Master Thesis

Industrial Engineer

Analysis and simulation of traffic management actions for traffic emission reduction

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Abstract

This thesis wants to present the reduction of air pollution caused by traffic by implementing certain actions. This topic takes importance after that the law 2008/50/EC was passed and the countries and concretely the cities have to fulfill with it.

To introduce the reader a description of the air quality situation in the Brunswick, which is the city where the scenario of the simulation is implemented, has been done in the section 4.

The actions are selected from the database MARLIS and are explained in the section 5. A pruning of this database has been done by the reason as not all the actions can be implemented in this thesis for reasons, explained below.

The software SUMO (Simulation Urban Mobility) which is the informatics tool to perform the simulation is explained in the section 6.

The section 7 explains how have been implemented the selected actions in to the simulation, and the section 9 shows the results of the simulation. In the section 10 are presented the conclusions.

The actions selected are to set a Tempo 30, an Environmental zone. The goal of this thesis is to show the effect of these actions and compare them with the examples of similar actions extracted from MARLIS and also find out if it is a proper action to be implemented.

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1. Introduction

The ambient air quality is known as an important issue nowadays and in the next decades. Therefore the European Union has created regulations in order to cut down the emissions of those gases that endanger the human health and the vegetation.

The directive that currently regulates the air condition in Europe is “2008/50/EC” and was passed by the European Parliament and the European Council on 21 may of 2008.

This directive lays down measures aimed to define and establish objectives for ambient air quality designed to avoid, prevent or reduce harmful effects on human health and the environment as a whole; assessing the ambient air quality in Member States on the basis of common methods and criteria; obtaining information on ambient air quality in order to help combat air pollution and nuisance and to monitor long-term trends and improvements resulting from national and Community measures; ensuring that such information on ambient air quality is made available to the public; maintaining air quality where it is good and improving it in other cases; promoting increased cooperation between the Member States in reducing air pollution.

This directive includes the following substances: sulphur dioxide, oxides of nitrogen, particulate matter (PM_{10}, $PM_{2.5}$), lead, benzene and carbon monoxide and ozone and defines concentration limits for every pollutant. In the case that a Member State in one of his areas or cities exceeds the limits of any of the contaminants, the European Union will apply a sanction proportional to the foul in order to dissuasive a future infringement.

Traffic has an important impact on the pollution in the urban areas. Traffic management has tools to face the pollution problems, actions that are indicated to reduce the air pollution and try to establish a more sustainable people behavior. In order to find out which are the most suitable actions for a certain area, traffic simulation is a very competent tool.

Traffic simulations allow to discover which could be the effect of the actions that want to be implemented, therefore a good simulation with realistic data can provide objective results which can be taken into account in order to implement new actions and show the future benefits to the population. The software used in this thesis is “Simulation of Urban Mobility” [1](SUMO), created by the German Aerospace Center[2] (DLR).

[1] More information http://sumo.sourceforge.net/
[2] More information www.dlr.de

A selection of actions to reduces the simulated air pollution of the city of Brunswick, which is the scenario that will work this thesis on, has been done. The aim of this thesis is find out the effects of these actions via a simulation and compare them with the plain case and with similar actions implemented in different cities.

2. Related works

This chapter presents works done on the air pollution and his approximation with the simulation. The following documents have common characteristics with this thesis.

The following three documents that are presented here are taken out from the Traffic Systems Planning and Transports Telematics[3] of the Technical University of Berlin.

A good study to try to understand the air pollution connected with the traffic management is [Kickhöfer; Hülsmann; Gerike; Nagel, "Rising car user costs: comparing aggregated and geo-spatial impacts on travel demand and air pollutant emissions", 2012]. This study explains that the cost of taking the car will rise in the following years and it studies whether that fact will involve a reduction of traffic. Within this study, the city of Munich was simulated with the software MATSim[4] comparing different car user costs and shows that when car user costs rise, the reduction of air pollutant emissions is higher than the decrease in car travel demand. In a more disaggregated analysis, we obtain that congestion relief is likely to lower emissions per vehicle kilometer on urban roads. However, we also find that congestion relief can lead to higher emissions per vehicle kilometer for high-speed arterials or tangential motorways.

A continuation of the study above is [Kichhöfer; Nagel. "Sustainability SI: Towards high-resolution first-best air pollution tolls: An evaluation of regulatory policies and a discussion on long-term user reactions" 2013]. This paper studies the application of a speed limitation to 30km/h in the inner city of Munich. And the results show that this measure is considerably less successful in terms of total emissions reduction. It reduces emissions of urban travelers too strongly while even increasing the emission of commuters and freight.

The document [Hülsmann, F.; Gerike, R.; Kickhöfer, B.; Nagel, K.; Luz, R.,Towards a multi-agent based modeling approach for air pollutants in urban regions, 2011] studies the possibility to approximate link travel times to emissions of pollutants. The pollution caused from the traffic activity is complex to calculate, as a lot of data for setting up the scenario is needed, the aim of this document is show if it is possible in a large scenario. In order to prove this hypothesis, a test scenario for a single road is set up in Frankfurter Ring in Munich. The results of this paper are difficult to validate because of the difference in travel times. And the implementation in large scenarios is complicated because in the single road test some simplification have been done that cannot be done in a large scenario.

[3] www.vsp.tu-berlin.de
[4] MATSim: Multi-Agent Transport Simulation (www.matsim.org)

The document [J. D. Vreeswijk, M. K. M. Mahmod, and B. van Arem, “Energy efficient traffic management and control—the eCoMove approach and expected benefits,” 2010] explain the way to face the air pollution caused by traffic with vehicle-to-vehicle and vehicle-to-infrastructure communication. This document is written inside the European research project eCoMove which aims to reduce the overall fuel consumption in traffic by 20 percent by means of energy efficient driving behavior.

The paper [How much does Traffic Congestion Increase Fuel Consumption and Emissions? Applying a Fuel Consumption Model to the NGSIM Trajectory Data, Treiber, M.; Kesting, A.; Thiemann, C. (2008).] has studied and presents a model for the instantaneous fuel consumption that includes vehicles properties, engine properties and gear-selection schemes and implements them for different passenger car types representing the vehicles fleet. This model can directly be used in microscopic traffic simulation software to calculate fuel consumption and derived emissions. They found that traffic congestion typically lead to an increase of fuel consumption of the order of 80% while the travelling time has increased by a factor of up to 4. They conclude that the influence of congestions on fuel consumption is distinctly lower than that on travel time.

The paper [Int Panis L., C. Beck C., Broekx S., De Vlieger I., Schrooten L., Degraeuwe B., Pelkmans L.,; PM, NO_x and CO_2 emission reductions from speed management policies in Europe. (2010)] discusses the effectiveness of the speed reduction in order to reduce the pollution. They analyzed the relative change in pollutants emitted before and after the implementation of a speed reduction measure for passenger cars on local roads (from 50km/h to 30 km/h) and trucks on motorways (from 90 km/h to 80km/h). Results indicate that emission of most classic pollutants does not rise or fall dramatically. For passenger cars the macroscopic and the microscopic approach indicate only minor changes to the emissions of NO_x and CO_2. For PM, the macroscopic approach predicts a moderate increase in emissions but microscopic results indicate a significant decrease. As a conclusion this paper present the scientific uncertainties that policy makers face when considering the implementation of speed management policies.

The paper [Keuken MP., Jonkers S., Wilmink IR., Wesseling J.; Reduced NOx and PM10 emissions on urban motorways in The Netherlands by 80 km/h speed management.(2010)] studies the effect of the speed limit of 80 km/h on zones of urban motorways in the Netherlands in order to improve the air quality of NO_2 and PM_{10}. This speed limit causes a reduction of the traffic dynamics which results in more free.flowing traffic with relatively less NO_x and PM_{10} emissions compared with the congested traffic. The effect on NO_2 and PM10 emissions of this speed action was studied in the cities of Rotterdam and Amsterdam. The study was performed in two different ways: firstly by measurements and by modeling the contribution to NO_x and PM_{10} concentrations on both sides of the motorways, and secondly by estimating the change in traffic dynamics and the effect on emissions. To conclude the paper the effect of the speed management is presented with a reduction of NO_x in the range of 5-30% and a reduction of PM_{10} between 5-25%. The emissions reductions by speed management at a specific motorway mainly depend in the ratio of congested traffic prior and after the implementation of speed management. The larger this ratio, the larger is the relative emission reduction. The impact on the air quality of 80 km/h for NO_x and PM_{10} is largest on motorways with a high fraction of heavy-duty vehicles.

The paper [Keller J., Andreani-Aksoyoglu S., Tinguely M., Flemming J., Heldstab J., Keller M., Zbinden E., Prevot A.; The impact of reducing the maximum speed limit on motorways in Switzerland to 80 km h^{-1} on emissions and peak ozone.(2008)] presents the effect of the implementation of a reduction on the speed limit, from 120 to 80 km/h, on the Swiss motorways under the conditions of a hot and dry summer, in order to improve the air quality. The results present a reduction of NO_x about the 4%, the volatile organic compounds (VOC) were not significantly affected, and the peak ozone levels decreased by less than 1%.

An important paper to present with this thesis is [Krajzewicz D., Flötteröd Y.; Simulative Untersuchungen abstrakter und realer Verkehrsmanagementansätze zur Emissionsreduktion.(2013)] since it works with the same scenario as this thesis. There are three simulations presented in this paper, introduction of a speed limit of 30 km/h on all the streets of the city, except the highways; implementation of a speed limit of 60 km/h on the same streets as above and the third one limit the speed on the highways to 80 km/h. The results explain that the city has any benefit when limiting the maximum speed to 30 km/h in order to reduce pollution, in the fact it even increases. The city at 60 km/h has also no improvements but the highways at 80km/h has an important reduction of the CO_2, which is the pollutant studied in this case. The results are completed with maps which show where the pollution has reduced or increased.

3. Description of the air pollution and specially caused by the vehicles

The aim of this document is to get down the concentration of the pollution caused by traffic. The following list presents the gases emitted by the traffic, according to the Union of concerned Scientists[5].

- Sulfur dioxide (SO_2): Motor vehicles create this pollutant by burning sulfur-containing fuels, especially diesel.
- Nitrogen oxides (NO_x): These vehicular pollutants can cause lung irritation and weaken the body's defenses against respiratory infections such as pneumonia and influenza. In addition, they assist in the formation of ozone and particulate matter.
- Volatile organic compounds (VOCs): in the European Union the definition for a VOC is any organic compound having an initial boiling point less than or equal to 250 °C (482 °F) measured at a standard atmospheric pressure of 101.3kPa and can damage the visual or audible senses.
- Particulate matter (PM_{10}, $PM_{2,5}$): these particles proceed from soot, metals and pollen. These particulates are thinner than 10 µm so can penetrate deep into lungs and causes serious threat to human health such as lung cancer or cardiopulmonary problems.
- Carbon monoxide (CO): this odorless, colorless gas is formed by the combustion of fossil fuels such as gasoline. Cars and trucks are the source of nearly two-thirds of this pollutant. When inhaled, CO blocks the transport of oxygen to the brain, heart, and other vital organs in the human body.
- Ozone (O_3): this is not emitted directly by vehicles but is created when nitrogen oxides and VOCs react with sunlight. Ozone at the ground level can be harmful to the human health into the respiratory system, causing coughing, choking and reducing lung capacity.

In this thesis only the NO_2 and the PM_{10} are taking into account because they overcome the EU limits and also because they are harmful to human health. The following tables show the limits set up by EU.

[5] http://www.ucsusa.org

Table 1: Limits of NO_2 set up by the European Commission

	Hourly limit value for the protection of human health (NO_2)	Annual limit value for the protection of human health (NO_2)	Annual critical level for the protection of vegetation and natural ecosystems (NO_x)
Upper assessment threshold	70 % of limit value (140 µg/m^3, not to be exceeded more than 18 times in any calendar year)	80 % of limit value (32 µg/m^3)	80 % of critical level (24 µg/m^3)
Lower assessment threshold	50 % of limit value (100 µg/m^3, not to be exceeded more than 18 times in any calendar year)	65 % of limit value (26 µg/m^3)	65 % of critical level (19,5 µg/m^3)

Table 2: Limits of PM_{10} set up by the European Commission

	24-hour average PM_{10}	Annual average PM_{10}
Upper assessment threshold	70 % of limit value (35 µg/m^3, not to be exceeded more than 35 times in any calendar year)	70 % of limit value (28 µg/m^3)
Lower assessment threshold	50 % of limit value (25 µg/m^3, not to be exceeded more than 35 times in any calendar year)	50 % of limit value (20 µg/m^3)

The main sources of emission from road vehicles are the exhaust gases and hydrocarbons produced by evaporation of fuel. When an engine is started, below its normal operating temperature, it uses fuel inefficiently and the amount of pollution produced is higher than when it is hot. These observations lead to the first basic relationship used in the calculation method:

$$\mathbf{E = E_{hot} + E_{start} + E_{evaporative}}$$

where:

E is the total emission;

E_{hot} is the emission produced when the engine is hot;

E_{start} is the emission when the engine is cold;

$E_{evaporative}$ is the emission by evaporation (only for VOC[1]).

PM_x comes in many sizes and shapes and can be made up of hundreds of different chemicals. Some particles, known as *primary particles* are emitted directly from a source, such as construction sites, unpaved roads, fields, smokestacks or fires. Others form in complicated reactions in the atmosphere of chemicals such as sulfur dioxides and nitrogen oxides that are emitted from power plants, industries and automobiles. These particles, known as secondary particles, make up most of the fine particle pollution in the country.

The traffic is the primary source of nitrogen oxides (NO_x) that convert to nitrogen dioxide (NO_2). Traffic is believed to be responsible for at least half of NO_x emissions in general and accounts for a higher proportion in urban areas.

4. State of the pollution in Brunswick

The city of Brunswick has nowadays two measuring stations of air pollution. They show the evolution of the PM_{10} and the NO_2 pollution per hour and the median per day in the last month.

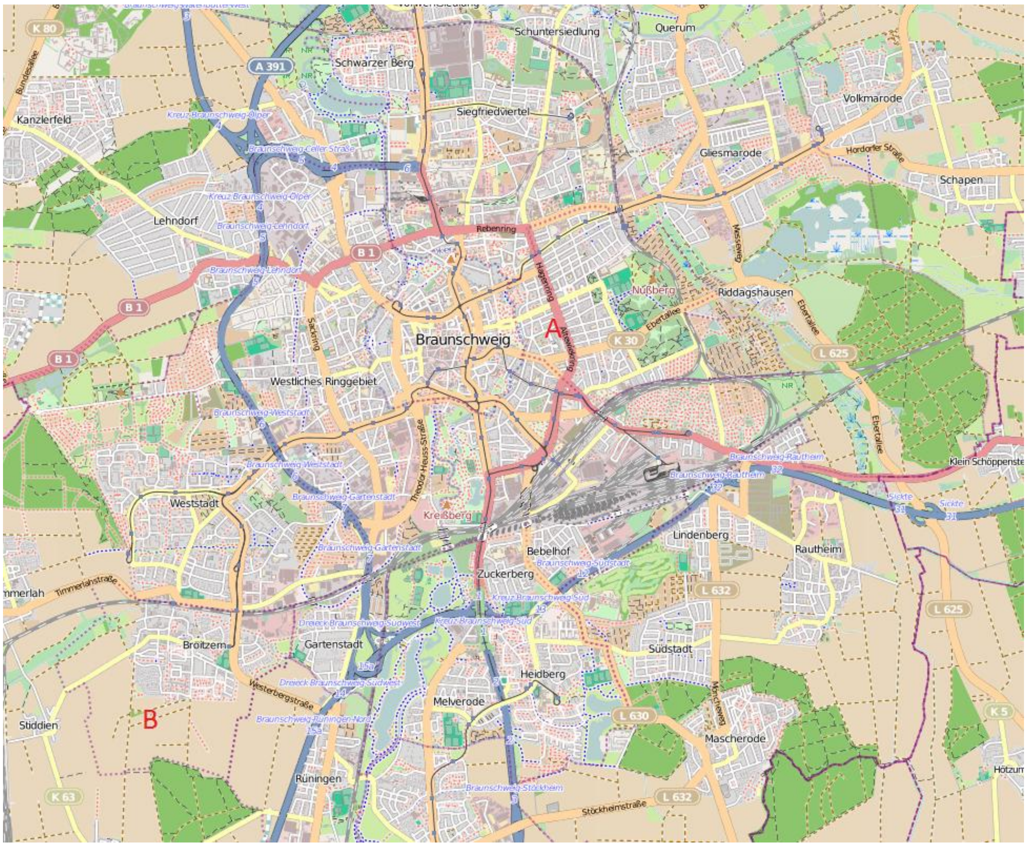


Image 1: Location of the two measure stations

One could suppose that Station A measures the pollution emitted from the traffic since it is located in the city center and the Station B measures the background air pollution since it is located in a secluded area. Therefore the pollution measured in the Station A has to be higher than in Station B. With this way an approximation of the pollution emitted for the traffic can be done, but to take the difference of pollution between the two stations as the pollution emitted exclusively for the traffic is not a good decision because of the air pollution can be originated from a high variety of causes.

The following Figure 1[6] shows the evolution of the pollution of NO_2 during a week for the two stations in Brunswick. As can be observed the measures in the station A are very higher and much influenced by the rush hours of the traffic than the measures in the station B which oscillate around 10µg/m^3. On the Figure 1 the difference between the working days and the weekend can be

[6] http://www.umwelt.niedersachsen.de/portal/live.php?navigation_id=2404&_psmand=10

identified for the station A. Given this fact one can suppose that the emissions of NO_2 are very influenced by the traffic. During this specific week the limit of 140µg/m^3 has not exceeded.

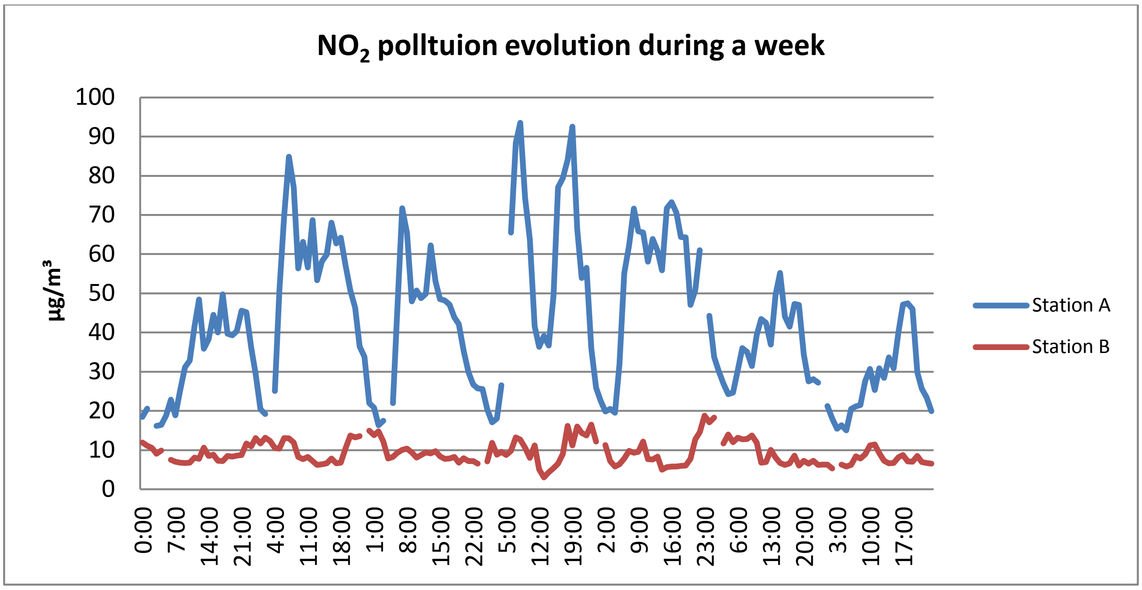


Figure 1: Evolution of the pollution of NO_2 measured in Brunswick

Figure 2 shows the evolution of the measures of PM_{10} on the two stations. The evolution of the two stations is very similar. The difference is that station A has a higher level of pollution due to being located in the center of the city. On this figure is not observed a difference between days, therefore the background of PM_{10} is very strong.

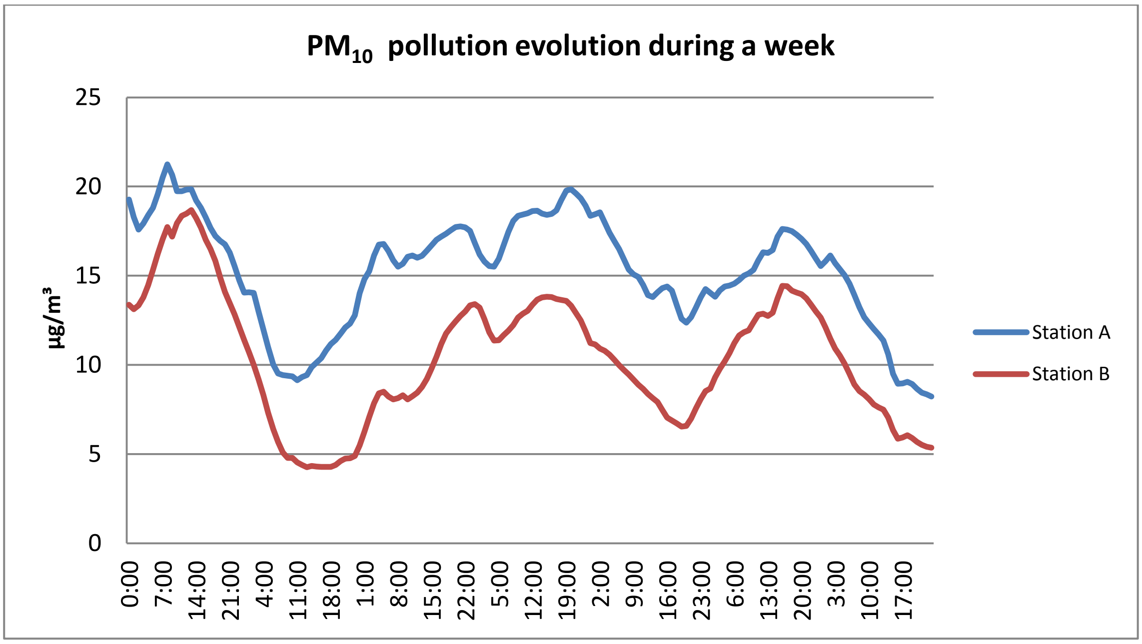


Figure 2: Evolution of the pollution of PM_{10} measured in the station B

The data have been taken at the week between 20-05-13 and 26-05-13. This is a working week in May, which can represent a random week during the year.

