# Potential of variable speed limits for emission and noise reduction on the E313 motorway to Antwerp, Belgium

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## Abstract
The E313 motorway between Liege and Antwerp is one of the busiest links in the Belgian road network. In the direction of Antwerp, traffic jams and accidents are frequent. Many accidents occur at the tail of traffic jams. To warn drivers, variable speed limit gantries and detector loops were installed every 750 metres. When a traffic jam is detected, the speed limit is gradually reduced on the upstream motorway section. This paper investigates the potential of the variable speed limits on emissions ($CO_2$, $NO_x$ and $PM_{10}$) and noise. Next to this, other measure are studied: 1) a general speed limit of 90 km/h 2) a broadening from 3 to 4 lanes 3) a traffic flow reduction. A traffic model of the motorway was constructed with Paramics. Emissions were calculated with VERSIT+ and noise levels with Harmonoise/Imagine. The variable speed limits have no discernible influence on emissions, noise and travel time. A general speed limit of 90 km/h results in a small decrease of emissions while an extra lane results in large emission reductions. Measures that reduce heavy congestion, without attracting more traffic, can decrease air pollutant emissions, but will increase noise emissions.

**Keywords:**
Variable speed limits, emissions, $CO_2$, $PM_{10}$, $NO_x$, noise, paramics, VERSIT+, Harmonoise/Imagine

## Introduction
The E313 motorway between the Belgian cities of Antwerp and Liege is a major link in the Belgian and European motorway network (see Figure 1). Its primary functions are: 1) an east-west link for long distance traffic. 2) A link between the harbour of Antwerp and the Ruhrgebiet in Germany. 3) Providing access from the Kempen, in the Northeast of Belgium, to the city of Antwerp and the capital area of Brussels. 4) Providing access to the large industrial areas along the Albert Canal which runs parallel to the motorway. On the busiest section near Antwerp up to 150 000 vehicles per day pass by. Because 23% are trucks, a passenger car equivalent of 180 000 vehicles per day is reached. All day long the traffic volume on this stretch of motorway lies over 90% of its maximum capacity. As a consequence traffic jams are a daily problem and accidents are frequent. In the direction of Antwerp 595 accidents occurred in the period 2006-2008 or almost 1 accident every 3 days. In the direction of Antwerp 24% of the accidents are related to traffic jams. Drivers do not notice the traffic jam in time and crash into the queuing vehicles. Other causes are a wet road surface and sharp turns on some approaches. Due to the high traffic density, each incident causes even bigger traffic jams.


**Figure 1 – The E313 motorway to Antwerp and the VSL gantry positions**

To tackle the problem of accidents at the tail of traffic jams, the Vlaams Verkeerscentrum (VVC - Flemish Traffic Centre) implemented variable speed limits (VSL) between Geel-Oost and Antwerpen-Oost. In 2007 the system was finished and equipped with a semi-automatic control. The infrastructure consists of gantries and loop detectors about every 750 m over about 40 km (black dots in Figure 1). Each gantry has a digital panel above each lane. This panel can display a speed limit or other traffic information. For example, in the case of an accident, an evacuation arrow or a red cross will be shown above a blocked lane. The loop detectors count vehicles and measure their speed. If a traffic jam is detected (high vehicle density and low speed), the speed limits on the upstream panels will be reduced gradually. Figure 2 shows the algorithm used to determine the speed limit shown at a gantry. Each gantry uses the speed and occupation measured at the next downstream gantry. The respective bands, in which the speed and occupation are lying, determine the speed limit. The bands overlap to build in some hysteresis in the system and to prevent nervous switching between two speed limits. The speed limit is only updated when the speed or occupation moves out of the overlapping bands. In a next step, the speed limits are equalized over each gantry. Finally it is checked if the difference between successive gantries is not bigger than 20 km/h. In this case the speed limits are reduced in steps of 20 km/h.

