introduction of variable speed management on urban motorways would lead to a 5.7% of NOx by road traffic (Goncalves et al. 2008). In Paris an on-field experiment comparing the benefits of a real-time control strategy in signalized intersection versus a time planned strategy showed that the first one can lead to a 4% reduction of CO_2 (Midenet et al. 2004).

Over the past decades, higher speed transportation has benefited economic development by enhancing mobility, decreasing travel times and facilitating access to goods, services and facilities(ECMT 2006). However, greater speeds have major adverse impacts regarding safety, environment and livability of urban areas (ECMT 2004).

Higher speeds retain high rates of social and industry support for different and sometimes misleading reasons e.g. automotive industry manufactures less fuel consumption motor vehicles able to travel in comfort at increasingly higher speeds, improvements in road infrastructures may bring a false sense of security when driving at higher speeds moreover, drivers used to think that higher speeds usually means reduced travel times. Nevertheless, the effects of speed in reducing travel times are generally overestimated especially in urban areas, where time savings are often small or negligible due to the short length of the trip and frequent stop and go cycles, the latest condition is usually related to the presence of numerous intersections, traffic lights, shopping areas or heavy congestion rates (Archer et al., 2008).

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From a macroscopic point of view, both air pollutant and CO_2 direct emissions from vehicle operations are function of average speed, total travel activity (km travelled), and vehicle technology and fuel efficiency. Traffic management strategies can affect the first two factors which indeed are closely related. Among all the traffic operation strategies, one of the most cost-effective ways to reduce road transport emissions is lowering speed limits (ECMT 2006; OECD/IEA 2005; TRB 2012).

Traditionally, speed limits have a twofold function (Archer et al., 2008). On the one hand they limit the maximum speed of a road for safety purposes and on the other hand they reduce dispersion in driving speeds which not only increases safety but also improves traffic flow efficiency. Like the Sweden Vision Zero, other numerous studies support the idea that lower speed limits lead to significant reduction in traffic accidents e.g. (Woolley 2005; Aarts & van Schagen 2006; De Pauw et al. 2013)

New trends aroused from the global concern in climate change and pollution also ascribe speed limits an energy conservation function. It is well known that during the 70s Oil Crises, the US government applied a national-wide speed limit reduction at 90km/h for fuel conservation purposes that remains almost 25 years. In 2011, this measure was replicated by the Spanish government reducing from 120km/h to 110 km/h the speed limit in highways for same reason, in this case the measure solely last for 4 months. There are a number of studies that have examined the relationship between lowering speed limits and emissions or fuel consumption reduction. In Germany a reduction of 4.8% of fuel consumption was achieved after lowering the speed limit at 100 km/h in motorways and at 80 km/h in extra urban roads (GIER 1996). In Austria lowering speed limits in highways from 130 km/h to 100km/h lead to a 17% reduction in NO_x and a 25% in CO_2 emissions (ECMT 1996). A study conducted in Rotterdam, Netherlands, shows emissions reduction of 5-30% in NO_x emissions after reducing the speed limit from 100 km/h to 80 km/h in an urban ring road (Keuken et al. 2010).

1.1 Case study background

Madrid is a city of about 3.5 million inhabitants and its metropolitan area reaches 6 million. The city is surrounded by three ring motorways; two of them encircle the city itself.

In 2004, Madrid City Council launched a plan to re-design its inner ring-road, M30, supported by a socioeconomic study where the environmental and operational benefits of the remodeling were evaluated. Time and CO_2 emission savings accounted for the 75% of the socioeconomic benefit of the program (Monzon 2007).