The followings Figure 3 and Figure 4 show the evolution of the pollutants during a day. These figures want to be compared with the results from the simulation in order to see if the evolution keeps the same shape, and then establish a relation between the traffic pollution and the evolution of the pollution measured on the stations.

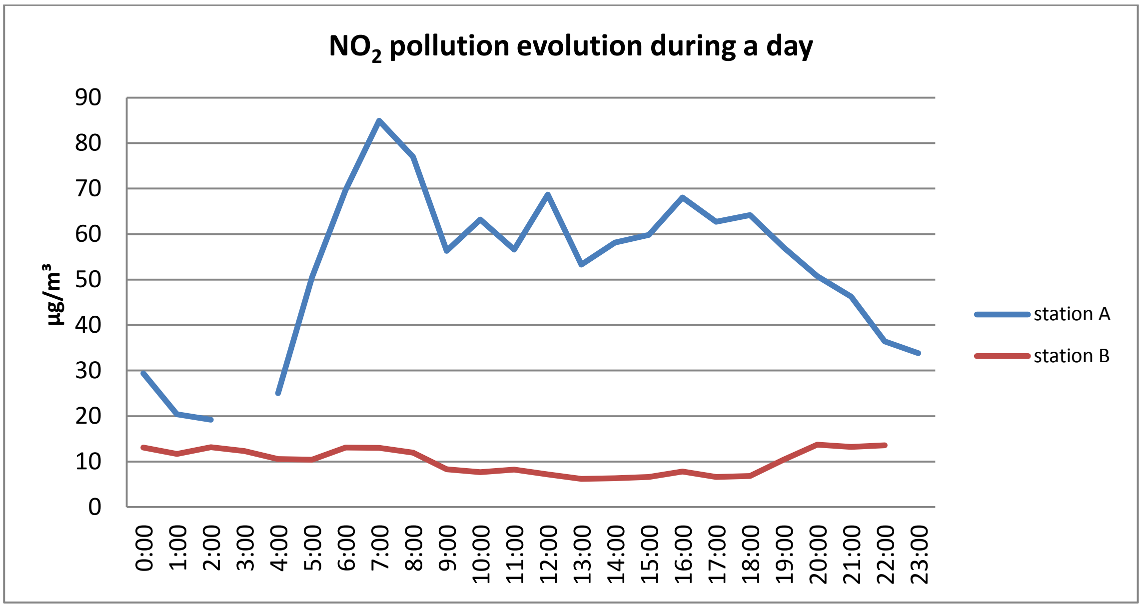


Figure 3: Evolution of the NO_2 pollution during a day

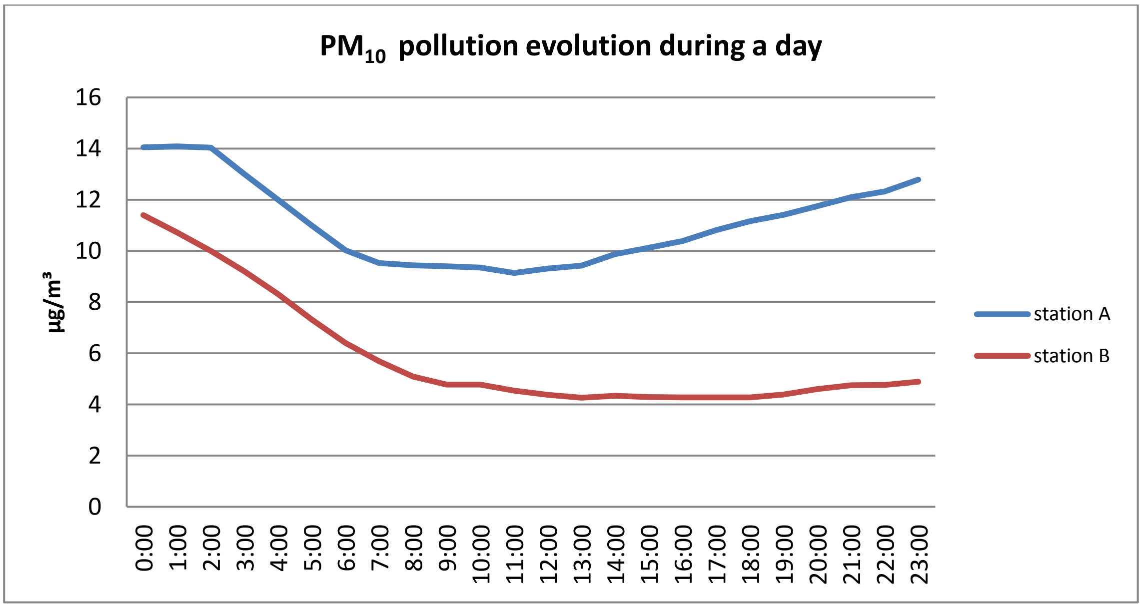


Figure 4: Evolution of the PM_{10} pollution during a day

According to a study of the air quality in 2012 in Niedersachsen[7] the following tables show the state of the air pollution in Brunswick in the last 5 years.

Table 3: Evolution of the pollution of PM_{10} in Brunswick

Year	Year medium (µg/m³)		Number of times that the day's median have exceed 50 µg/m³		Maximum of day's median (µg/m³)	
Limit value	40		35		--	
	Station A	Station B	Station A	Station B	Station A	Station B
2012	25	18	15	7	112	104
2011	28	20	27	16	96	84
2010	27	19	20	15	106	98
2009	23	17	6	3	106	74
2008	24	17	3	3	74	70

Table 4: Evolution of the pollution of NO_2 in Brunswick

Year	Year medium (µg/m³)		Number of times that the hour's median have exceed 200 µg/m³		Maximum of hour's median (µg/m³)	
Limit value	40		18		400	
	Station A	Station B	Station A	Station B	Station A	Station B
2012	44	14	0	0	165	73
2011	50	13	6	0	275	71
2010	51	16	1	0	274	97
2009	52	15	2	0	241	85
2008	54	15	1	0	233	76

All the values are under the limit set up by EU, except the year medium of NO_2 in the station A (the station located in the inner city) and this is fact that has to be solved implementing future actions on the traffic or on another scopes which NO_2 emit. However the NO_2 year medium has reduced in the last 5 year, therefore whit this tend to be under the limits in one or two years.

The followings Figure 5 and Figure 6 show the evolution of the year median in the last years. Station A is newer and only has data from 2008 on.

[7] www.umwelt.niedersachsen.de

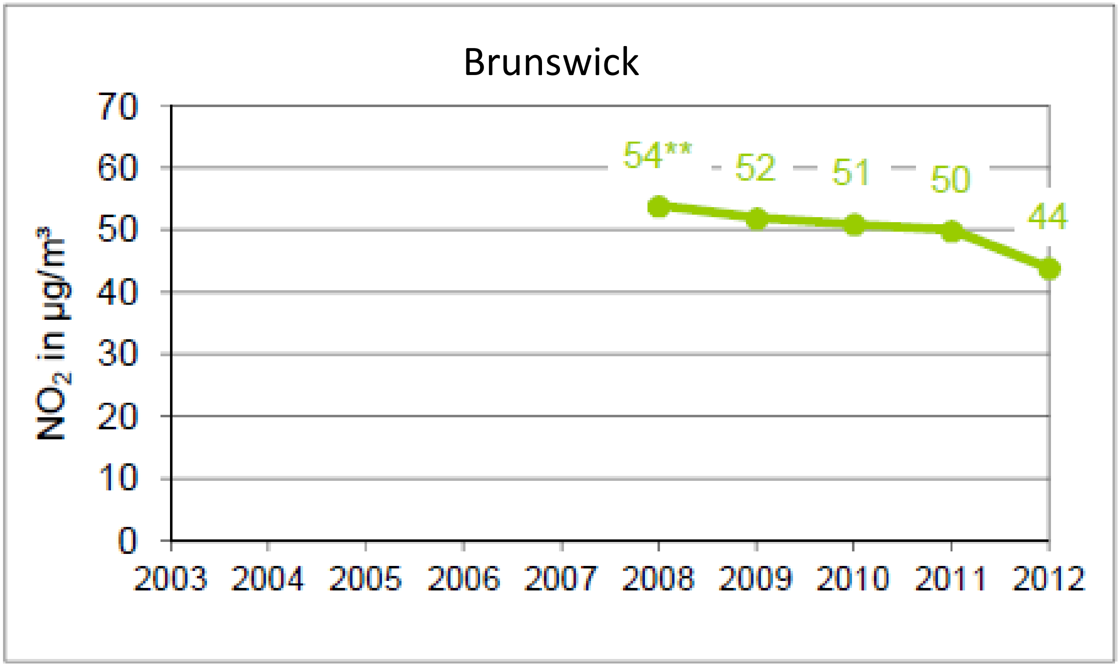


Figure 5: Evolution of the year median of NO_2 at Station A

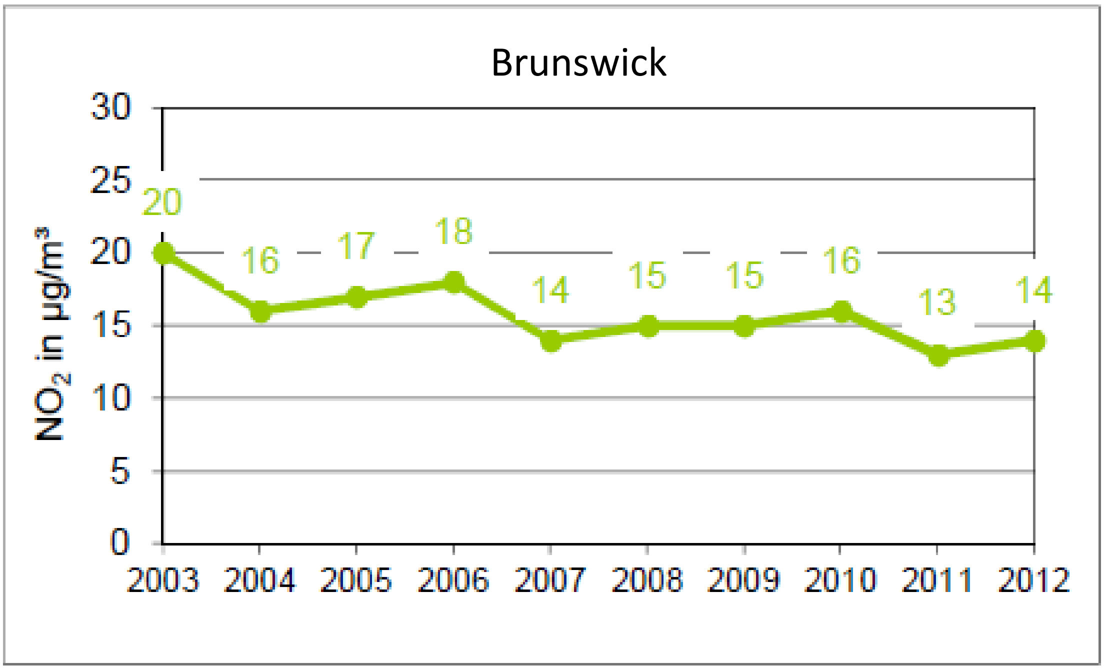


Figure 6: Evolution of the year median of NO_2 at Station B

The values in Station A show that the year median is still over the limit value established by the European Commission. Therefore more actions have to be implemented and it is the object of this thesis to look for alternative that make possible to get down this levels of pollution.

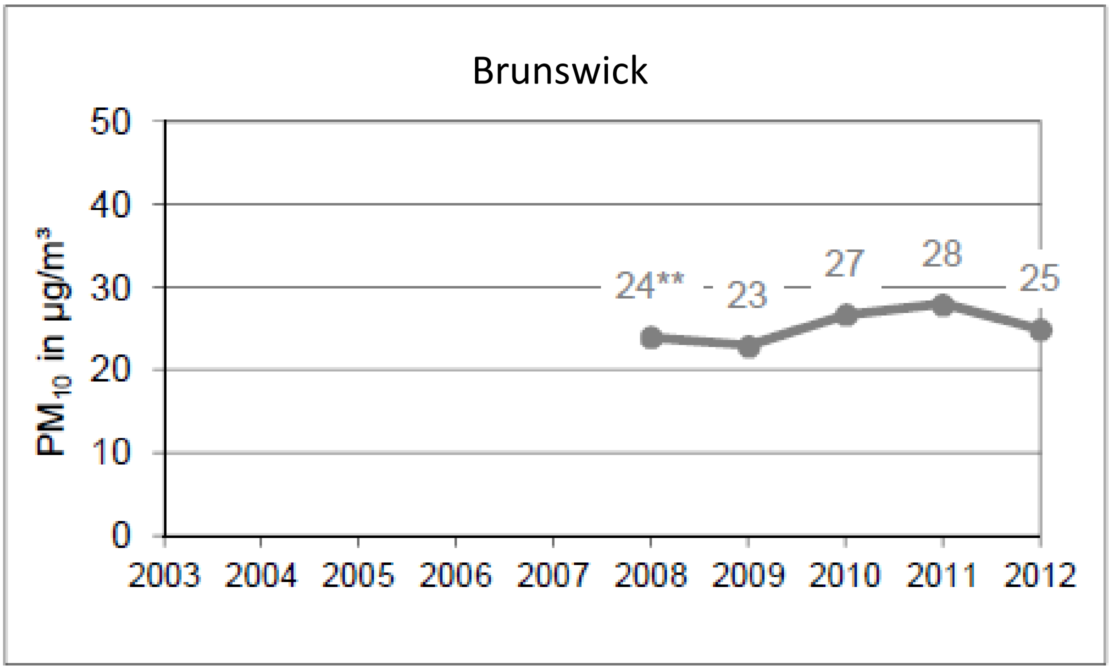


Figure 7: Evolution of year median of PM_{10} at Station A

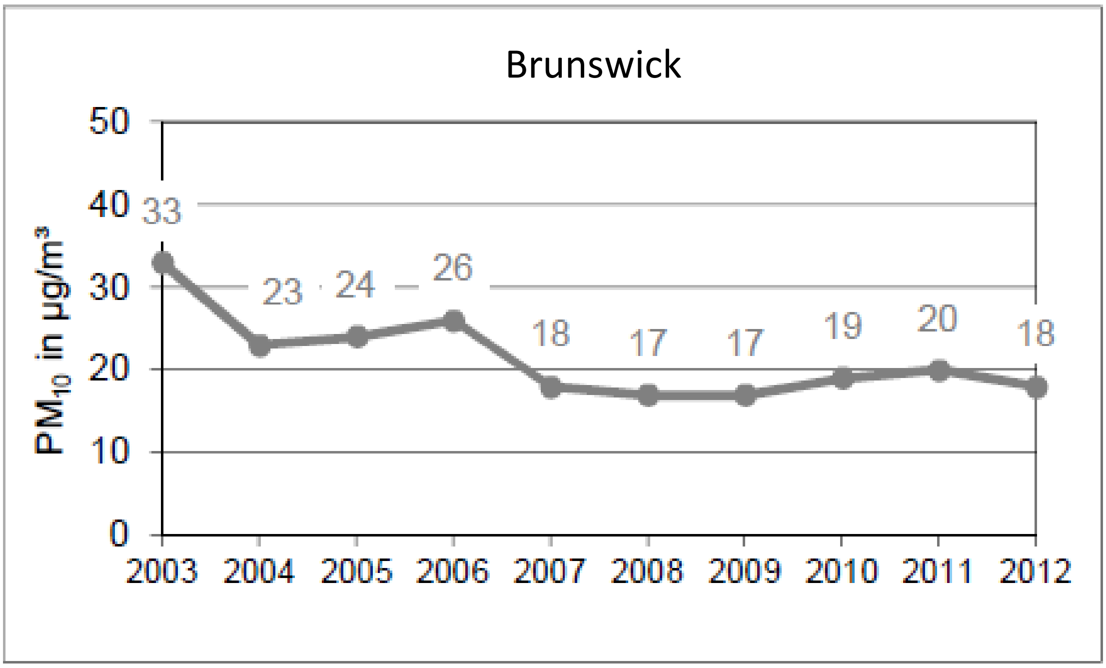


Figure 8: Evolution of year median of PM_{10} at Station B

The concentration of PM_{10} remains under the EU limit. That means that Brunswick is not obligated to improve his air quality in PM_{10} but it is one of the aims of the governments to have lower levels of air pollution.

These figures were shown to inform the reader how the situation of the air pollution in Brunswick is nowadays; therefore the measures of the stations are not going to be compared with the results from the simulation. Air pollution can be caused from other sources and is not possible to distinguish which percentage of these measures that corresponds to traffic.

The only thing that is going to be compared is the shape of the graphics that show the evolution during a day. If the graphics of the simulation have the same pattern, then it can be supposed that the shape of the pollution evolution measured on the station is caused mainly by traffic.

5. Actions and Actions Selection

This section describes the database MARLIS where the actions have been taken from and how a small number of actions has been selected. Choosing a certain action depends on criteria that will be described below.

5.1. Description of MARLIS

MARLIS is a database created by Federal Highway Research Institute (Bundesanstalt für Straßenwesen or Federal Highway Research Institute, BASt). The Federal Highway Research Institute is a technical and scientific institute of the Federal Ministry of Transport, Building and Urban Development (Bundesministeriums für Verkehr, Bau und Stadtentwincklung, BMVBS). It gives to the Ministry decision support on technical questions and transport policy.

The database MARLIS, in its 3.0 Version, offers the description and the evaluation of 3665 actions about air pollution on roads and their impact on concentrations of air pollutants in Germany and abroad. This database was created to help to take the right decision on actions selection depending on the local conditions and the effects achieved in similar cities.

The goals to create MARLIS were,

- Set up, describe and evaluate structural, traffic legality and others measures already performed to clean the air of the routes
- Describe the efficiency of the measures on air pollutant concentrations in the affected areas
- In particular, considering the air pollutants PM_{10} and NO_2
- Create a database with the possibility of a targeted selection of actions and prioritization by various criteria

All the actions saved in MARLIS can be identified under certain criteria. The actions can be separated by,

- Categories
    - Automotive engineering, fleet of cars
    - Infrastructure and construction actions
    - Traffic management
    - Public transport
    - Bike and pedestrian traffic
    - Traffic limitation
    - Flow improvements

  - Stationary traffic
  - Delivery traffic
  - Public relations
  - Other actions
- Pollutant to reduce
  - PM_{10}
  - NO_2
- Feasibility
  - Short term
  - Medium term
  - Long term
- Status
- Area of action
- Available quantified effect

And also where these actions have been implemented,

- Country
- State
- City

All the actions are also included in three fields: Asses transport, low emission and incidence of pollution efficiency.

- Asses transport, all the actions in this field are those that try to improve the traffic flows and the population uses more the public transport.
- Low emission, are actions in order to reduce the emissions emitted by traffic.
- Incidence of pollution efficiency, the incidence of pollution is the amount of pollutant breathed for the population; therefore these actions try to take out of the populated areas the maximum of pollutants.