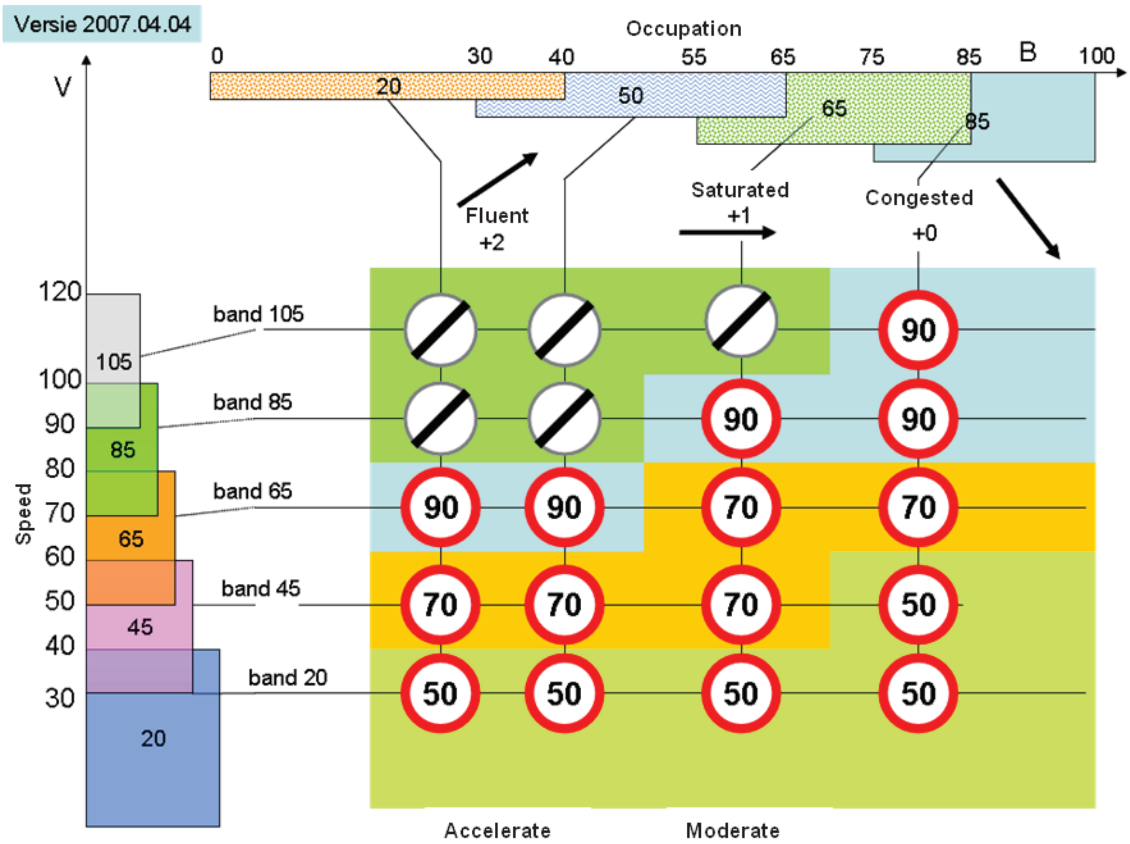


**Figure 2 – Control algorithm of the VSL gantries (Source: Vlaams Verkeerscentrum).**

The objective of this study is to evaluate the effect of VSL on tailpipe emissions ($CO_2$, $NO_X$ and $PM_{10}$) and on noise levels along the motorway. The study area is the section between Geel-Oost and Antwerp (Figure 1). The VSL system warns people in advance of a traffic jam further ahead. Hence, they are able to slow down more gradually instead of braking at the last moment when they see the traffic jam. This may have a small effect on emissions and noise. The speed limits are not compulsory but merely a recommendation and warning. If in reality the variable speed limits are ignored, there will be no effect. In Paramics, the speed limit reductions are adhered to, so Paramics will overestimate the effects.
Next to VSL other measures will be studied:

1. The VSL signs can also be used to deliberately reduce speed limits to reduce air pollution as in [1-3]. The effect of a 90 km/h speed limit will be evaluated.
2. An extra lane between Ranst and Antwerp. There are no plans to build this lane but in the other direction the emergency lane is made available for traffic during the rush hours.
3. Reduction of the traffic flow. This could be the effect of road pricing, higher fuel taxes or a modal shift to public transport or cycling.