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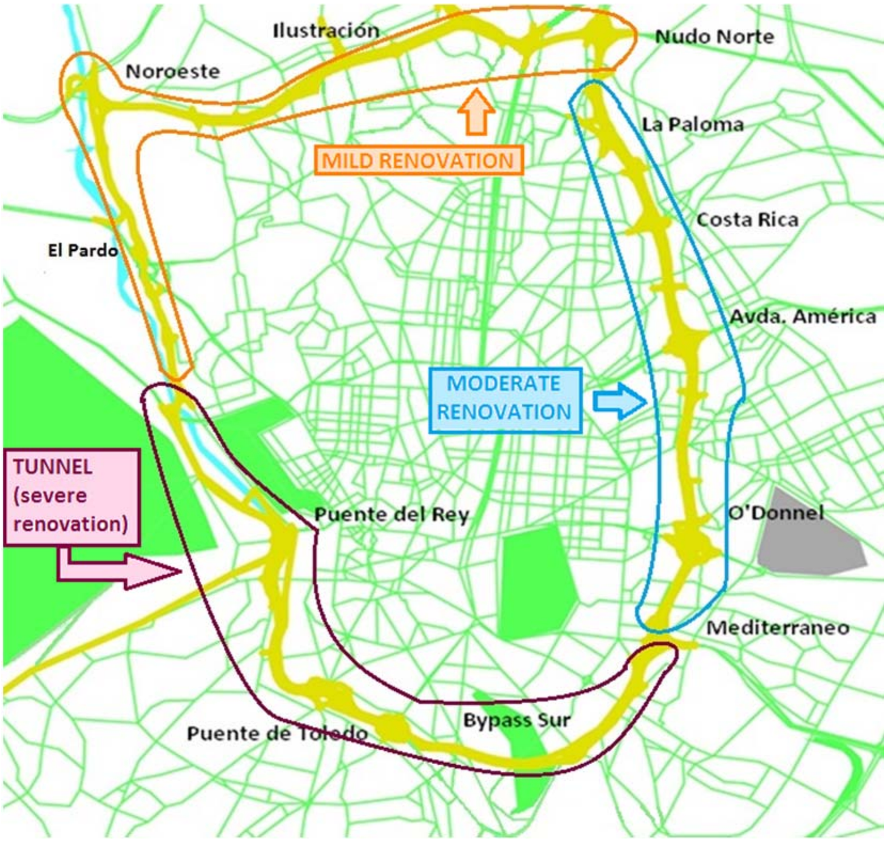

Figure 1- M30 layout and division by sectors according to the restoration degree

M30 ring-road is again fully operative since 2007. It is a 32.5 km long, 3+3 lanes urban motorway, except for about 1.5 km in the north area -area number 9, Ilustracion- where becomes a signalized urban road.

In broad terms, the renovation consisted of a more uniform layout and better integration with urban arteries. It included the construction of about 12km of tunnels although only 8.8 km of them belongs to M30 layout, the remaining ones include links with other roads, service roads and branch lines. More than 20 links were also redesigned (Monzon et al., 2005.).

Table 1 presents the main characteristics of the ring road. For dissemination purposes of the study, it has only been consider the main layout of the M30, excluding the majority of service roads and branch lines. The ring-road has been divided in three sectors according to their restoration degree. Each of them was as well divided in smaller subareas.

- **Mild renovation sector**: This area, about 10km long, comprises another four subareas; area number 7 -El Pardo- is the closest to the west tunnel section and it has not been renovated at all. The north area of the ring road was slightly renewed. A new access was built from the signalized urban area towards a major road; the northwest service road was enhanced and its connection with the west area of M30 was widening to three lines.

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- **Moderate renovation sector:** In the East section of the M30 ring-road the improvement plan looked for the enhancement of the transfers between side and central lanes eliminating all the left side exits. All the links of this section were also renovated. The closest subarea to the tunnel section is area number 5 –Mediterraneo-.
- **Total renovation sector:** The South and South-West of M30 were completely buried to solve the congestion problems of the South area and also to recover the livability on the river side eliminating the barrier effect of the former road. The planned speed limit for tunnel sections was 90km/h as it was settled in the open air sections, however for safety reasons, speed limit in tunnels was finally settled at 70km/h..

In Table 1, network length refers to the length of the links in the traffic model and it counts separately both driving directions and different capacity lanes of the same transversal section. Driving length represents the actual length someone travels when driving in one direction. Network capacity is the aggregated capacity of each of the sections and subareas and represents the maximum traffic intensity they can support in an hour. The Average Daily Traffic (ADT) refers to the number of vehicles traveling through a section or subarea of the M30 in a 24-hour period.

