DOCTORAL DISSERTATION

EMISSION PREDICTION OF THE MOBILE SOURCES AND EFFECT ESTIMATION OF THE COUNTERMEASURES IN ULAANBAATAR

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EMISSION PREDICTION OF THE MOBILE SOURCES AND EFFECT ESTIMATION OF THE COUNTERMEASURES IN ULAANBAATAR

BY

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Thesis submitted to the Graduate School of Environmental Engineering, The University of Kitakyushu in fulfilment of the requirement for the Degree of DOCTOR OF ENGINEERING

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Declaration

I hereby declare that this thesis has not been previously submitted to any other university or institution for obtaining an academic degree. Accept quotations and data which are properly cited, this thesis contains my original works. The thesis is only submitted to The University of Kitakyushu in fulfilment of the requirement for a degree of Doctor of Engineering.

Kitakyushu, Japan

September 2018

Bayasgalan Batjargal

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Kitakyushu, Japan, September 2018

Bayasgalan Batjargal

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Abbreviations

CHP	Combined Heat-and-Power Plants
PM	Particulate matter
CO	Carbon monoxide
CO_2	Carbon dioxide
NOx	Nitrogen oxides
SO_2	Sulphur dioxides
CH	Hydrocarbons
HOB	Heat Only Boilers
CFWH	Coal Fired Water Heaters
MNS	Mongolian National Standard
WHO	The World Health Organization
Euro	European emission standards
EPA	Environmental Protection Agency
VKT	average annual km traveled by a vehicle
EF	Emission factor
GVW	Gross vehicle weight
VDS	Vehicle detecting system
HDV	Heavy duty vehicles
LDV	Light duty vehicles
EMEP/EEA	European Environmental Agency
km/h	kilometer/hour
g/km	gram/kilometer
g/km/t	gram/kilometer/ton

Abstract

Air quality and air pollution control are tasks of international concern as, for one, air pollutants do not refrain from crossing borders and, for another, industrial plants and motor vehicles which emit air pollutants are in widespread use today. Owing to their rapidly increasing numbers and very limited use of emission control technologies, motor vehicles are emerging as the largest source of urban air pollution in the developing world. Polluted air causes annoyances, when it occurs in high concentrations in these cities, constitute a serious health hazard.

Comparing the statistical data of 2015 with that of 2000, the total population of Ulaanbaatar city increased 1.8 times, the length of roads increased 1.6 times and number of vehicles increased 7.8 times. Most of these vehicles are second hand, about 72% of all vehicles passed more than 10 years. Sulphur content of supplied fuel in Ulaanbaatar city is approximately 200 ppm for gasoline and 1200 ppm for diesel. On the other hand, in Japan, Europe, and U.S.A, low sulphur fuel supply such as 50 ppm (Euro 4) or 10 ppm (Euro 5) is indispensable to ensure function of emission reduction system. Particulate matter (PM_{10}, $PM_{2.5}$), sulphur dioxides (SO_2) and nitrogen dioxides (NO_2) concentrations on the roadsides of Ulaanbaatar are 2 to 2.5 times higher than the Mongolian National Air quality standard, 2-6.3 times higher than the World health organization Air quality guideline.

It becomes necessary to make use of all the scientific tools available for the management of the atmospheric environment.

Emission inventories are now regarded as indispensable tools for a wide range of environmental measures such as management of chemicals as well as the prevention of air pollution. The quantitative emissions estimates provided by an inventory promote a better understanding of the actual emissions and help to raise the awareness of both policy makers and general public. Estimated future emissions provide important information for setting emissions targets. An accurate and comprehensive emission inventory helps governments to make quantitative assessments of the source contributions to air quality, adopt effective strategies with regard to air pollution, develop and implement effective policies that reduce emissions and enables them to plan cost-effective strategies.

The emission inventory in main roads was prepared, the vehicle emission prediction dynamic model was developed and the effectiveness of some countermeasures as applying the new gas exhaust standard and using fuel additives was assessed. Then, to compare the results obtained in real situations (current situation) with those in the scenario in which fuel additive was used and the Euro 4, Euro 5 vehicle emission standard was applied.

For the main roads, the annual emission of NO_x was 6905.7 ton and PM was 301.7 ton. In consideration to vehicle type, the truck and bus accounted 49% and 34% of NO_x emission, 30% and 15 % of PM emissions respectively. The passenger cars accounted 17% and 55% of NO_x and PM emissions. In consideration to vehicle age, vehicles with over 10 years accounted 96% and 82% of NO_x and PM, with 4-9 years accounted 3% and 17%.

The vehicle emission prediction model was developed from 2015 to 2040, using system dynamics which is a methodology for studying and managing complex systems that change over time. The HDVs and vehicles in service for more than 10 years

accounted for a significant proportion of the total pollution. In comparing 2015 with 2040, the total vehicle population was increased by 3.9 times, the total vehicle emission level was increased by 4.3 times. The real situation and two kinds of scenario were compared: scenario 1, the Euro 4 standard for all vehicles was applied from 2015, and the Euro 5 standard for all vehicles from 2020. Scenario 2, which was same as scenario 1 but all vehicles except over 10 years. The result of scenario 1, by converting to the Euro standard, the emission level in the real situation showed that NO_x was 1/3, PM was 1/7-1/37, and CO was 1/3-1/5. As a result for the scenario 2, the emission level in the real situation was reduced NO_x by 0.8%-22%, PM by 10%-38%, and CO by 4%-27% respectively from 2015 to 2040.

The vehicle fuel additive (Lubricon A-112M) was tested to improve fuel quality. Results were shown that for the vehicle with a gasoline engine, when using the fuel additive, the emission level of NO_x was decreased by an average of 1.69 to 1.87 times (26%–37%). For the vehicle with a diesel engine, when using the fuel additive, the emission level of NO_x was decreased by an average of 1.04 to 1.51 times (4%–30%). The purpose of this study was to assess the effectiveness of using fuel additives and applying the new gas exhaust standard in Mongolia. In this scenario, the Lubricon A-112M fuel additive was used in 30% of all vehicles from 2016, and the Euro 4 standard was used for all vehicles except those over 10 years old, from 2020. The emission level of NO_x and PM was reduced by 8% and 13% when using fuel additive from 2016 to 2020, and approximately 6%–22% and 16% –30% when applying the Euro 4 standard from 2020 to 2040.

For the scenarios of the first year, the vehicle emission of NO_x and PM was reduced by 4% and 16% approximately when Euro standard applied all vehicles except over 10 years old. Furthermore, vehicle emissions decreased significantly year by year during the scenarios because the vehicle population of 0-9 years old was increased. Therefore it is not good effective to apply new emission standard without decreasing vehicle population with over 10 years old.

Chapter 1. Background of this study

1.2 Overview of Ulaanbaatar, Mongolia

Mongolia is a landlocked country located between China and Russia. Mongolia is the world's 19th-largest country, its total land area is 1,564 million square kilometers (km^2). The most sparsely populated fully sovereign country in the world, with a population of around 3 million people. As of mid-2005, the total population of Mongolia was estimated at 2.6 million, with an annual growth rate of 1.5%. The country's population density is one of the lowest in the world, with only 1.5 persons/km^2. Its urban population, estimated at 60.2% of the total population, has increased by an average of 2.6% annually[1)].

About half of Mongolia is at an altitude of 1,400 meters (m) or more above mean sea level, which makes it one of the highest countries in the world. The altitude ranges from 560 m at the lowest point of Khokh Nuur in the eastern steppes to 4,374 m (the highest) at Khuiten Peak in the Altai Mountains. Average temperatures of Mongolia are below freezing from November through March and about freezing between April and October. The months of January and February have average temperatures of -20°C, with winter nights of -40°C. Ulaanbaatar has the lowest average temperature of any national capital in the world. It has an extreme continental climate with long, cold winters and short summers, during which most of its annual precipitation falls[1)].

Ulaanbaatar had an estimated 1.363 million residents as of 2015. The city is the center of Mongolia's political, economic, cultural, and educational activities. About half of all the residents live in apartment blocks. Of these, about 80% are supplied with central heating and hot water from three combined heat-and-power plants (CHP); 7% by heating boilers (275 of them in the city, with the majority connected to a centralized heating network); and 13% by individual stoves. The rest of the residents live in individual dwellings called ger (traditional tent dwelling), where coal and fuel-wood are used for heating. Ger areas are found on the outskirts of the city [1, 2)].

The main sectors of the Mongolian economy are mining, agriculture, and light industry. Its main export products are copper, gold and other minerals, cashmere products, meat, etc., while its main import products are oil, equipment and machinery, food, and consumer products. Mongolia has three primary sources of energy—traditional (biomass), conventional (fossil fuels, such as coal and oil), and alternative energy (mostly renewable). Coal is the most abundant fossil fuel and a highly utilized source of energy. Coal consumption is typically allocated to power stations (66%), heating in houses (21%), and ger areas (13%). A large amount of lignite coal is used as household fuel in Mongolia especially in the winter season. Lignite is the most abundant and cheapest fuel, it will remain as the main source of energy and heating in the future[1)].

Comparing the statistical data of 2015 with that of 2000, the total population of Ulaanbaatar city increased 1.8 times, the length of roads increased 1.6 times and number of vehicles increased 7.8 times. This data shows intensive growth of vehicles. Sixty percent of the motor vehicle fleet in Mongolia is found in Ulaanbaatar. For the vehicle and engine type, 76% of all vehicles are passenger car, 19% are trucks, 52% are vehicles with petrol engine and 27% are vehicle with diesel engine. For the manufactured country, 65% of all vehicles were manufactured in Japan and 60% are Toyota. It shows Mongolians prefer Japanese car. Most of these vehicles are second hand, about 72% of all vehicles passed more than 10 years, also for the vehicle type 71% of passenger cars, 80% of trucks, 73% of buses passed more than 10 years[2)]. In connection with living standard in Mongolia, the used cars are re-used. Public transportation in Ulaanbaatar and other urban centers is mainly by bus, microbus, (van), trolleybus, and taxis (Figure 1.1-1.6).

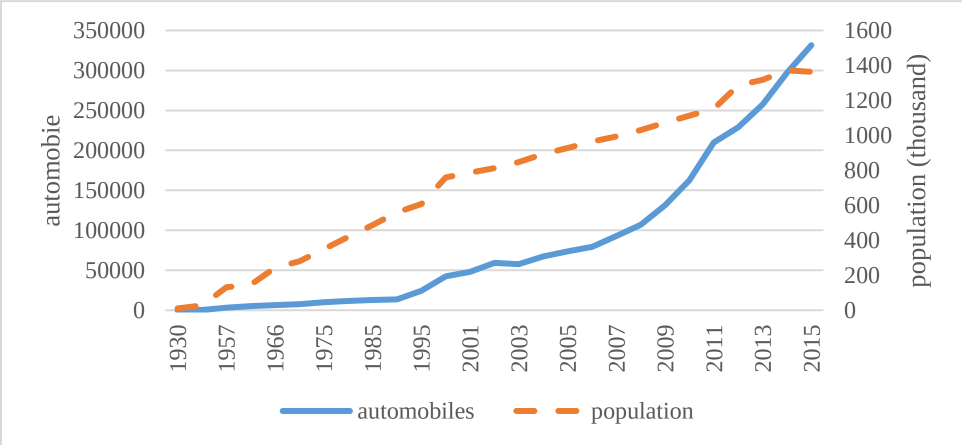


Figure 1.1 Growth of population and automobiles

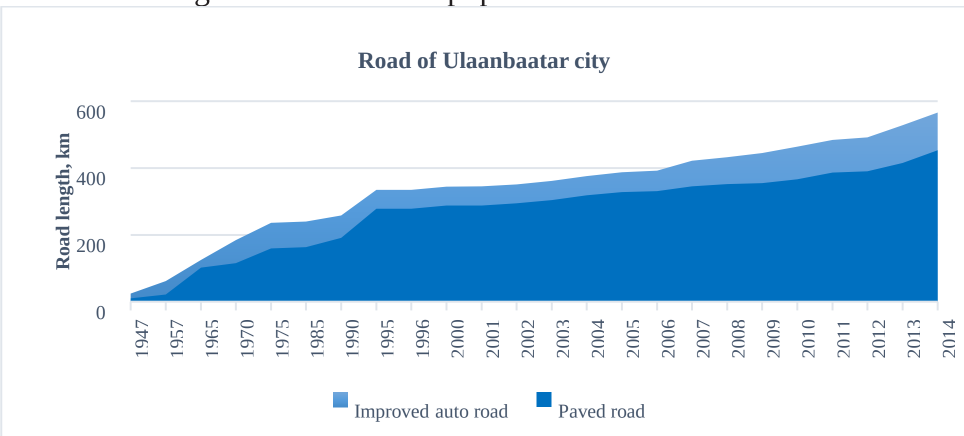


Figure 1.2 Growth of road length

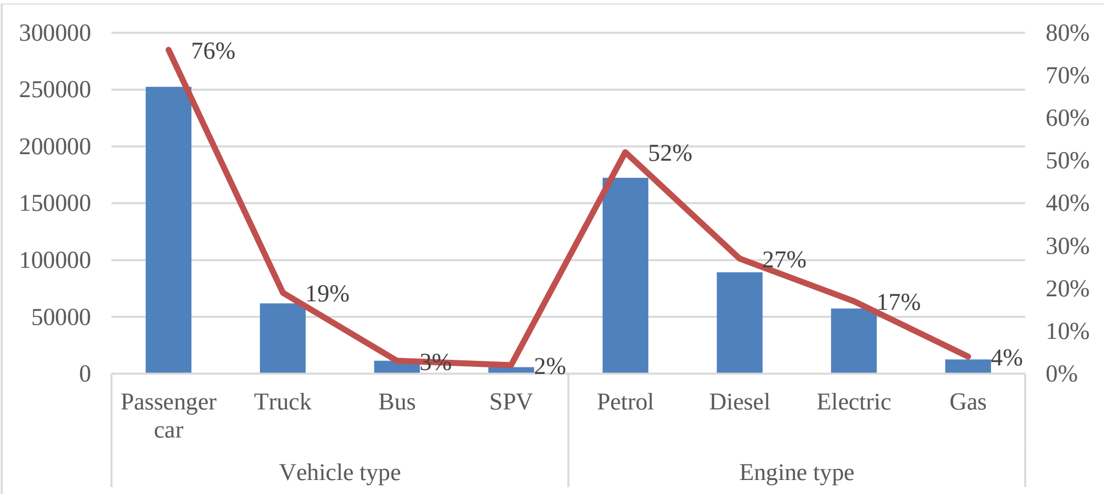


Figure 1.3 Vehicle and engine type

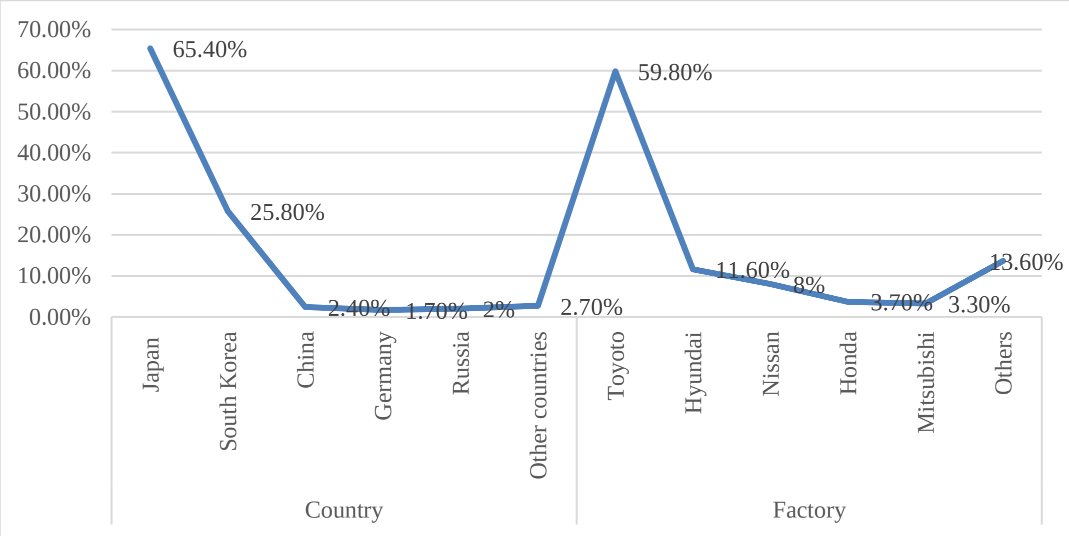


Figure 1.4 Manufactured country and factory

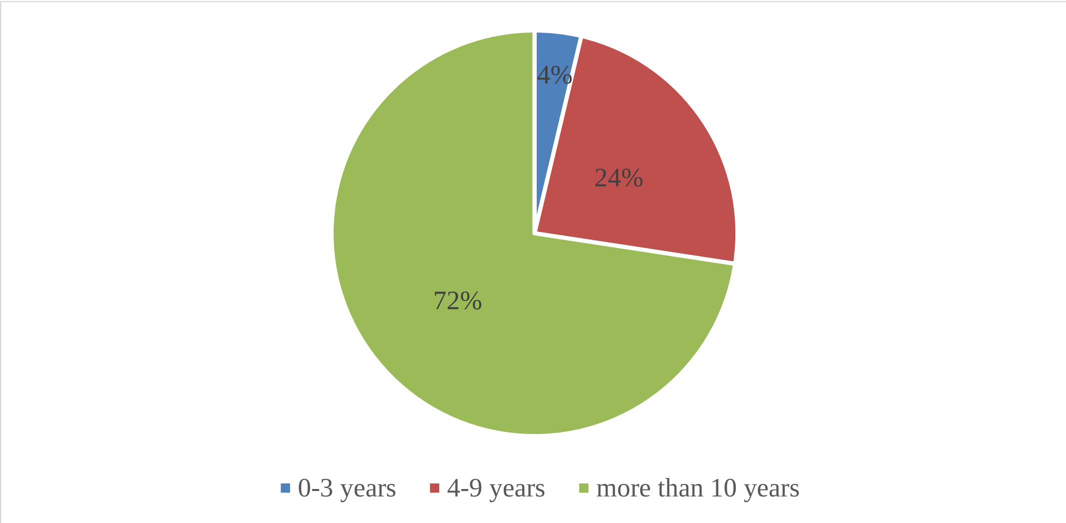


Figure 1.5 Average age of vehicles

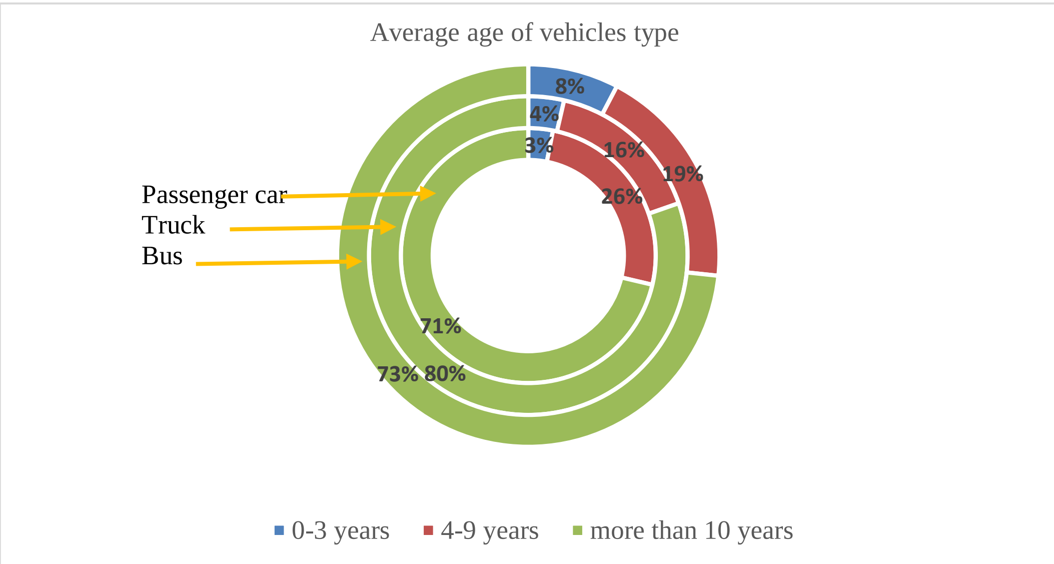


Figure 1.6 Vehicle age by type

1.2 Air pollution in Ulaanbaatar

Hundreds of millions of people currently live in areas with air pollution far higher than that thought to be "healthy" air. Of particular concern are the high levels of ozone, particulate matter (PM), carbon monoxide (CO), and air toxics that are ubiquitous in metropolitan areas worldwide. This pollution leads to increases in lung cancer, respiratory illness, and other chronic and acute toxic effects[3)].

Mongolia is a coal rich country with limited options for energy sources, heavily dependent on the coal which contains a great amount of water and ash resulting in dust-emitting characteristics. The major emission sources are coal combustion at the old 3 coal fired power plants (the Power Plant No.4, No.3 and No.2) for power and heat generation, about 200 Heat Only Boilers (hereinafter HOBs), about 1,000 small boilers such as Coal Fired Water Heaters (hereinafter CFWHs), numerous traditional stoves and wall stoves at more than 130,000 families at Ger areas. In addition to the coal combustion, increasing vehicle emissions, wind-blown dust from ash ponds of the power plants and other fugitive sources are also contributing to the severe air pollution. In recent years, traffic congestion and emission have increased dramatically due to population density and economic development in Ulaanbaatar[4)].

There are 12 ambient air quality monitoring stations in Ulaanbaatar City. These stations have been measuring ambient concentrations regularly. It measures every 5-30 minutes for 24 hours continuously. Data is processed and transmitted. Also there is wireless and data logger which collects all data for 6 months[4)].

The air pollution at Ulaanbaatar city has been severe, especially in the winter season. Major pollutants have been particulate matters including dust, PM_{10} and $PM_{2.5}$. According to National Agency for Meteorology and Environment Monitoring of Mongolia, the highest monthly average value of PM_{10} ambient concentration showed as much as 1,000 $\mu g/m^3$ during the winter in 2011 and all monitoring sites showed high concentration of PM_{10} exceeding the Mongolian ambient air quality standards (MNS) posing serious health risks on the citizens. PM concentration of MNS is 2 times higher than The World Health Organization guideline (WHO). The average annual value of contaminators is generally decreasing but it is still higher than the MNS. Also other parameters such as SO_2 and NO_2 are problematic throughout the year, occasionally exceeding the MNS. The average monthly value of contaminators is decreasing in summer but NO_2 does not change. It is related to traffic emission[4)] (Figure 1.7-1.9).

Figure 1.7 Air pollution same point in different season

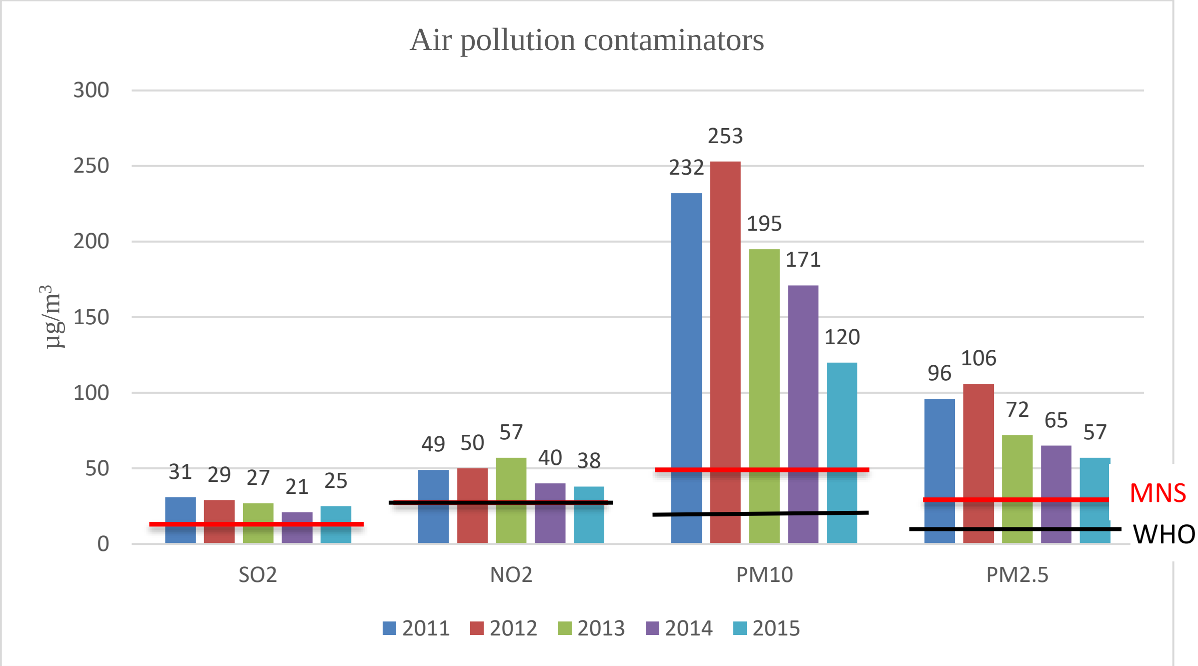


Figure 1.8 Average year concentration of contaminators

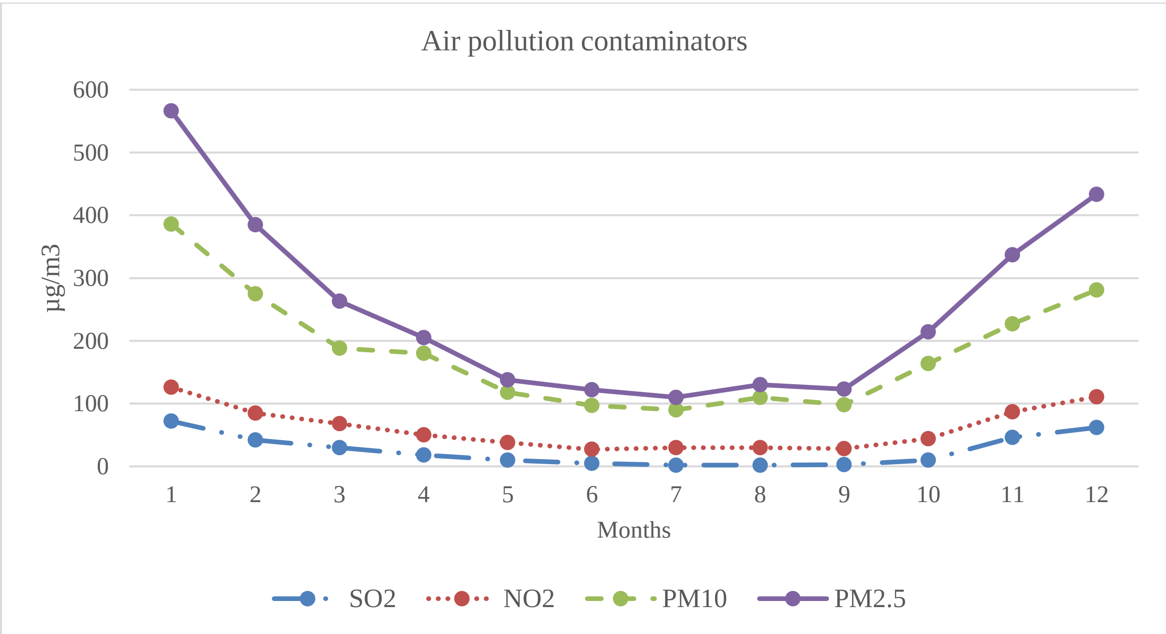


Figure 1.9 Average monthly concentration of contaminators (2015)

1.3 Mobile sources on air pollution

Owing to their rapidly increasing numbers and very limited use of emission control technologies, motor vehicles are emerging as the largest source of urban air pollution in the developing world. Epidemiological studies show that air pollution in developing countries accounts for tens of thousands of excess deaths and billions of dollars in medical costs and lost productivity every year. Without timely and effective measures to mitigate the adverse impacts of motor vehicle use, the living environment in the cities of the developing world will continue to deteriorate and become increasingly unbearable[5)].