**The Paramics traffic model of the E313 motorway**
A model of the E313 was constructed in Quadstone Paramics. The first step was to implement the road network. All relevant features of the highway were taken into account:

1. Between Geel-Oost and the junction with the E34 highway in Ranst there are 2 lanes with a speed limit of 120 km/h.
2. After the E34 merges with the E313 there are 3 lanes with a speed limit of 120 km/h.
3. VSL gantries were placed as in Figure 1. The positions were provided by the Flemish Traffic Centre (VVC).

Three types of vehicles were used in the simulation: passenger cars, light trucks and heavy trucks. These types correspond to the types for which traffic counts were available and for which emission functions are defined in VERSIT+ and Imagine [5], the air pollutant and noise emission models.
The second step is the definition of the traffic load. The VVC provided traffic counts of a normal morning (Monday 28/2/2011) between 6 am and 10 am every 5 minutes. Counts were available for the approaches, exits and some intermediate points. The counts were split up in three vehicle types: light vehicles, light trucks and heavy trucks.
Also the destination of the traffic entering the network has to be defined. There was no information about the destinations of the incoming vehicles. To obtain such data, number plate recognition on all entrance and exit points is needed. Hence, each entering flow was distributed over all possible exits proportionally with the total vehicle count on each exit. The flow on the exits was made to match the counts as close as possible. A perfect match is not possible because during the whole simulation the total inflow does not match the outflow. The simulation starts with an empty network but at the end there are still vehicles on the network. However, the imbalance is small (0.7% of the total number of cars and 0.4% of the total number for trucks). Because the flows on approaches and exits match, also the flows on intermediate points on the highway will match closely.
The VSL gantries were put in place but the control strategy had to be simplified. The overlapping speed and occupancy bands could not be taken into account in the standard implementation of VSL in Paramics.

**Effect of VSL on air pollutants and noise emissions**

For each scenario, without and with VSL, 5 model runs with different seeds were done. The seed determines the random release of vehicles within each time interval of five minutes. Both scenarios use the same 5 seeds. The results are in Table 2. The application of VSL reduces the average speed significantly from 42.0 to 40.7 km/h (paired t-test with p-value=0.0004). As a consequence the distance travelled and the total emissions decrease. These changes occur within the period from 6 to 10 am. A part of the trips is moved outside this time interval. The change in emissions per kilometre gives a better idea of what VSL does with the emissions. All emissions increase a little and the increase of CO2/km and PM10/km is significant. This is further explained in Figure 3. This figure shows the average trip emissions in g/km as a function of the average trip speed. Emissions are minimal around 90 km/h and they rise sharply at lower speeds and a little at higher speed. Both scenarios are represented on the graphs with red dots.

**Table 2 - Average results of 5 runs without and with VSL, relative differences and p-values of a paired t-test.**

| Scenario | Distance (km) | Speed (km/h) | $CO_2$ (ton) | $NO_x$ (ton) | $PM_{10}$ (ton) | $CO_2$ (g/km) | $NO_x$ (g/km) | $PM_{10}$ (g/km) |
|---|---|---|---|---|---|---|---|---|
| NOVSL | 360280 | 42.0 | 170.79 | 0.7563 | 0.03573 | 474.0 | 2.099 | 0.09918 |
| VSL | 357234 | 40.7 | 170.75 | 0.7517 | 0.03566 | 475.9 | 2.104 | 0.09983 |
| rel. diff. | -0.85% | -3.27% | -0.46% | -0.60% | -0.19% | 0.39% | 0.24% | 0.66% |
| p-value | **0.0004** | **0.0112** | **0.0314** | 0.0982 | 0.2765 | **0.0185** | 0.3561 | **0.0050** |

Because in reality the variable speed limits are not compulsory, we can conclude that they will have very limited influence on air pollutant emissions. The only indirect effect on emissions is the prevention of accidents. Accidents cause traffic jams that reduce the average trip speed and will increase the emissions per distance travelled as shown in Figure 3.