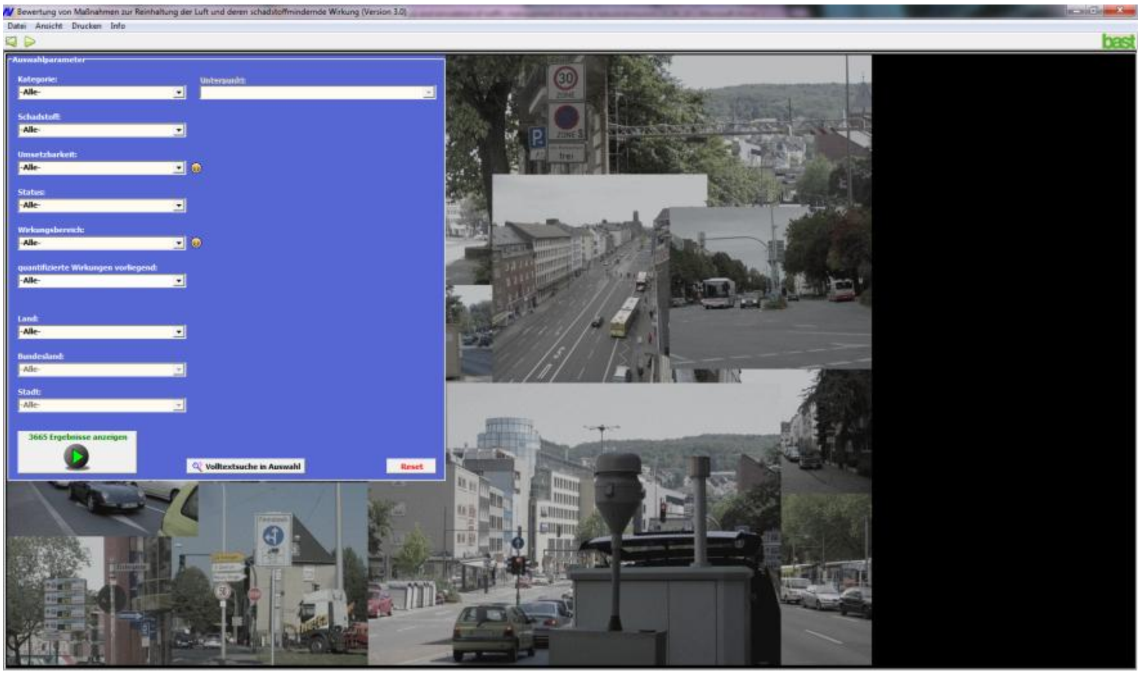
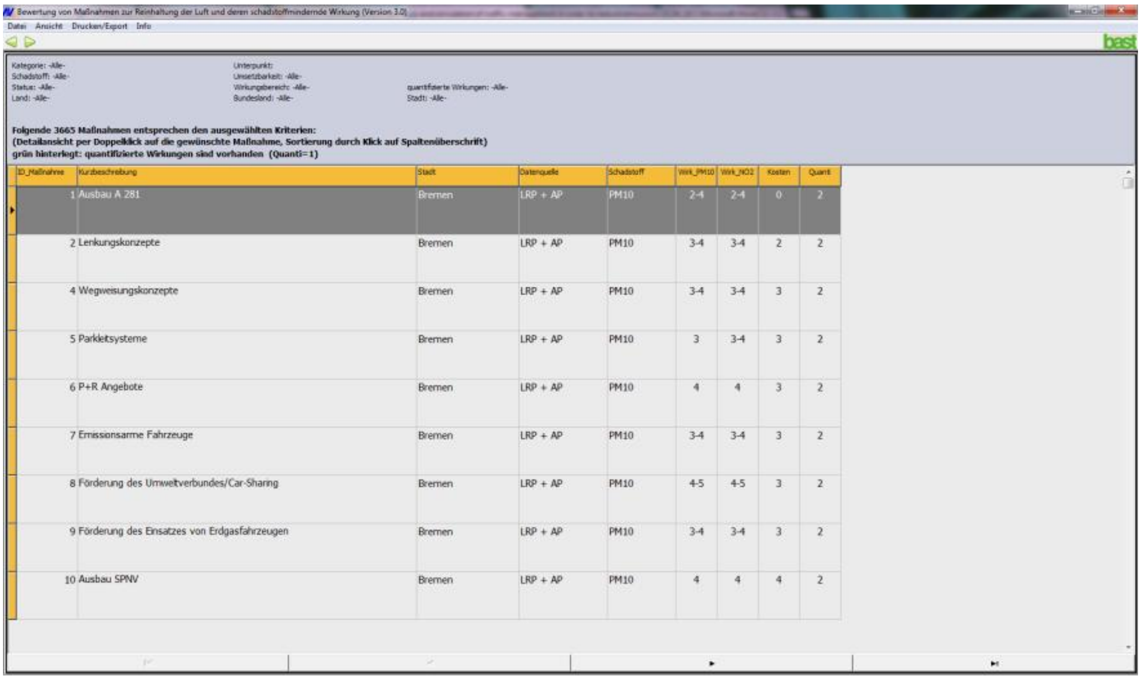


Image 2: Initial screen of MARLIS

MARLIS plots a list with the actions that fulfill the introduced criteria. This list shows the name of the action, the city, the data origin, pollutant, efficiency in order to reduce NO_2 or PM_{10} and cost of the action.



ID_Maßnahme	Kurzbeschreibung	Stadt	Datenquelle	Schadstoff	Wirk_PM10	Wirk_NO2	Kosten	Quanti
1	Ausbau A 281	Bremen	LRP + AP	PM10	2-4	2-4	0	2
2	Lenkungskonzepte	Bremen	LRP + AP	PM10	3-4	3-4	2	2
4	Wegweisungskonzepte	Bremen	LRP + AP	PM10	3-4	3-4	3	2
5	Parkleitsysteme	Bremen	LRP + AP	PM10	3	3-4	3	2
6	P+R Angebote	Bremen	LRP + AP	PM10	4	4	3	2
7	Emissionsarme Fahrzeuge	Bremen	LRP + AP	PM10	3-4	3-4	3	2
8	Förderung des Umweltverbundes/Car-Sharing	Bremen	LRP + AP	PM10	4-5	4-5	3	2
9	Förderung des Einsatzes von Erdgasfahrzeugen	Bremen	LRP + AP	PM10	3-4	3-4	3	2
10	Ausbau SPNV	Bremen	LRP + AP	PM10	4	4	4	2

Image 3: List of actions

If an action is selected MARLIS plots a screen with the description, the efficiency, a map where the action has been implemented and a short explanation of the experiences after the realization.

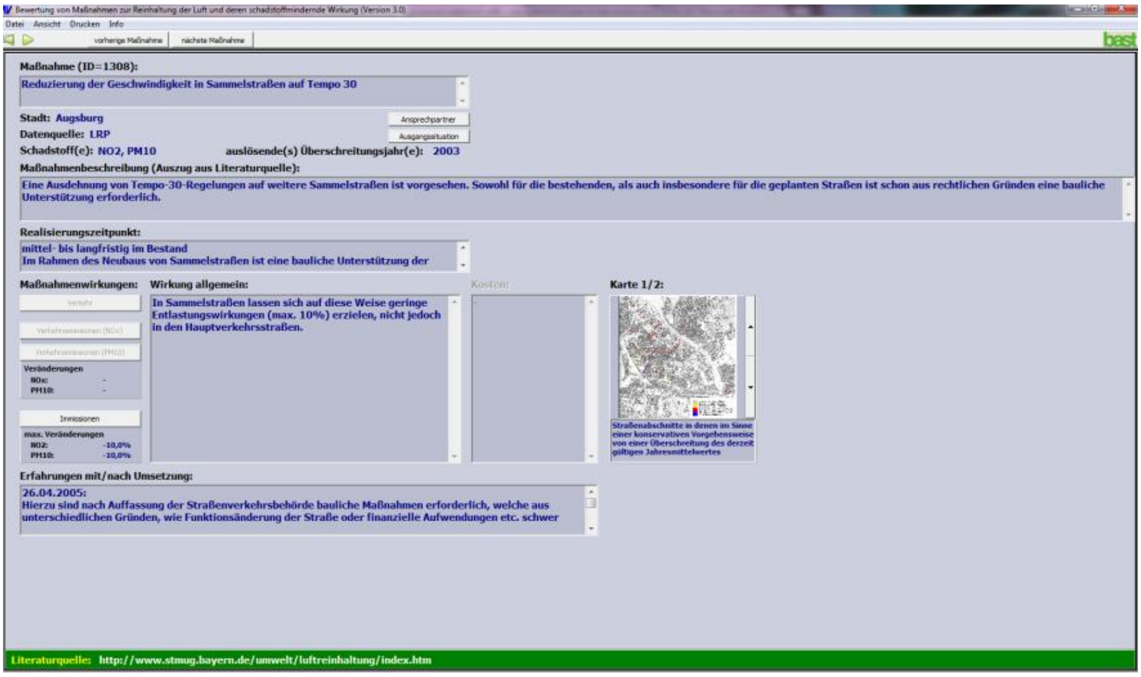


Image 4: Description of the selected action

MARLIS also offers the chance to search actions with keywords; therefore a specific kind of actions can be found.

Apart from the description of the database MARLIS, this section also wants to present the effect on the air pollution that the actions have, which is the more important data that can be extract form this database.

In the following graphics the classification of all actions described in MARLIS is showed, depending on their effect on NO_2 and PM_{10} reduction. It is very useful when selecting the actions.

- 0 = counterproductive
- 5 = non certifiable effect
- 4 = low effect (Pollution's reduction until 1 µg/m^3)
- 3 = medium effect (Pollution's reduction > 1 µg/m^3 until 5 µg/m^3)
- 2 = high effect (Pollution's reduction > 5 µg/m^3 until 10 µg/m^3)
- 1 = very high effect (Pollution's reduction > 10 µg/m^3)

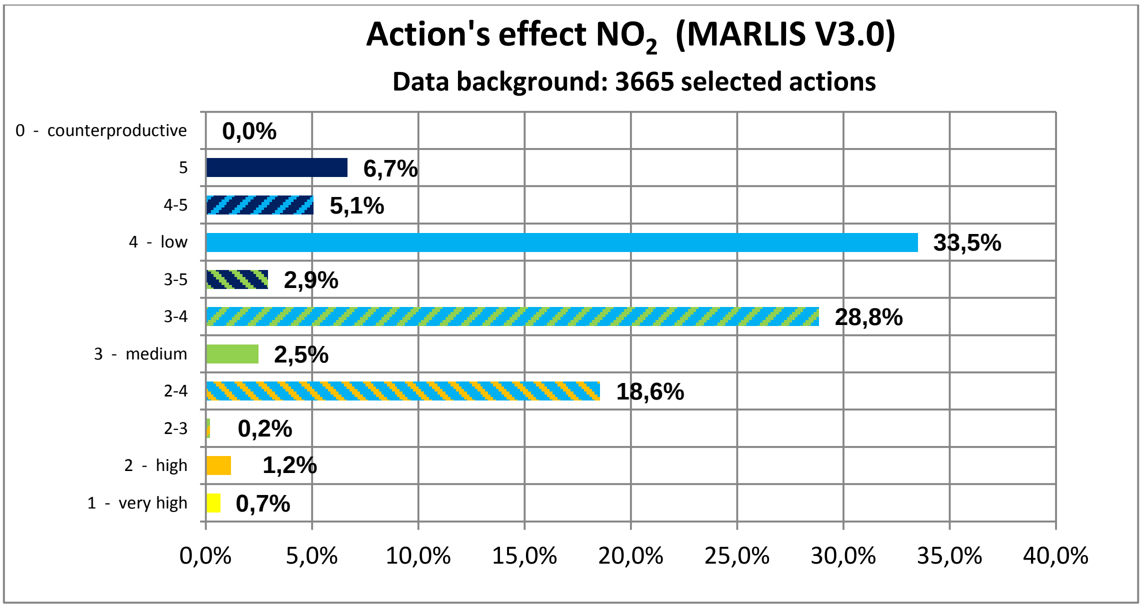


Figure 9: Action effect NO_2

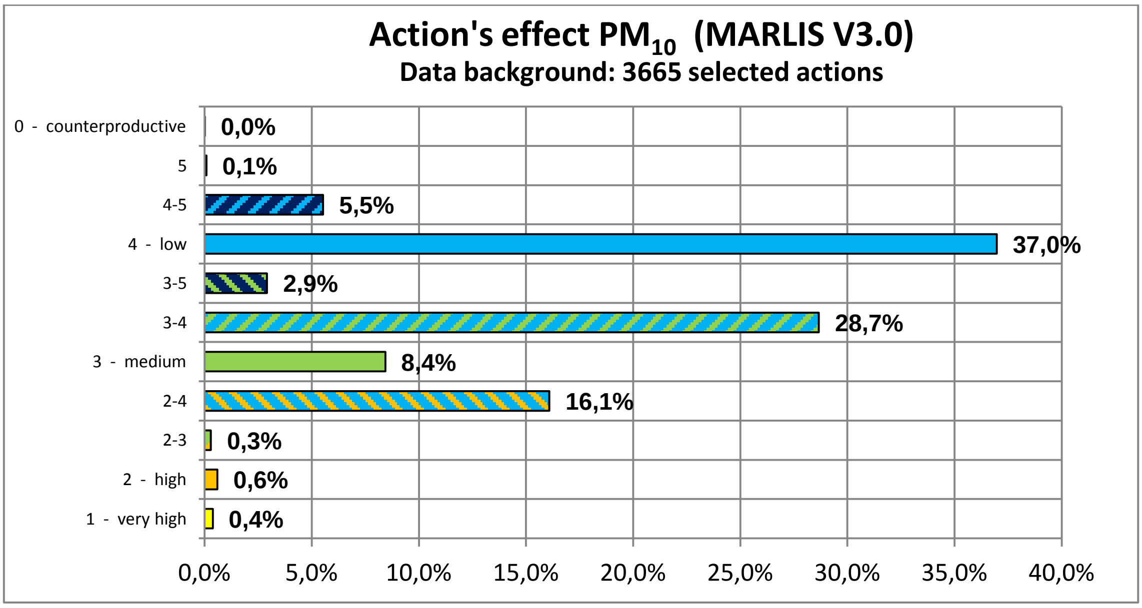


Figure 10: Action effect PM_x

The majority of the actions are defined between two values; therefore the specific effect of a certain action is not very exact, but it can be seen that almost all the actions have only a little effect on the reduction on traffic emissions, and more than 37% of the actions have a reduction of the pollution less than 1µg/m^3.

5.2. Methodology of the actions selection

An important work for this thesis is to select the correct actions to perform on the scenario, because it has a very important role on the conclusion of this thesis and on the effect on air quality.

As it has been shown before, not all the actions have the same effect on the air pollution and also not all of the actions affect on the same way to the scenario. There are actions that have an effect on a specific area but almost do not reduce the total emission within the scenario and there are actions that reduce the total emission but it is hardly to control where the reduction occurs. For these reasons the selection and the analysis of the scenario have to be done exhaustive to find the more suitable action for each case.

The present database “MARLIS Version 3.0” contains 3665 actions implemented in different cities and all of them could be attempted to be implemented in a simulation but the aim of this thesis is to simulate the more suitable actions for the selected scenario.

The selection of the action has been done by a pruning the database, because there are actions that are not suitable to be implemented within the scenario for several reasons. Two ways have been implemented to cut down the amount of actions. The first is to directly delete categories from MARLIS and the second is pruning the database with keywords.

The pruning of the categories has been done though a script that deletes all the actions that belong to a certain category listed in MARLIS. The actions in a category have a lot in common therefore the reasons to delete a category are assumed for all the actions forming it. The reasons to delete the categories are described below.

Table 5: Description of the reason to prune the categories and de amount of actions deleted in each category.

Categories	Reasons to prune	Amount of pruned actions
Infrastructure and construction	A very good knowledge about the traffic/infrastructure would be needed.	547
	It is assumed that it would be very specific for a concrete area, hardly being usable for other cities.	
Automotive engineering, fleet of cars	To work with the existing vehicles.	354
	Change the public vehicles depends on the budget of the governments	
	Change the fleet of private vehicles it is long term action	
Bike and pedestrian traffic	The demand including all models of transport is not available.	245
	Models that describe how many people are moving form car to bikes given a certain actions are not directly available and are beyond the simulation's scope.	
	Bike and pedestrian traffic do not pollute therefore is not important to simulate them.	
Public relations	These actions inform the population about ways to improve the air pollution. Models that describe how this information affects on the sustainable behavior of the people and how many people will follow the recommendations are not available.	219

Deleting the named categories is not enough to find out the suitable actions for the city of Brunswick but any other complete category can be removed, therefore pruning through keywords has been applied on the database. This pruning is executed through a script which reads the description of the remaining actions in the database and look for the keywords listed below. Whether a keyword is found in the description of the action, this action is deleted.

The advantage of pruning the database with this way is that actions can be deleted more specifically and the only actions that remain in the database will be the actions that have to be studied to be implemented on the scenario.

The keywords used in the thesis are classified in some general concept depending on the group of actions that they represent; some of the groups of actions deleted with keywords are related with the categories pruned above. Therefore the same reasons are used to justify their removal. For the groups of actions, which are not related with any category, the reasons for their removing are given.

The list below announce the general concept of related keywords and the reasons of their removal.

- Bike: Radweg[8] (bike route), Radverkehr (traffic of bikes), Rad(bike)
    - Category: Bike and pedestrian traffic
- Street improvements: Ausbau, Neubau(new constriuction), Aufbau(construction), modernization, Wegweiser(signal post), signage, Reinigung(clean the street)
    - Apply changes on the streets it is not the aim of this thesis
- Vehicle: Diesel, Erdgas, Filter, Fuel, Fuhrpark (vehicle fleet)
    - Category: Automotive engineering, fleet of cars
- Actions trying to change to a more sustainable mind: inform, promote, encourage, guidelines, collaboration, Schule (school), educate, Förderung (encouragement) , Schulung(schooling), Training,
    - Category: Public relations
- Public transport: S-bahn(train), S-bahnnetz(train net), Bus, Fahrplan (timetable), ticket, ssb(train)
    - Public transport could be perform but SUMO does not simulate trains and does not have implemented the real bus system.
- Building: wärme (heating)
    - Category. Infrastructure and construction
- Parking: Parksuchverkehr (traffic which look for a parking), Parkraum (parking), Parkleitsystem(car-park routing system), park ride, park
    - In the scenario the parking traffic is not represented
- Vegetation: Baum(tree).
    - These are not a traffic management actions
- Traffic lights: LSA(traffic light), Ampel(traffic light)
    - The traffic lights actions could be a good collective to take into consideration because it can be simulated with SUMO and also they offer good yield to reduce the pollutants, but the matter is that on the scenario is not implemented the real traffic lights system, therefore there is no sense into modify and improve a not real traffic lights system.
- Toll
    - Models that describe how the drivers will react against the toll are not available.

[8] The database is written in German and the keywords had to be in German.

- Appling a toll is a very specific action and extreme action and other option can be founded

Table 6: Number of actions deleted with keywords

	Amount of pruned actions
Keywords	1919

After applying the pruning, the database has to be analyzed again in order to verify if all the action that has remained are useful for the aim of this thesis. With this analysis the actions have been classified in three big groups, Speed limits, Driving bans and Environmental zone in total in the database remain 381 actions.

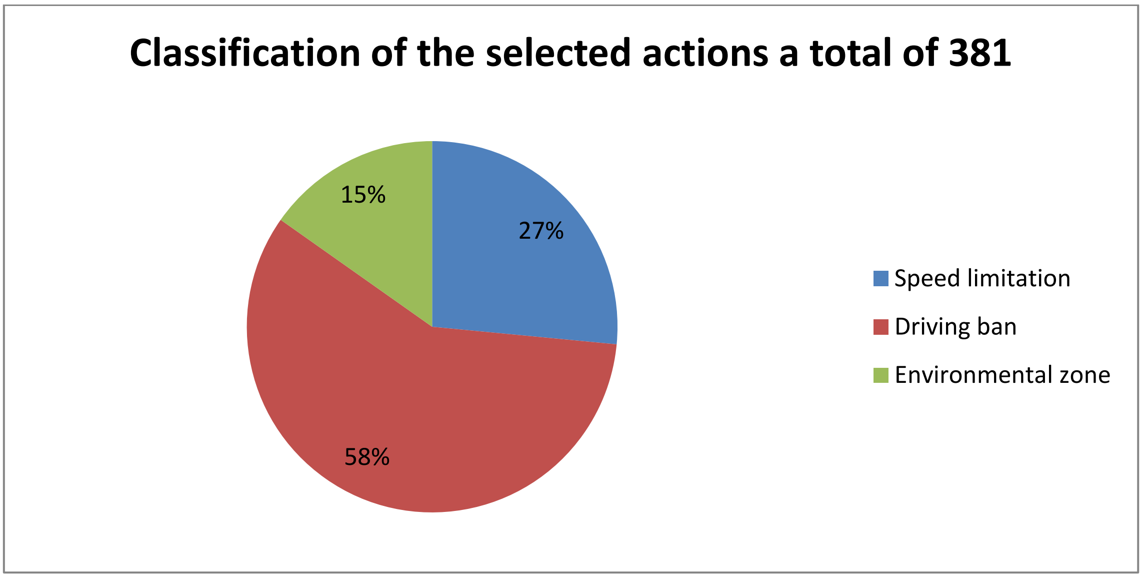


Figure 11: Classification of selected actions

All of these actions in the categories can be implemented in SUMO. But it is not the aim of this thesis to simulate all the actions, besides a lot of these actions are same action repeated in several cities. Actions from the different categories have been studied and observed how they have worked in other cities.

At the end, 381 actions remained as selected. The following section 5.3 explains the selected actions.

The driving bans actions are suitable for this thesis and they could be implemented with SUMO, but they are not simulated due to a lack of time in order to implement them on the software.

5.3. Description of the actions selected

This section presents the remaining actions and their effect on the air pollution. They have been selected in order to be implemented in the software SUMO. In the section 7 the implementation of the actions is described.

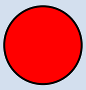
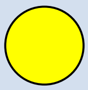
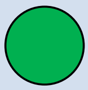
5.3.1. Environmental zone

The Environmental zone (EZ) is a geographically defined area which looks for restricting or deterring access by specific polluting vehicles or only allow low emitting vehicles.

The class of "Environmental Zone" covers all the actions about the implementation of an environmental zone in a city. The environmental zone prevents that the most polluting vehicles enter the area where the inhabitants works or live. The environmental zones are implemented in crowded areas, often around the center of the city.

The environmental zone distinguishes four groups of vehicles according with the European Emission Standards, which classified the vehicles depending on their emission. These four groups are differentiated with a sticker: any sticker for the group 1, the red sticker for the group 2, the yellow one for the group 3 and the green one for the group 4. The plate number of the vehicle is also printed in this sticker and the sticker is located on the front glass of the cars to be seen for the competent authorities.

Table 7: Classification of the restrictions in an environmental zone

Pollutant group	**1**	**2**	**3**	**4**
Sticker	Any sticker			
Requisition for Diesel	Euro 1 or worse	Euro 2 or Euro 1 + particulate filter	Euro 3 or Euro 2 + particulate filter	Euro 4 or Euro 3 + particulate filter
Requisition for Petrol	Without catalytic converter according Anl. XXIII StVZO			With catalytic converter according to Anl. XXIII StVZO or Euro 1 or better

Nowadays the vehicles are distinguished by the European Emission Standards, which regulate the amount of emissions that a car of new construction can emit. Therefore this regulation does not affect the user but the car manufactures as they have to improve the technology in order to accomplish the requirements of the EU.

The following two tables, the Table 8 for passenger cars and the Table 9 for the HDV, describe the amount of each pollutant that a car can emit and the year of implementation of every norm.

