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The Effect of a green wave on traffic emissions

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Abstract

The demand for transport is closely linked with economic development. It is a contributor to prosperity, but a too high traffic volume reduces the efficiency of the transport system by increasing journey time, fuel consumption, driver stress as well as vehicle-based emissions. Of the EU urban population 80-90% is exposed to too high levels of PM10. Currently 20% of the population lives in areas where the 24-hour air quality limit for PM10-concentrations is exceeded more than the accepted 25-days per year. When looked at NO2-concentrations in Europe, emissions widely exceed the existing 40 µg/m3 average annual limit value, especially around crossings. The city of Kapfenberg, in which this research was done, lies in an area under the monitoring of the Austrian air quality law, (Immisionsschutzgesetz – Luft) and needs to look for a reduction of emissions. One way to reduce the emissions, is reducing the traffic by reducing capacity of urban roads. However, this will lead to more stop-and-go traffic and therewith a rise of the emission amount. Another way to reduce the emissions, is to homogenises the traffic flow by creating a green wave for the main direction, guaranteeing a free flow over several traffic lights. This will lead to a sustainability reduction of the emissions. By using three different models (VISSIM, HBEFA and Car2) the emission reduction by applying a green wave was calculated. Some emissions (pollutants), showed a remarkable decrease. Nitrogen dioxide and particulate matter have decrease more than 50%. Others, like carbon monoxide, carbon dioxides, sulphur dioxide and fuel consumption had smaller decreases. The reduction of CO2 was found to be 178.824,88 kg when one compares the current green wave with the static program. Thus, a green wave has quite a large impact on the emissions when it is changed from a stop-and-go situation into a homogenised green wave situation.

Keywords:

Green wave, emissions, air pollution, traffic lights

Motivation and central question

The demand for transport is closely linked with economic development. It is a contributor to prosperity, but an excessively high-traffic volume reduces the efficiency of the transport system by increasing journey time, fuel consumption, driver stress as well as vehicle-based emissions. [Krugman, 1979]

Of the EU urban population, 80-90% is exposed to too high levels of PM_{10}. Currently, 20% of the population lives in areas where the 24-hour air quality limit for PM_{10}-concentrations is exceeded more than the accepted 25-days per annum. When looking at NO_2-concentrations in Europe, emissions widely exceed the existing 40 µg/m^3 average annual limit value, especially around crossings. [EEA, 2012]

The city of Kapfenberg, in which this research was done, lies within an area under the monitoring of the Austrian air quality law [Bundeskanzleramt Rechtsinformationssystem, 2008] and needs to look for a reduction of emissions.

One way to reduce the emissions, is reducing the traffic volume by reducing the capacity of urban roads. However, this can lead to more stop-and-go traffic which has a negative influence on the reduction of the emission amount. Another way to reduce the emissions, is to homogenises the traffic flow by creating a green wave for the main direction, guaranteeing a free flow over several traffic lights. This will lead to a reduction of the emissions. The goal therefore, is to research if and what the impact of a green wave is on the emissions of traffic and the air quality.

Geographical situation

Kapfenberg is a city between Vienna and Graz and is one of the larger cities in the northern part of the province Styria. Just a few kilometres away the city Bruck an der Mur is situated. Due to the proximity and share of shops and services between both cities, there is a large traffic stream over the provincial road B116 between these cities (See figure 1). The provincial road B116 is therefore the main road connecting between both cities, on a local as well as a regional scale. The traffic lights on the B166 were placed to secure a safe and efficient distribution of the traffic between both cities.