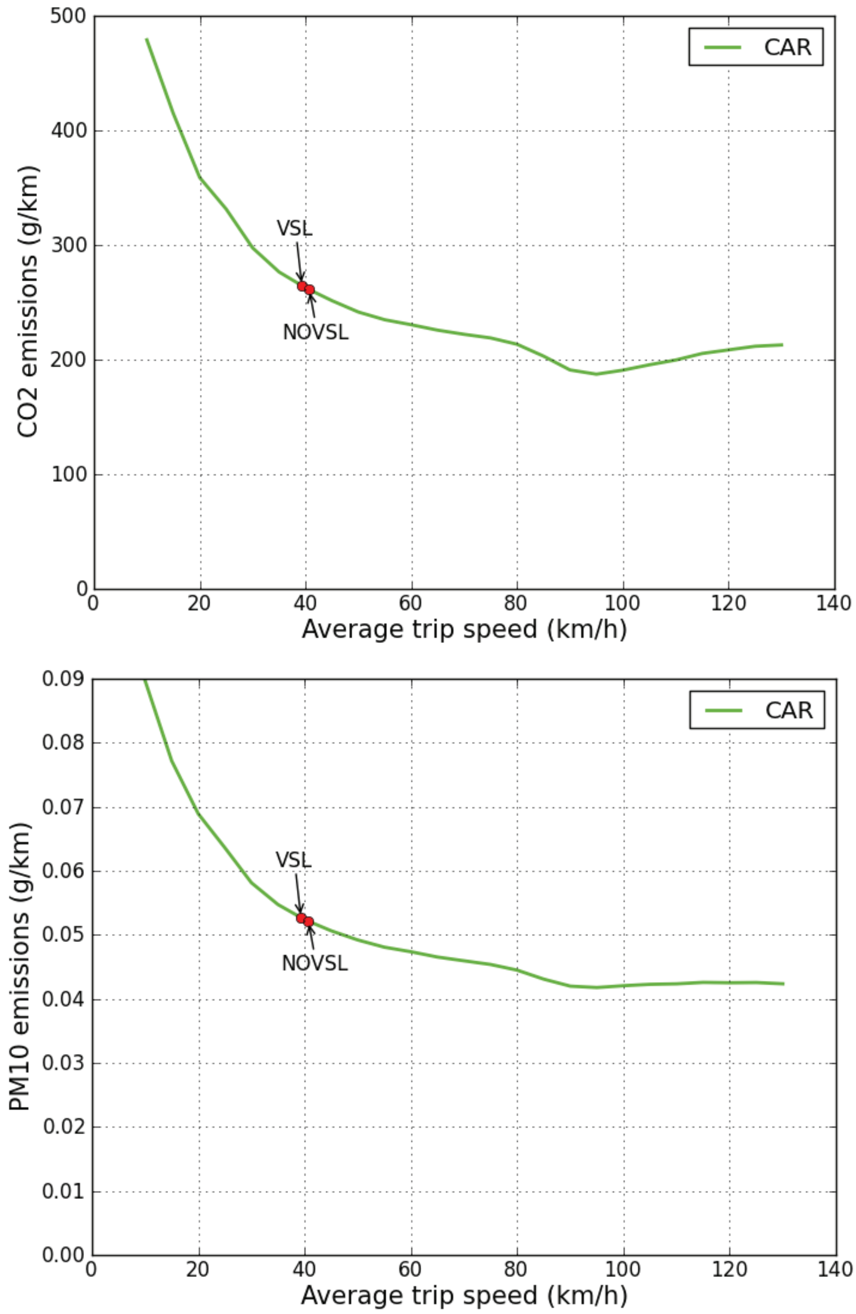


**Figure 3 - Emissions of $CO_2$ and $PM_{10}$ in g/km as a function of average trip speed for passenger cars.**


**Figure 4 - Location of the receiver points along the E313 for noise calculations.**

In order to assess the influence of the implementation of VSL on noise levels along the freeway, a series of receiver points were placed along the freeway. The locations of these receivers are shown in Figure 16. All receivers were placed north of the E313 freeway, at a distance of 15m from the centre of the rightmost lane, and at a height of 1.5m. Receivers 1 and 2 were placed near the ring road of Antwerp, receivers 3 and 4 in between Antwerp and Ranst, and receivers 5 and 6 in between Ranst and Herentals. The odd-numbered receivers were placed next to a VSL sign board, while the even-numbered receivers were placed in between sign boards. Instantaneous noise levels at the location of these receivers were calculated using the ISO 9613 sound propagation model, based on the instantaneous sound power calculated for all vehicles on the freeway. Subsequently, the equivalent sound pressure level for the 4-hour simulation period was calculated. Table 3 summarizes the change in LAeq,4h (average over 5 runs) due to the VSL implementation. A decrease in noise levels was found for all locations and for all simulation runs. However, decreases were very small. The largest decrease in levels is found along the stretch of freeway between Ranst and the Antwerp ring road, with a decrease of about 0.5 dBA at most, which could be expected based on the small decrease in average speeds. Traffic jams build up in the upstream direction from Antwerp, and therefore the VSL will be in effect first in this stretch of road. Nevertheless, as with the case of air pollutant emissions, the implementation of VSL has only a small influence on noise levels.

**Table 3 - Average changes in sound pressure level (LAeq,4h) at 15m from the E313 freeway, resulting from an implementation of VSL, and from a network wide speed limit reduction to 90 km/h.**

| Location | No VSL | Implementation of VSL | | Speed limit to 90 km/h | |