With high emission sources the path from emission to deposition is very long: hence, air pollutants are diluted before they reach their final destination where they take effect. A high source altitude also permits dispersion of the pollutants over a large area. With low source altitudes, e.g., automobile emissions, air pollutants can reach the human respiratory system by the shortest route[6)].

Pollution intake is also determined by the number of people in polluted areas, how long they stay there and what they do. Time–activity patterns, particularly residence or work near busy roads (or both), and time spent in traffic are critical for population exposure. In-vehicle exposures are especially high for primary exhaust gases and PM. Groups with high levels of exposure include people who live near busy roads or who ventilate their residences with air from road canyons with heavy traffic, road users (such as drivers, commuters and pedestrians) and people whose jobs require them to spend a long time on the roads. The epidemiological and toxicological evidence on the effects of transport-related air pollution on health has increased substantially in recent decades. The transport-related air pollution affects a number of health outcomes, including mortality, non-allergic respiratory morbidity, allergic illness and symptoms (such as asthma), cardiovascular morbidity, cancer, pregnancy, birth outcomes and male fertility. Transport-related air pollution increases the risk of death, particularly from cardiopulmonary causes, and of non-allergic respiratory symptoms and disease. Though only a few studies have been conducted, a significant increase in the risk of heart attack (myocardial infarction) following exposure to transport-related air pollution has been reported. Other studies and the experimental evidence indicate changes in autonomic nervous system regulation and increased inflammatory responses, as a result of exposure. Cancer, too, is a problem. A few studies suggest an increased incidence of lung cancer in people exposed to transport-related air pollution for long time[7)].

An air pollution survey in 2004 conducted by the Municipal Professional Inspection group in Ulaanbaatar investigated the occurrence of respiratory disease in the population by age and has correlated this with ambient concentrations of NO_x and SO_2. The highest correlation was observed for the occurrence of asthma for people between ages 25 and 64 and bronchitis for infants less than a year old. The study conducted by WHO reported a strong statistical link between air pollution and respiratory disease requiring hospitalization among children in Ulaanbaatar and Tungkhel areas in 2002. Two studies conducted in 1996 and 2001 also reported the negative impact of air pollution on the physical growth of children (World Bank 2004)[1)].

Vehicle emission depends on three main factors as vehicle age, road condition, and vehicle fuel quality in Mongolia.

The most vehicles are second hand in Mongolia, about 72% of all vehicles passed more than 10 years. The used cars are re-used because of living standard. Before 2006, there was no tariff rate on passenger cars in Mongolia, and there was no limit to the vehicle age. According to the Excise Tax Law of June 24, 2006, the vehicle age classified as 0-3 years, 4-6 years, 7-9 years, and over 10 years, had been subject to tax rate on the every age classification and a high tax rate on the old cars with over 10 years. Hybrid, electric and gas-operated cars had been exempt from excise tax, according to the law changes on Feb. 24, 2010. It was a positive decision to public use of the automobile for dominating hybrids. However, since no age limit has been set, 15-20 year old hybrids and gas operated cars had been imported. The vehicle excise tax rate was increased, and Hybrid, electric, gas-operated cars had been charged an excise tax, according to the law changes in 2017. One thing that is not regulated by these changes, an excise tax of the trucks and buses was not classified to their age. That is why, too old trucks and buses are imported (Law on excise tax in Mongolia).

Most of countries have two regulations which are exhaust gas regulation by inspection agency and exhaust gas regulation for new vehicles. On the other hand, complementary regulations in Mongolia have high tariff rate for vehicles of 10 years and older, and use prohibition of vehicles for public transportation of 12 years and older. However, exhaust gas regulation for new vehicles in Mongolia does not exist. As the result of law framework, even though new vehicles of heavy duty bus were imported for public transportation from 2009, most of them were selected high emission engines[4)].

Comparing the statistical data of 2015 with that of 2000, the total length of roads increased 1.6 times and number of vehicles increased 7.8 times. As a result, the auto-road traffic and related congestion has intensified.

70% of vehicles on the road is locked traffic congestion in Ulaanbaatar. In order to reduce road traffic, the decision to restrict cars from the state number began in 2012. To evaluate this decision, researchers made mathematical and computer models to compare statistical data on the traffic congestion rates. As a result, there was no difference before and after decision, so traffic congestion was not decreased. It is better to restrict cars, depending on traffic census per week and traffic conditions[8)].

Sulphur content of supplied fuel in Ulaanbaatar city is approximately 200 ppm for gasoline and 1200 ppm for diesel. On the other hand, in Japan, Europe, and U.S.A, low sulphur fuel supply such as 50 ppm (Euro 4) or 10 ppm (Euro 5) is indispensable to ensure function of emission reduction system[4)]. High sulphur content fuel decreases the catalytic conversion capacity of a system, thus increasing the emissions.

There are 2 ambient air quality monitoring stations near to road side as UB2, UB4. Particulate matter (PM_{10}, $PM_{2.5}$), sulphur dioxides (SO_2) and nitrogen dioxides (NO_2) concentrations on the roadsides of Ulaanbaatar are 2 to 2.5 times higher than the MNS, 2-6.3 times higher than the WHO. As shown in Table 1.1, NO_2 exceeds the MNS at roadside monitoring stations over the whole year and on 93-95% of all measuring days. SO_2, PM_{10}, $PM_{2.5}$ exceed the MNS at roadside monitoring stations on 37-51% of all measuring days. As shown in Table 1.2, Figure 1.10 and 1.11, the monthly average concentration of NO_2 exceeds the MNS and WHO over the whole year. The other pollutants SO_2 and PM concentrations also peak during the colder season. The monthly average concentrations of PM_{10} exceeds the WHO whole year[4)].

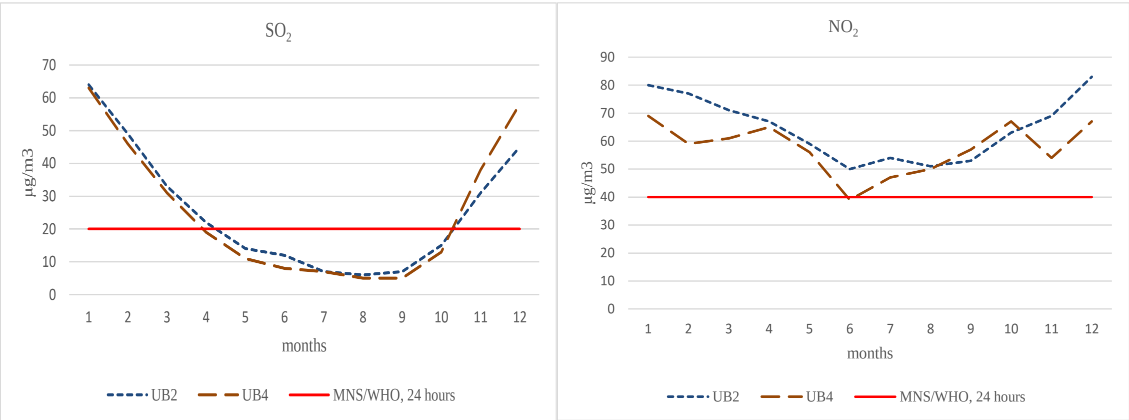


Figure 1.10 Monthly SO_2 and NO_2 on the roadside

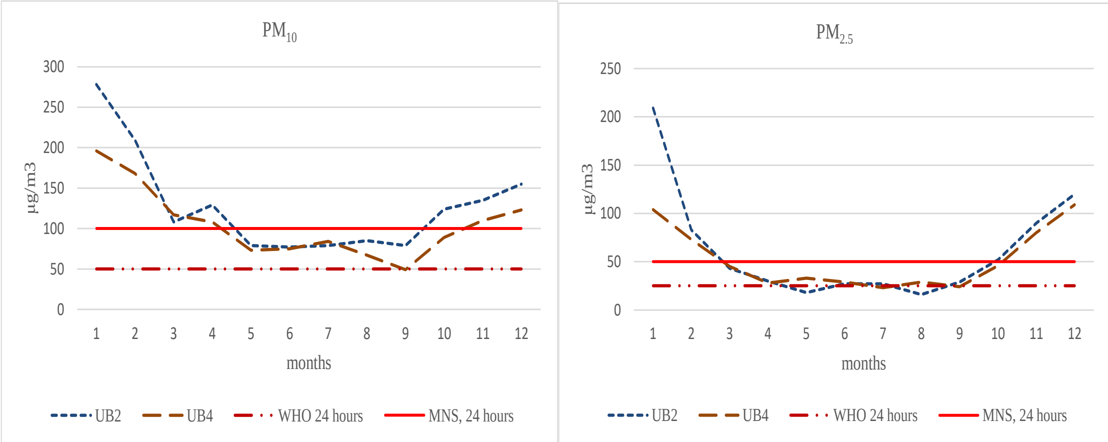


Figure 1.11 Monthly PM on the roadside

Table 1.1 Air quality on the roadside

Air quality standard										
Pollutant, µg/m³			SO_2		NO_2		PM_{10}		$PM_{2.5}$	
WHO		24 hours	20		40		50		25	
		1 year	-		-		20		10	
MNS		24 hours	20		40		100		50	
		1 year	10		30		50		25	
Air quality monitoring station										
Data 2015			UB2				UB4			
		Unit	SO_2	NO_2	PM_{10}	$PM_{2.5}$	SO_2	NO_2	PM_{10}	$PM_{2.5}$
Average concentration of year		µg/m³	25	65	124	63	27	58	106	53
Average concentration of 24 hours	Maximum concentration	µg/m³	97	118	546	436	148	124	398	284
	Measurements day	days	344	342	342	337	333	349	332	343
	Exceeded (MNS)	days	159	326	173	126	147	323	138	133
		%	46	95	51	37	44	93	42	39

Table 1.2 Monthly air quality on the roadside (2015)

Pollutant, µg/m³	Months	1	2	3	4	5	6	7	8	9	10	11	12
SO_2	UB2	64	49	33	22	14	12	7	6	7	15	31	45
	UB4	63	46	31	19	11	8	7	5	5	13	38	58
NO_2	UB2	80	77	71	67	59	50	54	51	53	63	69	83
	UB4	69	59	61	65	56	39	47	50	57	67	54	67
PM_{10}	UB2	278	209	108	129	79	77	79	85	79	124	135	155
	UB4	196	168	117	108	73	75	84	67	49	89	110	123
$PM_{2.5}$	UB2	209	83	43	30	18	27	27	16	29	52	90	120
	UB4	104	73	45	28	33	29	23	29	24	46	80	109

1.4 Existing studies

Some similar studies are mentioned.

Sulphur dioxide emitted by thermal power plants and from transport in Kosovo is transported via prevailing winds to other locations. Through its journey, this SO_2 gas undergoes a series of chemical reactions that ultimately transform it into sulphuric acid (H_2SO_4) which is deposited as acid rain. As a consequence of NO_2 emissions from electricity production and transport in Kosovo, the ozone (O_3) is formed as photochemical smog due to sunlight, which triggers the breakdown of NO_2. They modeled the impact of SO_2 and NO_2 emissions from energy system and transport in Kosovo on acid deposition and chemical smog locally. In model they consider the role of SO_2 and NO_2 pollution control technologies on mitigating these impacts[9)].

This paper takes the urban transport in Beijing as a case and builds a system dynamics model for analysis of the motorization trend and the assessment of CO_2 emissions mitigation policy. It is found that the urban transport condition and CO_2 emissions would be more serious with the growth of vehicle ownership and travel demand. Compared with the baseline do-nothing scenario, the CO_2 emissions could be reduced from 3.8% to 24.3% in 2020 by various transport policies[10)].

Hanoi is one of the largest cities in Vietnam, now is facing with the serious air pollution problems which is mainly contributed by transport vehicles. In this paper, they used the dynamics model to build an age-cohorts model to estimate and predict the emissions from vehicle fleet of Hanoi by the year 2040 as well as assess the effectiveness of the management measures. The results shows that motorcycles is the main traffic air pollution source of Hanoi, accounting for 98% CO emissions, 75% NO_x emissions, 81% PM emissions and 98% HC emissions. Among that, the motorcycles at the age from 3 to 9 years is the largest contributors with 57,72% CO emission, 58,5% HC emission, 62,53% NO_x emission, and 54,29% PM emission. It's estimated that, up to the year 2040, motorcycles still is the majority emission source, with a proportion of about 89% CO, 63% NO_x, and 69% PM emissions[11)].

Combustion particles from marine engines are complex mixtures of organic compounds, soot, sulphate, metals and other inorganic species. Their composition and abundance are determined both by fuel and engine characteristics. Health risks from particles are thought to be related to the size of particles and chemical composition of particles which makes particle mass a coarse parameter for indication of how harmful emissions are. This article presents emission measurements conducted on board two ships with a focus on comparing number concentrations of ultrafine particles (Dp\100 nm) in diluted exhaust for three different fuel qualities[12)].

Based on the request by the Government of Mongolia, the Government of Japan provided technical assistance through JICA 'Capacity Development Project for Air Pollution Control in Ulaanbaatar City' phase 1 during 2010 to 2013, phase 2 during 2013 to 2017, which focused on the capacity development of the Air Quality Department of Capital City and other relevant agencies at city and national level especially to control the emission sources. Within this project, the dispersion simulation model of ISC-ST3 and CALPUFF which include all sources of air pollution in Ulaanbaatar was implemented. Also, they developed all sources inventory for this dispersion simulation models. JICA Experts thought that in ISC-ST3 model used in the past cannot consider the secondary generating process, and decided to build an air dispersion simulation model by CALPUFF that can partially consider the secondary generating process. CALPUFF is the model developed by Scire etc. in 1995 to correspond to advection and dispersion of the pollutant by non-steady-state change in an air current in a maritime area and complex geometry. In an air current field generated by three dimension air flow model, the advective dispersion calculation of pollutant is implemented by the advective puff[4)].

This paper describes results of the research on particulate emissions from direct-injection common- rail (DI CR) diesel vehicle fuelled with research fuels of differing sulphur content. The sulphur content of the research fuels varied from 2000 ppm through 350 ppm (EURO III) and 50 ppm (EURO IV limit, which will be in force in the European Community from 1 January 2005) up to less than 5 ppm. The experiment was undertaken on a passenger car with a high-speed, four-cylinder turbocharged, latest technology diesel engine with swept volume of about 2 dm^3. The experiments confirmed the distinct influence of sulphur content in diesel fuel on particulate emissions[13)].

The aim of this work is to evaluate the performance of a gasoline engine using different fuel blends of propanol/gasoline. Set of laboratory tests were carried out to investigate the engine performance using four-stroke petrol engine under different operating conditions. The influence of various fuel blends of propanol/gasoline on the engine fuel consumption and its pollutants emission was investigated. The engine maps (fuel consumption & emissions) were used in vehicle simulation code so that the road vehicle performance within the cities according to a standard driving cycle could be determined. The results indicated that the use of propanol/gasoline fuel blend can improve the fuel economy by 2.84% for the blend ratio (propanol/gasoline 15%). Moreover, it decreases the pollutants emission of vehicle engine, especially hydrocarbon, carbon monoxide by 14.18% and 10.87% respectively. Also, the simulation results indicated that the vehicle fuel consumption is improved and the pollutants emissions of for carbon monoxide and hydrocarbon are decreased[14)].

Chapter 2. Objective and methodology

2.1 Objective

Air quality and air pollution control are tasks of international concern as, for one, air pollutants do not refrain from crossing borders and, for another, industrial plants and motor vehicles which emit air pollutants are in widespread use today. In a number of the world's expanding cities smog situations are a frequent occurrence due to the number and emission-intensity of air pollution sources. Polluted air causes annoyances, when it occurs in high concentrations in these cities, constitute a serious health hazard. How important clean air is to life becomes apparent when considering the fact that humans can do without food for up to 40 days, without air, however, only a few minutes[6)].

It becomes necessary to make use of all the scientific tools available for the management of the atmospheric environment. One of these tools is the air pollutant emission inventory. What quantities of air pollutants are emitted and where do they come from? The best way to answer these questions is to prepare an air pollutant emission inventory. Emission inventories are now regarded as indispensable tools for a wide range of environmental measures such as management of chemicals as well as the prevention of air pollution. The quantitative emissions estimates provided by an inventory promote a better understanding of the actual emissions and help to raise the awareness of both policy makers and general public. A current emission inventory can be used as the basis for estimating future emissions according to projected likely changes in socio-economic indices (e.g. population growth, changes in energy use per unit activity), lower emission factors, fuel switching and so forth. It will be important information for air quality management decision-making. Estimated future emissions provide important information for setting emissions targets[15)]. An accurate and comprehensive emission inventory helps governments to make quantitative assessments of the source contributions to air quality, adopt effective strategies with regard to air pollution, develop and implement effective policies that reduce emissions and enables them to plan cost-effective strategies.

The purpose of this study was to estimate vehicle emission, define future emission, and assess effectiveness of some countermeasures. For that, the vehicle emission inventory in main road was prepared then the vehicle emission prediction model was developed based on it. Vehicle emission prediction model can be used emission calculation and management evaluation of countermeasures for policymakers and researchers.

2.2 Methodology

In order to demonstrate how vehicle emission affects air pollution, it is estimated that how much toxic emissions are emitted into the air.

The emission inventory from main roads was prepared, the vehicle emission prediction model was developed and the effectiveness of some countermeasures as applying the new gas exhaust standard and using fuel additives was assessed. Then, the results obtained in real situations (current situation) with those in the scenario in which fuel additive was used and the Euro 4, Euro 5 vehicle emission standard was applied, were compared (Figure 2.1).

Based on the available data, vehicle emissions were estimated using two approaches: First one, emissions were directly calculated in the parameters related to traffic census, road length, emission factors. There is not vehicle detecting camera at every road intersection in Ulaanbaatar. These cameras count traffic census. Only 24 vehicle detecting cameras are along the main road. Also, they have portable traffic census counter and they used it another 26 points along the main road. So this traffic census data in 50 points along the main road was used to estimate vehicle emission in the main road. This approach is more realistic to road situations but it can only estimate main roads emission, not total vehicle emission.

The second one calculated the total sum of the aggregate emissions as using vehicle population statistical data, average annual km traveled by a vehicle (VKT), and emission factor. There is not detailed research work of the data of VKT. The VKT data of Capacity development project for Air pollution control in Ulaanbaatar city report was used this study. They could collect the VKT public transport, but guessed VKT of passenger cars.

The vehicle emission prediction model was developed from 2015 to 2040, using system dynamics which is a methodology for studying and managing complex systems that change over time. System dynamics models are policy tools that examine the behavior of key variables over time. Historical data and performance goals provide baselines for determining whether a particular policy generates behavior of key variables that are better or worse when compared to the baseline or other policies. The emission prediction was divided 2 parts as emission component and prediction of vehicle population. The vehicle average exponential growth and scrapped rate from 2007 to 2015 was used prediction of vehicle population.

Finally, the countermeasures of the reducing vehicle emissions were compared. The emission factor data of Euro 4 and Euro 5 in European environmental Agency Air pollutant emission inventory guidebook 2016 was used to countermeasures of vehicle emission.

The emission factor measurement on Lubricon A112M fuel additive was conducted first time in Mongolia. Also, this EF measurement result was used to countermeasures.

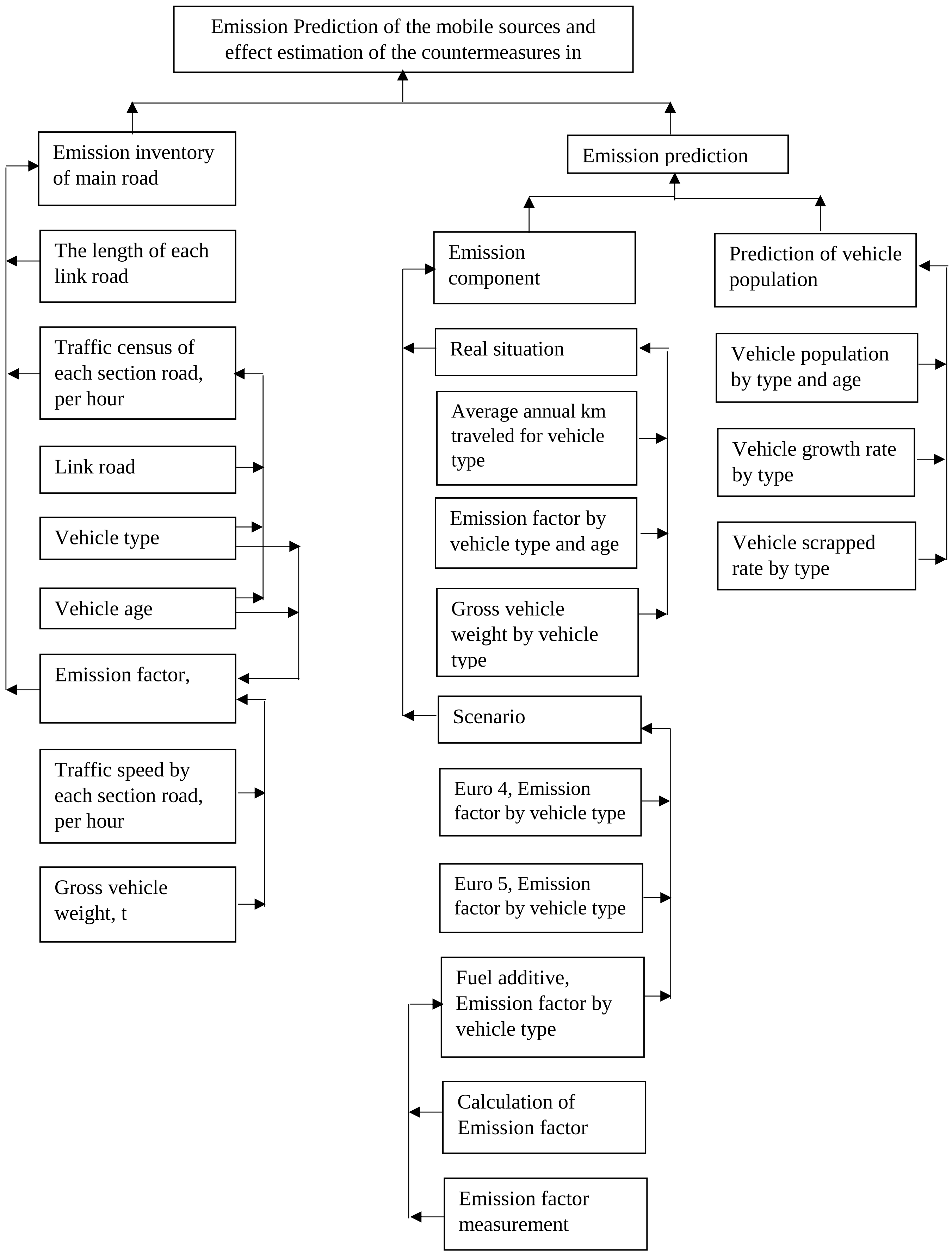


Figure 2.1 Methodology structure

Chapter 3. Emission inventory of vehicles in main road

3.1 Introduction

An emissions inventory is a database that lists, by source, the amount of air pollutants discharged into the atmosphere during a year or other time period. Emissions inventories are an essential input to mathematical models that estimate air quality. The effect on air quality of potential regulatory actions can be predicted by applying estimated emissions reductions to emissions inventory data in air quality models[16)]. An emission inventory of road mobile source is an accounting of the amount of vehicle emission.

The quantitative emissions estimates provided by an inventory promote a better understanding of the actual emissions and help to raise the awareness of both policy makers and the general public. Through this process, the major emission sources can be identified, priorities for emission reduction defined and any data gaps requiring further work are revealed[15)].

The purpose of the research is to determine and estimate total exhaust of air–polluting substances to be emitted from auto mobiles which pass by main roads of Ulaanbaatar city on the basis data of 2015.

3.2 Method

The purpose of this study was to find out how much vehicle emission emitted from main road. And what is the reason? This is an important question because people consider that the main reason of air pollution is coal fuel, therefore, they don't care about the mobile sources in Mongolia. It is true but the second reason is the mobile source. Therefore, it is needed to pay attention to the second source of air pollution. Also, currently there has not been calculation of mobile sources of air pollution based on measured emission factor yet.