Table 1- M30 ring road main characteristics

			Network length (km)	Driving length (km)	Network Capacity (veh/hour)	Current ADT
Moderate renovation	1	La Paloma	1.51	0.57	5,728	215,881
	2	Costa Rica	7.58	2.88	6,384	231,732
	3	America	10.58	4.02	6,582	263,136
	4	O'donnel	8.30	3.15	6,740	289,990
	5	Mediterraneo	6.70	2.54	5,637	293,451
	Subtotal: Moderate renovation		34.66	13.17	6,357	266,500

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Total renovation	6 Tunnel	20.50	8.80	6,779	107,894
	Subtotal: Total renovation	20.50	8.80	6,779	107,894
Mild renovation	7 El Pardo	9.45	3.59	6,000	112,750
	8 Noreste	7.78	2.95	6,047	76,894
	9 Ilustracion	4.41	1.68	5,543	64,192
	10 Nudo Norte	6.32	2.40	6,011	105,250
	Subtotal: Mild renovation	27.95	10.62	5,943	93,422
	TOTAL: M30 Ring-road	83.12	32.59	6,322	169,162

This paper examines the environmental and traffic performance consequences of reducing the speed limit the 8.8 km tunnel section of M30 ring-road from 90km/h to 70km/h using a macroscopic transport model (VISUM) and the EMEP/EPA methodology to assess road transport emissions and air pollutants.

2. METHODOLOGY

To evaluate the environmental and traffic performance effects of the reduction of the speed limit in the 8.8 km tunnel section, a macroscopic traffic model for 2010 based on the origin-destination matrices of Madrid City Council was used. Traffic models are commonly used to generate the required traffic data input to emission models (Smit et al. 2008).

The modeled area comprises the whole region of Madrid with a road network of about 6,500 km. The affection of the traffic from border regions is negligible compared with the internal traffic of the region. The Household Mobility Survey of 2004 was used to calibrate and adjust these OD matrices as well as real traffic volume observed through 491 measurement points placed around Madrid Region. Nevertheless, additional (cell, row and column) deviation restrictions were imposed to prevent an uncontrolled distortion between the original OD matrix and the adjusted matrix.

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Two different scenarios have been defined.

- Scenario 1 – Total renovation sector (tunnels) at 90km/h: It simulates the actual Madrid traffic situation in 2010 but with the speed limit in the tunnel sector at 90 km/h.

- Scenario 2- Total renovation sector (tunnels) at 70km/h: It simulates the actual Madrid traffic situation in 2010 but with the speed limit in the tunnel sector at 70 km/h.

PTV-Visum software was used for transportation modeling. The model was developed for three different time periods: morning peak hours (AM), afternoon peak hours (PM) and off- peak hours (HV), using its corresponding OD matrix for the average hour of the period. These periods have been defined using traffic volume data from 32 measurement points of 2008 and 2009 allocated along the main and side lanes of Calle30. Those hours with a traffic volume lower than 3% of the day traffic volume were rejected. The remaining hours were analyzed taking into account the trip percentage of the O/D matrix for each period.

For the current evaluation, peak hours are those with more than a 6,2% of the daily traffic and off peak hours are those with less than 5,06% of the daily traffic.

- Morning Peak : 2 hours
- Afternoon Peak : 5 hours
- Off -Peak: 8 hours

2.1 Traffic performance

Traffic performance will be evaluated not only for the Total Renovation Sector (tunnels) but also for the rest of the urban ring-road. It is well known that reductions of the 22.2% of the posted speed limit will substantially affect traffic volumes (vehicles-km) and average speeds (vehicles-hour) of the links where this measure is directly applied. Nevertheless, it is also interesting to evaluate how this measure affects the performance of the ring-road as a whole and see how and at what extent traffic volumes, travel times, average speeds and saturation rates change because of the implementation of the new measure.