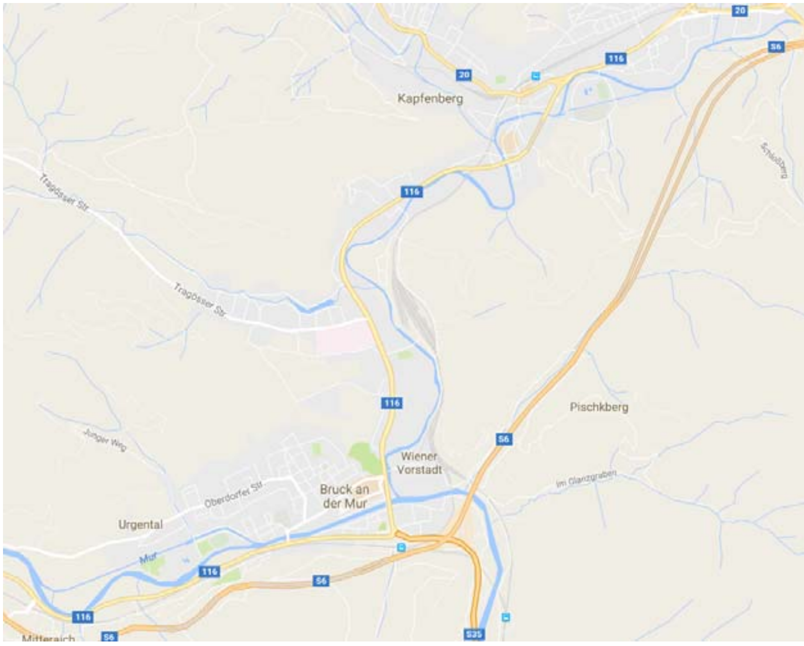

Figure 1: B116 between Kapfenberg and Bruck an der Mur [Google, 2017]

Methodological Background

Traffic drives on fuels which unfortunately do emit substances at the end of the burning process. Knowledge on these emissions has improved over the years and draw a worrisome picture. The different sorts of emissions, each have their own impact on the air quality, ranging from a local to a global scale and within affecting the health of people. Laws have been setup to steer these unwished for situations, like the DIRECTIVE 2008/50/EC on ambient air quality and cleaner air for Europe [European Union, 2008].

Trends within the fuel sector transfers away from fossil fuels towards sustainable energy sources like electro mobility or hydrogen fuel. This trend could lead to a reduction of the emissions and therefor to a different outcome of the environmentally pollution over the upcoming years. Although many studies have been conducted towards the exhaust gases and their pollution, the following statement of the Transport Research Laboratory shows a rough estimation of the emissions caused by a litre of gasoline:

"Each litre of fuel that is burnt produces, in very approximate terms, 100 grams of carbon monoxide, 20 grams of volatile organic compounds, 30 grams of oxides of nitrogen, 2.5 kilograms of carbon dioxide and a variety of other emissions including lead compounds, sulphur compounds and fine particles.'' [Transport Research Laboratory, 1999]

Research towards air pollution and emissions identified carbon monoxide, oxides of nitrogen, unburnt hydrocarbons and particulate matter as the main air quality pollutant emissions from petrol and diesel engines, which are regulated by the Euro emissions standards. [European Union, 2007] Carbon monoxide, oxides of nitrogen, and un-burnt hydrocarbons are gases, and therefor mostly invisible. Particulate matter is usually invisible although under certain operating conditions diesel engines will produce visible particles, appearing as smoke. Petrol engines will also produce visible particles if they are burning engine oil or using too much petroleum, for example, following a cold start. Fine particles can also be produced by tyre and brake wear. Unlike emissions of CO_2, emissions of the air quality pollutants are not directly linked to fuel consumption.

Modern cars produce only quite small quantities of air quality pollutants, but the emissions from large numbers of cars add to a significant air quality problem. [Department for Transport United Kingdom, 2016] Pollutant emission levels depend more on vehicle technology and the state of maintenance of the vehicle. Other factors, such as driving style, driving conditions and ambient temperature also affect them. However, as a starting point, all new passenger cars must meet minimum EU emissions standards, as stated in the Clean Air For Europe (CAFE) regulations. [European Commission, 2015]

Expectations of a green wave

Traffic and its negative side effects, such as stop-and-go driving, have an impact on the world we live in. To prevent stop-and-go traffic on urban roads, the introduction of a green wave can help to increase traffic safety and street capacity, reduce waiting time, improve fuel use, and in the end, reduce the emissions. A green wave can be described as a way of travelling in a synchronized flow. This way of driving differs from a free flow as it has a coherent speed and a more or less controlled high density. This can also be found during the optimal moments of a free flow; however, it can easily break down to congestion out of a free flow state if one of the cars suddenly changes its speed. The synchronized traffic however tries to let the entire traffic move at the same speed, which creates less incentive or possibilities to change to a different, not optimal, speed. The high density and moderate speeds mean that the flow rate is almost as high as it could possibly be. Moreover, coherent flow is a safe state because it reduces two of the main causes of highway accidents – differences of speed and lane changes. [Ball, 2004]