The vehicle emission in main road was calculated in weekday and weekend. Then annual total emission was estimated. Currently, the emission factor measurement of NO_x and PM was conducted, this research data was used. The emission from main road was calculated by multiplying hourly traffic census by vehicle type to emission factor by travel speed and the road section length. The vehicle emission depends on traffic speed. Data such as length of the roads, traffic census, average speed, age of auto mobiles, emission factor were used in order to estimate overall emission (Figure 3.1). Microsoft excel was used for this calculation. This formula is following[4)]:

$$\boldsymbol{Q = \sum (EF * Cnt * Len)}$$

Q	Emission (g)
EF	Emission Factor (g/km, g/km/t)
Cnt	Traffic census of each road Section
Len	Road Section Length (km)

$$\boldsymbol{EF = f(m, v)}$$

f	Function (depending on Emission Factor)
m	Vehicle emission (g/km, g/km/t)
v	Traffic Speed (km/h)

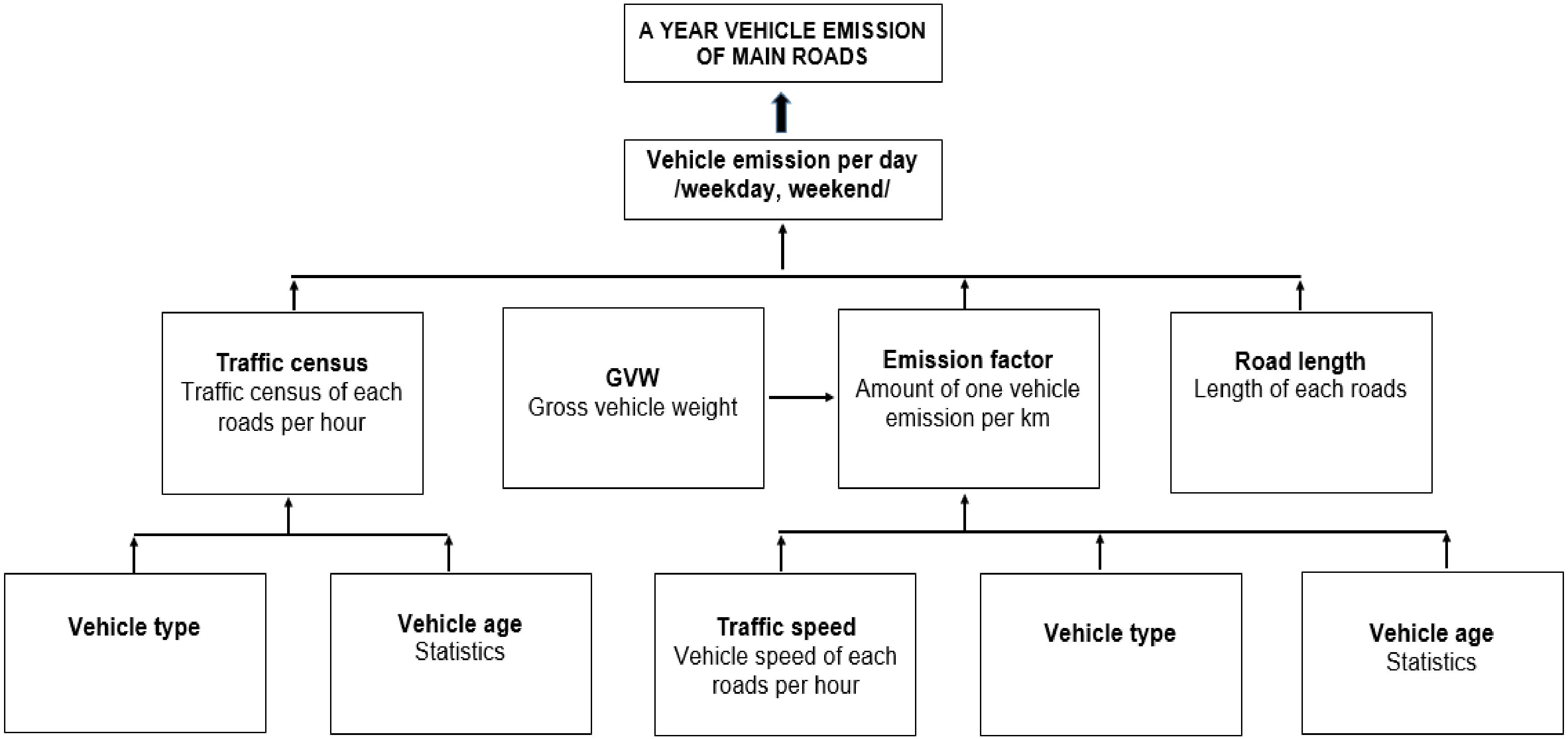


Figure 3.1 Study methodology

Vehicle emissions are affected by driving patterns, traffic speed and congestion, altitude, temperature, and other ambient conditions; by the type, size, age, and condition of the vehicle's engine; and, most importantly, by the emissions control equipment and its maintenance[17)].

3.2.1 Traffic census

Traffic census data was required to classify by hour, vehicle type and vehicle age. The Ulaanbaatar city traffic control center has 24 vehicle detecting cameras and also one portable counter. The vehicle detecting cameras are permanent operation, but their data is not full because of routine maintenance. All of vehicle detecting cameras data is not full of 365 days. The portable counter counts traffic census quarterly in the roads without vehicle detecting system (VDS). That is why the data of only weekday and weekend was chosen. The data of traffic census and traffic speed was selected from two sources as VDS and Portable counter. VDS was positioned in 24 points of Ulaanbaatar and portable counters were positioned in 26 points, so the main road was divided 50 link roads. But the vehicle type was not regarded, there was an only total number of vehicles[18)]. Therefore, it required to estimate vehicle type on all points. There was also one research of traffic intensity and speed in 2010 which used to estimate vehicle type[19)].

This study covered 50 link roads (50 points) which means 100 section roads (with counter-flow line). It means that the main road was divided by link road following the every traffic census counter (VDS, portable counter) (Table 3.2, 3.3).

It was possible to take data of weekday and weekend from VDS but it was not for the portable counter. That is why only weekday data from a portable counter was taken.

Vehicle type was divided 7 classification: Passenger cars were divided small car and large car. The large car included as microbus, jeep, Van. The trolleybus is a public transport vehicle with rubber tyres that is driven by electricity supplied from a wire above the road. Also, trucks were divided by their gross vehicle weight (GVW). If GVW is more than 3 ton, it is the large truck. If GVW is less than 3 ton, it is the small truck. Others included motorcycle, bicycle etc. (Table 3.1).

Every road has ID as r1.1 and r2.1 which direct west to east (→) or north to south (↓). The road r1.2 and r2.2 etc. which direct east to west (←) or south to north (↑), are counter-flow line. The traffic speed and traffic census is showed every hour. VDS's points are near to city center and portable's points are little far from city center. There is not enough electricity wire for trolleybus above the roads. That is why the trolleybus traffic is few. Also, it depends on the weather condition usually people do not use motorcycle and bicycle, so this kind of traffic is few. The large trucks are prohibited from driving on the road in the city center (Table 3.4, Figure 3.2).

Table 3.1 Vehicle type

Vehicle type	Vehicle type ID
Small car (passenger car)	1
Large car (microbus, jeep, van)	2
Trolleybus	3
Bus	4
Small truck (GVW ≤ 3 ton)	5
Large truck (GVW > 3 ton)	6
Others (motorcycle, bicycle)	7

Table 3.2 Traffic census counter

Counter	Road ID	Counting points
VDS	r1.1 - r24.2	24
Portable counter	p1.1 – p20.2	16
	L3.1 – L28.2	10

Table 3.3 The weekday traffic census data of r1.1 road

Time	Vehicle speed km/h	Traffic census vehicles	Vehicle type ID						
			1	*2*	*3*	*4*	*5*	*6*	*7*
00~01	31	322	233	65	0	19	3	1	0
01~02	28	288	200	80	0	5	2	0	0
02~03	38	261	185	65	0	7	5	0	0
03~04	35	254	175	70	0	6	3	0	0
04~05	36	280	193	70	0	7	9	0	1
05~06	41	245	170	62	0	5	7	0	0
06~07	30	247	167	66	0	4	9	0	0
07~08	26	282	246	19	0	6	10	0	1
08~09	24	417	263	144	0	7	3	1	0
09~10	17	645	450	177	0	9	8	1	0
10~11	26	754	549	186	0	16	4	0	0
11~12	33	1123	753	348	0	17	6	0	0
12~13	18	1146	936	185	0	15	10	0	0
13~14	12	1213	896	258	0	29	24	5	0
14~15	13	1117	818	286	0	3	10	0	0
15~16	16	1090	848	212	0	7	13	0	10
16~17	18	1091	879	193	0	0	19	0	0
17~18	13	883	776	101	0	0	6	0	0
18~19	11	628	544	85	0	0	0	0	0
19~20	13	560	508	52	0	0	0	0	0
20~21	32	534	445	89	0	0	0	0	0
21~22	31	433	365	68	0	0	0	0	0
22~23	29	402	256	146	0	0	0	0	0
23~00	25	327	297	20	0	0	10	0	0
Total		14539	11153	3045	0	160	162	8	12

Table 3.4 Traffic census by roads

№	Street name	Road	Road length, km	Road ID	Day	Total traffic census a day	Vehicle type						
							1	*2*	*3*	*4*	*5*	*6*	*7*
1	Zaluuchuud avenue	National Museum of Natural history ↔ Mongolian University of Science and Technology	0.55	r1.1	weekday	17027	12981	3639	0	197	189	11	11
					weekend	14539	11153	3045	0	160	162	8	12
				r1.2	weekday	17765	13464	3862	0	260	143	26	10
					weekend	15604	11945	3307	0	206	115	23	8
2		Mongolian University of Science and Technology ↔ Sansar tunnel	1.41	r2.1	weekday	13256	10332	2630	0	135	144	6	9
					weekend	12727	9894	2552	0	130	137	5	10
				r2.2	weekday	16613	12525	3665	0	254	139	20	11
					weekend	13928	10604	3002	0	189	108	18	7
3	Ikh Surguuli street	Central tower ↔ Ulzii center	1.02	r3.1	weekday	11695	8538	2812	0	207	111	8	19
					weekend	10525	7827	2399	0	183	92	7	17
				r3.2	weekday	10406	7941	2272	0	145	28	9	11
					weekend	10572	8090	2283	0	151	27	11	10
4		Baruun 4 zam ↔ Geser temple	0.82	r4.1	weekday	16441	12424	2903	0	336	592	176	10
					weekend	15726	12661	2283	0	242	414	118	9
				r4.2	weekday	14304	11102	2212	0	404	430	114	42
					weekend	14377	11351	2235	0	300	364	104	24
5		Geser temple ↔ Nogoon nuur circle	0.8	r5.1	weekday	11522	8690	2073	0	243	410	98	9
					weekend	10170	8061	1565	0	178	289	73	4
				r5.2	weekday	9991	7689	1611	0	301	303	62	26
					weekend	9393	7315	1526	0	218	255	64	14
6		Khurd Co., Ltd ↔ Nogoon nuur circle	0.93	r6.1	weekday	15907	11684	3106	0	396	586	130	4
					weekend	14428	10544	2873	0	357	531	120	4
				r6.2	weekday	18975	13992	3857	0	529	388	206	3
					weekend	18096	13194	3783	0	535	401	180	3

№		Road	Road length, km	Road ID	Day	Total traffic census a day	Vehicle type						
							1	*2*	*3*	*4*	*5*	*6*	*7*
7		100 ail intersection ↔ Khurd Co., LTD	0.76	r7.1	weekday	16180	11576	3361	0	467	638	132	6
					weekend	14420	10326	3004	0	399	564	122	5
				r7.2	weekday	17458	12456	3788	0	587	450	172	4
					weekend	17045	12109	3750	0	588	434	161	4
8		100 ail intersection ↔ Sansar NIK fuel station	1.12	r8.1	weekday	14200	10221	2920	0	383	548	123	5
					weekend	14349	10331	2964	0	379	551	122	5
				r8.2	weekday	16788	12068	3616	0	545	400	154	4
					weekend	17846	12746	3905	0	594	447	151	4
9		Sansar NIK fuel station) ↔ Zuun 4 zam	0.92	r9.1	weekday	24016	17874	4473	0	542	911	209	7
					weekend	19543	14549	3667	0	430	725	168	5
				r9.2	weekday	12526	8859	2764	0	433	349	117	4
					weekend	12177	8583	2718	0	424	343	106	3
10	Sukhbaatar street	Khurd Co., Ltd ↔ National Museum of Natural history	0.73	r10.1	weekday	19310	14169	4938	0	6	122	31	44
					weekend	13255	9902	3229	0	39	70	2	13
				r10.2	weekday	12426	9013	3219	0	63	80	35	16
					weekend	11132	7899	3043	0	98	65	16	9
11		National Museum of Natural history ↔ Central Post office	0.6	r11.1	weekday	10521	7744	2682	0	4	61	15	16
					weekend	10399	7737	2556	0	32	62	2	10
				r11.2	weekday	15548	11343	3955	0	84	104	41	20
					weekend	13355	9512	3604	0	134	79	18	8
12	Sambuu street	National Museum of Natural ↔ Geser temple	1.07	r12.1	weekday	8468	6492	1763	0	98	104	4	6
					weekend	7782	5954	1624	0	94	101	4	7
				r.12.2	weekday	8957	6820	1939	0	111	69	14	4
					weekend	8416	6400	1826	0	106	67	13	4
13	Enebish street	Nogoon nuur circle ↔ Ekh nyalkhas	1.22	r13.1	weekday	17634	11772	4448	0	240	950	199	23
					weekend	15222	10144	3851	0	215	821	171	20
				r13.2	weekday	15334	11118	2995	0	212	800	189	20
					weekend	13786	9925	2742	0	199	730	173	18

№		Road	Road length, km	Road ID	Day	Total traffic census a day	Vehicle type						
							1	*2*	*3*	*4*	*5*	*6*	*7*
14z	Peace avenue	Tsamba Garav center ↔ Sapporo circle	0.71	r14.1	weekday	22677	14577	5165	1	813	1153	948	21
					weekend	22036	14621	4871	0	714	1177	643	11
				r14.2	weekday	25719	17709	5434	3	880	1029	634	31
					weekend	23466	15722	5451	2	729	1072	479	11
15		Sapporo circle ↔ Material Impex	1.62	r15.1	weekday	21241	16558	3317	2	688	490	169	18
					weekend	19758	15420	3092	1	631	440	156	18
				r15.2	weekday	24150	18988	3429	2	756	717	231	27
					weekend	21711	17119	3061	2	650	636	220	22
16		Material Impex → Baruun 4 zam	1.09	r16.1	weekday	11739	9270	1780	0	337	247	96	9
					weekend	10453	8206	1623	1	310	223	83	9
				r16.2	weekday	14648	11805	1898	1	391	408	131	14
					weekend	12193	9805	1601	1	322	340	113	11
17		Baruun 4 zam ↔ Erel Insurance	1.57	r17.1	weekday	22240	16571	4742	80	653	134	26	34
					weekend	23445	17622	4881	83	661	135	28	35
				r17.2	weekday	21278	15494	4756	116	762	65	38	46
					weekend	20584	15117	4498	112	720	58	37	41
18		Erel Insurance ↔ Central Post office	0.32	r18.1	weekday	12977	9501	2902	49	421	72	13	19
					weekend	14095	10510	3032	47	399	74	15	19
				r18.2	weekday	12481	8975	2840	74	508	39	17	28
					weekend	12687	9244	2830	62	471	30	18	31
19		Central Post office ↔ Zuun 4 zam	2.02	r19.1	weekday	26660	20395	4934	145	966	188	4	27
					weekend	23242	18163	4018	124	767	146	5	21
				r19.2	weekday	26740	20624	4710	149	1001	220	17	19
					weekend	21599	17007	3600	102	711	156	9	15
20	Nyamyanju street	Narantuul market ↔ Zuun 4 zam	1.22	r20.1	weekday	15677	10778	3689	0	346	602	245	17
					weekend	14609	10634	3192	0	283	444	50	7
				r20.2	weekday	20979	14317	5043	0	471	674	466	8
					weekend	18940	13572	4218	0	307	788	41	14

№		Road	Road length, km	Road ID	Day	Total traffic census a day	Vehicle type						
							1	*2*	*3*	*4*	*5*	*6*	*7*
21	Olypm street	Traffic Police office, right intersection	1.09	r21.1	weekday	20364	13886	5743	0	160	207	357	12
					weekend	19294	13117	5514	0	153	197	302	11
				r21.2	weekday	27163	19712	6904	0	103	316	102	26
					weekend	25172	18101	6557	0	143	276	76	20
22	Chinggis avenue	Central Post office ↔ 120 circle	2.05	r22.1	weekday	19961	13754	4851	38	660	425	224	10
					weekend	18285	12023	5298	47	537	256	124	1
				r22.2	weekday	27354	18683	7062	61	911	413	216	8
					weekend	24199	15991	6685	43	695	478	294	14
23	Narnii zam	Narantuul Market ↔ Traffic Police office	1.27	r23.1	weekday	9371	5397	2570	0	68	601	724	10
					weekend	9392	5426	2572	0	65	577	745	8
				r23.2	weekday	13469	7371	3540	0	87	1306	1150	14
					weekend	13223	7160	3463	0	78	1283	1227	12
24		HERMES center ↔ Traffic Police office	4.32	r24.1	weekday	13790	8348	3379	0	52	1026	975	10
					weekend	13247	8064	3209	0	51	978	934	10
				r24.2	weekday	20930	11840	5041	0	64	1596	2324	66
					weekend	19329	10883	4621	0	60	1464	2237	64
25	-	Tsaiz Left side	2.56	p1.1	weekday/ weekend	6163	4544	976	0	75	466	94	7
				p1.2		11989	8308	2176	0	184	1099	212	10
26	-	Bayanburd ↔ Nogoon nuur circle	1.64	p5.1	weekday/ weekend	16304	9083	4917	0	379	1517	379	29
				p5.2		7710	4366	1776	0	160	1204	191	13
27	Industrial street	Whole street	4.4	p6.1	weekday/ weekend	13709	5975	5250	0	657	43	1773	11
				p6.2		9201	4559	2345	0	522	32	1733	9
28	Chinggis avenue	APU Co., Ltd ↔ Khan Uul District office	1.19	p7.1	weekday/ weekend	7727	4227	2609	25	276	370	214	4
				p7.2		7378	4717	1926	15	243	286	188	3
29	Engels street	Narnii guur ↔ Baruun 4 zam	1.86	p8.1	weekday/ weekend	14971	6599	5587	0	833	85	1856	11
				p8.2		10005	4901	2678	0	566	48	1801	11
30	Chinggis avenue	Khan Uul District office ↔ the end of Workers avenue	1.39	p9.1	weekday/ weekend	13986	7852	4637	42	438	546	466	5
				p9.2		5612	3515	1507	13	189	236	150	2

№		Road	Road length, km	Road ID	Day	Total traffic census a day	Vehicle type						
							1	*2*	*3*	*4*	*5*	*6*	*7*
31	Zaisan street	Zaisan intersection	1.96	p10.1	weekday/	6925	2959	2696	0	309	26	930	5
				p10.2	weekend	2826	1415	745	0	163	16	484	3
32	-	Yarmag road	7.98	p11.1	weekday/	17397	10809	4018	0	844	568	1153	5
				p11.2	weekend	16274	8327	5510	0	788	560	1083	6
33	Worker's street	Whole street	3.29	p12.1	weekday/	14588	6333	5586	0	727	51	1880	11
				p12.2	weekend	6465	3169	1598	0	309	27	1355	7
34	Unur street	Whole street	2.26	p13.1	weekday/	11575	8313	2450	0	34	597	154	27
				p13.2	weekend	6471	4345	1463	0	238	331	80	13
35	Peace avenue	Unur khoroolol ↔ Geology intersection	1.98	p14.1	weekday/	11511	7219	2697	1	461	638	480	13
				p14.2	weekend	7125	4969	1412	1	221	291	224	7
36	Uildverchnii evlel street	Whole street	1.28	p15.1	weekday/	11511	7521	2588	5	525	659	200	13
				p15.2	weekend	7125	4690	1624	1	250	481	74	6
37	-	Bayankhoshuu	4.27	p16.1	weekday/	9693	6596	2174	3	330	453	131	7
				p16.2	weekend	8193	5423	1853	1	275	558	75	7
38	7 buudal road	Chingeltei	3.34	p17.1	weekday/	3963	2977	581	0	98	252	48	6
				p17.2	weekend	3927	2980	604	0	72	225	43	3
39	-	16 back road /Tsaiz/	3.23	p19.1	weekday/	13091	9300	2540	0	379	800	43	29
				p19.2	weekend	8224	5009	2350	0	199	627	36	3
40	-	Law Enforcement University ↔ Chuluun ovoo intersection	2.96	p20.1	weekday/	3944	2270	984	8	136	439	102	6
				p20.2	weekend	9706	6064	2233	13	264	873	251	8
41	Nogoon nuur street	3th school - the end of Nogoon nuur streer	1.2	L3.1	weekday/	6676	4559	1604	0	149	297	57	10
				L3.2	weekend	4802	3274	1083	0	63	264	117	3
42	Tsagdaa street	Whole street	1.63	L4.1	weekday/	9086	6392	1858	0	122	622	80	13
				L4.2	weekend	4529	3064	927	0	16	450	67	6
43	-	Zuragt ↔ Bayankhoshuu intersection	7.25	L9.1	weekday/	13861	9992	2521	0	285	870	186	7
				L9.2	weekend	6602	4894	1139	0	138	323	104	4
44	Peace avenue	Tavan shar	2.52	L11.1	weekday/	2870	1765	593	0	97	245	160	10
				L11.2	weekend	1720	1019	452	0	42	138	67	3

№		Road	Road length, km	Road ID	Day	Total traffic census a day	Vehicle type						
							1	*2*	*3*	*4*	*5*	*6*	*7*
45	-	Sonsgolon road	5.81	L12.1	weekday/	4314	2062	1192	0	146	401	510	2
				L12.2	weekend	2514	1203	621	0	118	245	326	2
46	Khasbaatar street	Whole street	2.23	L15.1	weekday/	7112	4806	1731	0	16	445	95	19
				L15.2	weekend	9240	6269	2065	0	317	459	108	23
47	Ard Ayush avenue	Whole street	3.46	L16.1	weekday/	18274	13035	3871	37	585	712	20	14
				L16.2	weekend	19644	13205	4888	32	687	789	31	11
48	Baga toiruu	whole avenue	2.59	L20.1	weekday/	11556	8555	2515	0	216	242	15	12
				L20.2	weekend	14918	10639	3740	0	192	317	19	11
49	Amarsanaa street	Whole street	0.94	L24.1	weekday/	13937	11309	2014	76	220	236	62	21
				L24.2	weekend	8359	6811	1288	22	116	91	22	8
50	Peace avenue	Kempinski intersection ↔ Officer's palace intersection	2.26	L28.1	weekday/	8007	5755	1685	45	263	213	25	21
				L28.2	weekend	18322	12399	4498	159	623	532	44	68
		Total road length	104.71										