For large urban road networks, traffic models usually generate macroscopic traffic data for each road link in the network (e.g. Smit et al. 2008). The model used provide information about length (km), traffic intensity (vehicles/hour), capacity (vehicles/hour), average speed (km/h) and travel times per network link.

The following traffic indicators have been used to evaluate the traffic performance of the urban highway:

- VKT (Vehicles Kilometers Travelled): It represents traffic volume as a product between traffic intensity (number of vehicles crossing a specific section in an hour) and section length. It is often referred as an indicator or traffic demand. It

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characterizes the traffic flow over a road link on an average hour of a day. The model gives three different values of traffic intensity, one for each average hour of the three defined periods: morning peak hour (AM), afternoon peak hour (PM) and off-peak hours (HV). Taking into account that the testing measure of this study - lowering the speed limit from 90km/h to 70 km/h- does not change neither the length nor the capacity of the links, both saturation (traffic intensity divided by section capacity) and traffic volume are synonyms of traffic intensity when speaking in relative terms.

- VEH (vehicles per hour): It represent the total travel time of all vehicles in a link or in a segment of the road for an average hour of the three defined periods. The average daily travel times have been calculated using the same formulation than for the average daily traffic.

2.2 CO2 and NOx emissions

The "EMEP/EEA emission inventory guidebook 2009" for road transport was used to quantify CO_2, and NO_x emissions. The guide specifies different types of analysis depending on the data available. Since both traffic volume (vehicles-km) and average speed (km/h) are available using a macroscopic traffic model, the Tier3 methodology was used.

To apply the Tier3 methodology, the rate of Madrid's vehicles per category was determined attending to fuel type, motor engine and the reduction emissions technology associated. As explained before, results of the macroscopic traffic model feed the emissions model. Traffic flows and average speed are the main inputs for the model which, implicitly, takes congestion rates into account.

The methodology considers two different types of emissions: hot and cold-start emissions. Cold-start emissions take place under urban, rural and highway driving conditions. However, they seem to be most likely for urban and rural driving, as the number of starts in highway conditions is relatively limited (Ntziachirstos & Samaras 2012).Since the assessment of GHG and air pollutant emissions will be elaborated for an urban highway, cold-start emissions have not been taken into account in this evaluation. The basic formula for estimating hot emissions for a given time period in the case study was:

emission [g] = emission factor [g/km] × no. of vehicles [veh]× mileage per vehicle [km/veh]

For each emission type, the methodology provides different consumption factors based on 2 or 3 speed ranges by vehicle category.

3. RESULTS

Table 2 presents the daily variation of traffic performance parameters and emissions rates

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after the implementation of the 70 km/h speed limit along the tunnel sector. A reduction of 22.2% of the speed limit in tunnels leads to a smaller reduction of daily average speeds in tunnels, 17.76%. Deviation in average speed in the rest of the sector of the road is trivial. Notice that tunnels' closest subareas experience slight increase in average speed mainly due to the effect of the transition from a 70km/h section to a 90km/h section. Results are aggregated for both driving directions; the fact that in these areas total average speed variation is positive means that the 'tunnel effect' is more powerful driving out of the tunnel than driving into the tunnel. Considering the ring-road as a whole, lowering speed limits 22.2% in less than a third of its length, leads to a 4.76% reduction in average speeds. This reduction is mainly due to the reduction of average speeds in the tunnel sector.

As explained in the Methodology section, variation in traffic volumes and variation in saturation rates for this traffic measure will be the same. As expected, the measure generates an important reduction in traffic volume in tunnels, almost a 13%. As with averages speeds, traffic volume variation in open air sectors is marginal. While in tunnel most distant areas, a little increase in traffic volume can be observed, in speed transition areas a decrease in traffic volume occurs. There is a 3.56% reduction in traffic volume and saturation rates for the whole urban highway.

Several studies (e.g. Shefe and Rietvel 1997) conclude that impacts of lowering speed limits on travel times remain questionable. In this case, considering M30 as a whole, travel times remain virtually unchanged. In tunnel sections they increase 3.27% but this raise is compensated by the 3.09% lessen in the mild renovation sector.