|---|---|---|---|---|---|
| | LAeq,4h (dBA) | LAeq,4h (dBA) | Change (dBA) | LAeq,4h (dBA) | Change (dBA) |
| 1 | 73.21 | 73.12 | -0.09 | 73.05 | -0.16 |
| 2 | 73.55 | 73.03 | -0.52 | 73.35 | -0.20 |
| 3 | 74.48 | 74.13 | -0.34 | 74.17 | -0.30 |
| 4 | 74.57 | 74.27 | -0.30 | 74.24 | -0.34 |
| 5 | 75.15 | 75.11 | -0.04 | 74.43 | -0.71 |
| 6 | 75.41 | 75.38 | -0.03 | 74.69 | -0.73 |

**Evaluation of other measures on the E313**

The model that was developed to evaluate the effect of VSL can be used to assess the effect of other measures that could be taken.

*A general speed limit of 90 km/h*

The VSL panels could be used to impose a permanent maximum speed of 90 km/h. The reduction was implemented in the Paramics model of the E313. Figure 3 and Table 4 show that a considerable reduction of $CO_2$ and $NO_x$ emissions can be achieved when the maximum speed is reduced from 120 km/h to 90 km/h. Table 5 shows the results in real traffic. The effects are smaller than shown in Table 4 because most of the time vehicles are not able to drive more than 90 km/h. However, significant reductions of $CO_2$ and $NO_x$ are achieved.

Table 3 also summarizes the results of the speed limit reduction on noise levels at the receiver locations defined in the previous section. It is found that noise levels decrease due to a speed limit reduction, up to 0.7 dBA for the stretch of freeway between Ranst and Geel-Oost. In contrast to the VSL implementation, the largest effect is found more upstream of the E313 motorway, as this stretch is less affected by traffic jams and thus initial average speeds are higher than downstream of the E313 freeway. It has to be noted that here we only consider the morning rush hour with the associated traffic jams; the effect of a network-wide speed limit reduction will obviously have a much larger effect on noise levels during periods of the day with lower traffic volumes.