Table 8: EURO Norm for Passenger cars (Category M*), g/km

Tier	Date	CO	THC	NMHC	NO_x	$HC+NO_x$	PM
Diesel							
Euro 1	July 1992	2.72	-	-	-	0.97	0.14
Euro 2	January 1996	1.0	-	-	-	0.7	0.08
Euro 3	January 2000	0.64	-	-	0.5	0.65	0.05
Euro 4	January 2005	0.5	-	-	0.25	0.3	0.025
Euro 5	September 2009	0.5	-	-	0.18	0.23	0.005
Euro 6	September 2014	0.5	-	-	0.08	0.17	0.005
Petrol							
Euro 1	July 1992	2.71	-	-	-	0.97	-
Euro 2	January 1996	2.2	-	-	-	0.5	-
Euro 3	January 2000	2.3	0.2	-	0.15	-	-
Euro 4	January 2005	1.0	0.1	-	0.08	-	-
Euro 5	September 2009	1.0	0.1	0.068	0.068	-	0.005
Euro 6	September 2014	1.0	0.1	0.068	0.06	-	0.005

Table 9: EURO Norm for Heavy Duty Vehicles Engines, g/km (smoke in m^{-1})

Tier	Date	Test cycle	CO	HC	NO_x	PM	Smoke
Euro 1	1992	ECE R-49	4.5	1.1	8.0	0.612	
Euro 2	1996	ECE R-49	4.0	1.1	7.0	0.25	
Euro 3	2000	ESC & ELR	2.1	0.66	5.0	0.1	0.8
Euro 4	2005	ESC & ELR	1.5	0.46	3.5	0.02	0.5
Euro 5	2008	ESC & ELR	1.5	0.46	2.0	0.02	0.5
Euro 6	31.12.2013	ESC & ELR	1.5	0.13	0.4	0.01	

There are different levels of restriction in the environmental zone. There are environmental zones that allow driving though the vehicles with minimum the yellow sticker and there are more restricted where the green sticker is needed. If a vehicle without the right sticker enters in the environmental zone area is fined.

MARLIS offers the possibility to show the effect of group of actions. The following Figure 12 and Figure 13 show pollution reduction effect of all the environmental zone actions.

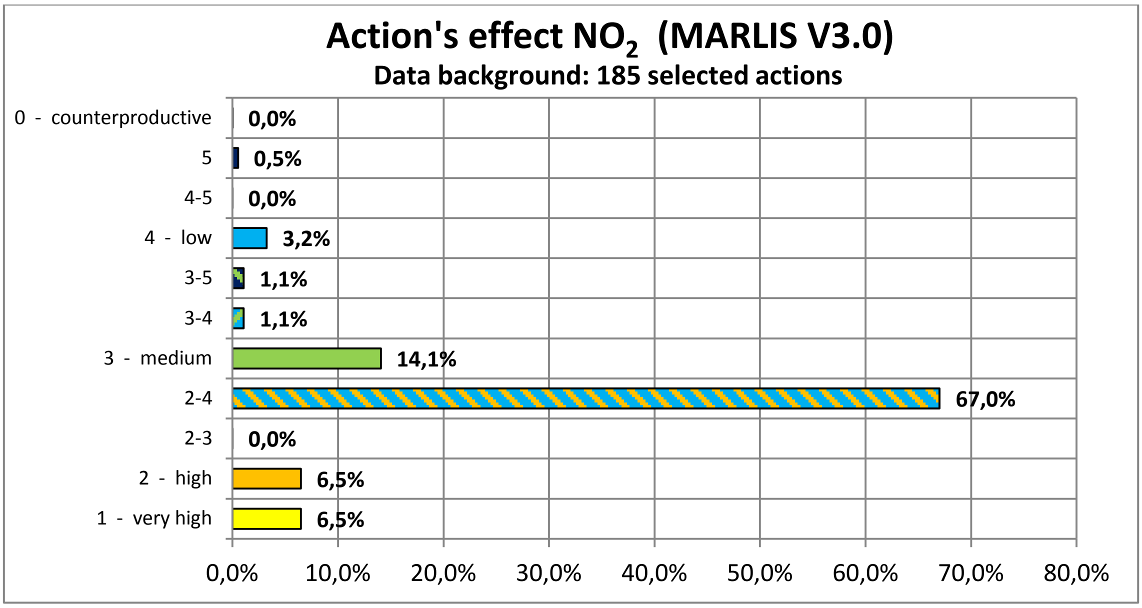


Figure 12: Action's effect NO_2 in the subsection Environmental zone

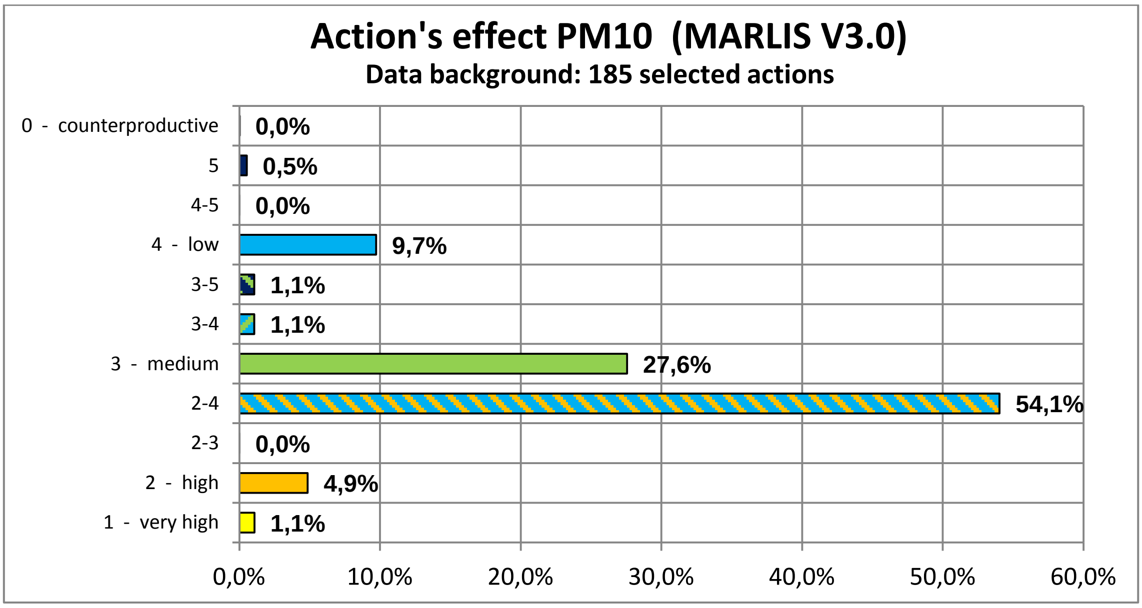


Figure 13: effect PM_{10} in the subsection Environmental zone

The assumptions on the impact, that the implementation of an environmental zone has, are on the state of the traffic of the city, the drivers that have not a car good enough to get into the selected area have to buy a new car if they want to go in, what can generate public problems. In the first time after the implementation could be studied to perform measures in order to relax the impact on the population without resources to buy a new car.

Another impact is that the cars, which previously entered the area, but are now forbidden, have to change their route what means that the other ways of the city will have to absorb them and maybe that it is translated into a raise of the pollution.

The best impact is that the vehicles that will cross the area will be the vehicles that pollute less, and it has to be seen if that action is translated in a reduction of traffic in this area or whether with the prohibition of the polluting vehicles the allowed vehicles will use more these streets.

5.3.2. Speed limits

The speed limits regulations, as their name indicate, are actions which try to control the traffic through applying changes on the velocity of the streets or areas.

The speed limits actions have a very wide field of possibilities, but the common and the interesting point for this thesis is the control of the velocity in order to reduce the air pollution.

In this thesis, it has been decided to implement a specific speed limit action, the “Tempo 30”, which limits the velocity to a maximum of 30km/h. Normally the area of implementation of such actions is the city center and the living areas.“Tempo 30” can also be implemented on some specifics streets, which have a lot of traffic where the levels of pollution are high or where a lot of people are exposed to these emissions.

The followings Figures show the pollution reduction effect of the Tempo-30 actions.

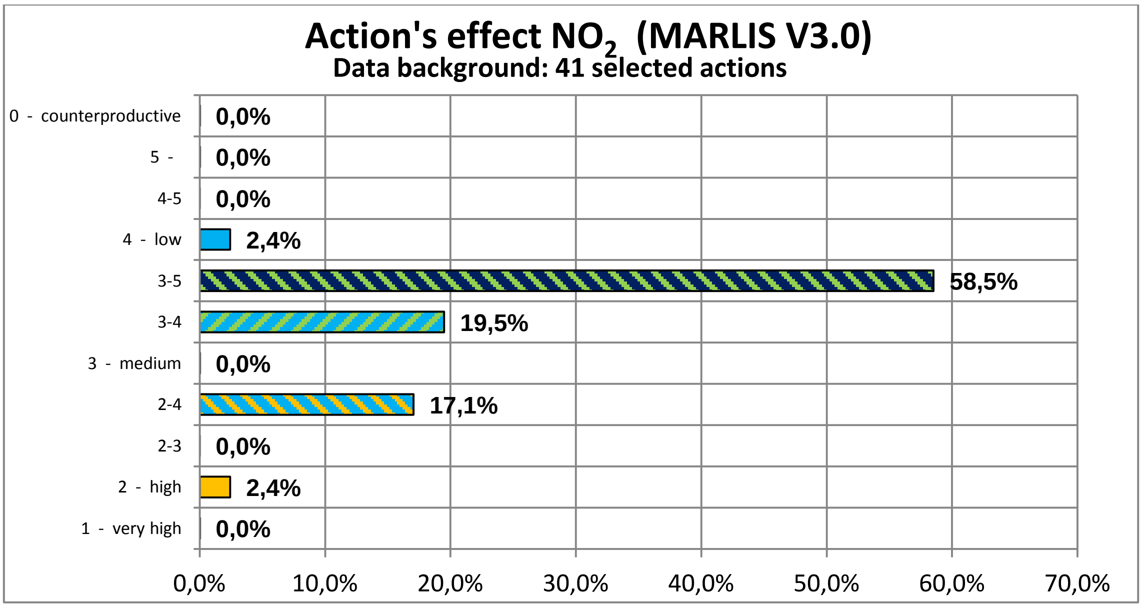


Figure 14: Action’s effect NO_2 in the subsection Tempo 30

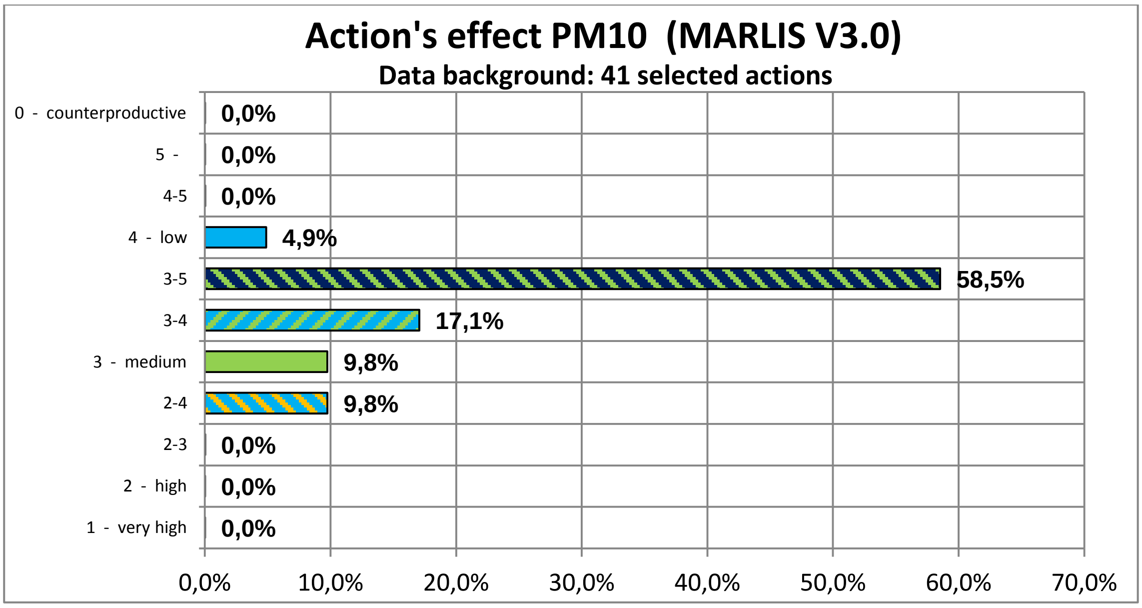


Figure 15: Action's effect PM_{10} in the subsection Tempo 30

The implementation of speed limits in the living areas has sense since the user who drove before on these streets just because it was the fastest way to get to his destination, now with the reduction maybe takes another route in order to not drive at 30km/h. Therefore one of the sources of the reduction of the pollution of "Tempo 30" is that the numbers of vehicles that will drive on the selected areas are less than with the base case. But on the other hand the unlimited streets will have to incorporate the vehicles that do not want to drive on the limited streets therefore the pollution may raise in other areas of the city.

With the simulation it is wanted to validate these assumptions and find out whether are correct.

5.4. MARLIS actions related

This section presents real-world examples, listed in the MARLIS database, of the selected actions described above. The effects of these actions in other cities can be compared with the result of the simulation to see whether and action is more effective in one city or in another.

5.4.1. Speed limit

In MARLIS there are a lot of different kinds of actions about speed limitation, but is Tempo 30 in all the living areas has been selected for this thesis, because this actions reduces the pollution directly where the population spends the most the time and presents a significant reduction.

Tempo limit 30 has been implemented in a lot of cites but which cities suits better with the scenario of this thesis are the examples set up in Passau and in Tübingen, because in these two cities the action Tempo 30 has been performed in all the living areas instead of some selected streets. The effect of this action is 3-5 (0 µg/m^3 until 5 µg/m^3) reducing pollution.

MARLIS, apart from the description of the actions, also offers the experiences after the application of an action. The action from Passau has an experience description, which says that this action has to be revised, because the Tempo 30 can be counterproductive in some streets

In Tübingen since 1991 a speed limitation to 30km/h is set up in all the living areas in the city.

These two actions explained above have not described their effect on percentage, in order to compare the results of the simulation with the database MARLIS a median of the Tempo 30 actions, those which have an effect in percentage available, has been done. The result is that the effect of a Tempo 30 action should be between 10 – 20% for the two pollutants.

5.4.2. Environmental Zone

MARLIS describes the environmental zones applied in Münster in Germany on 01/01/2010. Münster is city big as Brunswick with a population around 290.000 inhabitants, what makes that the effect of the actions could be similar.

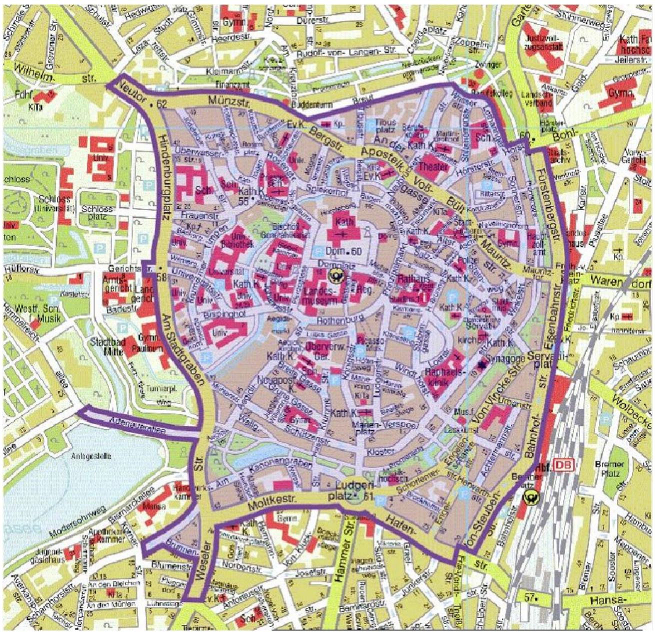


Image 5: Environmental zone in Münster

The environmental zone is applied around the city center where the most polluted streets were detected. After the implementation of this action the reduction of the pollutants was, as shown in the following table,

Table 10: Effects of the environmental zone in Münster

Pollutant reduction	PM_{10}	NO_x
Traffic emissions	-13%	-31%
Inmission	-	-12%

The environmental zone of Münster allows vehicles with an EURO Norm above Euro 2 to enter, so the vehicles with the yellow sticker can drive in this area. The environmental zone implemented in Münster is more permissive with the pollutant vehicles, which means that the reduction of the air pollution is lower against the implementation of a more restricted environmental zone.

The measurement station is in Weseler street, left-down corner of the image 5, and before the implementation of the action it measured an immission level of NO_2 of 58 $\mu g/m^3$ and after the application the measure descend until 51 $\mu g/m^3$.

With the MARLIS classification this actions has an effect on the PM_{10} reduction of 3 (Pollution's reduction > 1 $\mu g/m^3$ until 5 $\mu g/m^3$) and on the NO_2 reduction of 2 (Pollution's reduction > 1 $\mu g/m^3$ until 5 $\mu g/m^3$).

6. Introduction to the simulation

In this section, the technical issues are presented, first of all the software which will be used to simulate and get the results. The second part describes the scenario of the city of Brunswick implemented on this software and which possibilities it offers.

6.1. Description of SUMO

A complete description of SUMO can be found in [Krajzewicz, Erdmann, Behrisch, Bieker. Recent Development and Applications of SUMO – Simulation of Urban MObilitiy.(2012)], and the traffic model implemented in SUMO is described in [Krajzewicz, Hertkorn, Wagner, SUMO (Simulation Urban MOblity)]. The present chapter tries to present the software to the reader.

SUMO[9] ("Simulation of Urban Mobility") is a microscopic, inter- and multi-modal, space-continuous and time-discrete traffic flow simulation platform. There were two reasons in order to create SUMO, the first was to support the traffic simulation community with a free tool into which own algorithms can be implemented and the second was to make the simulation open source so as to gain support from other institutions, Zaik[10], University of Lübek, University of Innsbruck, Techische Universität München, Politecnico di Tornio, University of Wroclaw.

The SUMO suite has some applications that help to prepare and analyze the simulation; the following topics present the most important ones:

- Road Network Generation

SUMO represents the road networks as graphs, nodes, which are the intersections, connected by edges, which are the roads. With SUMO the road networks can be generated with the application named "netgenerate" or with "netconvert". "netgenerate" can create 3 different kind of abstract road networks, "manhattan", "spider-net" or random networks. In all of them there is a set of options that can be changed.

"netconvert" is a road network importer, it can convert networks from other traffic simulators like VISUM[11] or MATSim and also can read other digital road networks such as OpenStreetMap. *netconvert* also reads the SUMO-specific XML-representation of a road network which allows the highest degree of control. But most of the available digital road networks are originally meant to be used for routing purposes, so there is a lack of important information for the simulation such as

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[9] http://www.iariajournals.org/systems_and_measurements/sysmea_v5_n34_2012_paged.pdf pag.128-136

[10] http://www.zaik.de

[11] VISUM software created by PTVgroup see more on www.ptvgroup.com

number of lanes, traffic lights position and plans, etc. One solution is improving the more complicated intersections manually.

- Vehicles and Routes

SUMO is a microscopic traffic simulation, that means that each vehicles is defined using a unique identifier and it is described with departure and arrival properties, like the lane to use, the velocity or the exact position on the edge.

It is very difficult to define the demand for a scenario because a city of Brunswick's size has about 2 Mio drivers per day, starting and ending at different positions, therefore SUMO works with "origin/destination matrices" (O/D matrices). SUMO has an application "od2trips" that function is converting O/D matrices to single vehicle trips, but from "od2trips" are only obtained the start and the end of the trip and the simulation requires the list of all edges to pass. This is done using the duarouter application. SUMO includes two more applications "jtrrouter", which uses definitions of turn percentages at intersections for computing the routes through the network, and "dfrouter", which computes routes by using information form inductive loop or other cross-section detectors.

- Simulation

The application "*sumo*" performs a time-discrete simulation with a default step of 1s. SUMO uses an extension of the stochastic car-following model developed by Stefan Krauβ[12]. However other models are included: the intelligent driver model (IDM)[13], Kerner's three-phase model[14] and the Wiedemann model[15].

SUMO has two versions to simulate, "*sumo*" is a command line application and "*sumo-gui*" offers a graphical user interface showing the simulation.

- On-line Interaction

To enable on-line interaction the API is called "TRaCI" for "Traffic Control Interface". With this application the client can access values into almost all the simulation tools such as lanes, edges,

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[12] S. Krauß, "Microscopic Modeling of Traffic Flow: Investigation of Collision Free Vehicle Dynamics," PhD thesis, 1998.

[13] M. Treiber and D. Helbing, "Realistische Mikrosimulation von Strassenverkehr mit einem einfachen Modell," Symposium Simulationstechnik (ASIM), 2002.

[14] B. Kerner, S. Klenov, and A. Brakemeier, "Testbed for wireless vehicle communication: A simulation approach based on three-phase traffic theory," in Proceedings of the IEEE Intelligent Vehicles Symposium (IV'08), pp. 180–185, 2008.

[15] R. Wiedemann, „Simulation des Straßenverkehrsflußes," in Heft 8 der Schriftenreihe des IfV, Institut für Verkehrswesen, Universität Karlsruhe, 1974.

traffic lights inductive loops, vehicles and interactions. This permit complex interactions like modeling special behavior of individual vehicles.

SUMO has been used in studies according with the following topics:

- Vehicular Communication may be the most important application of SUMO suite is modeling traffic with V2X – vehicle-to-vehicle and vehicle-to-infrastructure-communication[16].
- Route Choice and Dynamic Navigation
- Traffic Light Algorithms
- Evaluation of Traffic Surveillance Systems

The aim of this thesis is calculate and reduce the emissions of the vehicles and SUMO can simulate and give the sum of the emissions.