When studying CO_2 and NOx emissions' variation, it can be observed that the implementation of the new speed limit policy bring about a reduction in both kinds of emissions in the tunnel sector. While CO_2 emissions decrease almost a 15%, NOx emissions diminish more than a 16%. The effect on open air areas is negligible therefore the 4% and 4.6% reduction in CO_2 and NOx emissions respectively for the whole M30 is mainly due to its variation in the tunnel sector.

Table 2 – Daily variation of traffic performance parameters and emissions rates after lowering the speed limit from 90 km/h to 70 km/h in the Total Renovation Sector

Differences of traffic parameters and emissions rates between scenarios			Network length (km)	Driving length (km)	ADT	(Scenario 1 – Scenario 2) / Scenario 1				
						TRAFFIC PERFORMANCE			EMISSIONS	
						VKM	VEH	SPEED	CO_2	NOx
Moderate renovation	1	La Paloma	1.51	0.57	215,881	1.66%	3.77%	-1.15%	2,53%	2,08%
	2	Costa Rica	7.58	2.88	231,732	0.83%	1.99%	-0.62%	0,95%	0,82%
	3	America	10.58	4.02	263,136	0.34%	0.50%	-0.46%	0,17%	0,17%
	4	O'donnel	8.30	3.15	289,990	-0.20%	-1.37%	0.23%	-0,48%	-0,34%
	5	Mediterraneo	6.70	2.54	293,451	-1.57%	-1.81%	0.47%	-1,47%	-1,40%
		Subtotal: Moderate renovation	**34.66**	**13.17**	**266,500**	**0.07%**	**0.20%**	**-0.17%**	**0,04%**	**0,02%**
Severe renovation	6	Tunnel	20.50	8.80	107,894	-12.69%	3.27%	-17.76%	-14,43%	-16,36%
		Subtotal: Severe renovation	20.50	8.80	107,894	-12.69%	3.27%	-17.76%	-14,43%	-16,36%
Mild Renovation	7	El Pardo	9.45	3.59	112,750	-4.17%	-11.58%	2.34%	-5,27%	-4,26%
	8	Noreste	7.78	2.95	76,894	-0.87%	-1.17%	0.03%	-0,65%	-0,64%
	9	Ilustracion	4.41	1.68	64,192	1.60%	1.59%	-0.78%	1,71%	1,67%
	10	Nudo Norte	6.324	2.40	105,250	2.65%	3.56%	-0.69%	2,53%	2,43%
		Subtotal: Mild renovation	**27.95**	**10.62**	**93,422**	**-0.92%**	**-3.09%**	**0.66%**	**-1,29%**	**-0,97%**
TOTAL: M30 Ring-road			**83.12**	**32.59**	**169,162**	**-3.56%**	**-0.01%**	**-4.76%**	**-4,06%**	**-4,60%**

Table 3 presents the hourly variation of the traffic performance indicators after the implementation of the 70 km/h speed limit along the tunnel sector. In tunnels, variation in average speed among periods is less than 10% as it is traffic volume variation, except during off-peak hours when traffic volume is considerable lower than in peak hours.

However travel times in tunnels differ enough from one period to another. Difference between AM and PM are explained by the cumulative effect of those little variations in average speed and traffic volume. During the morning period, traffic volume is about 10% larger than during the afternoon and average speed is about 10% slower than during the afternoon; therefore travel times during morning peak-hours are larger (7.73%) than in afternoon peak-hours (4.20%).

Travel times during off-peak hours in tunnels only raise 1.57% because, while average speed diminishes 17.8%, traffic volume reduction is also very important (14.14%) and it compensates the effect of average speed reduction.

Two main reasons explain why daily variations in travel times remain practically unchanged. On the one hand, as explained in Table 2, the raise in tunnel travel times is compensated by the diminish in mild renovation sector travel times and on the other hand, although travel times considerably increase during peak hours, these only represent 7 of the 15 hours considered for the modeling.