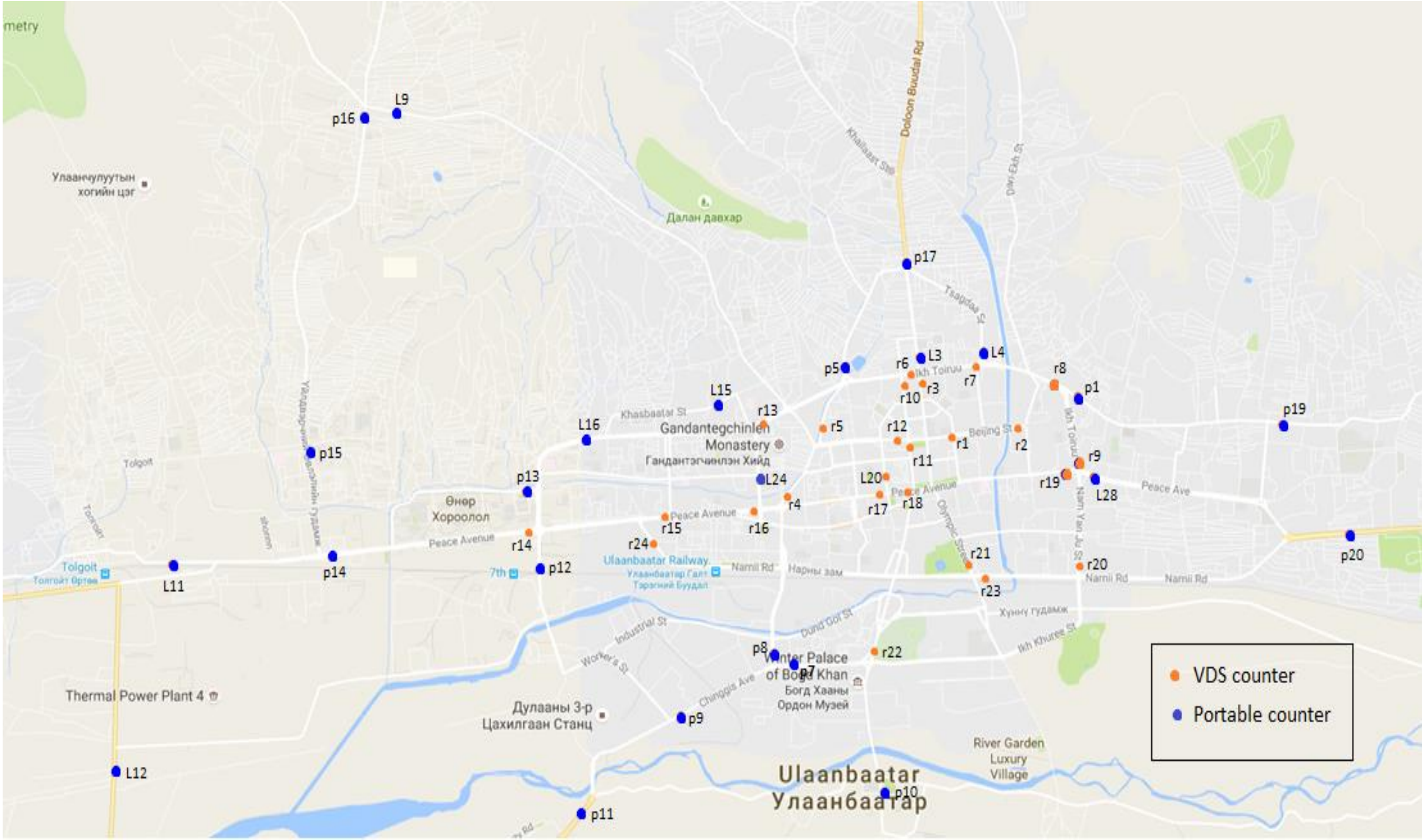


Figure 3.2 Traffic census counters location

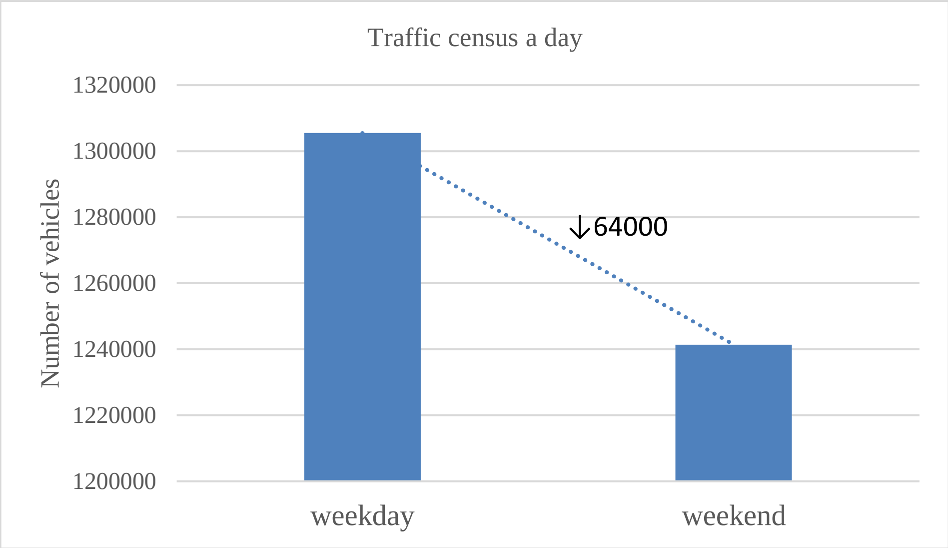


Figure 3.3 Traffic census per day

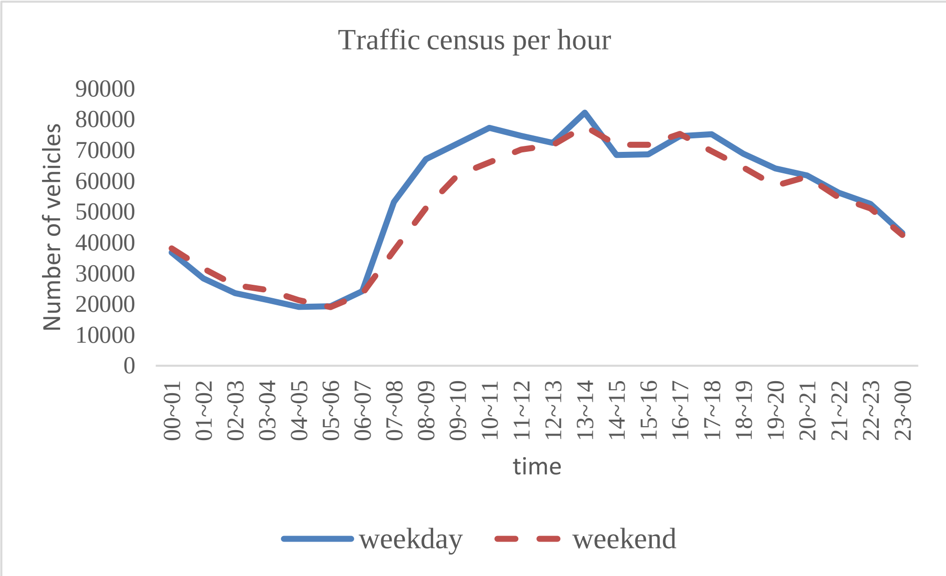


Figure 3.4 Traffic census per hour

VDS data was used to compare the traffic census of weekday and weekend. Loading of traffic census in weekday was higher 64000 vehicles in comparison to weekend. In consideration to loading of hourly traffic census, loading in the morning (07-11 AM) on weekend was lower than the weekday and loading in the midafternoon (14-16 PM) on weekend was little higher and afternoon (16-20 PM) on weekend was lower, loading in the evening (20-23 PM) was similar to the weekday (Figure 4.3, 4.4). Traffic census of the main road was about 470 million vehicles a year. For the vehicle type, 69% of the all traffic census was a small car and 23% of that was a large car. It meant 92% was a passenger car. Buses and trucks were 8% of the all traffic census. People usually prefer their own private car to public transport because the public transportation is not well developed in Mongolia. There is no set time table, but buses pass stops at approximately 10-15-minutes. Also, buses are crowded, not clean and comfortable (Figure 3.3, 3.4, Table 3.5).

Table 3.5 Traffic census a year

Vehicle type ID	Vehicle type	Average traffic census million vehicles/km/year	
1	Small car	322.8	68.7%
2	Large car	107.4	23%
3	Trolleybus	0.4	0.1%
4	Bus	12	2.5%
5	Small truck	15.5	3.2%
6	Large truck	11.2	2.4%
7	Others	0.5	0.1%
	Total	469.8	

3.2.2 Road length

Roads with two lanes or above and near to downtown was considered as main road. Overall 50 link roads (100 section roads) were covered in the research. The length of the link road was estimated using Google Map. 23% of all paved roads in Ulaanbaatar was covered in this study. Total main roads length was 104.7 km (paved roads of Ulaanbaatar city are 453 km), (Figure 3.5).

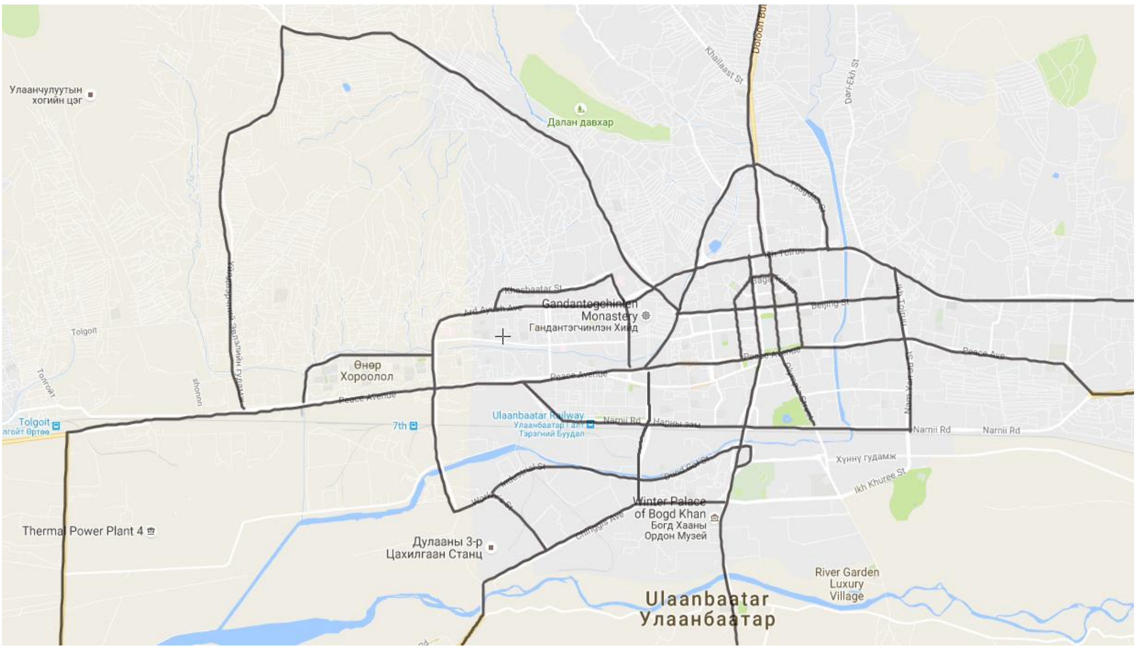


Figure 3.5 Main roads were covered in the study

3.2.3 Traffic speed

Daily average speed on main road was 30 km/h. As the speed is lower, as emission factor increases. Traffic speed was different on location of the roads. Only VDS data was used to compare the traffic speed of weekday and weekend (Table 3.6).

The ratio of traffic speed between the weekday and weekend was related to the roads location. On roads near to trade and service center, also road in the northern and southern border, the traffic speed was lower because of high traffic intensity. In consideration to loading of hourly traffic speed, loading in the morning (00-9 AM) on weekday was higher than the weekend and loading in the afternoon (10 AM - 17 PM) on weekday was lower and loading in the evening (17-23 PM) on weekday was little higher (Figure 3.6, 3.7).

Table 3.6 Traffic speed by hour (weekday)

Time *Road ID*	*00~01*	*01~02*	*02~03*	*03~04*	*04~05*	*05~06*	*06~07*	*07~08*	*08~09*	*09~10*	*10~11*	*11~12*	*12~13*	*13~14*	*14~15*	*15~16*	*16~17*	*17~18*	*18~19*	*19~20*	*20~21*	*21~22*	*22~23*	*23~00*	*AVG speed km/h*
r1.1	26	25	27	27	24	26	25	24	22	21	20	20	18	20	18	13	14	17	12	18	21	23	24	25	21
r1.2	25	24	30	26	23	26	22	23	35	35	35	36	24	22	21	15	16	18	12	16	19	19	22	24	24
r2.1	35	34	40	38	47	50	36	36	38	32	21	17	26	22	21	15	15	15	13	17	19	24	29	32	28
r2.2	25	26	30	28	31	28	23	23	35	26	42	34	26	21	17	21	18	17	12	13	18	16	20	23	24
r3.1	18	14	18	18	16	19	21	22	16	18	15	17	15	13	19	13	12	11	10	7	7	10	13	15	15
r3.2	24	23	26	25	25	24	25	26	20	14	14	13	13	12	13	14	13	13	11	11	10	14	17	19	17
r4.1	45	42	56	56	50	45	41	38	73	77	39	25	26	32	27	19	33	27	14	18	23	23	29	30	37
r4.2	35	36	45	42	45	45	38	33	32	23	21	16	17	21	18	14	18	21	18	15	20	24	27	29	27
r5.1	22	19	22	24	20	18	22	30	59	59	61	63	49	38	39	40	46	33	21	19	20	15	18	19	32
r5.2	17	16	18	18	18	18	20	26	26	18	33	41	31	24	27	29	25	25	26	16	18	16	17	18	23
r6.1	45	57	75	55	65	67	55	40	46	38	21	16	31	37	30	20	21	27	38	58	41	39	38	39	42
r6.2	33	42	56	40	43	37	34	26	43	31	40	32	30	35	24	28	25	29	35	47	38	25	27	27	34
r7.1	30	32	44	32	58	43	36	27	31	16	18	15	27	25	19	18	10	11	16	38	36	34	32	25	28
r7.2	22	24	32	23	38	24	22	17	29	14	34	30	27	24	16	25	13	12	15	30	33	22	22	18	24
r8.1	32	42	51	42	52	45	34	28	36	29	15	13	24	27	22	14	16	21	28	51	33	29	29	29	31
r8.2	23	31	38	31	34	25	21	18	33	24	30	26	23	25	18	19	19	22	26	41	30	19	20	20	26
r9.1	39	49	63	44	48	43	40	34	44	30	50	38	34	41	27	22	18	15	20	26	26	32	35	35	36
r9.2	54	66	64	60	74	77	65	54	48	36	26	19	35	44	33	16	15	14	22	33	28	49	49	50	43
r10.1	28	28	33	29	30	30	27	27	40	39	36	34	30	22	24	25	25	24	25	22	24	22	24	24	28
r10.2	33	42	56	37	44	37	28	27	43	21	27	19	18	17	11	16	16	16	18	28	35	26	29	26	28
r11.1	23	20	32	25	27	36	25	28	27	21	28	20	17	33	29	11	11	10	15	18	18	16	20	20	22
r11.2	35	34	42	40	42	47	34	38	38	33	32	23	28	40	36	33	37	39	36	34	27	28	30	32	35
r12.1	12	13	24	22	29	36	21	17	21	30	13	12	19	21	21	9	14	18	14	19	14	17	16	13	19
r12.2	9	10	18	16	19	20	13	11	19	25	25	24	19	20	17	13	17	19	13	15	13	11	11	9	16

Time *Road ID*	*00~01*	*01~02*	*02~03*	*03~04*	*04~05*	*05~06*	*06~07*	*07~08*	*08~09*	*09~10*	*10~11*	*11~12*	*12~13*	*13~14*	*14~15*	*15~16*	*16~17*	*17~18*	*18~19*	*19~20*	*20~21*	*21~22*	*22~23*	*23~00*	*AVG speed km/h*
r13.1	37	32	36	39	32	30	30	38	45	50	59	47	49	48	46	42	58	43	26	36	35	25	28	29	39
r13.2	29	27	29	30	29	30	28	33	34	33	32	31	31	31	31	31	32	32	32	31	30	26	27	28	30
r14.1	25	35	45	34	38	31	28	25	37	11	37	30	31	34	18	29	27	30	39	51	36	23	23	23	31
14.2	33	40	34	54	49	69	44	33	51	14	41	41	35	25	21	31	30	25	17	21	15	18	24	28	33
r15.1	20	23	22	15	23	13	17	29	44	34	47	38	35	41	25	33	29	32	38	43	41	23	24	22	30
r15.2	25	26	16	25	29	29	27	39	61	41	52	52	39	31	29	35	32	27	17	18	17	18	25	27	31
r16.1	20	23	22	15	23	13	17	29	44	34	47	38	35	41	25	33	29	32	38	43	41	23	24	22	30
r16.2	25	26	16	25	29	29	27	39	61	41	52	52	39	31	29	35	32	27	17	18	17	18	25	27	31
r17.1	32	29	32	23	25	28	24	30	20	15	28	19	26	33	17	14	21	29	13	21	26	24	27	29	24
r17.2	18	19	18	17	17	18	18	18	19	19	18	18	17	17	16	15	14	13	12	13	16	17	18	18	17
r18.1	11	11	13	11	12	13	10	12	13	11	11	14	17	19	11	11	12	14	12	11	9	8	8	9	12
r18.2	6	7	8	9	9	8	8	7	13	14	7	13	11	10	10	12	8	6	11	7	6	6	5	5	8
r19.1	68	69	72	75	72	68	65	50	48	37	32	24	32	38	33	29	46	39	28	27	24	36	52	58	47
r19.2	38	45	48	56	56	59	49	43	46	47	21	23	21	20	32	32	30	18	25	16	15	25	34	37	35
r20.1	24	28	48	39	38	35	29	28	53	37	50	38	34	39	30	34	32	35	42	37	29	19	19	18	34
r20.2	54	56	55	54	56	57	56	51	35	39	41	22	20	23	15	19	18	16	23	28	46	48	51	52	39
r21.1	9	13	18	12	19	11	9	27	49	37	52	35	39	45	31	35	19	12	12	22	12	13	10	10	23
r21.2	20	25	20	16	27	18	17	48	32	39	42	20	23	27	15	20	11	5	7	17	19	34	26	30	23
r22.2	27	35	45	31	26	28	29	32	40	32	50	38	37	45	32	36	34	36	45	55	38	25	27	26	35
r22.2	61	70	51	43	37	45	56	57	26	35	41	22	22	27	16	20	19	16	24	42	61	65	71	77	42
r23.1	22	25	43	26	55	73	54	37	43	46	34	9	12	15	14	12	16	27	10	10	18	18	20	29	28
r23.2	31	26	40	34	44	49	34	33	42	43	42	31	43	50	47	41	46	43	19	20	22	21	26	27	36
r24.1	16	19	25	18	37	44	34	32	45	44	33	9	13	16	14	12	14	27	18	15	19	20	21	26	24
r24.2	23	20	23	24	30	29	21	29	43	41	41	33	45	53	47	41	38	43	34	31	24	24	29	25	33
p1.1	45	47	49	49	50	47	44	44	41	38	38	37	37	37	36	36	37	36	36	36	36	34	34	35	40
p1.2	53	55	54	53	52	54	53	48	38	36	39	33	34	31	31	32	32	33	31	33	35	32	32	33	40

Time *Road ID*	*00~01*	*01~02*	*02~03*	*03~04*	*04~05*	*05~06*	*06~07*	*07~08*	*08~09*	*09~10*	*10~11*	*11~12*	*12~13*	*13~14*	*14~15*	*15~16*	*16~17*	*17~18*	*18~19*	*19~20*	*20~21*	*21~22*	*22~23*	*23~00*	*AVG speed km/h*
p5.1	44	43	45	50	51	51	51	43	37	42	40	40	39	39	40	41	40	42	38	41	42	38	36	43	42
p5.2	45	46	44	48	50	52	53	50	46	44	40	40	42	42	40	41	43	41	40	40	39	38	37	44	44
p6.1	44	38	43	42	45	41	40	45	45	40	42	45	45	45	43	45	46	44	45	47	48	45	45	45	44
p6.2	48	43	43	34	45	45	46	45	45	42	45	45	46	41	45	45	44	43	45	46	50	46	39	44	44
p7.1	35	37	40	40	37	43	42	32	30	30	30	31	30	30	29	30	27	28	27	27	27	30	31	34	32
p7.2	30	33	40	37	36	32	31	25	21	22	23	22	20	21	21	23	20	19	21	20	22	25	27	28	26
p8.1	60	62	63	62	64	63	65	63	57	50	42	42	42	42	41	42	42	40	40	41	42	42	41	43	50
p8.2	55	56	57	57	59	58	58	57	52	48	39	40	38	41	37	38	39	37	37	40	38	40	39	40	46
p9.1	56	56	56	56	56	56	56	56	56	52	54	54	53	53	53	53	55	55	54	55	53	54	57	58	55
p9.2	50	50	50	50	50	50	50	50	50	44	46	48	46	45	45	46	46	47	46	48	47	50	51	54	48
p10.1	25	22	27	28	27	30	24	19	15	17	19	19	18	18	17	16	16	17	19	16	18	18	16	20	20
p10.2	25	22	26	25	28	27	25	25	24	24	24	24	24	24	24	21	22	22	23	22	23	22	21	23	24
p11.1	52	51	55	54	54	56	53	50	49	50	51	51	50	50	50	51	49	50	50	49	43	45	47	49	50
p11.2	60	56	58	62	58	58	60	56	54	57	58	59	56	55	54	55	55	53	55	52	47	50	53	57	56
p12.1	53	55	54	53	52	54	53	48	38	38	41	34	36	32	37	36	39	35	38	42	43	45	45	49	44
p12.2	45	47	49	49	50	47	44	44	41	39	40	35	37	35	39	33	39	34	32	39	41	41	42	45	41
p13.1	18	19	20	19	19	20	22	20	17	17	17	19	20	20	19	19	19	19	18	18	17	16	17	18	19
p13.2	20	21	21	22	23	23	23	22	19	19	17	18	19	19	18	18	18	16	16	14	15	15	17	19	19
p14.1	35	41	42	45	48	48	46	43	36	35	32	29	29	29	25	17	24	26	19	18	22	25	29	35	32
p14.2	39	42	48	49	52	50	46	33	28	28	24	24	25	25	23	24	24	24	25	24	26	25	28	33	32
p15.1	35	41	42	45	48	48	46	43	36	35	32	29	29	29	25	17	24	26	19	18	22	25	29	35	32
p15.2	39	42	48	49	52	50	46	33	28	28	24	24	25	25	23	24	24	24	25	24	26	25	28	33	32
p16.1	43	44	41	47	46	46	47	46	43	40	39	33	21	30	35	34	35	32	29	32	34	35	37	39	38
p16.2	42	44	43	46	45	44	42	41	40	38	38	34	27	31	34	35	35	32	31	33	34	36	36	37	37
p17.1	31	33	36	36	34	37	34	35	32	34	33	31	31	31	30	28	26	30	26	26	26	27	27	29	31
p17.2	35	36	37	38	37	36	33	33	32	34	32	32	32	30	31	29	26	30	26	26	26	27	29	30	32

Time *Road ID*	*00~01*	*01~02*	*02~03*	*03~04*	*04~05*	*05~06*	*06~07*	*07~08*	*08~09*	*09~10*	*10~11*	*11~12*	*12~13*	*13~14*	*14~15*	*15~16*	*16~17*	*17~18*	*18~19*	*19~20*	*20~21*	*21~22*	*22~23*	*23~00*	*AVG speed km/h*
p19.1	34	38	42	41	43	44	48	44	40	35	34	34	33	32	31	34	34	33	33	33	31	32	33	35	36
p19.2	29	36	39	40	40	45	46	39	32	29	28	30	29	28	27	28	29	26	24	26	27	28	31	32	32
p20.1	45	44	45	49	49	49	46	44	43	42	41	43	42	42	44	43	43	43	42	45	47	39	43	42	44
p20.2	46	50	48	51	47	54	50	47	45	43	40	42	41	43	42	41	41	40	40	40	40	38	40	41	44
L3.1	44	43	45	50	51	51	51	43	37	42	40	40	39	39	40	41	40	42	38	41	42	38	36	43	42
L3.2	45	46	44	48	50	52	53	50	46	44	40	40	42	42	40	41	43	41	40	40	39	38	37	44	44
L4.1	44	43	45	50	51	51	51	43	37	42	40	40	39	39	40	41	40	42	38	41	42	38	36	43	42
L4.2	45	46	44	48	50	52	53	50	46	44	40	40	42	42	40	41	43	41	40	40	39	38	37	44	44
L9.1	35	41	42	45	48	48	46	43	36	35	32	29	29	29	25	17	24	26	19	18	22	25	29	35	32
L9.2	39	42	48	49	52	50	46	33	28	28	24	24	25	25	23	24	24	24	25	24	26	25	28	33	32
L11.1	35	41	42	45	48	48	46	43	36	35	32	29	29	29	25	17	24	26	19	18	22	25	29	35	32
L11.2	39	42	48	49	52	50	46	33	28	28	24	24	25	25	23	24	24	24	25	24	26	25	28	33	32
L12.1	35	41	42	45	48	48	46	43	36	35	32	29	29	29	25	17	24	26	19	18	22	25	29	35	32
L12.2	39	42	48	49	52	50	46	33	28	28	24	24	25	25	23	24	24	24	25	24	26	25	28	33	32
L15.1	35	41	42	45	48	48	46	43	36	35	32	29	29	29	25	17	24	26	19	18	22	25	29	35	32
L15.2	39	42	48	49	52	50	46	33	28	28	24	24	25	25	23	24	24	24	25	24	26	25	28	33	32
L16.1	35	41	42	45	48	48	46	43	36	35	32	29	29	29	25	17	24	26	19	18	22	25	29	35	32
L16.2	39	42	48	49	52	50	46	33	28	28	24	24	25	25	23	24	24	24	25	24	26	25	28	33	32
L20.1	18	14	18	18	16	19	21	22	16	18	15	17	15	13	19	13	12	11	10	7	7	10	13	15	15
L20.2	24	23	26	25	25	24	25	26	20	14	14	13	13	12	13	14	13	13	11	11	10	14	17	19	17
L24.1	35	41	42	45	48	48	46	43	36	35	32	29	29	29	25	17	24	26	19	18	22	25	29	35	32
L24.2	39	42	48	49	52	50	46	33	28	28	24	24	25	25	23	24	24	24	25	24	26	25	28	33	32
L28.1	45	47	49	49	50	47	44	44	41	38	38	37	37	37	36	36	37	36	36	36	36	34	34	35	40
L28.2	53	55	54	53	52	54	53	48	38	36	39	33	34	31	31	32	32	33	31	33	35	32	32	33	40
AVG	34	36	40	39	41	41	38	36	37	33	34	30	30	31	28	27	28	27	26	28	28	28	29	32	

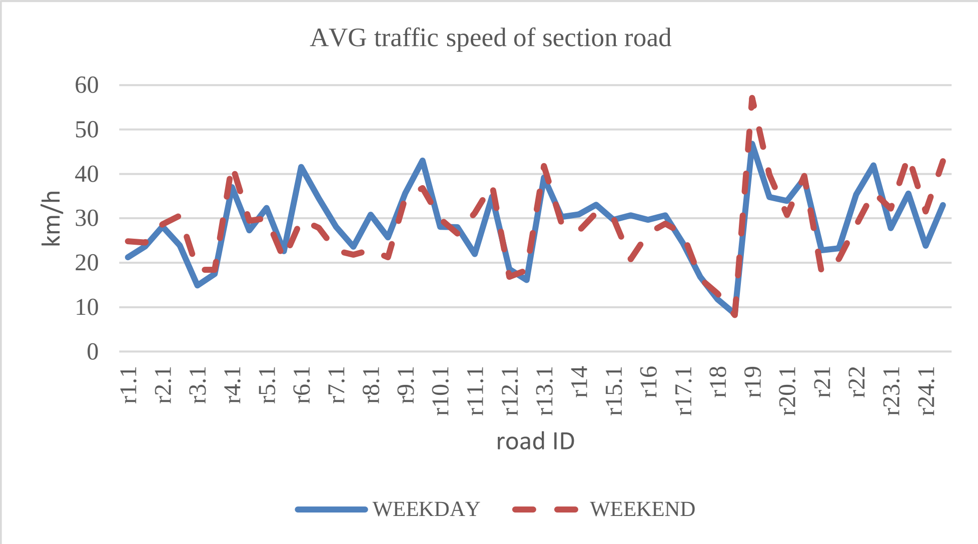


Figure 3.6 Traffic speed by roads

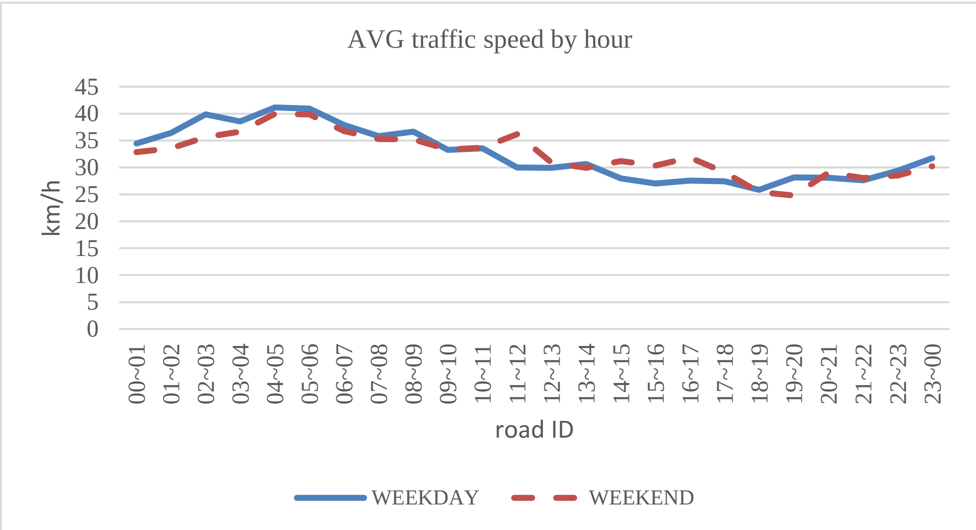


Figure 3.7 Traffic speed by hour

3.2.4 Emission Factor

The emission factor is the amount of pollutant emitted per km travelled by vehicles. Pollutant emission levels from in-service vehicles very depending on vehicle characteristics, operating conditions, level of maintenance, fuel characteristics, and ambient conditions such as temperature, humidity, and altitude. The emission factor was defined as the estimated average emission rate for a given pollutant for a given class of vehicles. Estimates of vehicle emissions were obtained by multiplying an estimate of the distance traveled by a given class of vehicles by an appropriate emission factor. Because of the many variables that influence vehicle emissions. Factors influencing motor vehicle Emissions[17)]:

a. Vehicle/Fuel Characteristics

- Engine type and technology—two-stroke, four-stroke; Diesel, Otto, Wankel etc.
- Exhaust, crankcase, and evaporative emission control systems in place—catalytic converters, exhaust gas recirculation, air injection
- Engine mechanical condition and adequacy of maintenance
- Air conditioning, trailer towing, and other vehicle appurtenances

- Fuel properties and quality—contamination, deposits, sulphur
- Deterioration characteristics of emission control equipment
- Deployment and effectiveness of inspection/maintenance

b. Fleet Characteristics

- Vehicle mix (number and type of vehicles in use)
- Vehicle utilization (kilometers per vehicle per year) by vehicle type.
- Age profile of the vehicle fleet
- Traffic mix and choice of mode for passenger/goods movements
- Emission standards in effect and incentives

c. Operating Characteristics

- Altitude, temperature, humidity (for NO_x emissions)
- Vehicle use patterns—number and length of trips, number of cold starts, speed, loading, aggressiveness of driving behavior
- Degree of traffic congestion, capacity and quality of road infrastructure
- Transport demand management programs

Accurate emission factors and an understanding of the conditions that affect them are obviously important for air quality planning and management. The most advanced computer models use statistical relationships based on thousands of emission tests performed on both new and used vehicles[17)].