Regarding emissions, SUMO can calculate them for each vehicle, taking the factors from "The Handbook Emissions Factors for Road Transport"(HBEFA)[17], which describes the emission factors for all vehicle categories (PC, LDV, HDV and motor cycles) each divided into different categories in order to cover all the traffic situations.

6.2. Description of Brunswick Scenario

Brunswick is a city in the state of Lower Saxony and has a population around 250000 inhabitants[18].

This scenario was performed for the Institute of Transport Research in the German Aerospace Institute in order to simulate the traffic of Brunswick with all the options that offers the software SUMO and to find improvements on the traffic and on the air pollution. The last update on this scenario was on the 24/07/2013.

The scenario of Brunswick represents all the streets of the city and the highways around. It covers an area 25 km E-W direction and 26km N-S with the city center in the middle of the scenario.

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[17] Hand book Emissions Factors for Road Transport see on www.hbefa.net
[18] http://en.wikipedia.org/wiki/Braunschweig

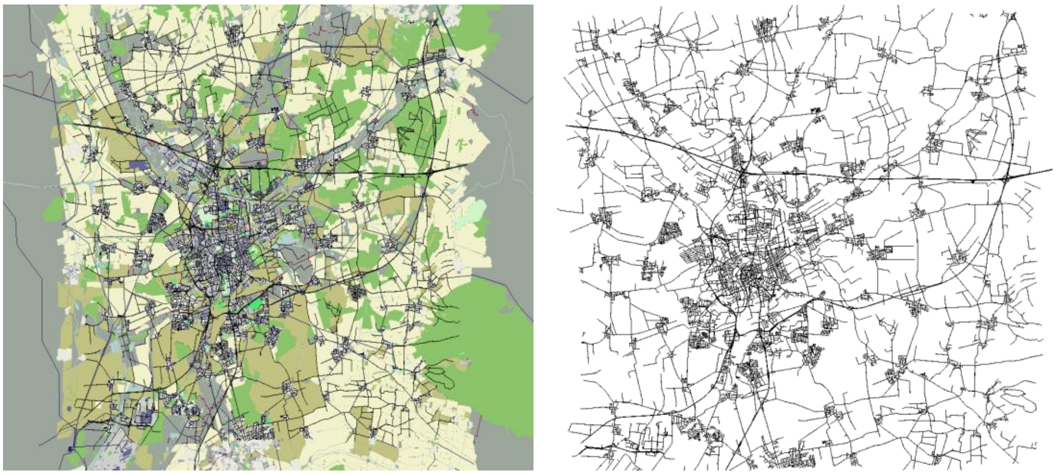


Image 6: Brunswick Scenario

This scenario is formed for 31294 edges and 13989 nodes. All the streets characteristics are set up as in the real-world except the traffic lights that are implemented with different times for their phases. 603049 passenger vehicles and 43955 HDV drive through this scenario every day of the simulation. These vehicles represent the demand of traffic on that area and that is supply by matrices of origin/destiny, these are implemented on the scenario.

The simulation of this thesis takes into account all the vehicles that are supposed to drive through that area every day. Any reduction of the vehicle number has been done. That contributes to a better reliability of the results but it also makes the simulation more complicated and longer.

The scenario has two aspects, the scenario showed on the left of the Image 6 that allows, apart from the edges, the possibility to know the function of the different areas of the city and the scenario on the Image 6 on the right side shows only the edges and their characteristics of them. The latter, is used to do the simulation due to being faster. The scenario also allows the user to personalize the aspect and color of the edges under some criteria as pollution, allowed speed …, and also the aspect and the color of the vehicles.

7. How to implement the actions

To implement an action on the software SUMO the scenario has to be prepared accordingly. The following sub-sections present how the chosen actions have been modeled within the Brunswick scenario for SUMO.

7.1. Tempo 30

In order to perform the Tempo 30 action the living areas in the city have been detected and selected. The selection of the living areas are done manually with the tool “netedit”, from the software SUMO, that allows to select a group of edges. The edges have been selected using annotations form the Open Streets Map (see Image 6, left). These data show which streets belong to which type of area (residential area, industrial area…). Therefore all the edges that belong to the residential area in Open Streets Map have been added to the selection.

Image 7: Edges in the residential area selection

Once the streets of the residential areas have been selected, all of them are set up to a maximum speed limit of 30 km/h. The edges that connect the living areas around the city center keep their default speed limit; due to Tempo 30 has not the aim to make the travel longer but to reduce the velocity in the living areas.

The total selection is of 19476 edges but the most of the selected edges had already at a speed limit of 30 km/h, that means that only on the 8.66% of the edges selected have been reduced the velocity.

In the city center there are pedestrian streets which have a speed limit of 5km/h but are also edges in the residential areas. These speed limits have not been changed, since it has no sense to rise up the velocity in pedestrian streets where only a certain type of vehicles can go in.

7.2. Environmental Zone

Two steps have to be performed to set up an environmental zone (EZ) within the simulation scenario. The first is to select the edges that represent those roads which belong to the EZ. The second is to change the simulation's road network's edges that belong to the EZ, so that they prohibit certain vehicle types.

The edges selected to for the environmental zone are those that are around the city center but within the first ring. These edges were selected with the tool "netedit".

Image 8: Edges that form the environmental zone

The ring around the environmental zone, Wileschenien ring, is not selected in order to give a fast way to drive around it to the vehicles that cannot go in.

As explained in point 5.3 there are two ways to implement the environmental zone, the first one is allowing the vehicles with EURO 2 + filter, EURO 3 and EURO 4 of diesel engine and for the petrol engine allow all the vehicles, except the petrol without catalyser, this is the more permissive mode. The more restrictive way to implement an EZ is to only allow vehicles with EURO 3 + particle filter or EURO 4 with diesel engine and for the petrol engine to allow all the vehicles except the petrol without catalyser. That means that there are some vehicles that until now they can move overall the scenario, and now they have some disallowed streets.

According with the HBEFA statistics the fleet of vehicles for a urban city in Germany as Brunswick in 2013 are, shown in Table 11 and Table 12,

Table 11: Percentage of vehicles that are not allowed in the permissive environmental zone

Euro Norms	Percentage of passenger vehicles (%)	Percentage of LDV (%)	Percentage of HGV (%)	Percentage of Bus (%)
petrol-others	0,87	0,61	-	-
diesel- EURO 1	0,45	5,02	1,09	2,21
diesel- EURO 2	1,83	10,2	5,50	10,41
diesel-others	0,11	1,72	2,08	2,62
Total	**3,26**	**17,55**	**8,67**	**15,24**

Table 12: Percentage of vehicles that are not allowed in the restricted environmental zone

Euro Norms	Percentage of passenger vehicles (%)	Percentage of LDV (%)	Percentage of HGV (%)	Percentage of Bus (%)
petrol-others	0,87	0,61	-	-
diesel- EURO 1	0,45	5,02	1,09	2,21
diesel- EURO 2	1,83	10,2	5,50	10,41
diesel- EURO 3	5,24	22,22	13,79	4,52
diesel-others	0,11	1,72	2,08	2,62
Total	**8,5**	**39,77**	**22,46**	**19,76**

These percentages of every type of vehicle cannot go into the selected area. Therefore it has to be described how deal with that in the simulation. There are four different cases of how vehicles interact with the EZ, depending on their route.

- Those which start their route in the environmental zone
    - The start point of these vehicles has to be changed for the first point on the border with the environmental zone.
- Those which their fastest route is crossing the environmental zone
    - These vehicles will find a new route to reach their destination.
- Those which end point is in the environmental zone
    - The end point has to be changed for the last point on the border with the environmental zone.
- Those which start and end point is in the environmental zone
    - These vehicles have to be removed from the simulation.

The restriction imposed for the environmental zone car cause that a user that needs to drive into the area, buys a new car and that means more cars in the environmental zone, therefore more pollution. But this assumption is not covered by this thesis.

8. Preparation of the scenario

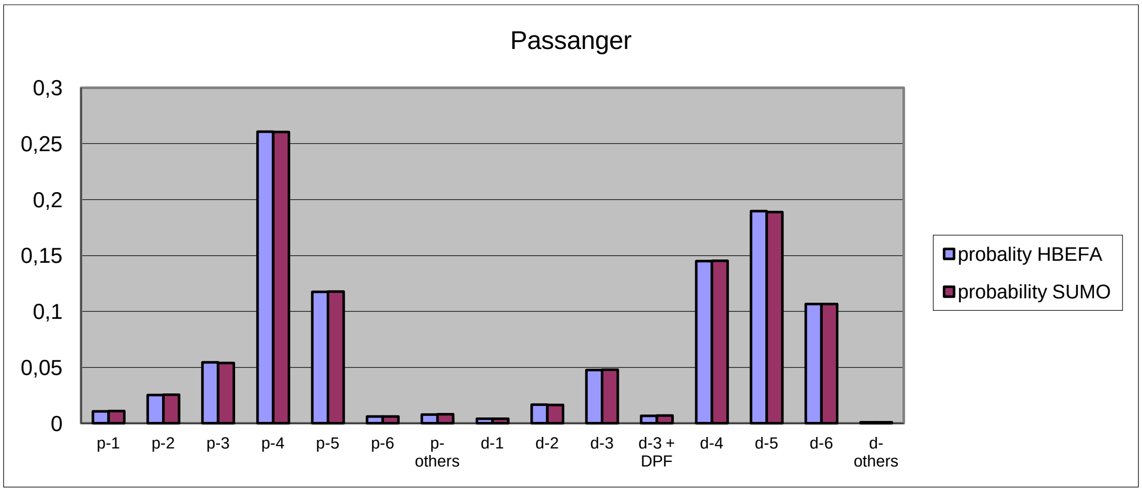
The preparation of the scenario is one of the most important points in order to do the simulation believable; therefore specifics vehicle classes for this scenario have been preformed.

8.1. Vehicles classes

The classes of vehicles implemented in this scenario are according with the data base HBEFA. The Handbook Emission Factors for Road Transport (HBEFA) provides emission factors for all current vehicle categories (PC, LDV, HGV, urban buses, coaches and motor cycles), each divided into different categories, for a wide variety of traffic situations. Emission factors for all regulated and the most important non-regulated pollutants as well as fuel consumption and CO_2 are included. What is used in this thesis of this database is the emissions factors of PM and NO_2 and also the description of the fleet of vehicles in an urban zone according to the EURO Norms.

The fleet of vehicles is taken out from the HBEFA which is described with three criteria, fleet of vehicles of the year 2013, in an urban area and in the country of Germany. It is divided in four classes (passengers, LDV<3.5t, HDV>3.5t and buses) and inside these classes the vehicles have been differentiated according to EURO-Norms. In this thesis the buses are not implemented because their routes are not available.

The following figures show the probability of every class with their subtypes according to the EURO Norms. The database HFEBA provides a probability but when it is introduced in SUMO it have a small change due to the number of vehicles in the scenario is fixed therefore the probability have to be adapted to this new value. The number of passenger vehicles in the scenario is 603049.



[19]

Figure 16: Comparison of the probabilities of the passenger class classified by EURO-Norms

[19] DPF: Diesel Particulate Filter

The total number of HDV is 43955. The LDV<3.5t represents the 50.6% of the total of HDV simulated in the scenario and the remaining 49.3% are HDV>3.5t.

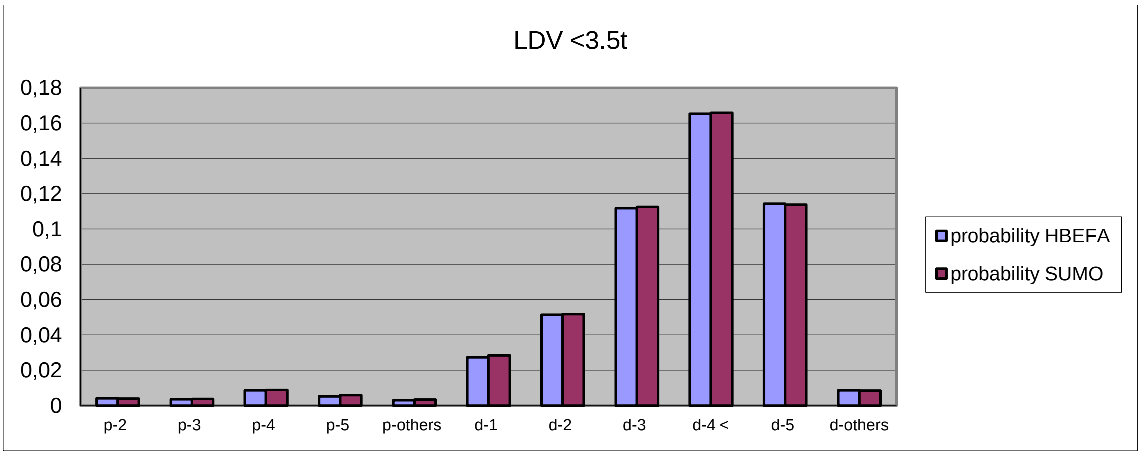


Figure 17: Comparison of the probabilities of the HDV <3.5t class classified by EURO-Norms

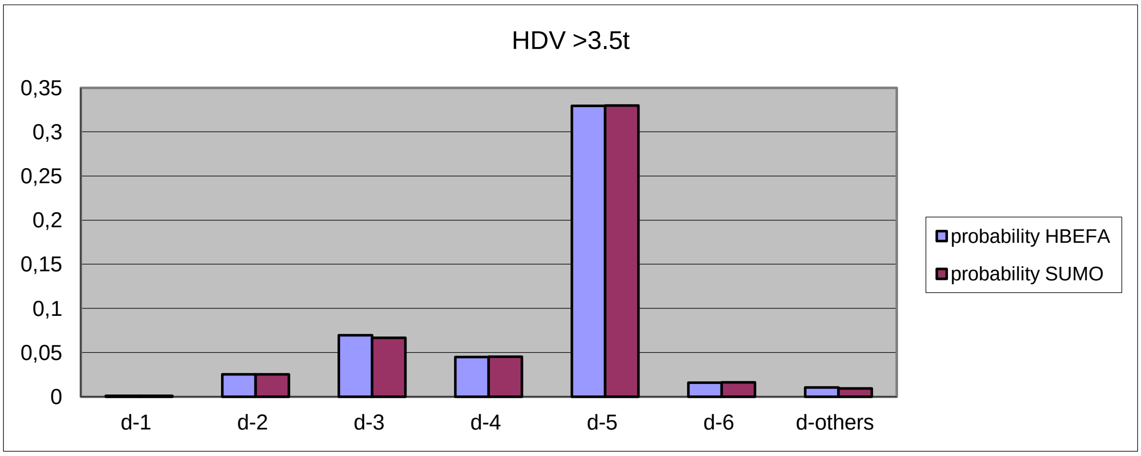


Figure 18: Comparison of the probabilities of the HDV >3.5t class classified by EURO-Norms

9. Simulation

This chapter presents the results obtained from the simulation of the different actions, Base Case, Tempo 30, Environmental zone. At the end are compared the results of each action with the effect of similar actions which are described in the database MARLIS and are also compared with the base case.

All the simulations of this thesis have been done with the software SUMO, with user assignment model [Gawron, Köln 1998, Simulation-Based Traffic Assignment]. The process of the simulation is explained in [Behrisch, M., Krajzewicz D., Wang Y., Comparing performance and quality of traffic assignment techniques for microscopic road traffic simulations. (2008)] the results have been taken after 100 iterations for the Base case and the Tempo 30 and after 60 iteration for the environmental zones cases, due to a lack of time. The used method is “inc_time3600”.

The version of scenario of Brunswick is of the day 24/07/2013 and the version of the software “SUMO” is of the day 24/07/2013.

The emission factors for the each vehicle type of the simulation are taken out from PHEMlight [[COLOMBO D4.1, 2013] COLOMBO consortium. COLOMBO project’s Deliverable D4.1: Draft of "Extended Simulation Tool PHEM coupled to SUMO with User Guide", October 2013 (yet unpublished)].

All the results of this simulation are taken after 24 hours, therefore there are the results during a day, and are not taken until the end of the simulation. The running vehicles after 24 hours on the simulation are almost the same for each case; therefore the vehicles that are not taken into account are the same. Therefore it can be assume that the delimitation of the simulation time into a day is correct.

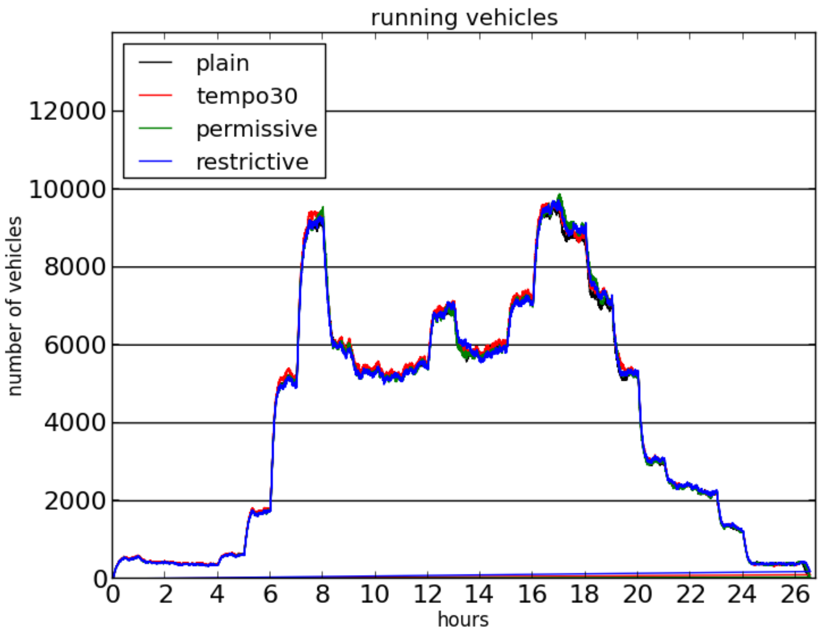


Figure 19: Running vehicles during the simulation

9.1. Base Case

The base case is simulated with the plain scenario. These results will be the benchmark for the actions that are going to be implemented, in this way it can be discovered if the action is beneficial for the city.

The amount of pollution on the plain scenario is 6.436t of NO_2 and 0.220t of PM_{10}. The following figures show how the pollution is distributed on the net. What can be observed form this figures is that the highways are the most polluted edges and some living areas and the center of the city have medium levels of pollution.

Figure 20: NO_2 emissions on the net in base case

The maximum of NO_x emitted on an edge is 57.59 g/km/h and the green represents the edges with pollution between 0 g/km/h and 0.0574 g/km/h, the yellow amounts of pollution between 0.0574 g/km/h and 5.749 g/km/h, and the red levels of pollution higher than 57.49 g/km/h.

Figure 21: PM_{10} emissions on the net in base case

The maximum PM_{10} emitted on an edge is 2.02 g/km/h and the green represents the edges with pollution between 0 mg and 0.002 g/km/h, the yellow amounts of pollution between 0.002 g/km/h and 0.202 g/km/h and the red levels of pollution higher than 2.02 g/km/h.

The implementation of actions affect also on the state of the traffic, therefore it has to be observed how it changes. The Figure 22 shows which edges are the most used ones, using the information about the number of vehicles entering on the edge. These edges do not have to be the most crowded edges, because every edge has a different number of lanes and different length. It is only to discover on which edges the vehicles are driving.

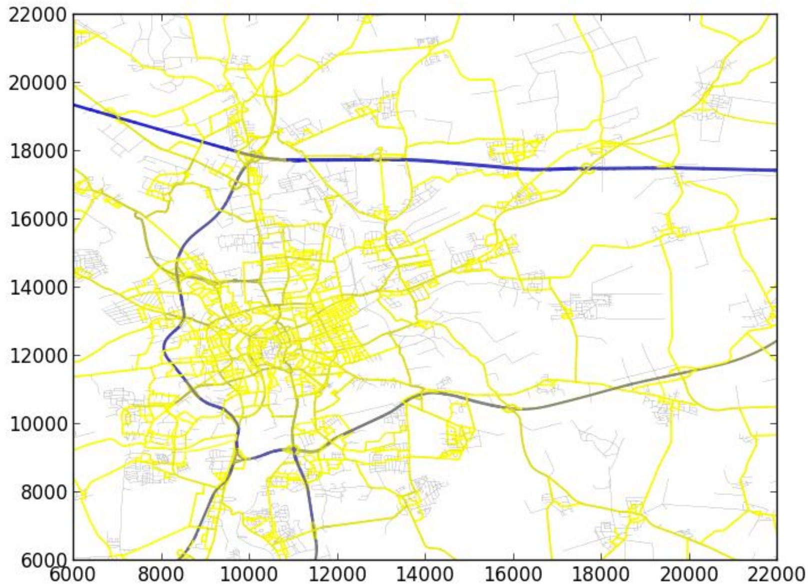


Figure 22: entered vehicles in base case

The maximum of entered vehicles in an edge is 46825 vehicles (per day) and the yellow represents the edges with less vehicles and the blue those with more.

If is compared the three figures above it can be observed that the edges where have entered more vehicles are those with higher levels of pollution and that fact is proved in the following Figure 23 and Figure 24, where trend of more entered vehicles means more pollution is observed.

The observed points above the trend line could be that on this edge there are traffic jams and for the same number of entered vehicles it has more pollution or on this edge some vehicles start they route and then are not counted as entered but they pollute.