Table 3 - Hourly variation of traffic performance parameters after lowering the speed limit from 90 km/h to 70 km/h in the Total Renovation Sector

		TRAFFIC PERFORMANCE [(Scenario 1 – Scenario 2) / Scenario 1]								
		VKM			VEH			SPEED		
		AM	PM	HV	AM	PM	HV	AM	PM	HV
1	La Paloma	-2.14%	2.05%	2.36%	-0.94%	4.69%	4.38%	1.32%	-1.56%	-1.52%
2	Costa Rica	-0.96%	0.72%	1.36%	-2.91%	1.54%	3.50%	1.02%	-0.53%	-1.08%
3	America	-1.52%	0.47%	0.72%	-3.80%	0.78%	1.39%	1.18%	-0.53%	-0.82%
4	O'donnel	-2.18%	-0.51%	0.49%	-3.99%	-1.36%	-0.72%	1.69%	0.94%	-0.58%
5	Mediterraneo	-2.81%	-0.79%	-1.75%	-7.34%	-0.09%	-1.50%	2.48%	-0.38%	0.49%
	Subtotal: Moderate renovation	**-1.76%**	**0.13%**	**0.48%**	**-3.71%**	**0.42%**	**1.05%**	**1.55%**	**-0.22%**	**-0.58%**
6	Tunnel	-10.22%	-11.36%	-14.14%	7.73%	4.20%	1.57%	-18.52%	-17.39%	-17.80%
	Subtotal: Severe renovation	**-10.22%**	**-11.36%**	**-14.14%**	**7.73%**	**4.20%**	**1.57%**	**-18.52%**	**-17.39%**	**-17.80%**
7	El Pardo	-1.77%	-2.18%	-6.01%	-9.39%	-10.00%	-13.11%	3.43%	1.15%	2.80%
8	Noreste	2.19%	1.10%	-2.87%	2.19%	1.26%	-3.53%	-0.24%	-0.15%	0.21%
9	Ilustracion	3.94%	1.75%	0.93%	4.37%	4.19%	-0.73%	-1.78%	-1.77%	0.08%
10	Nudo Norte	0.04%	1.04%	4.31%	-0.84%	2.75%	5.16%	0.96%	-0.48%	-1.23%
	Subtotal: Mild renovation	**0.06%**	**-0.13%**	**-1.66%**	**-2.85%**	**-1.99%**	**-3.83%**	**1.17%**	**0.13%**	**0.86%**
	TOTAL M30	**-3.42%**	**-2.96%**	**-3.97%**	**-1.23%**	**0.58%**	**-0.08%**	**-4.40%**	**-4.83%**	**-4.81%**

Table 4 presents the hourly variation of the emissions indicators after the implementation of the 70 km/h speed limit along the tunnel sector. It shows that the most important CO_2 and NOx emissions reductions occur during off-peak hours. This was expected because during these periods and due to lower saturation rates, most of the time driving at free flow speeds is possible. Lowering speed limits to 70 km/h means 22.2% lower free flow speeds.

The effect of the measure during peak hours is also important. During peak hours vehicles usually don't reach free flow speed; nevertheless, lowering speed limits generate less changing friction, less speed dispersion and greater headways which led to less shock waves (Noland, R.B. and Quddus 2005) , that lead to reduction in both CO2 and NOx emissions.

Table 4 - Hourly variation of traffic emission rates after lowering the speed limit from 90 km/h to 70 km/h in the Total Renovation Sector