At present emission factor standard based on both new and used vehicles in Mongolia has not been developed yet. JICA 'Capacity Development Project for Air Pollution Control in Ulaanbaatar City' which focused on the capacity development of the Air Quality Department of Capital City and other relevant agencies at city and national level especially to control the emission sources. Within this project, they carried out technical transfer with in-vehicle equipment for automobile emission measurement, conversion to emission factor. To build capacity, they gave on-board emission measurement system for vehicles and educated officers who were related to vehicle emission in 2014. This system installs to the target vehicle, the emission of all condition (acceleration, deceleration, constant speed, and stop) will be measured. The on-board emission measurement system is different and more advanced than the general portable exhaust gas analyzer. Thus, there was the vehicle emission factor measurement equipment for the first time in Mongolia. Currently, the measurements, which included emission concentrations of nitrogen oxides (NO_x) and particulate matter (PM), were conducted using 18 vehicles[4)]. Fourteen of these vehicles were gasoline engine and four of these vehicles were HDVs[4)]. The emission factors are closely related to traffic speed; therefore, the vehicle emission inventory requires to hourly traffic speed in every road. The emission factor was selected with regard to the classification and age of the vehicles. With lower speed, the emission factor increased (Table 3.7, 3.8, Figure 3.8-3.12).

In fact, close to the real condition as much data, but the vehicle emission inventory is new in Mongolia, therefore this study was based on the available data. Also, the advantage was that emission factor was measured in the given conditions. Furthermore, it needs to expand the number of measurements and create a database in Mongolia.

Table 3.7 Vehicle registration of EF measurement

№	Vehicle type ID	Manufacturer and name		Fuel type	Aging, years	Engine capacity, liter	Plate number	EF measurement period
1	1	Hyundai	Elantra	Gasoline	5	1.6	1320унм	2015.4.27-29
2	1	Hyundai	Sonata 6	LPG	6	2	3220унк	2015.4.14-16
3	1	Toyota	Prius 30	Gasoline	7	1.8	3855убя	2016.4.25-29
4	1	Toyota	Prius 20	Gasoline	6	1.496	2460унд	2014.10.13-15
5	1	Toyota	Mark2	Gasoline	11	1.998	8420унн	2014.8.19-21
6	1	Hyundai	Verna	Gasoline	12	1.34	0530убл	2015.4.21-23
7	1	Toyota	Carina	Gasoline	16	1.49	1135ухм	2016.4.11-15
8	1	Toyota	Prius 10	Gasoline	15	1496	1479уно	2014.10.7-10
9	1	Hyundai	Sonata 2	Gasoline	20	1.998	6442убн	2014.8.12-14
10	2	Hyundai	Starex	Diesel	9	2.4	0718үнү	2015.8.25-27
11	2	Hyundai	Grace	Diesel	19	2.476	9062яба	2015.9.8-10
12	2	Kia	Bongo	Diesel	20	2.7	1832убе	2016.4.18-22
13	2	Toyota	Land cruiser	Diesel	21	4.16	0898убк	2015.4.17-21
14	4	Zhongtong	LCK6103	Diesel	0	7.25	6082уне	2014.10.14-16
15	4	Ecobus	J-800T	Diesel	0	6.5	9287унк	2014.10.7-9
16	4	Daewoo	BS106	Diesel	5	11.051	7502убч	2014.8.26-28
17	4	Daewoo	BS106	DPF+Diesel	6	11.051	7502убч	2015.4.28-29
18	5	Hyundai	Porter	Nano diesel	16	2.47	6086убг	2015.9.1-3

Before this project, the portable exhaust gas analyzer which is used to measure concentration, conducted under stopped condition to improve vehicle emission, inspection and maintenance. This unit is still used by inspection agencies of Ulaanbaatar, for conducting vehicle emission inspection and regular maintenance. Vehicle emission factor, its standard and emission inventory etc. they are new in Mongolia, but now there is equipment to measure vehicle emission factor. Thus it is respected that emission factor standard and inventory guidebook will be soon in Mongolia.

It was estimated that the vehicle type ID 2≈5 and 4≈6 were same emission factor in this study. For vehicles with diesel engines, the emission factor unit is gram/kilometer/ton (g/km/t); therefore, it is necessary to multiply by GVW. The GVW of a LDV was 2.3 ton and of a HDV was 15.7 ton[4)].

The EF of small and large car were compared with Euro standard and the EF of bus was compared EMEP/EEA Air pollutant emission inventory guidebook 2016. For large car_NOx and PM, Euro 4 standard was divided 3.4 ton because GVW of large car is 2.3 ton. For bus_NOx and PM, Euro 4_EF was divided 15.7 ton because GVW of bus is 15.7 ton. Euro 4_EF quantity is from EMEP/EEA Air pollutant emission inventory guidebook 2016 (Figure 3.8-3.12).

Table 3.8 EF measurement result

Vehicle type ID	Manufacturer and name		Fuel type	Aging	Contaminators	Vehicle speed, km/h															
						5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
1	Hyundai	Elantra	Gasoline	5	NOx, g/km	0.74	0.51	0.43	0.4	0.37	0.35	0.34	0.33	0.32	0.31	0.31	0.3	0.3	0.29	0.28	0.28
1	Hyundai	Sonata 6	LPG	6	NOx, g/km	0.37	0.27	0.22	0.18	0.15	0.13	0.11	0.1	0.09	0.08	0.08	0.08	0.09	0.1	0.11	0.13
1	Toyota	Prius 30	Gasoline	7	NOx, g/km	0.02	0.06	0.07	0.06	0.06	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.05	0.06	0.06	0.07
1	Toyota	Prius 20	Gasoline	6	NOx, g/km	0.1	0.09	0.07	0.05	0.04	0.03	0.02	0.02	0.02	0.02	0.03	0.04	0.05	0.06	0.08	0.1
1	Toyota	Mark2	Gasoline	11	NOx, g/km	0.5	0.37	0.31	0.28	0.26	0.24	0.23	0.23	0.22	0.22	0.23	0.23	0.24	0.25	0.26	0.28
1	Hyundai	Verna	Gasoline	12	NOx, g/km	1.7	1.22	1.1	1.07	1.07	1.07	1.08	1.08	1.07	1.05	1.02	0.98	0.93	0.87	0.8	0.72
1	Toyota	Carina	Gasoline	16	NOx, g/km	1.38	1.17	1	0.85	0.72	0.61	0.52	0.44	0.39	0.35	0.33	0.33	0.35	0.39	0.44	0.51
1	Toyota	Prius 10	Gasoline	15	NOx, g/km	2.85	1.7	1.35	1.2	1.12	1.07	1.04	1.01	0.99	0.96	0.93	0.9	0.87	0.82	0.78	0.72
1	Hyundai	Sonata 2	Gasoline	20	NOx, g/km	2.47	1.8	1.5	1.34	1.29	1.32	1.44	1.63	1.9	2.24	2.66	3.15	3.72	4.35	5.07	5.85
2	Hyundai	Starex	Diesel	9	NOx, g/km/t	0.92	0.57	0.44	0.37	0.33	0.3	0.28	0.26	0.26	0.25	0.25	0.26	0.26	0.28	0.29	0.31
					PM, g/km/t	0.411	0.327	0.284	0.252	0.227	0.205	0.186	0.17	0.157	0.145	0.136	0.129	0.124	0.121	0.121	0.122
2	Hyundai	Grace	Diesel	19	NOx, g/km/t	0.92	0.52	0.38	0.31	0.27	0.24	0.22	0.21	0.2	0.2	0.2	0.2	0.21	0.21	0.22	0.24
					PM, g/km/t	0.098	0.077	0.068	0.062	0.059	0.057	0.056	0.056	0.057	0.059	0.062	0.066	0.071	0.077	0.084	0.092
2	Kia	Bongo	Diesel	20	NOx, g/km/t	1.26	0.65	0.46	0.38	0.34	0.31	0.28	0.26	0.24	0.22	0.2	0.17	0.14	0.11	0.07	0.03
					PM, g/km/t	0.097	0.074	0.065	0.059	0.054	0.049	0.043	0.037	0.031	0.024	0.017	0.009	0	0	0	0
2	Toyota	Land cruiser	Diesel	21	NOx, g/km/t	5.32	3.56	2.91	2.55	2.31	2.14	2.02	1.92	1.86	1.81	1.79	1.78	1.79	1.82	1.86	1.92
					PM, g/km/t	0.567	0.385	0.325	0.296	0.279	0.269	0.262	0.257	0.254	0.253	0.251	0.251	0.251	0.252	0.253	0.254
4	Zhongtong	LCK6103	Diesel	0	NOx, g/km/t	2.18	1.25	0.97	0.83	0.76	0.71	0.67	0.64	0.61	0.58	0.54	0.51	0.47	0.42	0.38	0.32
					PM, g/km/t	0.067	0.051	0.042	0.036	0.031	0.027	0.024	0.021	0.019	0.018	0.017	0.017	0.017	0.018	0.02	0.022
4	Ecobus	J-800T	Diesel	0	NOx, g/km/t	2.18	1.09	0.69	0.48	0.35	0.26	0.2	0.17	0.15	0.15	0.16	0.18	0.22	0.27	0.33	0.41
					PM, g/km/t	0.038	0.023	0.017	0.014	0.012	0.011	0.009	0.008	0.008	0.007	0.007	0.006	0.006	0.006	0.005	0.005
4	Daewoo	BS106	Diesel	5	NOx, g/km/t	3.23	2.09	1.67	1.42	1.26	1.13	1.04	0.97	0.91	0.87	0.84	0.82	0.81	0.81	0.83	0.85
					PM, g/km/t	0.11	0.094	0.085	0.079	0.075	0.074	0.074	0.076	0.08	0.086	0.093	0.102	0.113	0.126	0.14	0.156
4	Daewoo	BS106	DPF + Diesel	6	NOx, g/km/t	4.03	2.37	1.84	1.58	1.45	1.37	1.33	1.31	1.3	1.31	1.32	1.35	1.38	1.41	1.45	1.5
					PM, g/km/t	0.05	0.026	0.018	0.015	0.013	0.012	0.011	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.009	0.009
5	Hyundai	Porter	Nano diesel	16	NOx, g/km/t	1.08	0.55	0.38	0.31	0.27	0.25	0.23	0.22	0.21	0.2	0.19	0.17	0.16	0.14	0.11	0.09
					PM, g/km/t	0.131	0.117	0.11	0.106	0.105	0.107	0.111	0.118	0.127	0.139	0.153	0.17	0.189	0.211	0.235	0.262

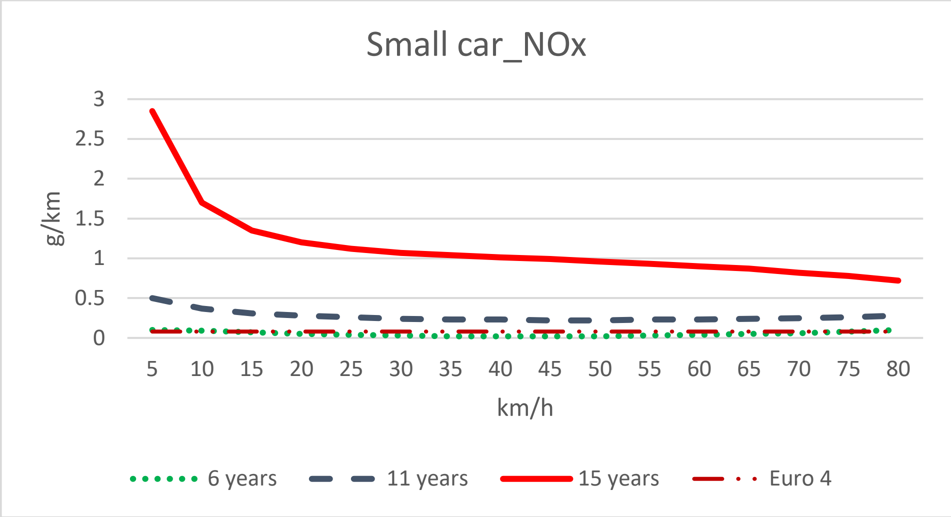


Figure 3.8 Emission factor measurement of small car

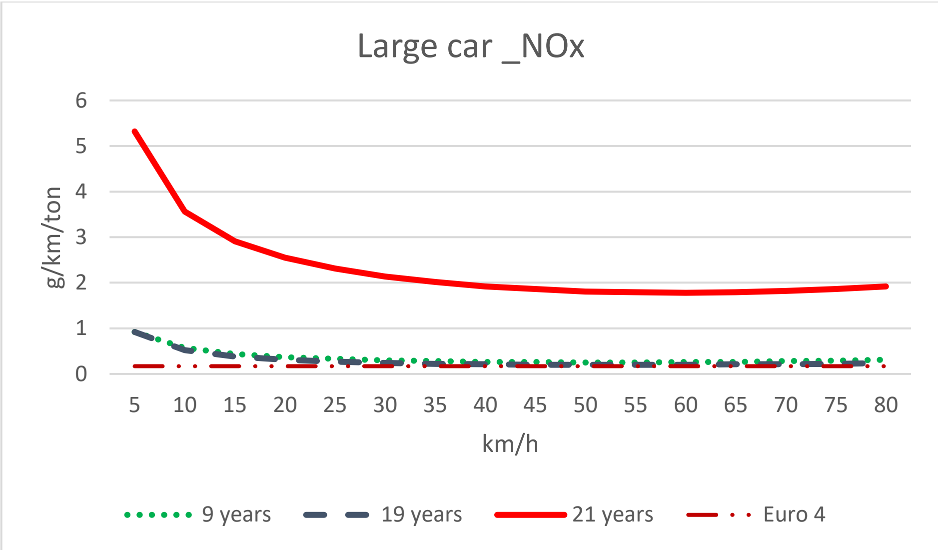


Figure 3.9 Emission factor measurement of large car_NOx

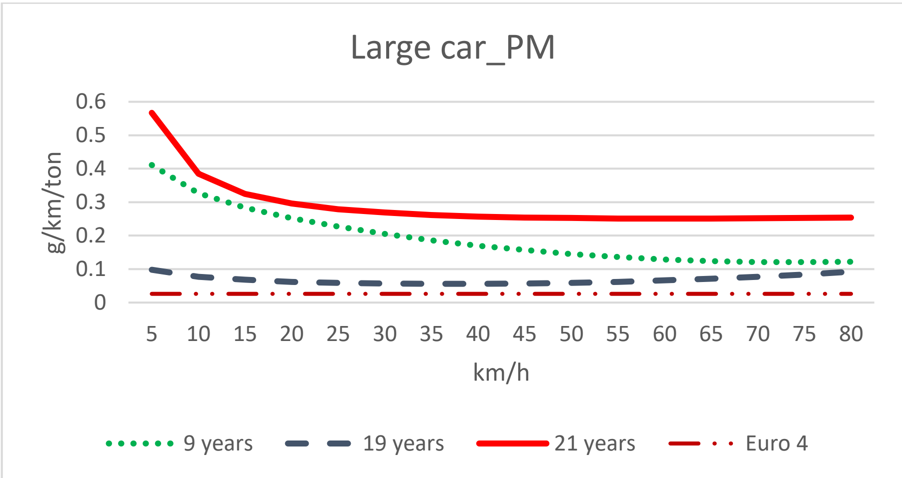


Figure 3.10 Emission factor measurement of large car_PM

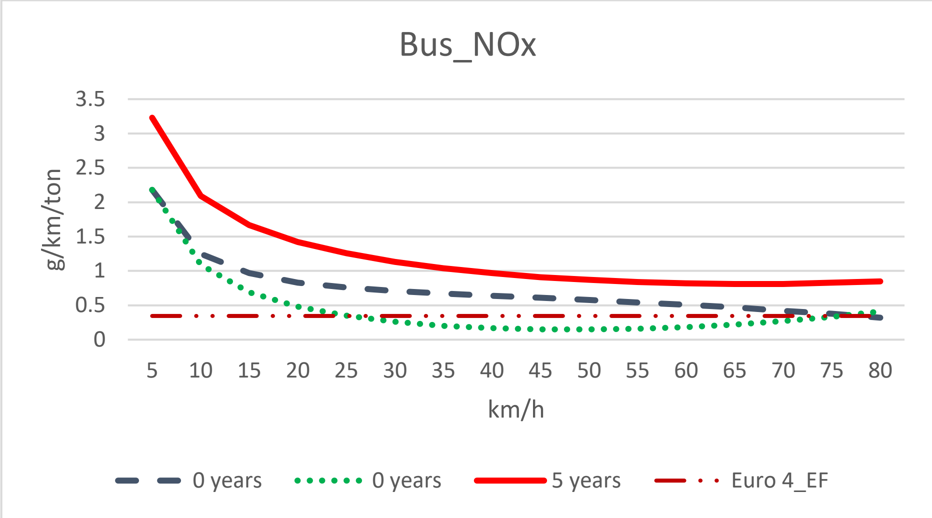


Figure 3.11 Emission factor measurement of bus_NOx

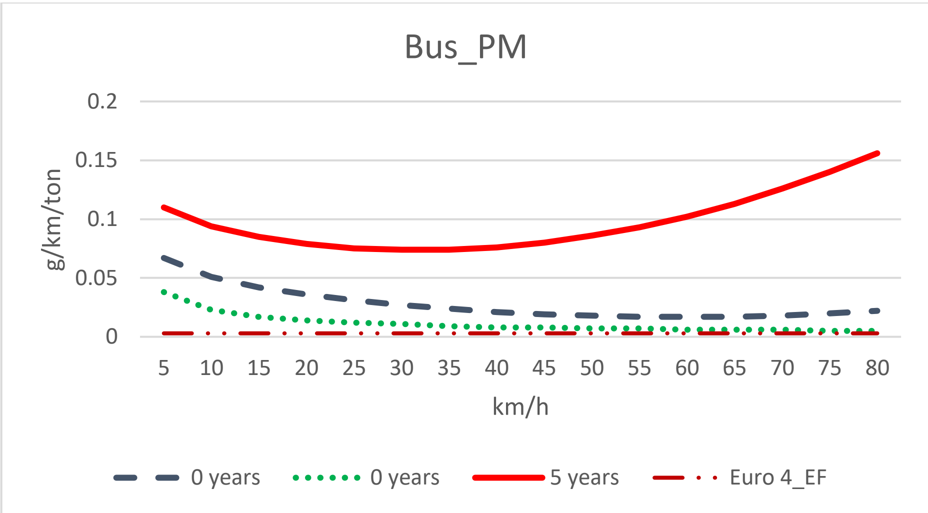


Figure 3.12 Emission factor measurement of bus_PM

The EF tended to decrease at high speeds, usually high emission emitted when the vehicle began to move. Also, the quantity of EF depends on vehicle age, but some cases are different. For Large car_PM, emission of vehicle with 9 years was higher than 19 years. It was related to the vehicle service because people usually do not care about vehicle service in Mongolia.

Comparing EF results with Euro 4 standard, for small car NOx, vehicle with 6 years was similar to Euro 4 standard but the vehicle with 11 years 2.8-6.3 times higher, vehicle with 15 years 9-35.6 times higher. For Large car NOx, both vehicles with 9 and 19 years emission was similar to Euro 4 standard when the vehicle speed was more than 20 km/h, but the vehicle with 21 years was 10-31 times higher. For Large car PM, vehicle with 19 years was 2.1-3.8 times higher, vehicles with 9 and 21 years were 5-21 times higher. For bus Nox, the emission was higher at the beginning of vehicle movement, bus with 5 years is 2.3-9.4 times higher. For bus PM, bus with 5 years is 25-53 times higher than the Euro 4 standard.

3.3 Result

In this section, the total emission of main road was estimated by hour, day, year and analyzed for each different vehicle type and link road.

Table 4.9 presented the vehicle emission percentage was shared in every link roads. In consideration to road ID, r19,22,23,24, p6,8,11,12,16 and L9,12 were the highest emissions. It meant also there were high traffic volume in these roads (Table 3.9, Figure 3.13).

In 2015, the weekdays were 262 days and the weekends were 103 days. The annual emission of NO_x was 6905.7 ton and PM was 301.7 ton. In comparing the weekday with the weekend, the total emission of weekday was more 0.93 ton, NO_x was more 0.96 ton, PM was more 0.02 ton (Table 3.10, Figure 3.14, 3.15).

The highest emission was produced 8 AM-2 PM because there was highest traffic census in that time. It was decreased 2 PM - 6 PM and then increased again until 8 PM. It is related to rush hour. There are higher emissions when people go to work and back to home. The vehicle emission of weekend was little lower than weekday (Figure 3.16, 3.17).

In consideration to vehicle type, the trucks and buses accounted 49% and 34% of NO_x emission, 30% and 15 % of PM emissions respectively. The passenger cars accounted 17% and 55% of NO_x and PM emissions. For passenger car, the large cars (jeep, van, microbus) produced most of the emissions. The buses and trucks accounted 8% of traffic census but for emission, they accounted 45% of PM and 83% of NO_x (Figure 3.18, 3.19).

In consideration to vehicle age, vehicles with over 10 years accounted 96% and 82% of NO_x and PM, with 4-9 years accounted 3% and 17% (Figure 3.20, 3.21).