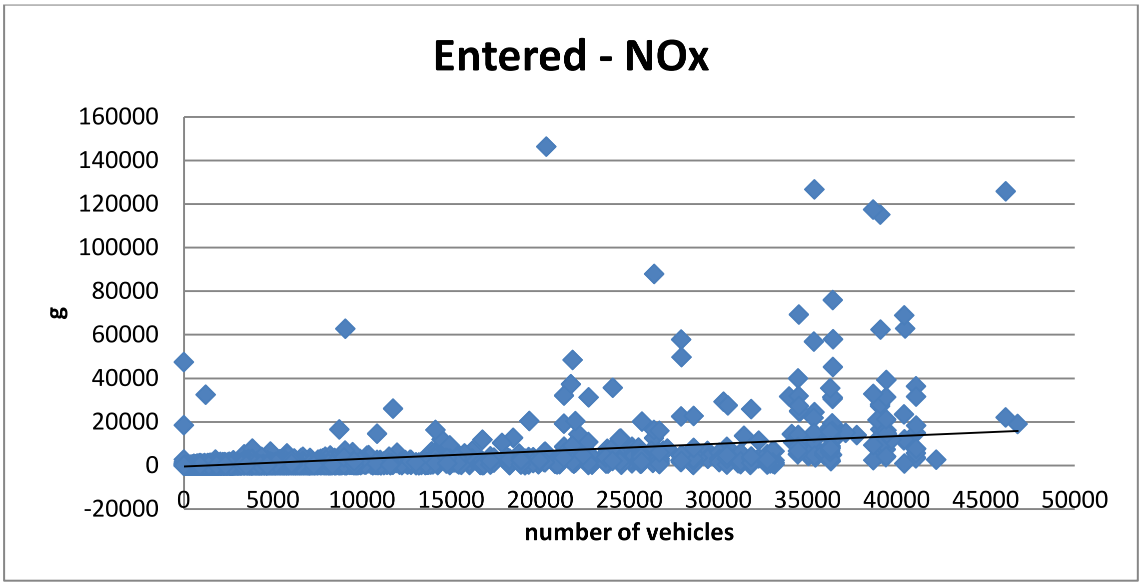


Figure 23: Evolution of the NO_x pollution against the entered vehicles

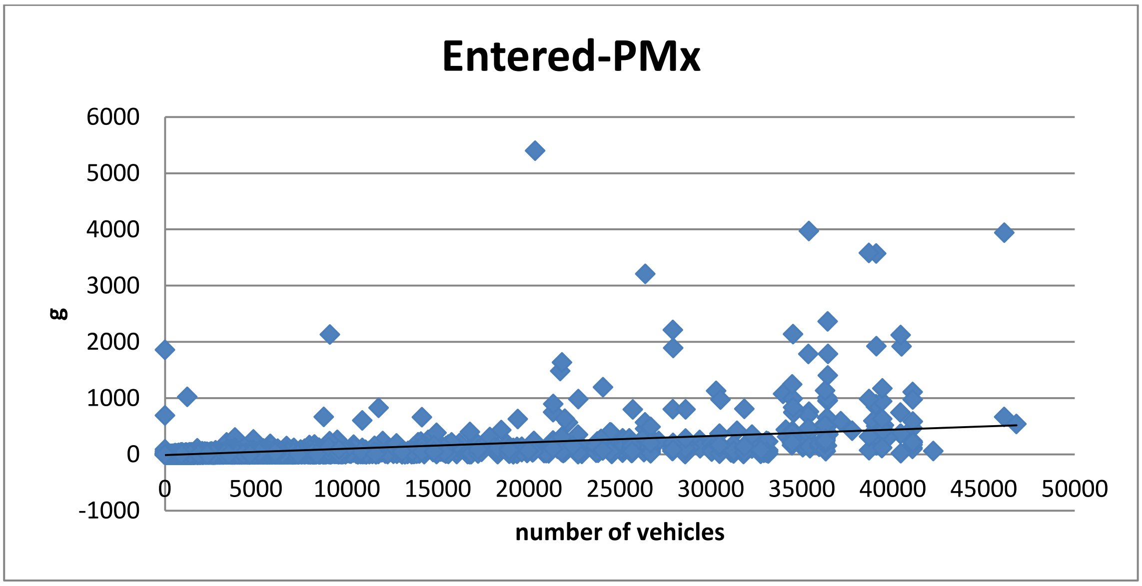


Figure 24: Evolution of the PM_{10} pollution against the entered vehicles

9.2. Tempo 30

This point presents the results of the "Tempo 30" action implementation. The performance of this action is explained above in the point 7.1. The action is set up with the same characteristics as Base Case, except the changes explained above.

The amount of pollution on the Tempo 30 scenario is 6.441t of NO_2 and 0.220t of PM_{10}, what represents an increase of 0.07% of NO_2 and 0.147% of PM_{10}, if it is compared with the base case. Therefore this action does not contribute with a benefit on the all scenario air pollution.

The following figures show the difference between the plain case and the Tempo30 case in entered cars, NO_x pollution and PM_{10} pollution. For all the figures that show difference between cases the blue means that the amount of the studied variable has reduced with the implementation of the action and the red means that it has been increased.

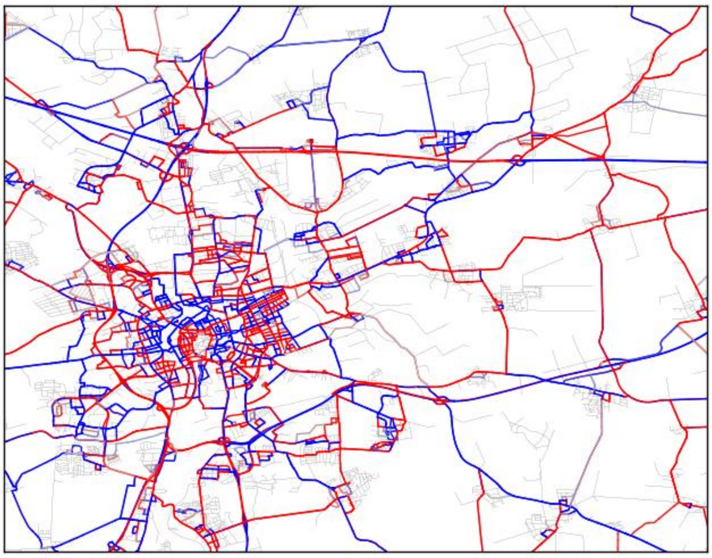


Figure 25: Difference of entered vehicles plain case and tempo 30

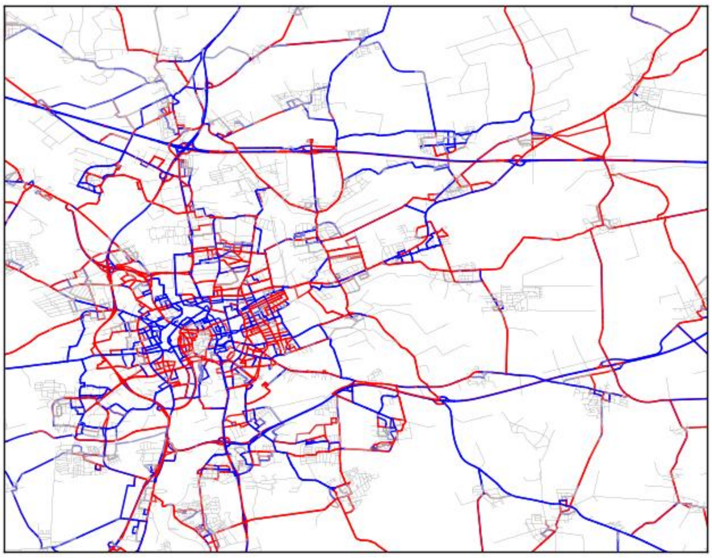


Figure 26: Difference of NO_2 amount of pollution vehicles plain case and tempo 30

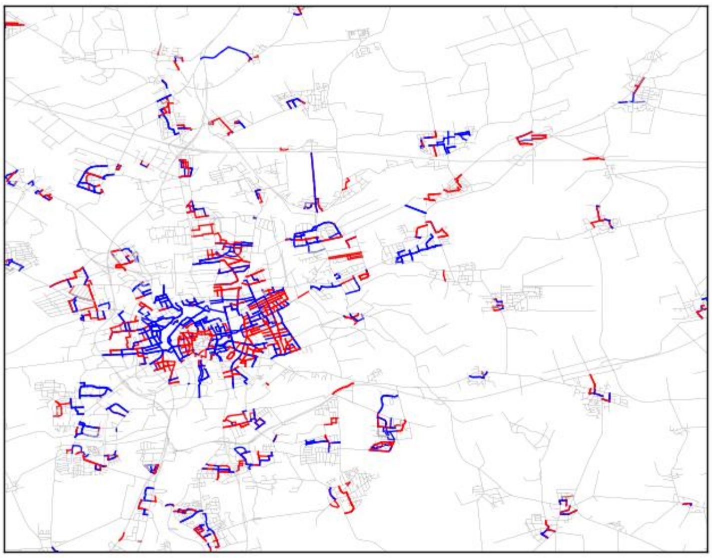


Figure 27: Difference of NO_2 amount of pollution vehicles plain case and tempo 30, only the edges in the selection

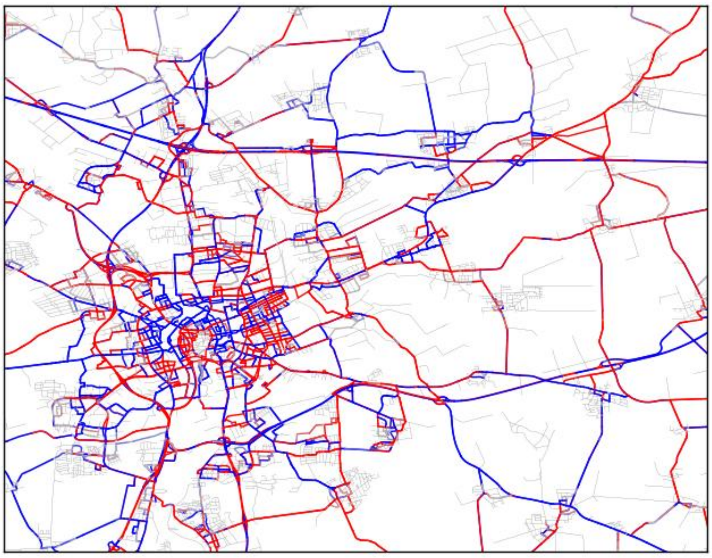


Figure 28: Difference of PM_{10} amount of pollution vehicles plain case and tempo 30

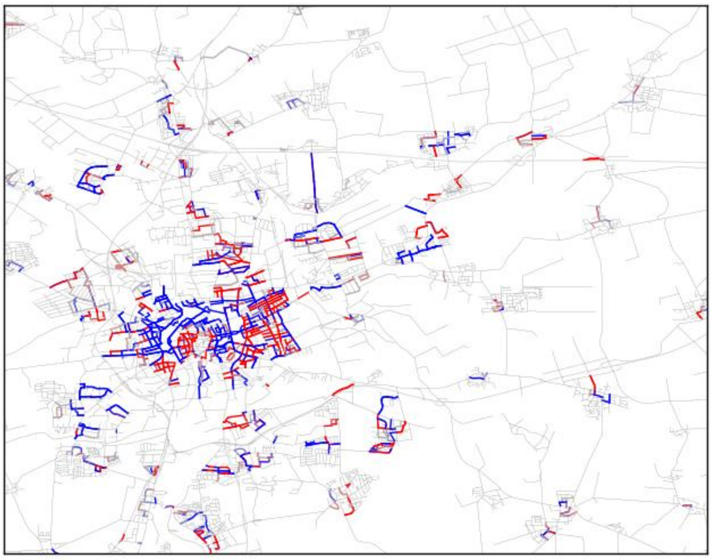


Figure 29: Difference of PM_{10} amount of pollution vehicles plain case and tempo 30, only the edges in the selection

The difference of the amount of vehicles and the amount of pollutants with the plain case has a similar behavior. In all of them the studied variable has reduced in some parts of the center of the city. But from the other side the pollution has increased on the edges that communicate the different living areas, and also on the left side of the city center.

The Figure 27and the Figure 29 show only the edges in the selection for this action, and here can be seen more clearly that in some streets the amount of pollution has increased.

In order to see how effective the Tempo 30 is, a study of how many edges have increase their pollution level has been done. For the implementation of this action 19819 edges have been selected. The table below shows that the "Tempo 30" has this consequence in some edges,

Table 13: Comparison of the edges selected for this action

	PM_{10}	NO_2
Number of edges more polluted	2065 (10,42%)	2086 (10,53%)
Increase of pollution (kg)	0.542	13.676
Difference between reduced and increased (kg)	1.433	40.01
Maximal difference in a single edge (kg)	0.00747	0.448

The results from this Table 13: Comparison of the edges selected for this action show that about the 90% of the selected edges have not increase their emission, therefore means that the reduction is extended through all the selected area and it is not concentrated in some edges. The amount of pollution that has increased in these edges is small against the total emission reduced in that area, due to it only represents a 30% for NO_2 and a 23 % for PM_{10} of the pollution reduced.

The action "Tempo 30" has not a high effect on the reduction of the air pollution for the all city, but it is more effective on the area where is implemented,

Table 14: Effect on the selection area

	Plain Case (kg)	Tempo 30 (kg)	Effect(%)
PM_{10}	7.527	6.096	-19.01
NO_2	195.582	155.608	-20.43

As it is explained above, one of the sources of the effect of this action is that the number of vehicles on the area is lower with the speed limitation. As it can be observed in the Figure 25 only in some edges have been reduced the amount of entered vehicles, but the difference of the amount of entered vehicles in the entire zone have been reduced a 15.14%. This fact shows that the vehicles look for another ways to get their destination.

What normally occurs with the implantation of this action is that the vehicles that do not want to drive slower through the living areas, take other ways, what it is transformed in more pollution outside the selected area.

Table 15: Pollution outside the selected area

	Plain Case (t)	Tempo 30 (t)	Effect (%)
PM_{10}	0.212	0.213	0.811
NO_2	6.233	6.276	0.701

An increment of the pollution outside the area means that the total pollution has almost not been reduced but it has moved out from the areas where the inhabitants spend more time. In general terms the effect of the action "Tempo 30" is the expected an it have caused an improvement of the air quality on the selected area.

9.3. Environmental zone

This section presents the results of the environmental zone simulation. The performance of this action is explained above in the point 7.2. This action it will be compared with the base case and with all other simulated actions.

First of all, it has to be explained which are consequences of implement the environmental zone since some vehicles which in the base case could drive through all the city, now according with their EURO–Norm class have forbidden to drive in the selected area. As is explained in the 7.2 the route has been modified by some vehicles.

The following table explains how many vehicles wanted to drive through the selected area and depending on the restriction level of the environmental zone change the number of cropped and removed.

Table 16: Number of passenger vehicles that are analyzed for the environmental zone

	Total number of vehicles	Cropped	Removed
Permissive environmental zone	603049	13054 (2.16%)	138 (0.02%)
Restrictive environmental zone	603049	46251 (7.67%)	476 (0.08%)

Table 17: Number of HDC vehicles that are analyzed for the environmental zone

	Total number of vehicles	Cropped	Removed
Permissive environmental zone	43955	5310 (12.08%)	7 (0.016%)
Restrictive environmental zone	43955	13426 (30.54%)	13 (0.03%)

The percentage of the cropped and removed from the simulation is lower than the percentages described in the Table 11 and in the Table 12, that is why that there are vehicles that do not start or end their route in the environmental zone, therefore they take another route to get their destination.

For this action two type of simulation have been done on with only one emission type and the other with the emission types according to the EURO Norms. It wants to be compared if there is a lot of difference between the results of each simulation. And if with only emission type assumable results are achieved.

With the implementation of this action the vehicles have changed their routes in comparison with the plain case. Now different vehicles drive on the environmental zone, and that can cause changes on the state of the traffic and also on the amount of pollution.

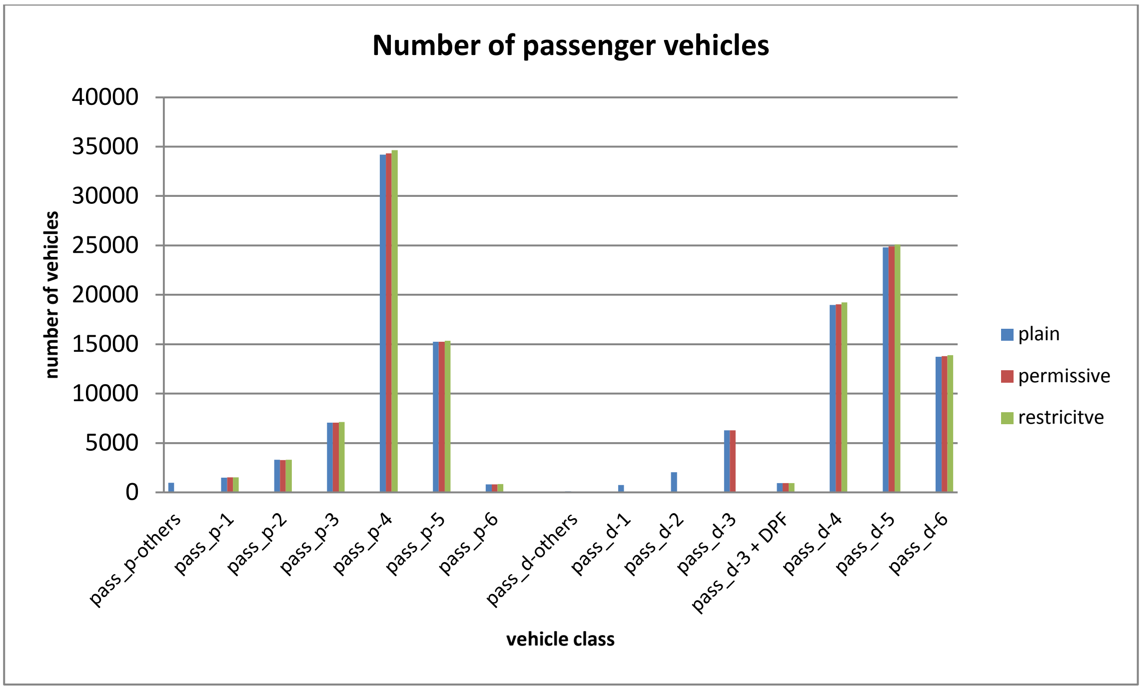


Figure 30: Distribution of passenger vehicles in the environmental zone

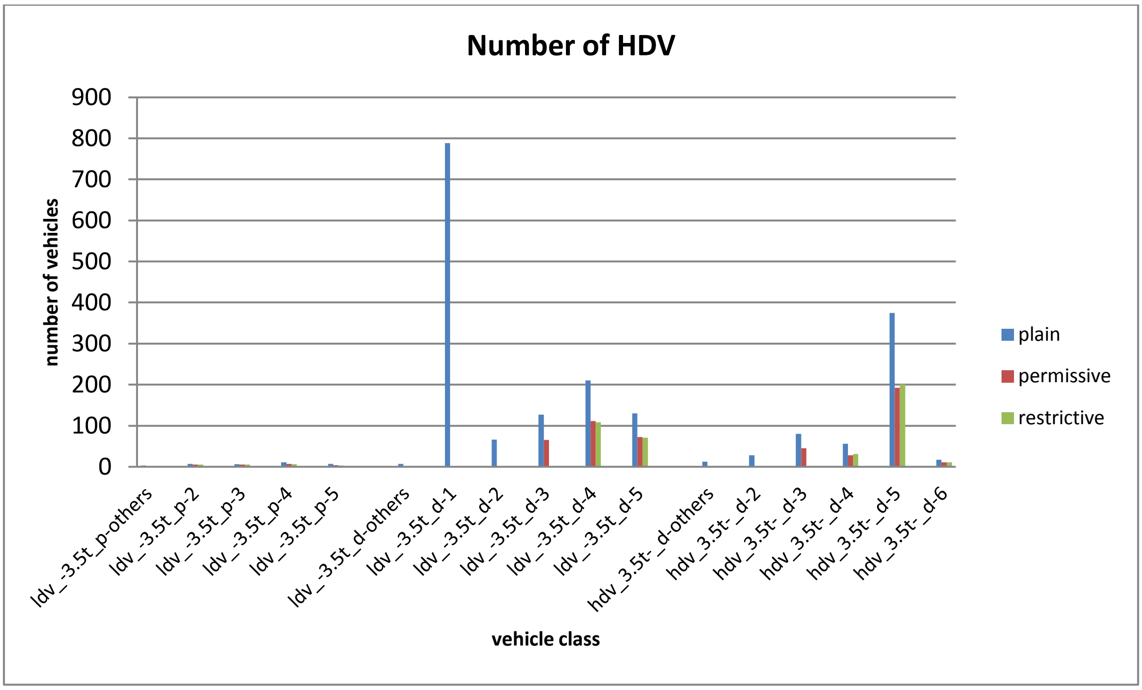


Figure 31: Distribution of HDV in the environmental zone

The Figure 30 and the Figure 31 show the number of the vehicles of each class that enters in the environmental zone after the implementation of the environmental zone. The total amount of traffic in the environmental zone has been reduced by a 3.65% for the permissive environmental zone and by a 7.71% for the restrictive one. Due to some vehicles types cannot drive in the area, some of the vehicles types which are allow have increased their presence in the zone. But also some of the vehicles can drive in the environmental zone in all cases have reduced their number.