			EMISSIONS [(Scenario 1 – Scenario 2) / Scenario 1]					
			CO2			NOx		
			AM	PM	HV	AM	PM	HV
Moderate renovation	1	La Paloma	-1,35%	3,22%	3,39%	-1,65%	2,60%	2,91%
	2	Costa Rica	-1,33%	0,83%	1,73%	-1,07%	0,72%	1,44%
	3	America	-1,98%	0,46%	0,55%	-1,66%	0,42%	0,49%
	4	O'donnel	-2,59%	-0,67%	0,17%	-2,21%	-0,53%	0,23%
	5	Mediterraneo	-3,57%	-0,57%	-1,54%	-2,85%	-0,64%	-1,55%
		Subtotal: Moderate renovation	-2,15%	0,21%	0,52%	-1,82%	0,16%	0,41%
Severe renovation	6	Tunnel	-12,09%	-12,55%	-16,29%	-14,19%	-14,55%	-18,10%
		Subtotal: Severe renovation	-12,09%	-12,55%	-16,29%	-14,19%	-14,55%	-18,10%
Mild renovation	7	El Pardo	-3,43%	-3,89%	-6,86%	-2,25%	-2,78%	-5,93%
	8	Noreste	2,23%	1,06%	-2,82%	2,19%	1,06%	-2,78%
	9	Ilustracion	4,37%	2,73%	0,29%	4,22%	2,24%	0,63%
	10	Nudo Norte	0,00%	1,38%	4,20%	0,11%	1,15%	4,07%
		Subtotal: Mild renovation	-0,53%	-0,59%	-2,03%	-0,08%	-0,30%	-1,72%
TOTAL: M30 Ring-road			**-4,14%**	**-3,25%**	**-4,59%**	**-4,52%**	**-3,82%**	**-5,15%**

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4. CONCLUSIONS

Traditionally, traffic management strategies were used for reducing congestion in urban environment; however these kinds of measures have been consigned to the sidelines when studying strategies to reduce road transport emissions. It is assumed that those measures that are used to decrease saturation rates in urban roads, will also benefit both fuel consumption rates and therefore GHG and air pollutants emissions. Although several studies that analyze the effect of some specific traffic management strategies can be found in literature, see e.g. Madireddy et al. 2011, Goncalves et al. 2008, Midenet et al. 2004 and Keuken et al. 2010; there is a lack of tools that evaluate traffic operation strategies from the emissions point of view allowing policy makers towards choosing the best fitted strategy for their cities.

From a macroscopic point of view, road transport emissions are highly correlated to traffic volumes and average speeds (Ntziachirstos & Samaras 2012). Speed reduction strategies affect both parameters. On the one hand, reduction in traffic volume is an indirect effect of lowering speed limits because the road results less attractive to drivers and on the other hand, falls in average speeds is a direct cause of lowering the free flow speed.

Lowering the speed limit from 90 km/h to 70 km/h (22.2% reduction) in less than a third of an urban ring road barely affect travel times when considering the ring-road as a whole. Travel times in tunnel sections where the measure was applied increase 3.27%. However travel times in tunnels differ enough from one period to another: in tunnel sections, increases in travel times during morning peak hours almost double increases during afternoon peak-hours which triple increases in off-peak hours. This occurs because, although changes in average speed are almost negligible amongst periods, changes in traffic volumes are considerable and therefore travel times by period are affected by the cumulative effect of average speed and traffic volume.

As expected, the measure generates an important reduction in traffic volume in tunnels and average speeds in tunnels, almost a 13% and 18% respectively. The effect in these parameters considering the M30 as a whole is less noticeable. There is an average speed reduction of 4.76% and traffic volume reduction of 3.56%.

As some other studies have shown (Dijkema et al., 2008; Farzaneh et al., 2010), the implementation of the new speed limit policy brings about a reduction in both CO_2 and NOx emissions –in this cases study reductions were 15% and 16% respectively-. Reduction in NOx is greater than reductions in CO_2 which can be explained because besides NOx emissions are directly linked to engine temperature and thus increase at high speed and load (ECMT 2004)

Lowering speed limits has been widely used for safety purposes and also, although less commonly, for fuel conservation purposes. Several studies have shown that lowering speed limits is a relatively straightforward and cost-effective speed management measure to

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reduce vehicle emissions, although they are not likely to be popular because of the common assumption that it can negatively affect traffic performance specially travel times (ECMT 2006; OECD/IEA 2005; TRB 2012). This study shows that lowering speed limits from 90 km/h to 70 km/h in an urban highway can provide significant benefits in terms of CO2 and NOx emissions reduction without substantially raise travel times.

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