**Table 4 - Effect of a reduction of the average trips speed from 120 to 90 km/h on emissions.**

| Veh. Type | Avg. trip speed (km/h) | $CO_2$ (g/km) | $NO_x$ (g/km) | $PM_{10}$ (g/km) |
|---|---|---|---|---|
| CAR | 120 | 208.5 | 0.6876 | 0.04251 |
| CAR | 90 | 191.0 | 0.5027 | 0.04199 |
| rel. diff. | -25.0% | -8.4% | -26.9% | -1.2% |

**Table 5 - Effect of a general speed limit of 90 km/h on emissions**

| scenario | Distance (km) | Speed (km/h) | $CO_2$ (ton) | $NO_x$ (ton) | $PM_{10}$ (ton) | $CO_2$ (g/km) | $NO_x$ (g/km) | $PM_{10}$ (g/km) |
|---|---|---|---|---|---|---|---|---|
| NOVSL | 360280 | 42.0 | 170.8 | 0.7563 | 0.03573 | 474.0 | 2.099 | 0.09918 |
| SPEED 90 | 360149 | 40.3 | 168.0 | 0.7374 | 0.03546 | 468.4 | 2.057 | 0.09890 |
| rel. diff. | -0.48% | -4.25% | -1.66% | -2.50% | -0.76% | -1.18% | -2.03% | -0.27% |
| p-value | **0.0088** | **0.0114** | **0.0017** | **0.0014** | **0.0271** | **0.0154** | **0.0045** | 0.4308 |

*A fourth lane between Ranst and Antwerpen-Oost*

A possible way to reduce congestion is increasing the capacity of existing roads. On the 28th September 2011 a 4th lane was opened between Antwerpen-Oost and Ranst in the direction of Liege (opposite direction of this study). This reduced travel times during the evening rush hour for people leaving Antwerp. There are no plans to do the same between Ranst and Antwerp but in the simulated network a 4th lane was added in the direction to Antwerp. Currently 2 highways with each 2x2 lanes join into one highway with 3x3 lanes in Ranst. This capacity drop causes traffic jams. Additionally, the approach of Wommelgem (between Ranst and Antwerp) is responsible for a big influx of vehicles.

**Table 6: Effect of a 4th lane between Ranst and Antwerp on emissions**

| Scenario | Distance | Speed | $CO_2$ | $NO_x$ | $PM_{10}$ | $CO_2$ | $NO_x$ | $PM_{10}$ |
|---|---|---|---|---|---|---|---|---|

| | (km) | (km/h) | (ton) | (ton) | (ton) | (g/km) | (g/km) | (g/km) |
|---|---|---|---|---|---|---|---|---|
| NOVSL | 360280 | 42.0 | 170.8 | 0.7563 | 0.03573 | 474.0 | 2.099 | 0.09918 |
| LANES | 385507 | 75.0 | 158.0 | 0.7116 | 0.03097 | 409.9 | 1.846 | 0.08033 |
| rel. diff. | +7.00% | +78.5% | -7.47% | -5.91% | -13.33% | -13.53% | -12.07% | -19.00% |

In Table 6 one can see that the average trip speed increases from 42 to 75 km/h with the addition of a 4th lane. Emissions decrease considerably because at the new trip average speeds emissions are lower (see Figure 3). It is important to mention that the traffic demand was not changed in this simulation. In reality, the decrease in travel time might attract more traffic. Thus, the total emissions on the highway with 4 lanes might be higher than in the 3-lane situation.