A lot of research has been conducted on the subject of a green wave. Research by [Madireddy et al., 2011] in 2011 came up with a relative conservative estimate of 10% less pollutants after installing a green wave. Two years later most of these researchers reinvestigated part of the study, and saw a similar result of 10% fewer pollutants as a conservative estimate, but also saw a possible improvement of up to 40% under perfect conditions, depending on traffic flow and signal timing settings. Traffic intensity and green time were found to have the largest influence on emissions, while the cycle time of a green wave did not have a significant influence on emissions.

Other research by [Rakha, Ding et al.,2003] saw that an improved driving style due to a green wave can lower CO emission by up to 17%, and NOx emissions by 48%. They found that speed and acceleration significantly affect the emission rates. Also vehicle accelerations become a more dominant factor on HC and CO emissions, especially at high speeds. Their final conclusion read that the introduction of a typical vehicle stop can increase a vehicle's emission rate by up to 100 percent when compared to a constant speed trip with an identical average speed.

Methodological procedure

To answer the question what the effect of a green wave on the traffic emissions, the static traffic light program and the green wave situation of the road connecting Kapfenberg to Bruck a/d Mur was simulated in Vissim 6. [PTV, 2014] VISSIM is one of the most used microscopic, multimodal traffic simulation software in the world and was created by PTV Transport Verkehr AG. The software offers flexibility in simulating many aspects leaving almost endless possibilities of variation in the properties of traffic links, behaviour and car types. The traffic data was obtained from the geographical information system of the province Styria. [Das Land Steiermark, 2014] Information from the road and its traffic dynamics was obtained by four sightings.

Traffic intensity estimates of side roads are based on the traffic generating model “Rekentool verkeersgeneratie”. [CROW, 2015] VISSIM has the limitations that it calculates with the emission data from the American car fleet, instead the Austrian or European fleet. [PTV, 2014] Therefore, the international program for emission factor HBEFA was used, which is characterized by providing the specific emission in g/km for all current vehicle categories for a wide variety of traffic situations. [Keller, 2010] For this project, the following pollutants were chosen: sulphur dioxide, carbon monoxide, nitrogen oxides, particulate matter and hydrocarbons for both, hot and cold emission factors.

Lastly, the calculating tool CAR2 was used to determine the air pollution along roads. [TML, 2014] CAR2 calculates the yearly average of the traffic emissions in a street on a height of 1.5 meter. To find the total emissions concentration, the concentration output by traffic is added to the background concentration in the area. The emissions are calculated by combining the amount of traffic, congestion, background concentrations, the tree factor and the type of street. [Province of Styria, 2014]

Results and conclusion

The results out of the models used, did not have the same outcomes nor units. Therefore, the outcomes had to be turned into units with a comparable character, such as percentages. After the units were comparable, the results of both scenarios were compared to find reliable emission outcomes out of the emission model HBEFA.

By comparing the outcome of VISSIM, the effect of the green wave could be investigated. The static traffic light situation emits 42% more emissions compared to the green wave situation.

The HBEFA model clearly shows the need of countering stop-and-go traffic. Passenger cars and trucks increase their fuel consumption with a rate of respectively 65% and 77%, compared to the homogenised situation.

	Baseline	Green wave	Improvement	
	stop –and-go	Free flow	Total kg	Percentage
CO	1705,17	1019,17	686,00	40,23%
HC	332,38	221,95	110,43	33,22%
NOx	3538,06	1370,7	2.167,36	61,26%
PM	62,32	29,66	32,66	52,41%
SO_2	2,769	1,549	1,22	44,06%
CO_2	405.710,28	226.885,40	178.824,88	44,08%

Table 1: Total emissions in kilograms per day

When closely examining the different emissions, some showed a remarkable decrease. Nitrogen oxides and particulate matter have a decrease of more than 50% (Table 1). Other emissions, like carbon monoxide, carbon dioxides, sulphur dioxide displayed less significant decreases. The reduction of CO_2 was found to be 178.824,88 kg per day when one compares the current green wave with the static program.

Thus, a green wave has quite a large impact on the emissions when it is changed from a stop-and-go situation into a homogenised green wave situation.

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