Table 3.9 Emissions by road ID

Road ID	NO_x, t		PM, t		Total emission, t	
	weekday	weekend	weekday	weekend	weekday	weekend
r1	0.056	0.046	0.004	0.003	0.060	0.049
r2	0.115	0.092	0.008	0.007	0.123	0.099
r3	0.085	0.077	0.005	0.005	0.091	0.082
r4	0.112	0.082	0.005	0.004	0.118	0.086
r5	0.081	0.064	0.004	0.003	0.085	0.067
r6	0.149	0.156	0.008	0.007	0.156	0.163
r7	0.151	0.145	0.007	0.006	0.158	0.152
r8	0.193	0.220	0.009	0.010	0.202	0.230
r9	0.150	0.137	0.008	0.007	0.156	0.144
r10	0.046	0.038	0.005	0.004	0.051	0.042
r11	0.032	0.029	0.003	0.003	0.035	0.032
r12	0.059	0.056	0.004	0.004	0.064	0.060
r13	0.153	0.139	0.010	0.009	0.158	0.144
r14	0.286	0.236	0.011	0.010	0.297	0.246
r15	0.355	0.362	0.015	0.014	0.370	0.375
r16	0.124	0.115	0.005	0.005	0.130	0.119
r17	0.361	0.352	0.016	0.016	0.378	0.368
r18	0.061	0.061	0.002	0.003	0.064	0.064
r19	0.471	0.305	0.022	0.018	0.493	0.323

r20	0.242	0.132	0.013	0.010	0.255	0.141
r21	0.193	0.199	0.013	0.014	0.207	0.212
r22	0.506	0.451	0.027	0.026	0.533	0.477
r23	0.343	0.303	0.012	0.012	0.355	0.315
r24	1.838	1.573	0.061	0.059	1.899	1.632
p1	0.193	0.155	0.011	0.010	0.204	0.165
p5	0.232	0.232	0.014	0.014	0.246	0.246
p6	1.876	1.876	0.062	0.062	1.939	1.939
p7	0.151	0.136	0.006	0.007	0.158	0.143
p8	0.863	0.863	0.029	0.029	0.893	0.893
p9	0.175	0.144	0.011	0.010	0.185	0.154
p10	0.488	0.488	0.011	0.011	0.499	0.499
p11	2.769	2.769	0.128	0.128	2.897	2.897
p12	1.362	1.362	0.041	0.041	1.403	1.403
p13	0.210	0.195	0.011	0.011	0.222	0.206
p14	0.326	0.273	0.012	0.011	0.337	0.285
p15	0.162	0.162	0.007	0.007	0.170	0.170
p16	0.421	0.421	0.022	0.022	0.442	0.442
p17	0.114	0.114	0.006	0.006	0.120	0.120
p19	0.346	0.305	0.020	0.019	0.323	0.323
p20	0.248	0.248	0.014	0.014	0.262	0.262
L3	0.059	0.059	0.004	0.004	0.063	0.063
L4	0.071	0.071	0.005	0.005	0.076	0.076
L9	0.707	0.762	0.035	0.036	0.742	0.799
L11	0.109	0.109	0.004	0.004	0.113	0.113
L12	0.749	0.749	0.021	0.021	0.769	0.769
L15	0.178	0.150	0.010	0.009	0.188	0.160
L16	0.640	0.640	0.035	0.035	0.675	0.675
L20	0.262	0.262	0.018	0.018	0.280	0.280
L24	0.057	0.057	0.003	0.003	0.060	0.060
L28	0.260	0.260	0.015	0.015	0.275	0.275
Total	19.19	18.23	0.83	0.81	19.97	19.04

Table 3.10 Total emissions by year

Pollutant		A day pollution, ton	Days of year	A year pollution, ton	Total, ton
NO_x	weekday	19.19	262	5027.9	6905.7
	weekend	18.23	103	1877.8	
PM	weekday	0.83	262	218.2	301.7
	weekend	0.81	103	83.5	

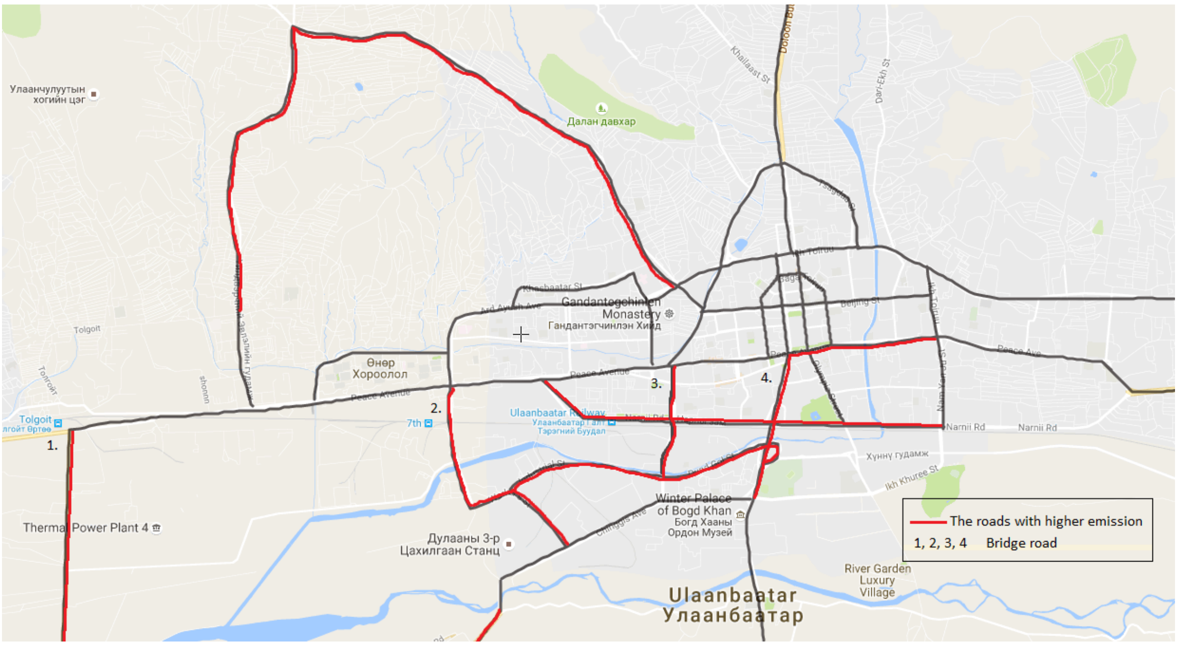


Figure 3.13 The roads with higher emission

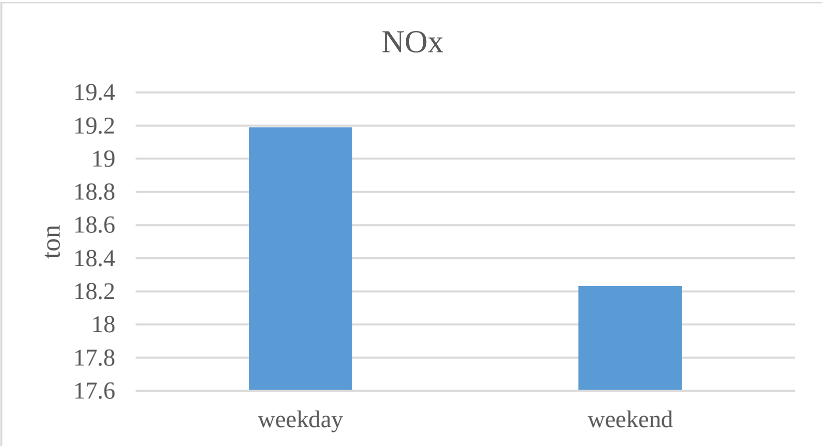


Figure 3.14 Comparison of NOx emission

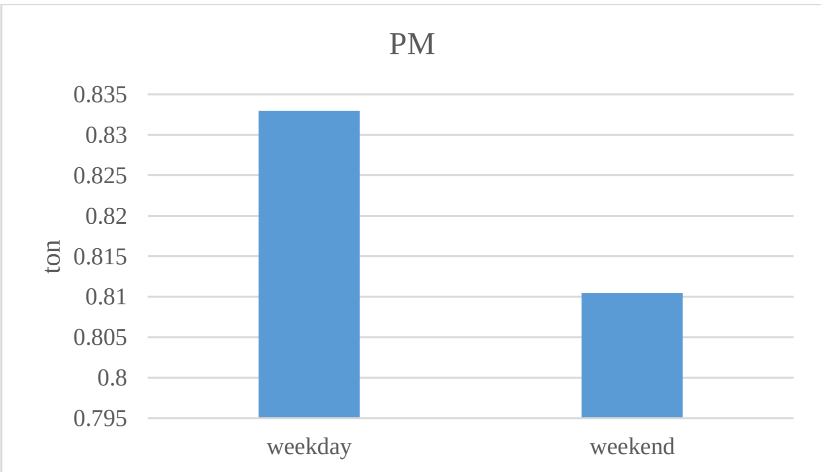


Figure 3.15 Comparison of PM emission

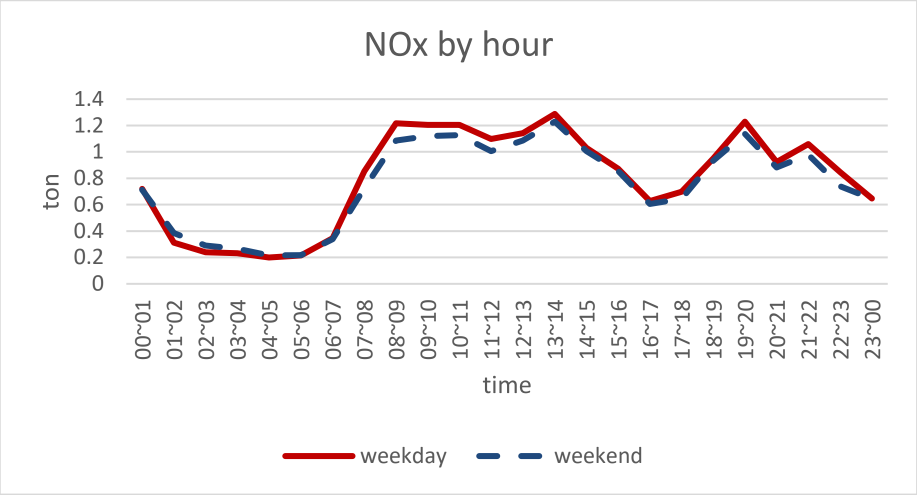


Figure 3.16 NOx by hour

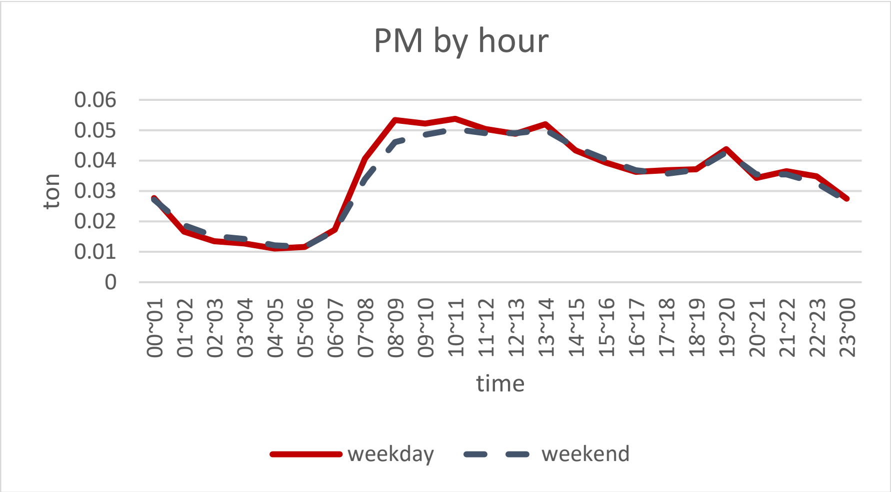


Figure 3.17 PM by hour

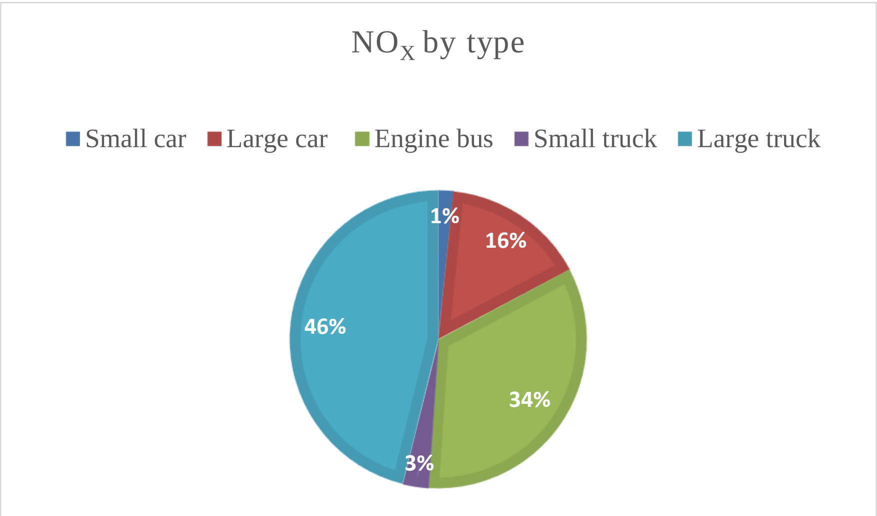


Figure 3.18 NOx by vehicle type

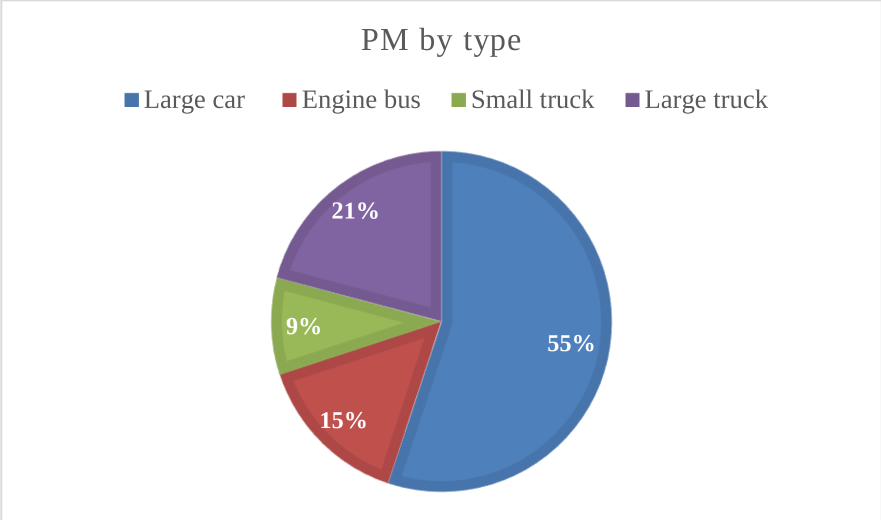


Figure 3.19 PM by vehicle type

Figure 3.20 NOx by vehicle age

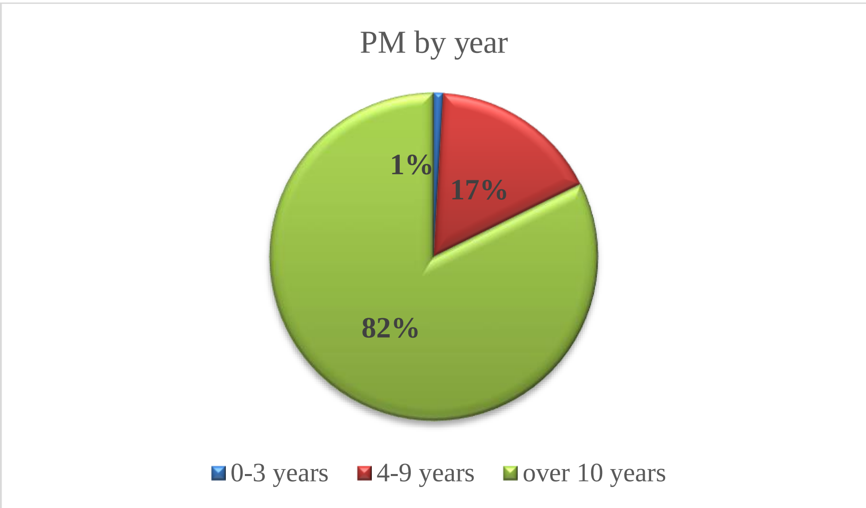


Figure 3.21 PM by vehicle age

3.4 Conclusion

There are 7 main bridge roads which cross the Tuul river and Dund-gol river in Ulaanbaatar city. Four of them were the highest traffic census and highest emissions. So, it means that there needs more bridge roads.

The vehicle emission factors were higher than developed countries, especially trucks and buses. The buses and trucks accounted 8% of traffic census but for emission, they accounted 45% of PM and 83% of NO_x. So it needs to take attention urgently for trucks and buses. The emission factors are depended on many factors which are vehicle fuel, speed, traffic condition, weather, vehicle service, vehicle age etc. Nowadays traffic congestion is serious problem in Ulaanbaatar. The vehicle population has been increased faster than the growth of roads. The emission factor increases when the vehicle speed decreases. This is also one reason for the vehicle emission.

There is only 24 VDS cameras and they do not work regularly because of organization budget. There does not have the budget for these camera's routine maintenance. I think also officers do not care about that. That is why only the traffic census's data of weekday and weekend was chosen for this study. The traffic census is very important to road and traffic planning, also for environmental study. If there is the annual traffic census data, our study is more realistic.

Currently, emission factor measurement was conducted for 18 vehicles in Mongolia. There is not the emission factor standard. It is new in Mongolia. Furthermore, it needs to expand the number of measurements and create a database. The measurements included emission concentration of NO_x and PM, so it is required to equipments which measure emission factor of other pollutants (CO, CO_2, HC etc.).

Considering the EF measurement, it was higher than other developed countries. It is related to fuel quality and the vehicle age respectively. The high sulphur content vehicle fuel is used in Mongolia.

3.5 NO_2 emission dispersion from traffic

The NO_2 concentration near to roadside was simulated using the METI–LIS software, which is a computer–based model developed originally by the Japan Ministry of Economy, Trade, and Industry. The roads of R17, 18, 19 were chosen and emission rate was calculated by these roads emission. The temperature of summer ideal day was selected for this study because I did not have the year data of Mongolian meteorology. This study used time series of hourly NO_2 concentrations for 24 hours.

Average summer temperature in Mongolia: 15.6°C

NO_2 emission: 9.52 g/m/h

Road length: 3.91 km

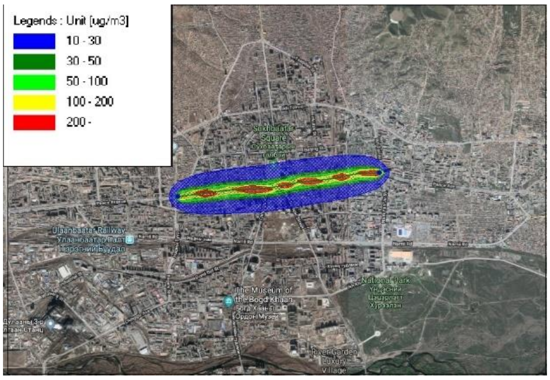
Road width: 20 m

The program METI–LIS, model ver. 2.03, is a Gaussian dispersion model and calculates concentrations in steps of one hour or less, therefore a minimum of meteorological data per each hour is necessary. This model includes point source, line source, building downwash, terrain effects, and line source emissions. The METI–LIS model adopted a downwash scheme based on that of the US Environmental Protection Agency's (EPA) Industrial Source Complex (ISC) model, but the parameters in the dispersion widths describing the downwash effect were improved by incorporating the results of wind tunnel experiments. Essential input data are emission rate and other emission conditions such as location, height, gas volume and temperature, and meteorological factors at every hour during the averaging period. The measured hourly NO_2 data–set was processed to match the pattern required by the program and were used as inputs in the model. Wind direction and speed, temperature, solar radiation and atmospheric stability were the meteorological data required for our analysis. This program can make calculations for point sources (fixed sources of emissions such as factories) and line sources (mobile emission sources, such as traffic). The calculation method selected in our study was for line sources. Input parameters were: object substance (chemical substance name and molecular weight), operation pattern (long–term), meteorology, the line source coordinates (emission rate, road width), receptors, etc. Sources with line–shaped characteristics are calculated in the model by numerically integrating the point–source plume equation[20]:

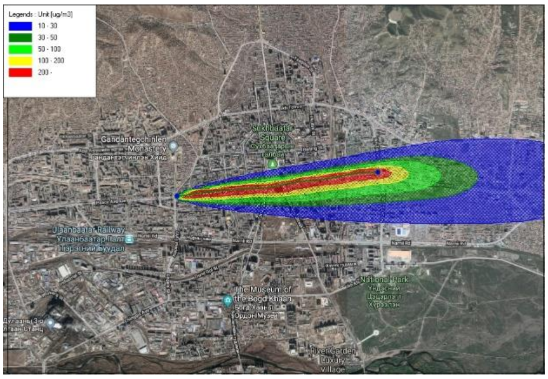
$$C(x,y,z)=\frac{Q}{2\pi\sigma_y u}\exp(-\frac{y^2}{2\sigma_y^2})[\exp(-\frac{(z-He)^2}{2\sigma_z^2})+\exp(-\frac{(z+He)^2}{2\sigma_z^2})]$$

Where C is the concentration (g/m^3), x is the downwind distance from the emission source (m), y is the crosswind distance from the emission plume centerline (m), z is the distance above the ground level (m), Q is the pollutant emission rate (g/s), He is effective plume–rise height, u is wind speed (m/s), ʍy is horizontal dispersion width (P–G curve) (m), ʍz is vertical dispersion width (P–G curve)(m).

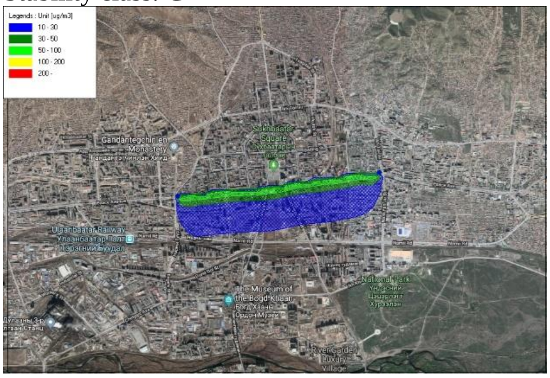
Dispersion result depended on meteorology data as wind speed, wind direction, and stability class highly. Dispersion range depended on wind speed and stability class. The highest concentration was wind speed 2 m/s and stability class F. The lowest concentration was wind speed 7 m/s and stability class C.



Wind speed: 0.3 m/s
Wind direction: South
Stability class: C

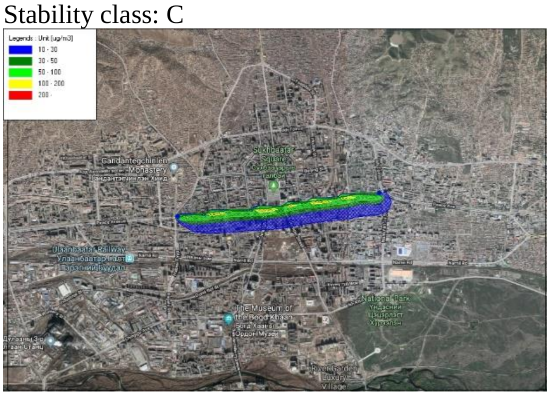


Wind speed: 1 m/s
Wind direction: West
Stability class: C

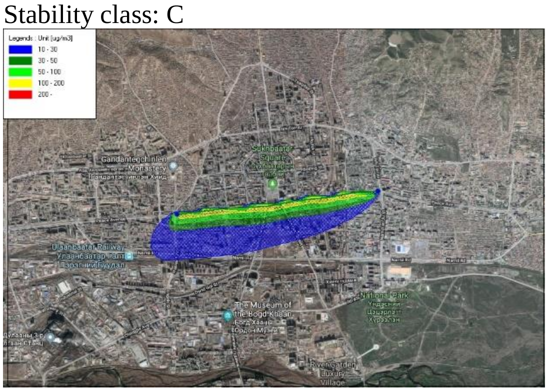


Wind speed: 4 m/s
Wind direction: North
Stability class: C

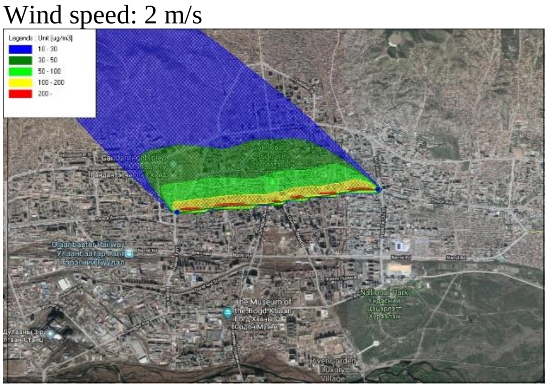
Wind speed: 7 m/s
Wind direction: East
Stability class: C



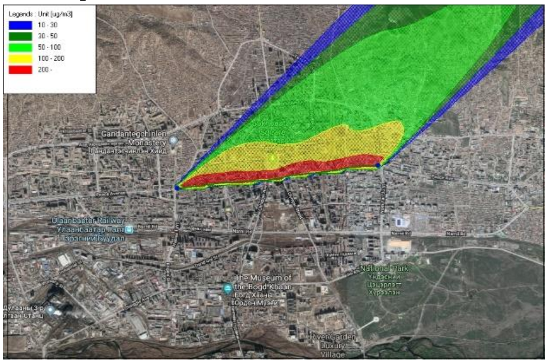
Wind direction: North west
Stability class: A
Wind speed: 2 m/s



Wind direction: North east
Stability class: B
Wind speed: 2 m/s



Wind direction: South east
Stability class: DD
Wind speed: 2 m/s



Wind direction: South west
Stability class: F
Wind speed: 2 m/s

Figure 3.22 Dispersion result of NO_2

Chapter 4. Estimation and prediction of road traffic emission in Ulaanbaatar

4.1 Introduction

Air pollution in urban areas is a growing concern throughout the world. Among the primary sources of urban air pollution are mobile sources (light duty and heavy duty vehicles). Vehicles burn gasoline or diesel fuel in their engines and emit carbon monoxide (CO), oxides of nitrogen (NO_x), unburned hydrocarbons (HC), and other airborne toxins (e.g., formaldehyde, benzene, or acetaldehyde). To better understand the role of mobile-source emission in urban areas, it needs to develop models that can help to predict total emission from these sources[3)].

Nowadays, the level of air pollution in the capital city of Ulaanbaatar, Mongolia, is increasing significantly. Its major contributors are raw coal combustion and automobile emission. In the last decade, the population of this capital city has increased 1.5 times and the number of vehicles has increased 4.5 times. As a result, the auto-road traffic and related congestion has intensified. Statistics for 2015 indicate that there were 331.5 thousand vehicles in Ulaanbaatar, and that 72% of all vehicles were more than 10 years old[2)]. In connection with the living standard in Mongolia, most vehicles are second hand.

For environmental data, particulate matter (PM_{10}, $PM_{2.5}$) and nitrogen dioxides (NO_2) concentrations on the roadsides of Ulaanbaatar are 1.4 to 4.3 times higher than the Mongolian National Air quality standards (MNS), and the annual average concentrations are (187-215, 50-79, and 41-65) µg/m^3, respectively. This is 1.02-10.7 times higher than the WHO standard ratio (see Table 4.1, Table 4.2). As shown in Figure 5.1, NO_2 in particular, exceeds the MNS at roadside monitoring stations over the whole year and on 97% of all measuring days[3)]. The level of Mongolian air quality national standard is two times higher than the WHO air quality standard[21)].