*A Reduction of the traffic demand*

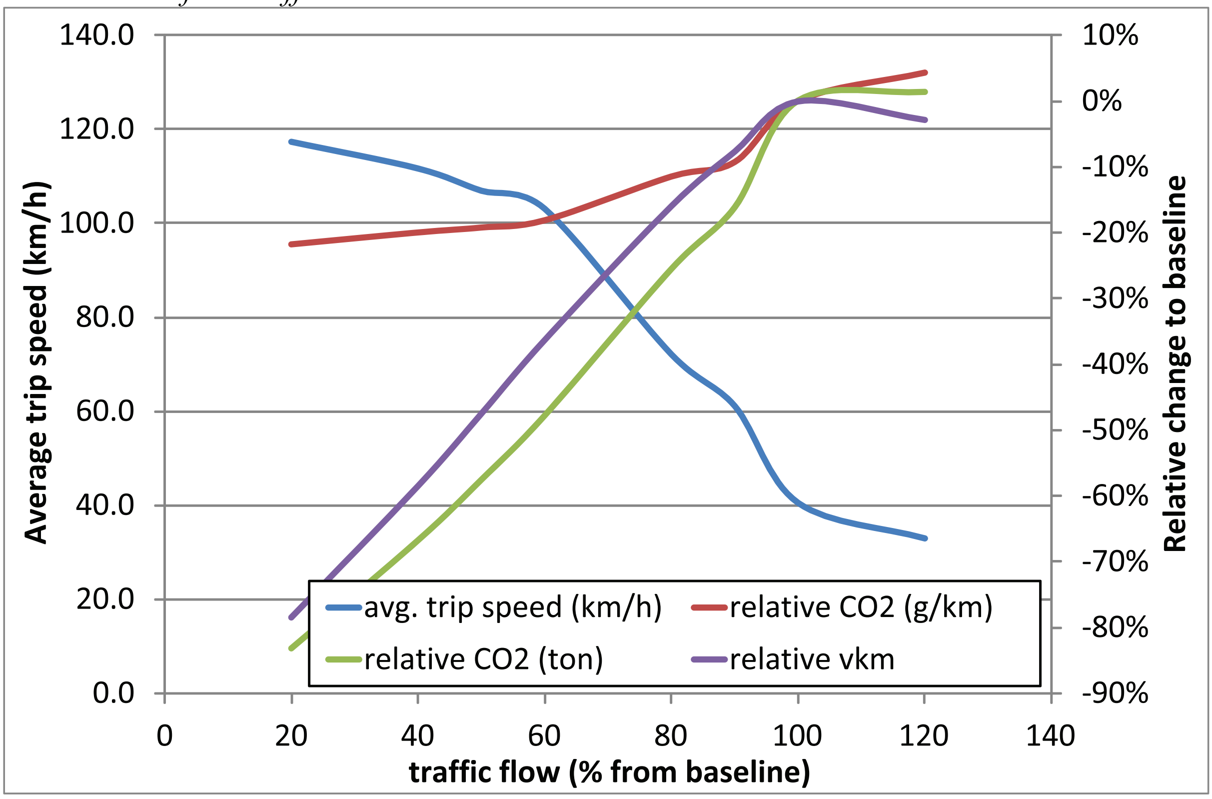


**Figure 5 - Average trip speed, emissions of $CO_2$ (total and per km) and vehicle kilometres on the E313 for different traffic demands.**

Another way to reduce pollution and congestion is road pricing or a fuel tax. These measures will reduce the traffic demand. Scenarios with other demands were simulated with Paramics. Runs were done with flows between 20% and 120% of the baseline scenario without VSL. Emissions were calculated with VERSIT+. Figure 5 shows what happens with the average speed, the vehicle kilometres and the emissions with respect to the reference situation without VSL. The total vehicle kilometres during the simulation go through a maximum near the baseline scenario (purple line). This means that even with higher flows on the entries, the number of vehicle kilometres does not rise. The traffic in the baseline situation is saturated. When the traffic load is increased the average trip speed goes down (blue line) and the emissions per kilometre (red line) go up (see also Figure 3). The total emissions just stagnate, because queues build up outside the study area. When the traffic flow is decreased the total emissions decrease faster than the vehicle kilometres. The traffic gets more fluid, average trip speed rises and vehicles emit less per kilometre. The picture for the emissions of $NO_x$ and $PM_{10}$ is similar.

## Conclusions

The model presented in this paper shows that VSL has only very little direct effect on air pollutant and noise emissions. However, there may be an indirect effect through the reduction of accidents and the corresponding congestion.

Air pollutant emissions are minimal around a speed of 90 km/h. Given that the current average speeds on the E313 during rush hour are so low, decreasing average speeds will lead to extra air pollution, but, on the other hand, will lead to lower noise levels along the freeway. Measures that enhance traffic speed without attracting more traffic can decrease air pollutant emissions, but will increase noise emissions. Two measures were modelled; an extra lane and a reduction of the traffic flow. Both measures increase the average speed, reduce emissions and increase noise. However, in practice reduced travel times attract more traffic and emissions will be higher than in the original situation. A congestion charge could solve this unwanted side effect.

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