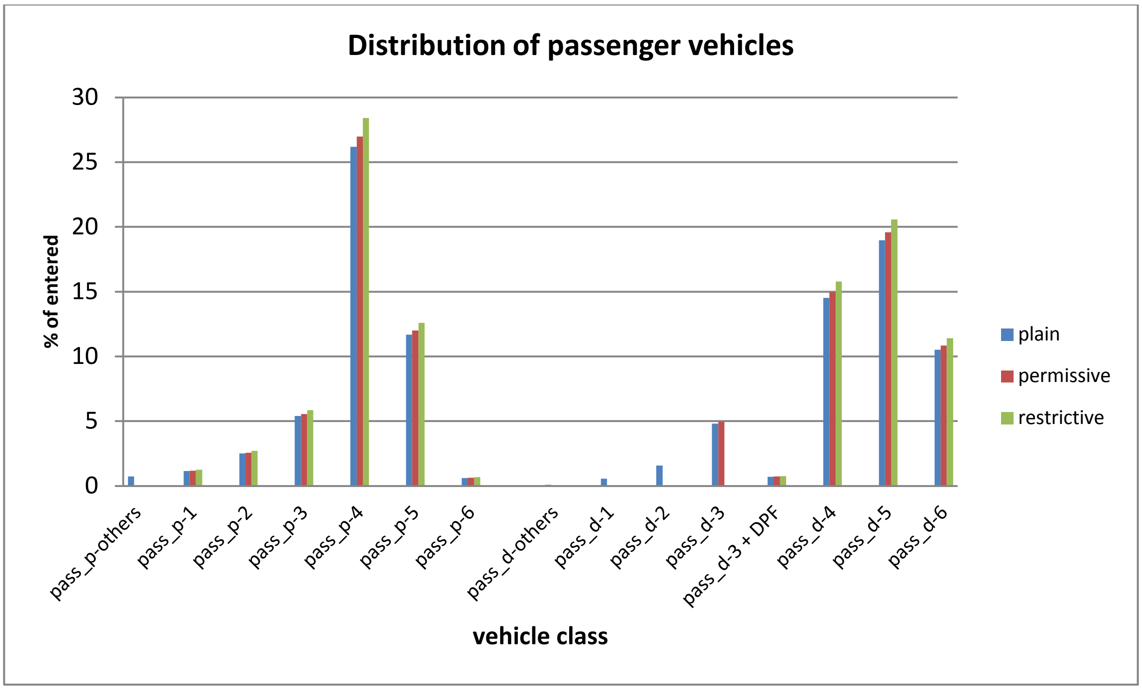


Figure 32: Distribution of passenger vehicles in the environmental zone

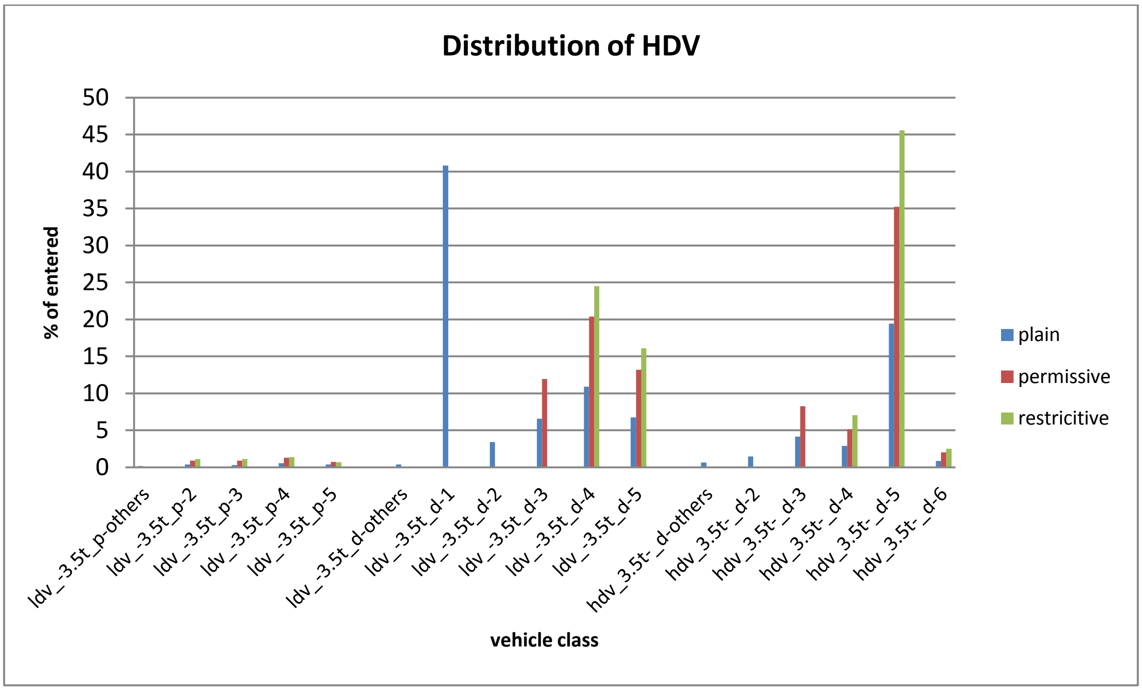


Figure 33: Distribution of HDV in the environmental zone

With the reduction of vehicles in the environmental zone the distribution of vehicles classes have changed, what it is explained on the Figure 32 and Figure 33.

The effect of this action on the amount of pollution on the scenario is described on the following table.

Table 18: Amount of pollution on the all scenario

	Plane Case	Permissive Environmental zone (t)	Effect (%)	Restrictive Environmental zone (t)	Effect (%)
PM_{10}	0.22	0.21	-4.25	0.211	-3.48
NO_2	6.43	6.19	-3.71	6.18	-3.83

The amount of total pollution reduction is not very high, but it changes if it is studied the area of implementation of the action.

The following figures show how the implementation of the environmental zone has impact on the distribution of the entered vehicles, NO_2 pollution and PM_{10} polluiton.

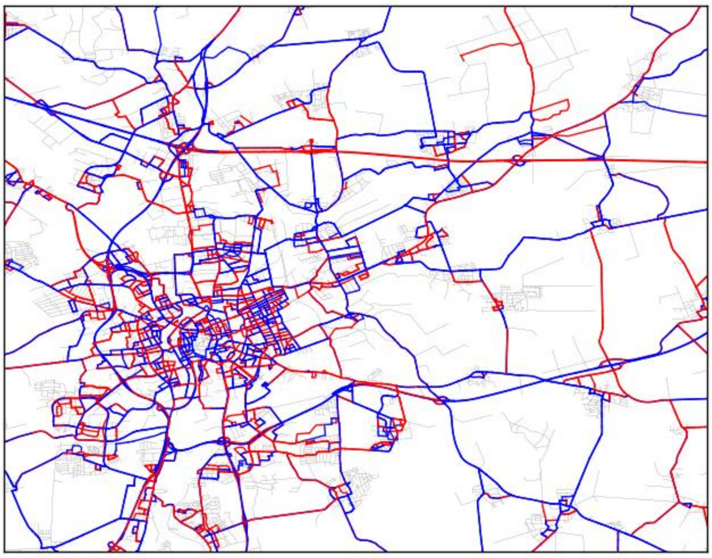


Figure 34: Difference of entered vehicles plain case and permissive environmental zone

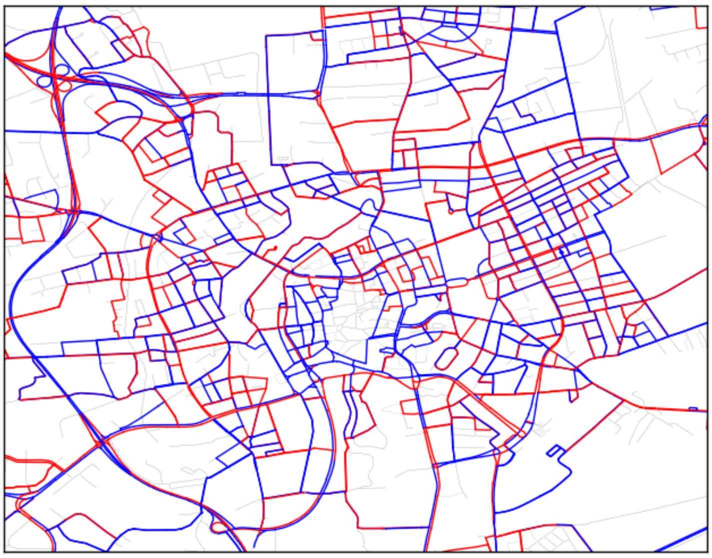


Figure 35: Zoom of the environmental of the Figure 34

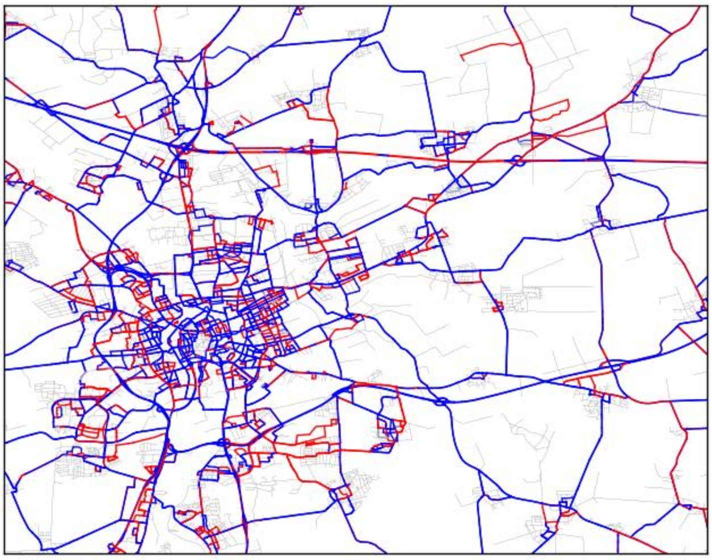


Figure 36: Difference of NO_2 amount of pollution vehicles plain case and permissive environmental zone

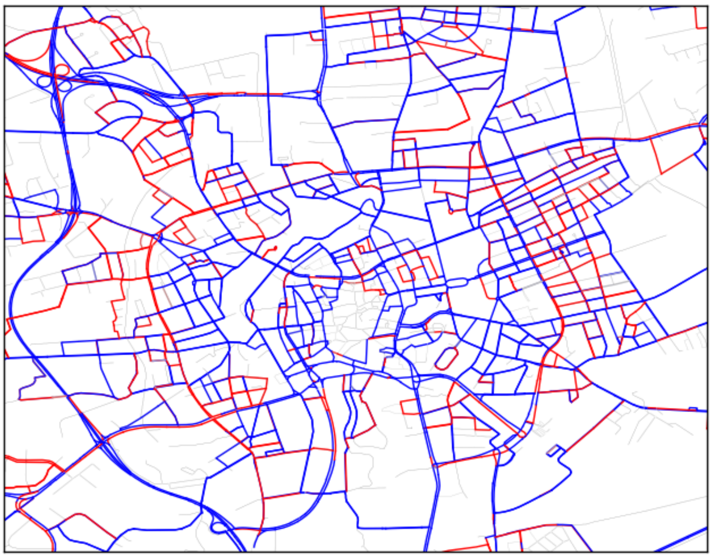


Figure 37: Zoom of the environmental zone of the Figure 36

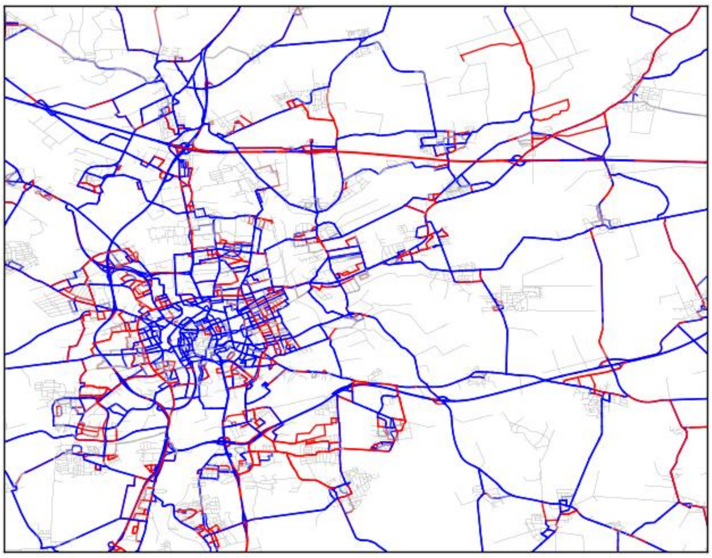


Figure 38: Difference of PM_{10} amount of pollution vehicles plain case and permissive environmental zone

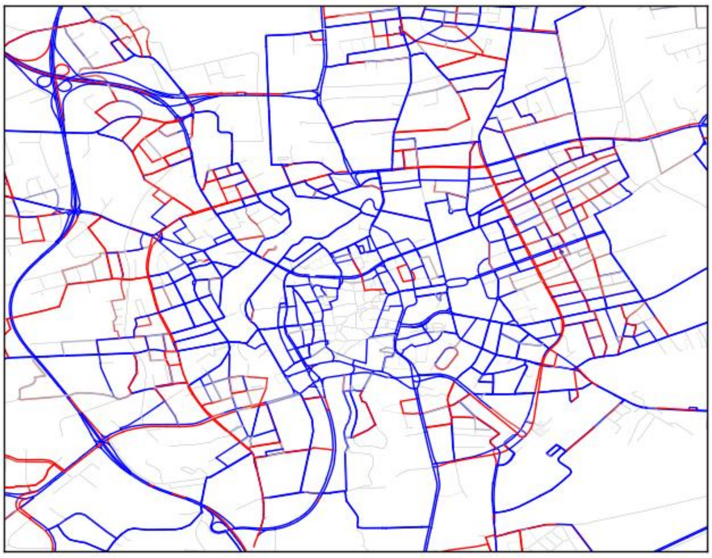


Figure 39: Zoom of the environmental zone of the Figure 38

These figures above show the effect on the city of the permissive environmental zone, the ring around the environmental zone have increase in entered vehicles and NO_x and PM_{10}. There are few edges that have increased their pollution in the environmental zone that can be caused because more allowed vehicles have entered in the area, but the most of the edges have reduced their air pollution.

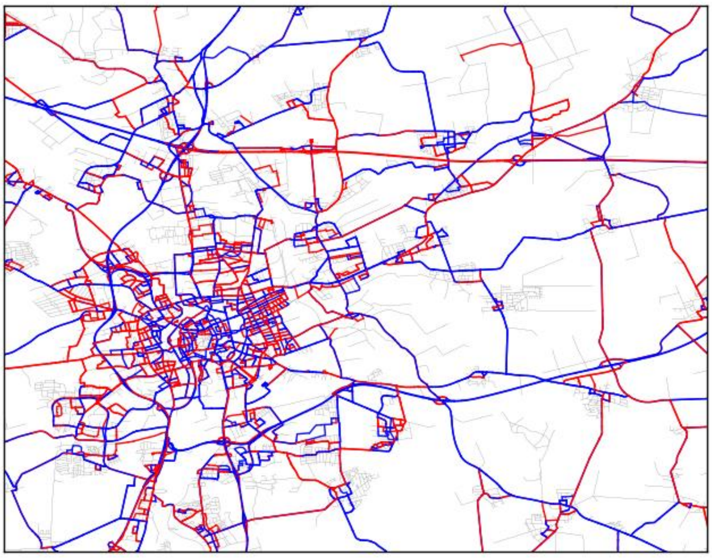


Figure 40: Difference of entered vehicles plain case and restrictive environmental zone

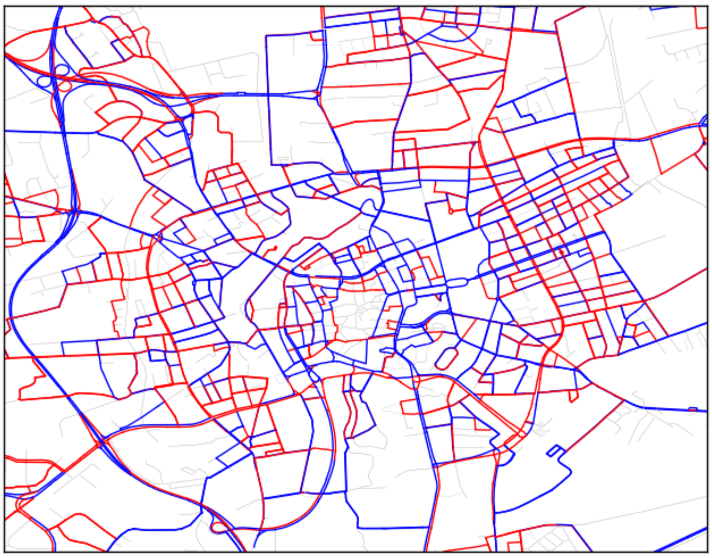


Figure 41: Zoom of the environmental zone of the Figure 40

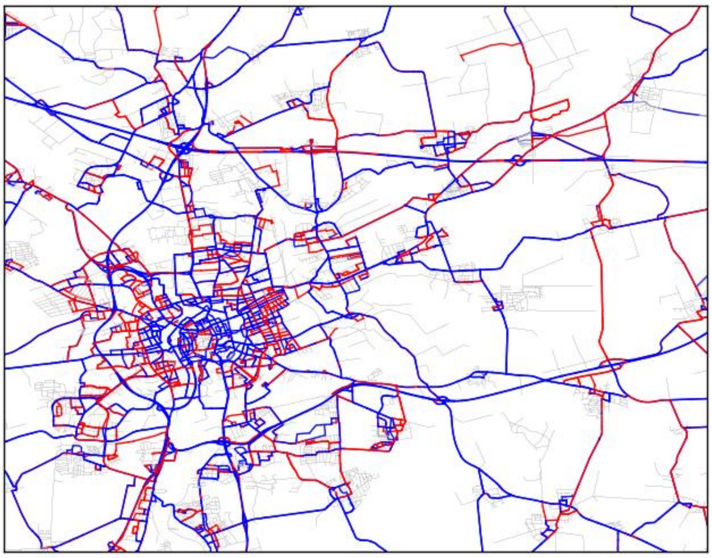


Figure 42: Difference of NO_2 amount of pollution vehicles plain case and restrictive environmental zone

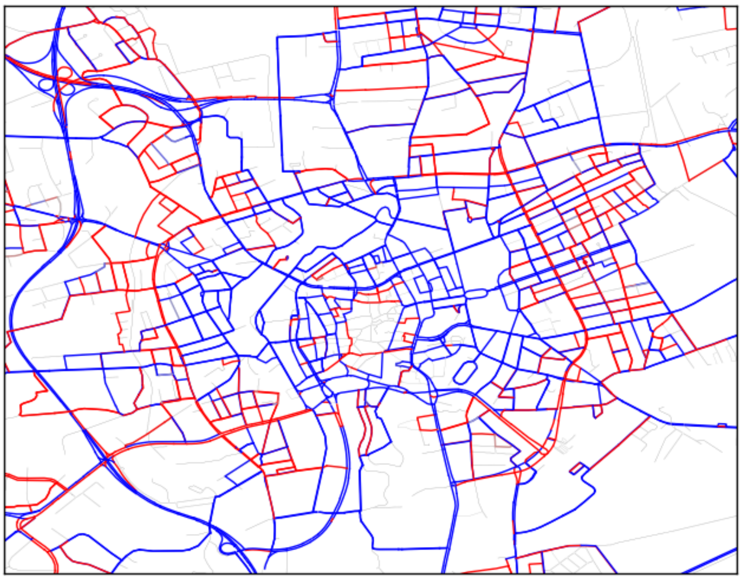


Figure 43: Zoom of the environmental zone of the Figure 42

Figure 44: Difference of PM_{10} amount of pollution vehicles plain case and restrictive environmental zone

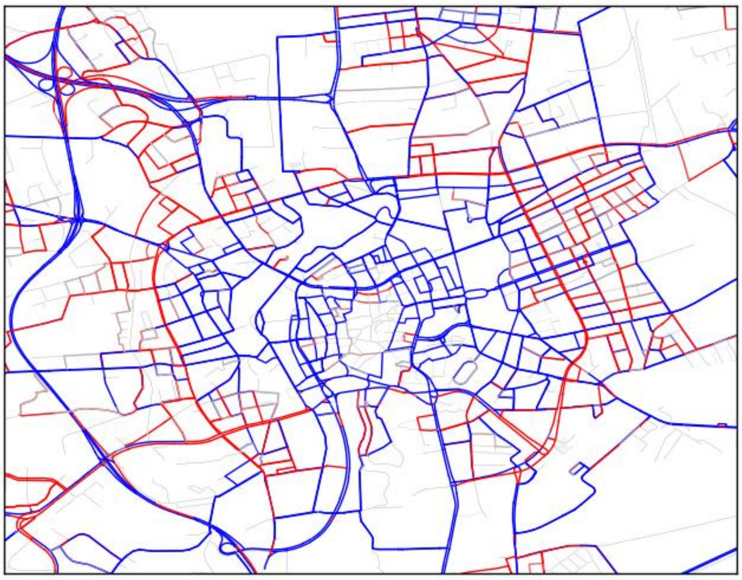


Figure 45: Zoom of the environmental zone of the Figure 44

A good indicator for the validity of the action is the effect that has on his working area.

Table 19: Effect on the environmental zone

	Plane Case (kg)	Yellow Environmental zone (kg)	Effect (%)	Green Environmental zone (kg)	Effect (%)
PM_{10}	4.98	3.51	-29.5	2.85	-42.62
NO_2	124.0	105.02	-15.30	89.77	-27.60

The results from the simulation are not very similar with the example from MARLIS (Environmental zone in Münster). In the simulation the amount on PM_{10} reduced is higher than the NO_2 amount, and in Münster is on the other way.

The vehicles that cannot drive through the environmental zone have to find another route to get their destination what can cause an increase of the air pollution on others parts of the city.

Table 20: Pollution outside the selected area

	Plane Case (t)	Yellow Environmental zone (t)	Effect (%)	Green Environmental zone (t)	Effect (%)
PM_{10}	0.214	0.207	-3.65	0.207	-3.36
NO_2	6.30	6.08	-3.48	6.09	-3.48

As the Wileschenien ring around the environmental zone is not included, it is possible that some vehicles have used in order to drive around the forbidden area.

Table 21: Pollution on the ring around the environmental zone

	Plane Case (kg)	Yellow Environmental zone (kg)	Effect (%)	Green Environmental zone (kg)	Effect (%)
PM_{10}	2.69	2.77	3.01	3.02	7.35
NO_2	69.44	68.78	-0.94	74.54	12.32

9.5. Comparison of the actions

This section presents the comparisons between the actions implemented in this thesis as on the traffic level as in the pollution level. And find out which is the better action to implement in this scenario.