Table 4.1 Annual average pollutant concentration in Ulaanbaatar 2014

Pollutant	Annual value in roadside of Ulaanbaatar (µg/m^3)	Exceedance ratio to air quality standard	
		MNS	WHO
PM10	187-215	3.7-4.3	9.3-10.7
PM2.5	50-79	2-3.2	5-7.9
NO_2	41-65	1.4-2.2	1.02-1.6

Table 4.2 Air quality standard

Pollutant		Average time	Air quality standard value (µg/m^3)	
			MNS	WHO
Nitrogen dioxides	NO_2	1 hour	-	200
		Annual	30	40
Particulate matter	PM10	24 hours	100	50
		Annual	50	20
Particulate matter	PM2.5	24 hours	50	25
		Annual	25	10

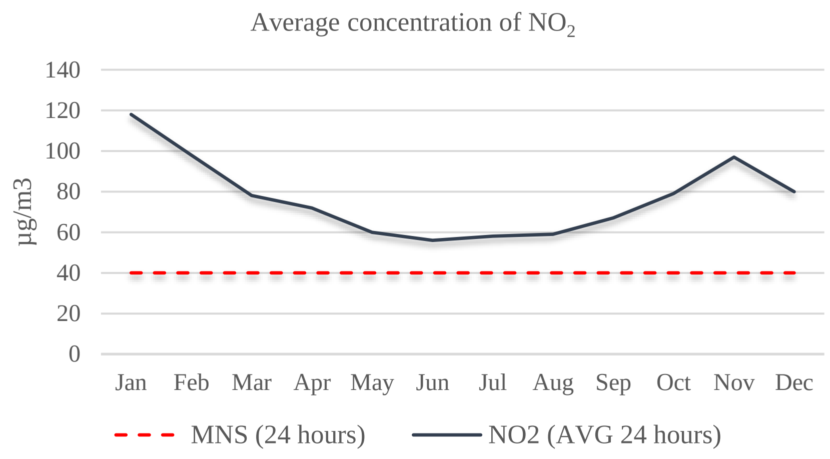


Figure 4.1 Average concentration of Nitrogen oxides in roadside

Virtually all environmental problems are inherently system dynamics problems. They all deal with environmental phenomena that change over time (i.e., they are dynamic) and involve numerous interrelated components (i.e., they are systems). Computer-based models of environmental systems help to understand how the environment changes and to make predictions on how it might evolve in the future[1)]. In this study, the software "Stella Professional"[22)] which is complete modeling tool for dynamic modeling, policy analysis, and strategy development, was used. To create an auto cohort model with leakage, to estimate and predict vehicle emission, and to assess the effectiveness of a new gas exhaust standard by the year 2040.

4.2 Methods

This study was conducted using data published by the Capacity Development Project for Air pollution Control in Ulaanbaatar city and with data from the Statistics Department of Ulaanbaatar.

To calculate emission from a given population of vehicles, the following equation was used[3)]:

$$Ei = \sum_j Vj * VKTj * EFij$$

Ei – the total annual emission of pollutant *i* (grams/year)
Vj – is the total number of vehicles of type *j* on the road during that year (vehicles)
VKTj – the average annual kilometers traveled for vehicle of type *j* (km/vehicle/year)
EFij – the average emission of pollutant *i* for vehicle type *j* (grams/km). (Note that EF is "emission factor.")

This formula is as same as the algorithm of European Environmental Agency air pollutant emission inventory guidebook 2016 and used for calculating vehicle emission[23)]. So, emission prediction is depended on vehicle population prediction.

4.2.1 Vehicle classification and statistical data

According to the emission inventory, vehicles are classified in two main groups: Light duty vehicles (LDVs) and heavy duty vehicles (HDVs). These two groups are classified into smaller groups according to their age of use in the statistical data. In this research, the trucks are classified as small trucks (GVW<3 ton) or trucks (GVW>3 ton) based on their gross vehicle weight. The buses are sorted by the total distance they are driven annually (VKT). Public buses are for public transport and private buses are for personal use. Moreover, the buses are further subdivided by capacity: 10-16 seats, 17-25 seats, and 26-45 [2), 4)]. The structure of the vehicle classification used in this research is shown in Figure 4.2.

The research did not estimate motorcycle emission because motorcycles account for only 0.43% of total vehicles[2)], and also because there is currently no emission-factor measurement result for motorcycles. The vehicle data for Ulaanbaatar city, which was provided by the city Statistics Department, is shown in Figure 4.3-4.4, and Table 4.3.

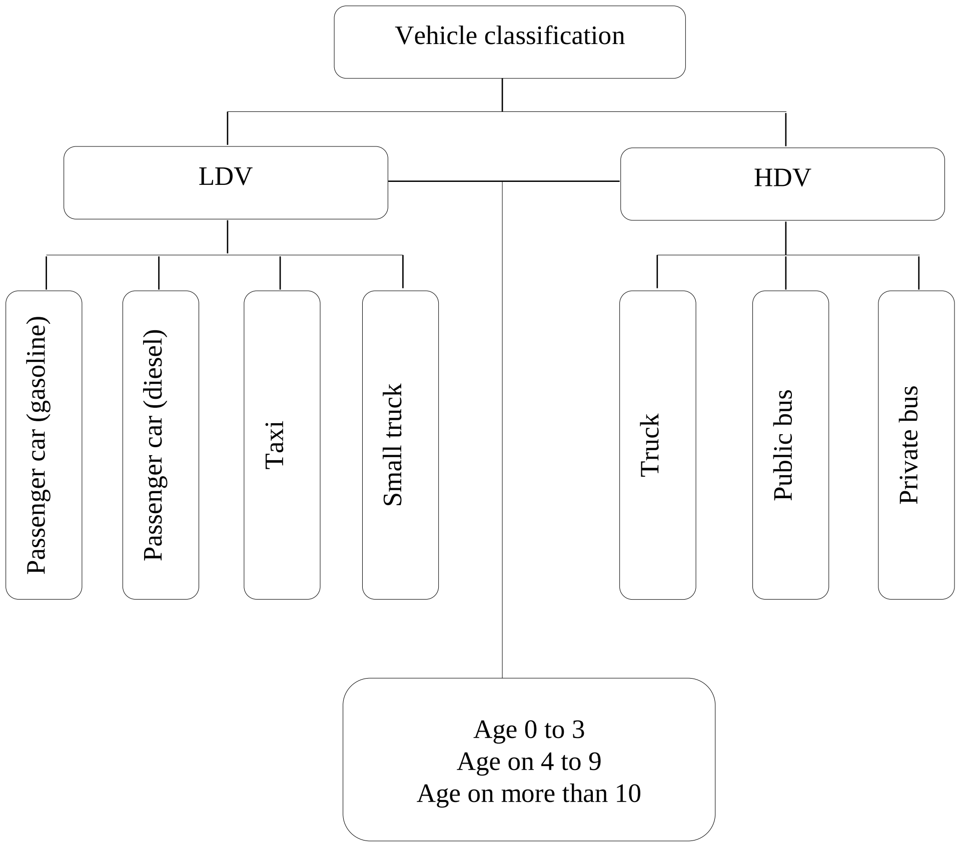


Figure 4.2 Vehicle classification of traffic census

Comparing the statistical data of 2015 with that of 2007, the total vehicle population has increased 3.6 times, the number of buses increased 1.8 times, and the number of trucks increased 4.3 times. The average growth in the number of vehicles was 17%.

In comparing the statistical data of 2015 with that of 2007, the number of vehicles that have been in service more than 10 years has increased 5.1 times, and has increased rapidly since 2009. Regarding vehicle categories, in 2015, data shows that 77.5% were passenger cars, 19% were trucks, and 3.5% were buses.

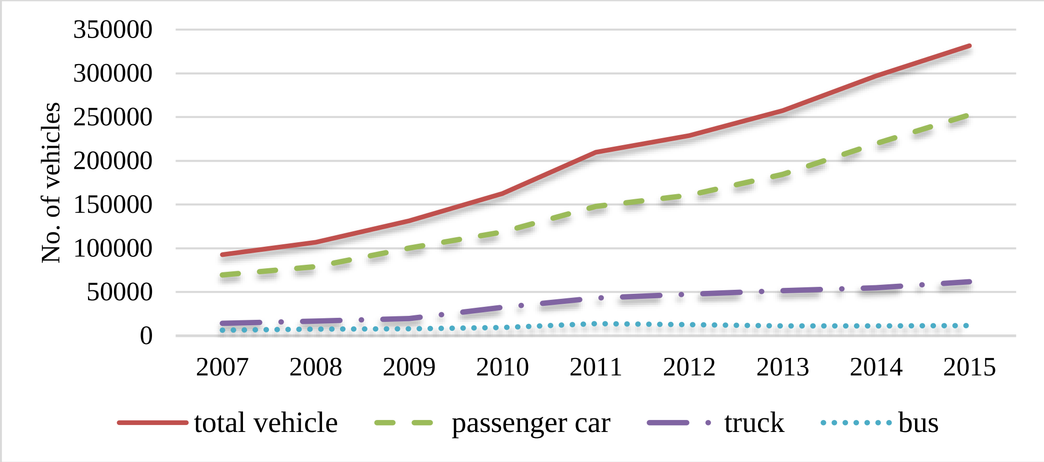


Figure 4.3 Growth of vehicle population

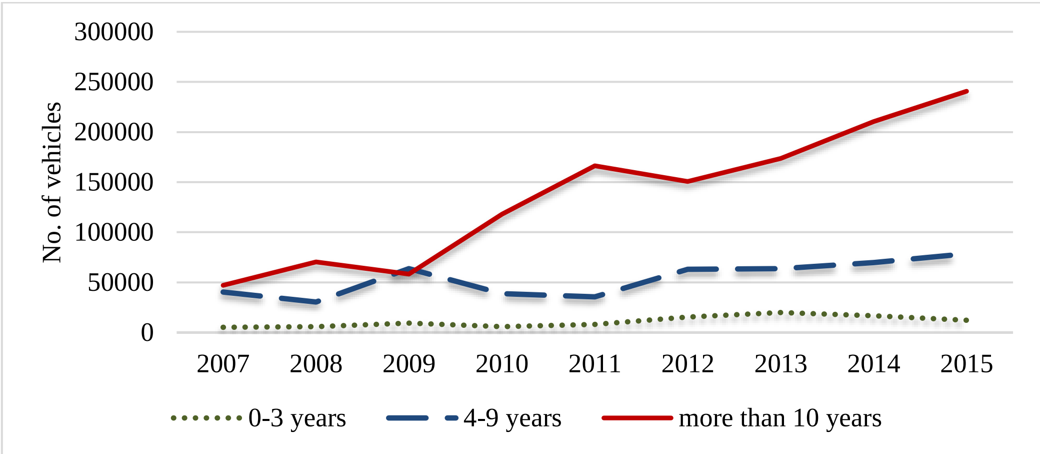


Figure 4.4 Age of vehicle population

Table 4. 3 Vehicle population

Vehicle classification			Population (No. of vehicles)		Proportion
Passenger car	Gasoline		234028		77.5%
	Diesel		17961		
	Taxi		593		
Truck	GVW<3 ton		43837		19%
	GVW>3 ton		17946		
Bus	Public	1665	10-16 seats	291	3.5%
			17-25 seats	61	
			26-45 seats	1313	
	Private	9795	10-16 seats	5240	
			17-25 seats	4064	
			26-45 seats	491	

4.2.2 The annual distance driven per vehicle

The VKT data of Capacity development project for Air pollution control in Ulaanbaatar city report was used, but there was no VKT data for trucks and private buses[4)]; therefore, those data was guessed (Table 4.4). It was guessed that VKT of trucks (GVW<3 ton) and private bus (10-16 seats) were the same as passenger car because there is not any VKT data of truck and private buses in Mongolia; also the use of these types of vehicles is common. The trucks (GVW<3 ton) are usually used for carrying goods and services. The trucks (GVW>3 ton) are uncommon because it is prohibited on the main road of the capital. If they want to travel on the main road, they need a permission[24)]. The private buses (10-16 seats) were usually used for public transport and personal use; however, the private buses (>16 seats) were only used for personal use. This is why VKT data of trucks and private buses is half of the passenger car except trucks (GVW<3 ton) and buses (10-16 seats).

Table 4.4 VKT for vehicle classification

Vehicle classification		VKT (km/year)	
Passenger car		12000	
Taxi		73000	
Truck	GVW<3 ton	12000	
	GVW>3 ton	6000	
		Public	Private
Bus	10-16 seats	7200	12000
	17-25 seats	7200	6000
	26-45 seats	15900	6000

4.2.3 Emission factor

Currently, an emission factor standard based on vehicles in Mongolia has not yet been developed, but research on emission factors of vehicle was begun in Mongolia in 2014. It was mentioned in chapter 3. Emission factors were selected from this measurement result for both of chapter 3 and 4. The measurements, which included emission concentrations of nitrogen oxides (NO_x) and particulate matter (PM), were conducted using 18 vehicles. Three of these vehicles were HDVs[4)]. The emission factors are closely related to traffic speed; therefore, it is needed to know the average traffic speed in Ulaanbaatar city. Data on traffic speed was selected using as source a vehicle detection system (VDS). A VDS was positioned at 24 measure points. The data was adjusted to match using the average weight method. The daily average speed on the road was 30 km/h[18)]. The emission factor was selected with regard to the classification and age of the vehicles. With lower speed, the emission factor increased. The graph of the emission factor is shown in Figure 4.5.

The gasoline and diesel used in Ulaanbaatar contain more sulphur and lead than do the fuels used in Japan. Although the average vehicle service level, road condition, and fuel quality are different with Japan, the emission factors for other pollutants were selected from the Japanese emission factors except for NO_x and PM because 65.4% of all vehicles and 74.8% of all passenger cars were manufactured in Japan[2)].

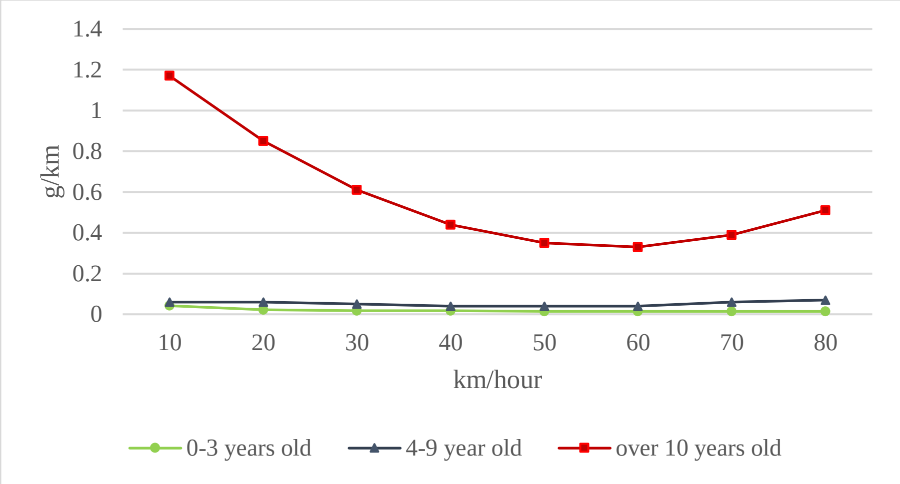


Figure 4.5 Passenger car (gasoline), emission factor of NO_x

Furthermore, to measure emission factors of NO_x and PM using Japanese equipment and method[4)]. According to the measurement result of NO_x and PM, the amount of emission factors were different depending on vehicle age. For example, NO_x emission factor of gasoline vehicle with engine >660cc was same quantity as Japanese emission factor (0-3 years old ≈ Japanese emission factor 2005, 4-9 years old ≈ Japanese emission factor 2000, over 10 years old ≈ Japanese emission factor 1978). To select the emission factors of other pollutants using that relationship, in other words, to compare real measurement result of NO_x, PM and Japanese emission factor table.

For vehicles with diesel engines, the emission factor unit is gram/kilometer/ton (g/km/t); therefore, it is necessary to multiply by GVW. The GVW of a LDV is 2.3 ton and of a HDV is 15.7 ton[4)].

4.2.4 Establishing system dynamics

System dynamics is a methodology for studying and managing complex systems that change over time and analyzing problems in which time is an important factor, which involves the study of how a system can be defended against or made to benefit from, the shocks which fall upon it from the outside world[25)]. System dynamics models are excellent tools to study problems that arise in closed-loop systems, systems in which conditions are converted into information that can be observed and acted upon in order to change the initial condition. System dynamics models are policy tools that examine the behavior of key variables over time. Historical data and performance goals provide baselines for determining whether a particular policy generates behavior of key variables that is better or worse when compared to the baseline or other policies. Furthermore, models provide an explanation for why specific outcomes are achieved. Simulation allows us to compress time so that many different policies can be tested, the outcomes explained, and the causes that generate a specific outcome can be examined by knowledgeable people working in the system before policies are actually implemented[26)].

Stella Professional is dynamic modeling software which helps researchers understand how the environment modifies and to make predictions on how it evolve in the future.

An "age-based cohort model" divides a population a number of different subpopulations (or cohorts) based upon age. Cohort models are used to model populations in which the activities of certain cohorts in those populations need to be tracked, and where the relative sizes of the cohorts can change dynamically over time. In addition, without a cohort model, one has no way of knowing how the population is distributed among age groups and how this distribution may change over time given certain perturbations to the system[3)].

A similar cohort system can be applied to vehicle populations and emissions inventories. A cohort model used for inventories will allow us to account for the higher emission contributions for older vehicles. A cohort model will also allow us to explore technology and policy interventions that impact only certain vehicle populations (e.g., scrappage programs that are aimed at reducing the number of older vehicles on the road).

When determining actual emissions from a population of vehicles, however, it must be recognized that emissions from different makes, models, and age of vehicles are not identical. Larger and older vehicles usually have higher emissions values than do newer and lighter vehicles. Vehicle size is a factor because they need to consume more fuel per mile driven. Thus, their emissions per mile tend to be higher. Vehicle age is a factor because as a vehicle gets older and accumulates miles, engine wear, improper maintenance, and loss of efficiency in catalytic converters lead to higher emissions. The Stella model included seven vehicle submodels, based on the seven vehicle classifications used for Ulaanbaatar (figure 4.2). The initial inflow to this series of vehicle cohorts represents vehicle purchases per time, and the final outflow represents vehicles that are finally scrapped after a long lifetime. The submodels included divisions of the vehicle population into four different subpopulations (cohorts) based upon age. Also, to add leakages for each cohort. These leakages represent untimely vehicle scrappage, either due to accidents or breakdowns. A higher scrappage rate for older vehicles because these would tend to break down more often than newer vehicles; however, some scrappage was applied to new vehicles due mostly to accidents. Each cohort had its own individual scrappage rate. Finally, an emissions component was added. This model's advantage is to conduct both vehicle population growth and the emissions inventory[3)].

The time in service of a LDV was considered 20 years; 25 years for a HDV. The number of vehicles purchases was defined by the composition of the average exponential growth rate from 2007 to 2015, and the total number of vehicles in each vehicle classification (Figure 4.6).

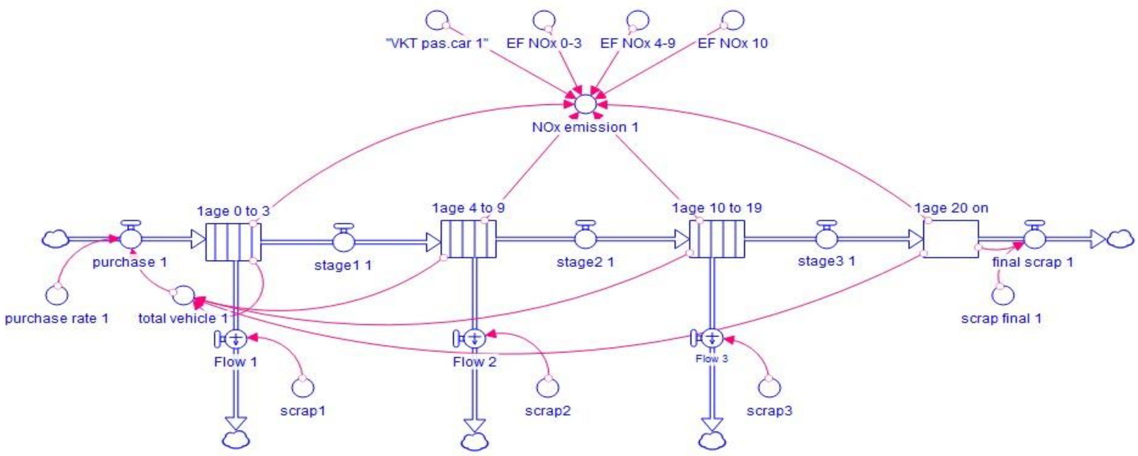


Figure 4.6 The passenger car cohort model with leakage

Table 4.5 Input data of age based cohort model

Vehicle type	Purchase rate	Vehicle population			
		0-3 years	4-9 years	10-19 years	20, 25 years
Passenger car with gasoline engine	0.09	7279	59829	148174	18746
Passenger car with diesel engine	0.09	559	4592	11374	1437
Taxi	0.05	18	152	399	24
Small truck	0.11	1584	7039	30830	4384
Truck	0.11	649	2881	12621	1795
Public bus	0.05	128	316	961	259
Private bus	0.05	754	1861	6788	392
Scrap rate	-	0.00132	0.001316	0.001316	-

4.3 Results and Discussion

4.3.1 Traffic emission in Ulaanbaatar city

In comparing the results in relation to vehicle classification, the HDVs were the main sources of NO_x and PM, accounting for 57% of NO_x and 70.1% of PM emissions.

The LDVs accounted for 58.4% of HC, 87.2% of CO, and 78.9% of CO_2. By vehicle age, 3.7% of the total emissions were from vehicles 0-3 years old, 25.9% from vehicles 4 to 9 years old, and 70.4% from vehicles > 10 years old. The emissions of PM and NO_x were 1% and 2% from 0-3 year old vehicles, 11% and 13% from 4 to 9 year old vehicles, 85% and 87% from 10 year old vehicles. The traffic emission calculated for 2015 is shown in Table 4.5 and 4.6.

Table 4.6 Traffic emission by vehicle type

Vehicle type	Vehicle emission (ton per year)				
	NO_x	PM	HC	CO	CO_2
LDV	2038.8	98.8	601.7	5657.0	613149.4
	43%	29.9%	58.4%	87.2%	78.9%
HDV	2704.3	232.0	428.4	829.6	164152.2
	57%	70.1%	41.6%	12.8%	21.1%
Total emission	4743.0	330.8	1030.1	6486.6	777301.6

Table 4.7 Traffic emission by vehicle age

Vehicle age	Vehicle emission (ton per year)				
	NO_x	PM	HC	CO	CO_2
0-3 years	90.6	3.7	7.6	59.9	29278.8
4-9 years	620.6	38.7	59.7	1183.8	202341.6
over 10 years	4031.8	288.3	962.8	5242.8	545681.2

4.3.2 Predicting emission in Ulaanbaatar city

The research also predicted a trend in vehicle emissions from 2015 to 2040. For the vehicle population, the vehicles over 10 years old were usually the highest number, even though the proportion could be reduced. This class accounted for 41.4% of total vehicles in 2040. The number of vehicles up to 3 years old, tended to increase rapidly from 2018. The vehicle population did not increase monotonously and the vehicle population except 0-3 years old decreased until 2020. It depended on the transit time of Cohort model. Each cohort (except the last) has a transit time (for LDV, first cohort-3 years, second cohort-5 years, third cohort-9 years). Thus, vehicles enter the first cohort, “ride” it for 3 years, and then enter the second cohort[1].

In comparing this result with that from vehicle classification, there was no difference: the HDVs were still the main sources of NO_x and PM and the LDVs were the main source of HC, CO, and CO_2. The vehicle emission tended to increase gradually from 2015 to 2027; then increased rapidly until 2040. The increase rate of emission was same quantity during that time. It is related to the growth of vehicle population.

In comparing 2015 with 2040, the total vehicle population was increased by 3.9 times, the total vehicle emission level was increased by 4.3 times. The emission level of NO_x, PM and CO_2 was increased about 4.2 times, and CO was increased 2.8 times. As the vehicle population increases inevitably, increase in traffic congestion. Currently, most of the major intersections in the city center are severely congested, resulting in average speeds of 5-8 km per hour near the center of the city during peak hours[27]. So that vehicle population increasing 4 times is not possible, not to improve traffic management and road condition, expand and build new roads network. That is why it is imagined the traffic congestion will not be big trouble in future. The vehicle emission in Ulaanbaatar from 2015 to 2040 is illustrated in Figure 4.7-4.12.