The amount of pollution on the scenario is a good indicator to describe how effective is an action, therefore the most effective action on this point is the permissive environmental zone.

Table 22: Amount of pollution on the all scenario

	Effect on PM_{10} reduction	Effect on NO_2 reduction
Tempo 30	0.15	0.07
Permissive EZ	-4.25	-3.71
Restrictive EZ	-4.38	-3.83

The two environmental zone reduce the amount of pollutant in the all scenario but the Tempo 30 increase it.

Another way to compare the actions is with the effect on their working area. However is difficult to compare the environmental zones and the Tempo 30 because they are not implemented in the same area.

Table 23: Effect on the specific working area

	Effect on PM_{10} reduction	Effect on NO_2 reduction
Tempo 30	-19.01	-20.43
Permissive EZ	-29.5	-15.3
Restrictive EZ	-42.62	-27.6

As it is the expected, the action that has more effect is the restrictive environmental zone.

The following figures show the evolution of the pollutants during the day in the simulation and are compared with the evolution extracted from the measure stations in Brunswick.

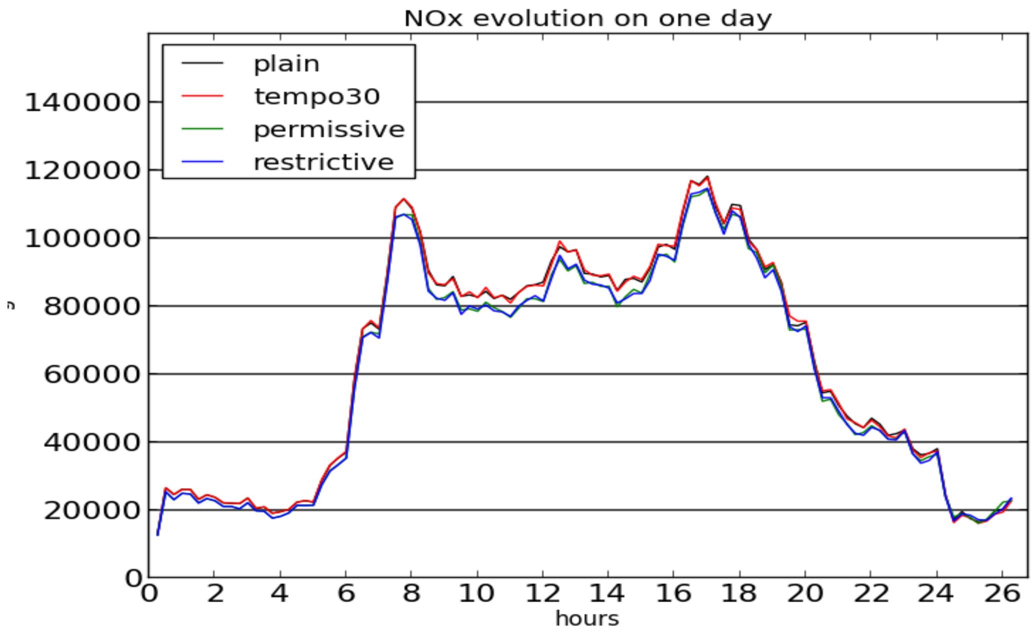


Figure 46: Evolution of the NO_2 pollution during the simulation on the whole scenario

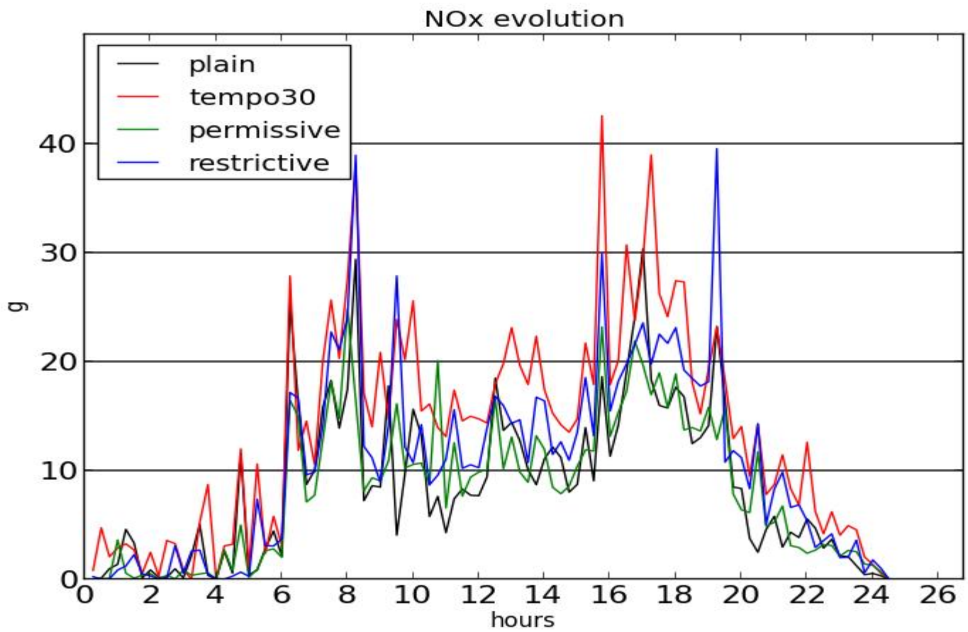


Figure 47: Evolution of NO_2 pollution during the simulation on the location of the station A

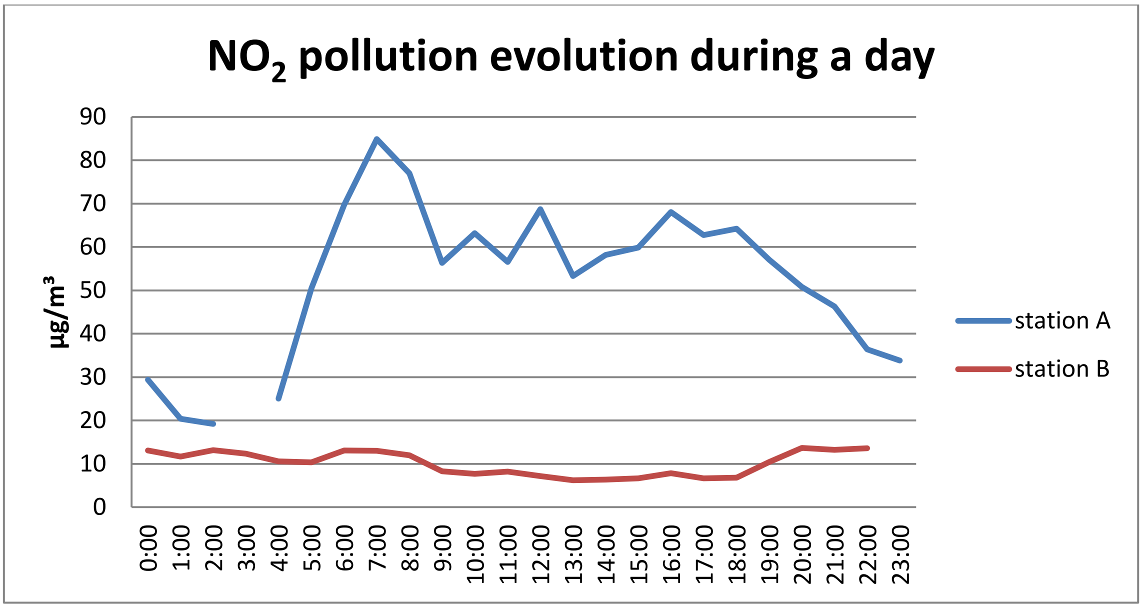


Figure 48: Evolution of the NO_2 measured on the stations

The evolution of NO_2 has a similar shape in the simulation as in the measuring station. That means that the pollution of NO_2 is very influenced by the traffic. The evolution from the simulation is also influenced by the rush hours.

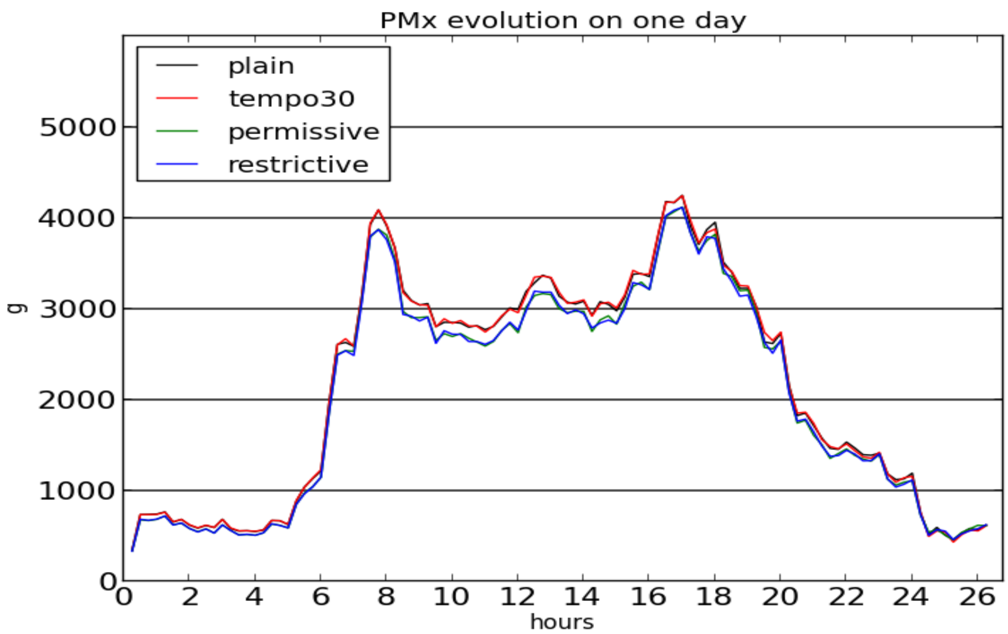


Figure 49: Evolution of the PM_{10} pollution during the simulation on the whole scenario

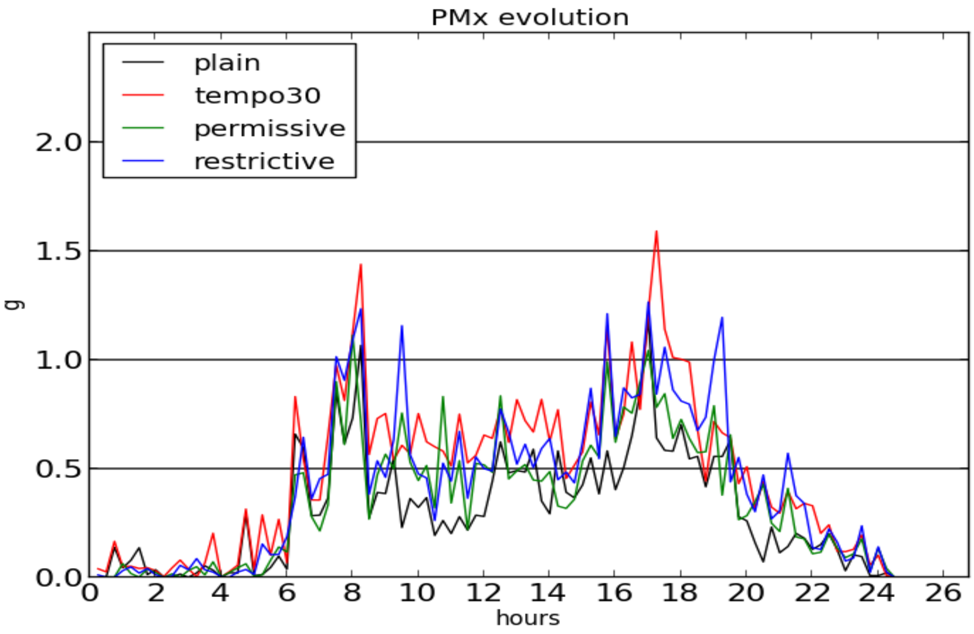


Figure 50: Evolution of PM_{10} pollution during the simulation on the location of station A

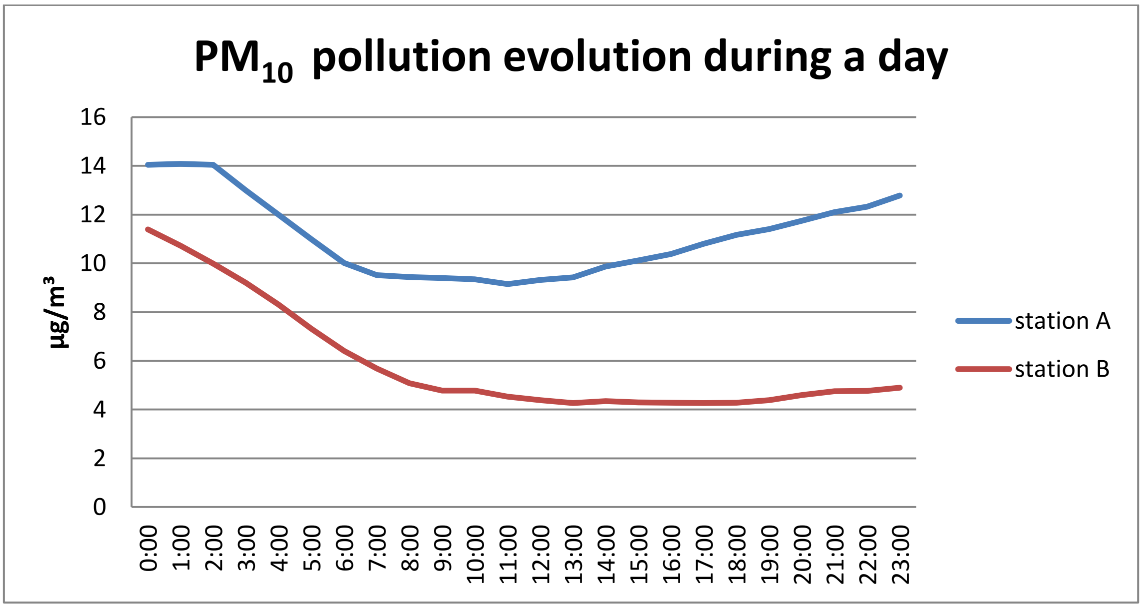


Figure 51: Evolution of the PM_{10} pollution measured on the station

The shape of the pollution of PM_{10} is not very similar to the shape of the PM_{10} emitted on the simulation, what can mean that the PM_{10} pollution has other important sources apart from the traffic. On the simulation the evolution is influenced by the rush hours and on the measuring station has not this influence.

What can be observed in both pollutants is that for all the cases of the simulation the shape of the evolution is the same but the two environmental zones have lower levels of pollution in comparison with the base case and the Tempo 30, especially during the valley hours between the two rush hours of the day.

On the Figure 47 and the Figure 50 can be observed that the implementation of the actions increase the amount of pollutants on the station A. The cause of that is the location of the station A is on the ring around the city center. In the environmental cases this ring is used to drive around the environmental zone, therefore is normal that has an increase of the pollution. And for the Tempo 30 case, this ring is also used to avoid the city center area which has a low velocity.

The following figures indicate the state of the traffic on the scenario, because maybe an action has a good effect on reducing the pollution but it causes deteriorations on the traffic with more time driving by the users or more vehicles at the same time, and it can generate a bad acceptation of the action by the inhabitants of the city.

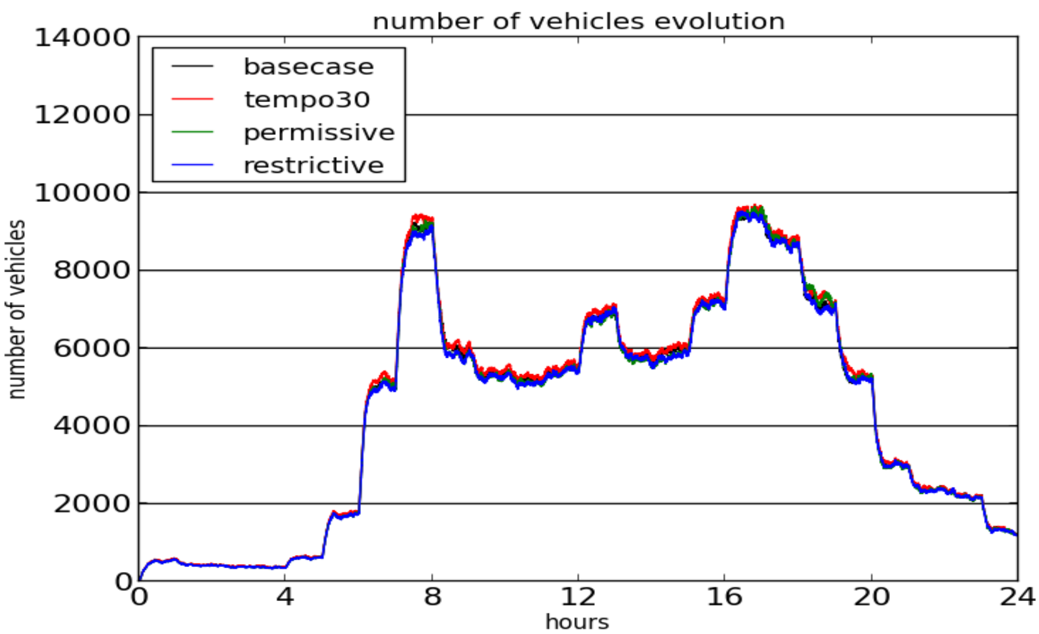


Figure 52: Evolution of the number of vehicles

The number of vehicles on the scenario are the almost the same in the four cases, that means that the actions implemented do not cause big number of jams.

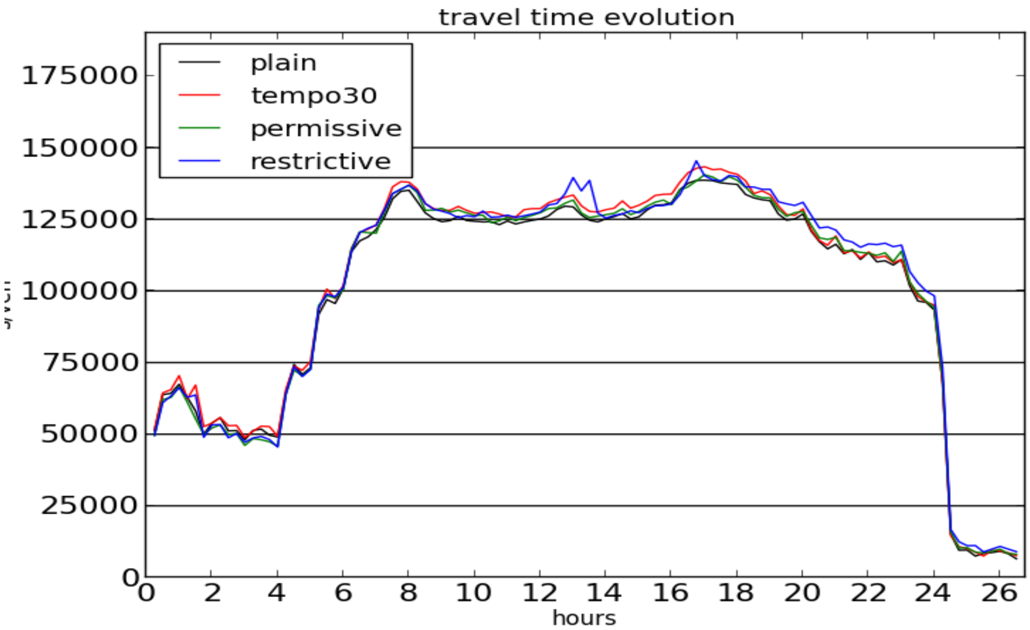


Figure 53: Evolution of the average travel time per vehicle

The average travel time per vehicle keeps almost the same shape for all the cases. That means that the implementation of this actions do not affect too much at the travel time of every vehicle. Only the restriction environmental zone and the tempo 30 increase a little the travel time.

10. Conclusions

The aim of this thesis is to compare the different implemented actions and find out which their effects on the simulated scenario are and whether these effects are similar with the effect of similar actions in the real-world.

All the three actions implemented in this thesis present improvements against the plain case. These improvements are more significant on the area of application of these actions, still the two cases of environmental zone reduces the pollutants on the all scenario, that can be caused by the treatment of the vehicles in these simulations, maybe with another kind of treatment this reduction will change. The implementation of the Tempo 30 contributes with a little increase of the pollution in the all scenario.

The action that reduces more the pollution in his area of application is the restrictive environmental zone, what is the expected result according to the effects described in MARLIS.

The comparison of the effect of the Tempo 30 with similar actions from MARLIS shows the same range of values. The comparison of the environmental zone with the example from MARLIS (environmental zone in Münster) presents different results.

One of the aims of this thesis was reduce the amount of pollutants on the city in order to fulfill with the limits set up by the EU. But this data are taken from the measuring stations and with the implementation of these actions the levels of pollutants increase on the area where the station A is located.

With the implementation an emission type for each class of vehicles according to the EURO Norms, the simulation has increment the accuracy of its results.

This simulation could be more realistic if a driving ban for the HDV > 7.5t in the first ring, which is already implemented in Brunswick, had been implemented, than the levels of air pollution in the city center would be lower. Apart from that this there are another actions implemented in Brunswick which are not taken into account on this thesis and could vary the results. They can be consulted in the following paper, [Niedersächsisches Ministerium für Umwelt und Klima schutz. “Luftreinhalte- und Aktionsplan”. Brunswick. 2007].

The implementation of the real traffic lights on the scenario will give it more possibilities to develop new actions or just to do more realistic the implementation of other actions due to the traffic lights have a very important role on the traffic.

Another improvement that can be implemented in this scenario is a model which describes how the population will react against the prohibition to go into the environmental zone, if the users will change their vehicle or they will not go in.

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