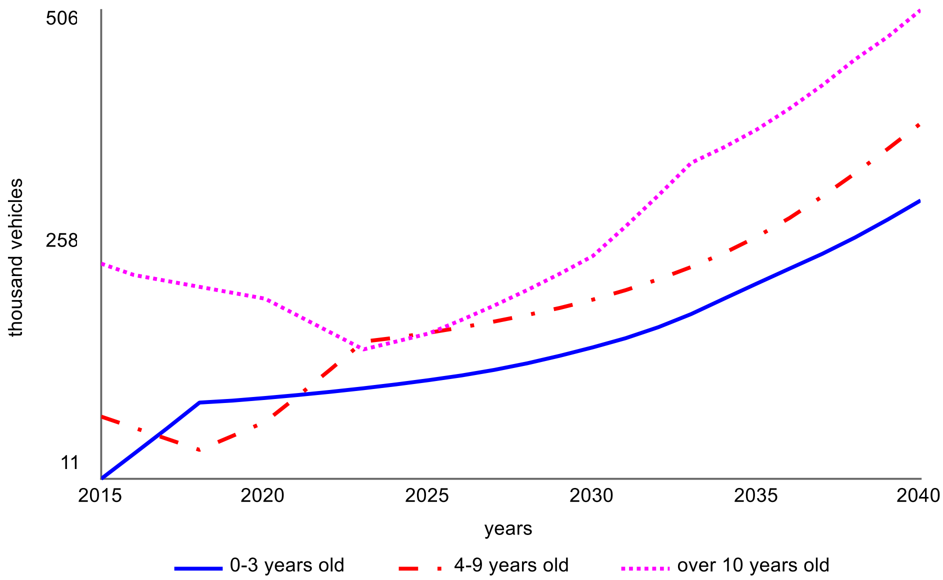


Figure 4.7 Predict of vehicle population

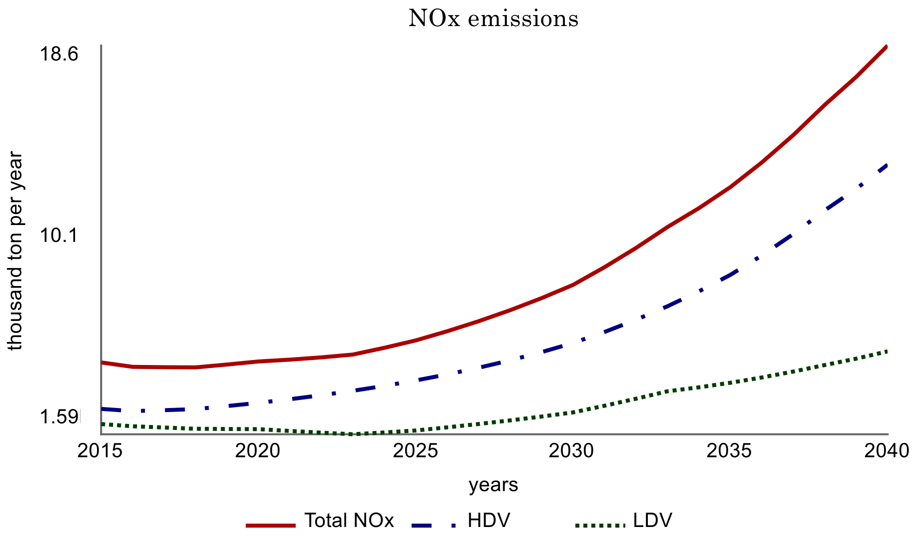


Figure 4.8 Predict of NO_x emissions

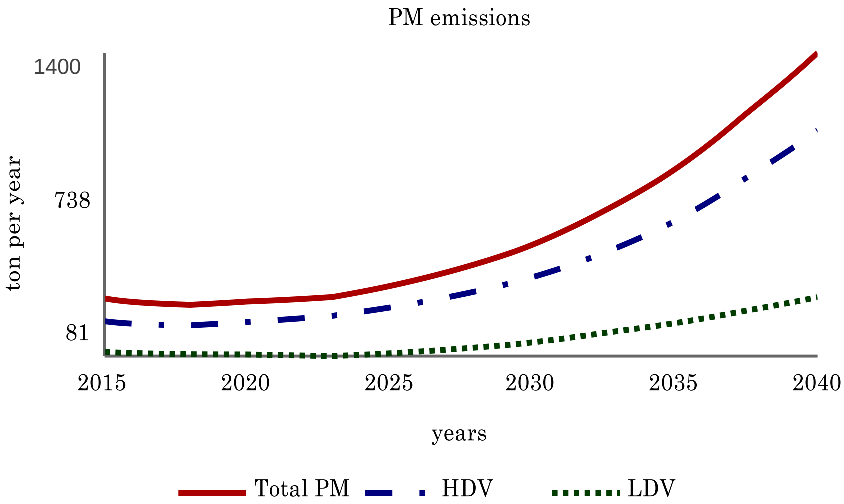


Figure 4.9 Predict of PM emissions

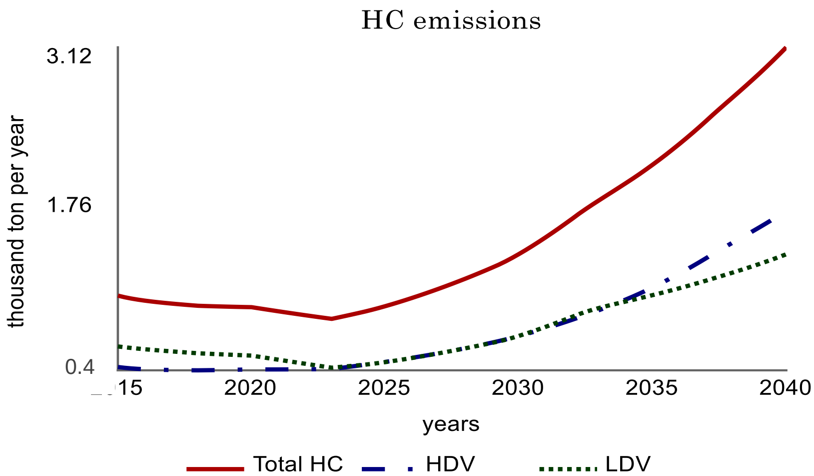


Figure 4.10 Predict of HC emissions

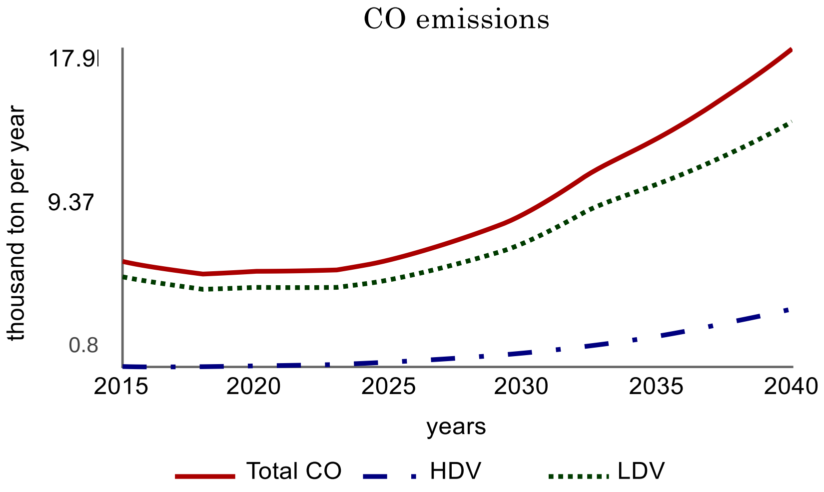


Figure 4.11 Predict of CO emissions

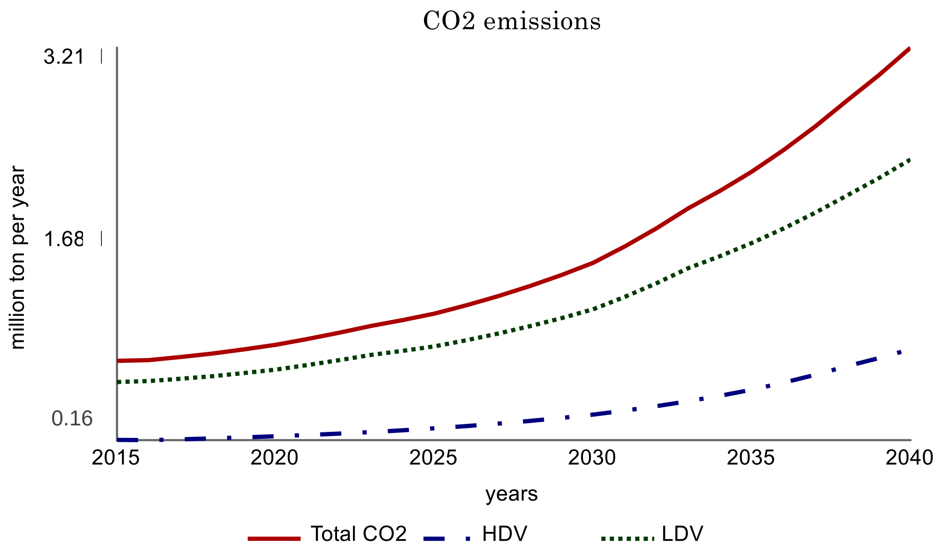


Figure 4.12 Predict of CO_2 emissions

4.3.3 New gas exhaust standard

Aiming to assess the effectiveness of applying a new gas exhaust standard. For that, the real situation and 2 kind of scenario in which the new gas exhaust standard was applied, were compared.

In this scenario 1, The Euro 4 standard for all vehicles was applied from 2015, and the Euro 5 standard for all vehicles from 2020[28)]. Hopefully, it is possible that the fuel quality, average vehicle maintenance level, and road situation will be improved. In Mongolia, all vehicles must be inspected to ensure that it conforms to regulations governing safety and emissions (HC, CO, CO_2) every year. However, the emission standard is not emission factor standard. Its measurement method is Non-Dispersive Infra-Red[29)]. The Euro standard is new in Mongolia, so it is difficult to apply Euro 4 or 5 standard for all vehicles. Since this scenario is an ideal scenario, the scenario 2 was set up as an additional scenario.

In this scenario 2, the Euro 4 standard for all vehicles except vehicles with over 10 years old was applied from 2015, and the Euro 5 standard for all vehicles except vehicles with over 10 years old from 2020[28].

The result of scenario 1, by converting to the Euro standard, the emission level in the real situation shows that NO_x was 1/3, PM was 1/7-1/37, and CO was 1/3-1/5 from 2015 to 2040 (Figure 4.13-4.15).

As a result for the scenario 2, the emission level in the real situation was reduced NO_x by 0.8%-22%, PM by 10%-38%, and CO by 4%-27% respectively from 2015 to 2040 (Figure 4.16-4.18). Euro standards emission level was close to the real situation until 2021, it was related to the vehicle population up to 10 years old dominated from 2021. Although vehicle population up to 10 years old was 27% of total population in 2015, it was 59% from 2023 until 2040 (Figure 4.19). The level of NO_x emission in Euro standard was more than real situation in 2015 because the emission factor of the vehicle with 0-3 years old in a real situation was lower than Euro standard (Figure 4.16).

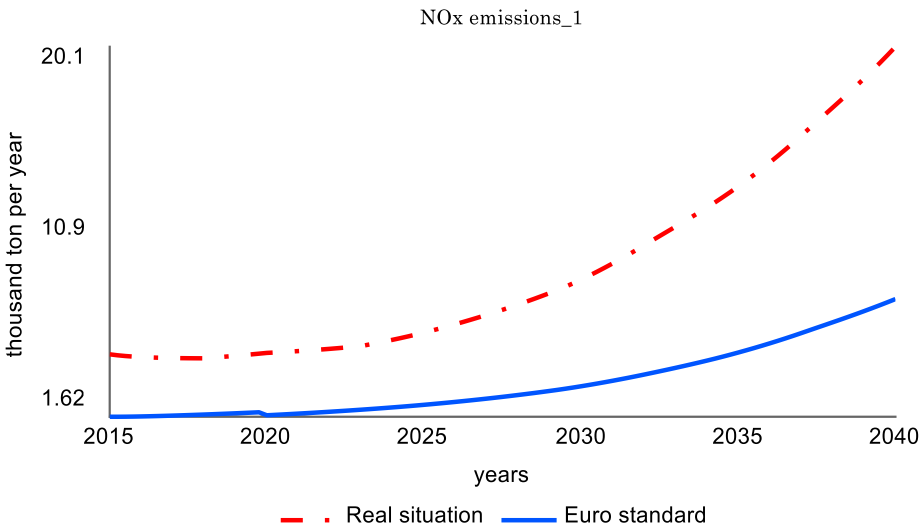


Figure 4.13 NO_x emissions scenario 1

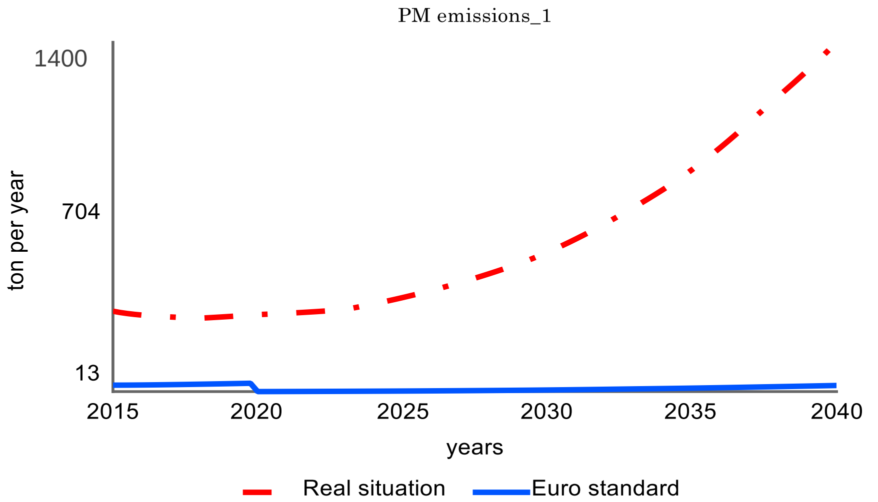


Figure 4.14 PM emissions scenario 1

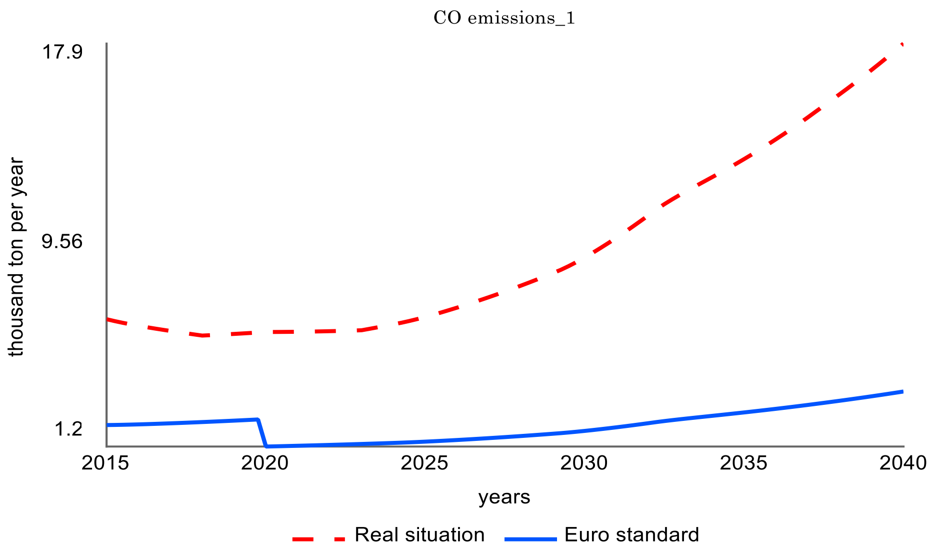


Figure 4.15 CO emissions scenario 1

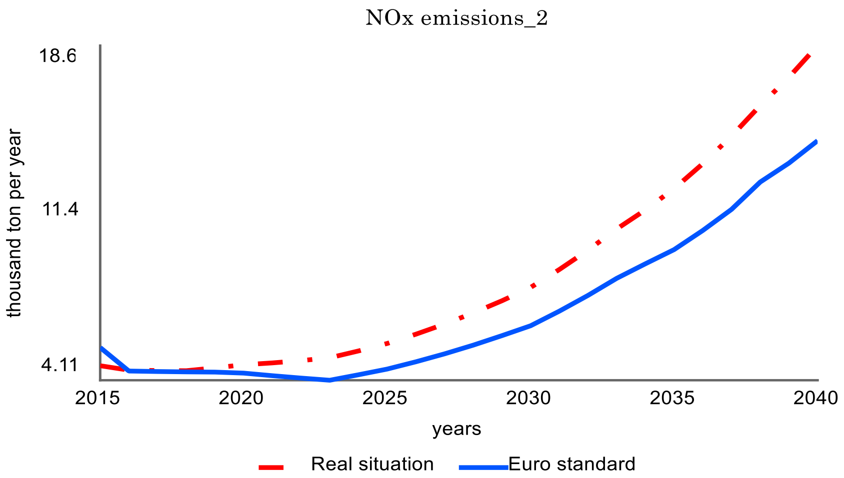


Figure 4.16 NO_x emissions scenario 2

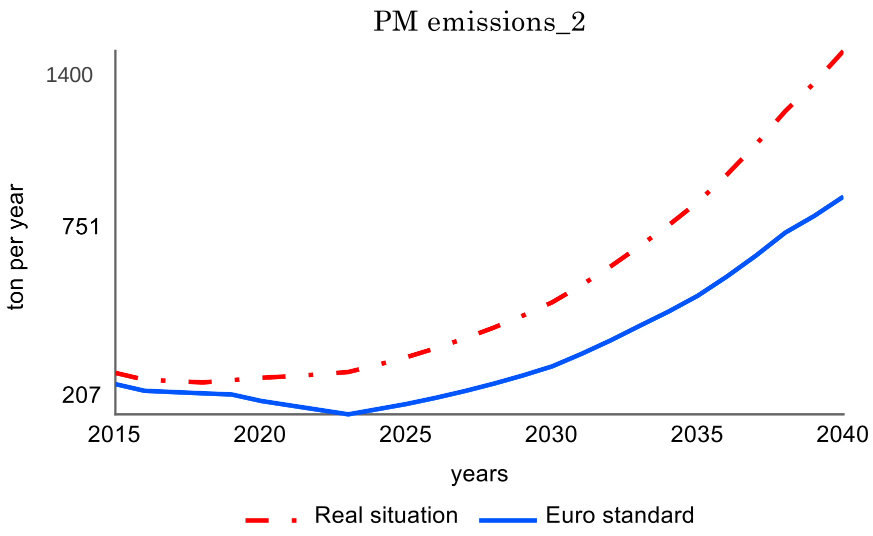


Figure 4.17 PM emissions scenario 2

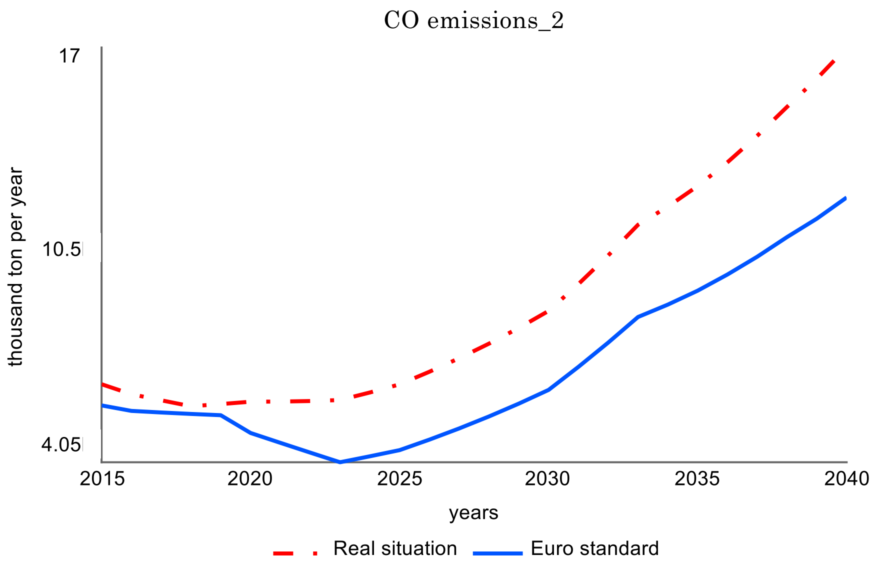


Figure 4.18 CO emissions scenario 2

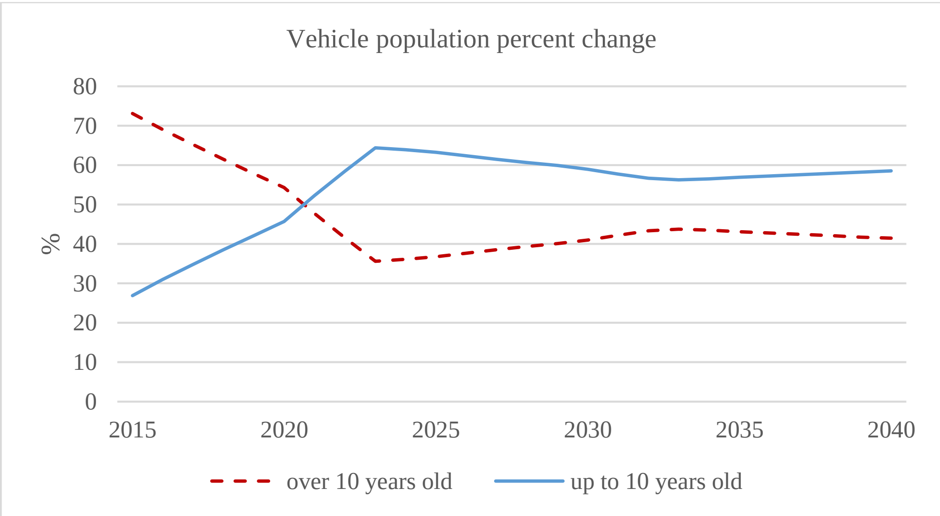


Figure 4.19 Vehicle population percent change by age group

4.4 Conclusions

The age-based cohort model for vehicles is a useful tool for prediction and for assessing regulatory mechanisms for vehicle emissions. This model also gave us the chance to identify which vehicle cohort would contribute the most to the annual emissions. The HDVs and vehicles in service for more than 10 years accounted for a significant proportion of the total pollution.

The data of VKT is essential component to vehicle emission calculation. Currently, there is not a database of VKT except public transport. Furthermore, it is necessary to record amount of odometer numbers when vehicle inspection for creating VKT database.

Considering the measurement results, the emission factors in Mongolia are higher than the emission standards in other countries, and differ for the same vehicle category depending on the vehicle age. This is why an emission factors were selected for each age group and category of vehicle. One reason of the high emission factors of vehicles in Mongolia are due to the lack of a vehicle emission standard there, and the fuel quality.

Chapter 5. On-Board measurement and emission prediction from vehicle engines using ordinary fuel and fuel additives in Mongolia

5.1 Introduction

In recent years, the level of air pollution in Ulaanbaatar city in Mongolia has increased greatly. The main sources of such air pollution consist of emissions from stationary sources and vehicles.

In the last decade, the number of vehicles in the capital city has increased more than 4.5 times. Sixty percent of motor vehicles in Mongolia can be found in Ulaanbaatar city. The increase in the number of vehicles has been high, and therefore, the load on roads and traffic congestion has become worse. As per statistics in 2015, there are approximately 331.5 thousand vehicles, out of which 72% are over 10 years old. Most of the people in the city use second-hand vehicles because of the low standard of living; approximately 96% of vehicles are four years or older[2)].

Currently, all petroleum products in Mongolia are imported. In 2015, 1,090 tons of fuel were imported, out of which 94% of the total was from Russia. With regard to fuel categories, diesel and gasoline constituted 59% and 39% of the total fuel, respectively, in 2015 (see Figure 5.1). The supply of fuel to Ulaanbaatar users was 44%. In recent years, the import of diesel fuel has decreased owing to mining activities[30)].

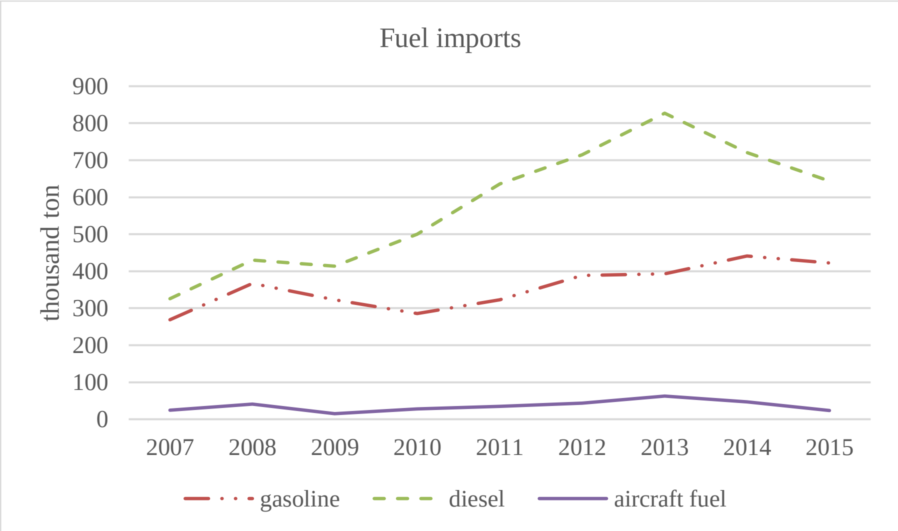


Figure 5.1 Fuel imports

Currently, the Mongolian National Standard (MNS) of vehicle fuel is similar to Euro 2 standard, but the sulphur content of diesel is four times higher than that of Euro 2 standard (see Table 5.1)[31)]. Considering the analysis results of fuel sample, the sulphur content in gasoline and diesel meets the MNS requirements, but the sulphur content in gasoline is two to eight times and diesel is 22 to 23 times higher than those of the Euro 4 standard, respectively. Sulphur content of supplied fuel in Ulaanbaatar city is approximately 200 ppm for gasoline and 1200 ppm for diesel. On the other hand, in Japan, Europe, and U.S.A, low sulphur fuel supply such as 50 ppm (Euro 4) or 10 ppm (Euro 5) is indispensable to ensure function of emission reduction system[4)].

Sulphur is a naturally occurring compound in crude oil. When fuel is burned the sulphur combines with oxygen (SO_x) to create emissions that contribute to decreased air quality and have negative environmental and health effects. The presence of sulphur in vehicle fuels also causes an increase in the release of other environmentally damaging compounds. High sulphur content decreases the catalytic conversion capacity of a system, thus increasing the emissions of nitrous oxides (NO_x), carbon monoxide (CO), hydrocarbons and volatile organic compounds. However, the benefit of having sulphur in vehicle engines is that it also acts as a lubricant. Thus, while decreasing sulphur concentrations in order to decrease vehicle emissions. Therefore, using fuel that contains a high quantity of sulphur, disrupts the normal operation of the system for filtering air pollutants in vehicles (see Table 5.2)[4)].

It is impossible to clean the air, or in particular to reduce air pollution from the transportation sector, without getting sulphur out of fuels. No significant air pollution reduction strategy can work without reducing sulphur to near-zero levels. Sulphur fouls conventional and advanced technologies to control vehicle emissions. Low-sulphur fuels are the key to reducing emissions from existing vehicles and enabling advanced control technologies and fuel-efficient designs for new vehicles[32)].

Table 5.1 Vehicle fuel standard

Vehicle fuel standard (ppm)					
Gasoline	*Euro 2*	*Euro3*	*Euro 4*	*Euro 5*	*MNS 217:2006*
Pb (Lead)	13	5	-	-	10
S (Sulphur)	500	150	50	10	500
Diesel	*Euro 2*	*Euro3*	*Euro 4*	*Euro 5*	*MNS 216:2006*
S (Sulphur)	500	350	50	10	2000

Table 5.2 Vehicle fuel sample result

Fuel category		The number of samples	Sulphur content (ppm)
Gasoline	AI-80	1	400
	AI-92	7	189
	NANO-92	2	239
	AI-95	5	117
	NANO-95	1	120
Diesel	-	6	1125
	NANO	1	1165

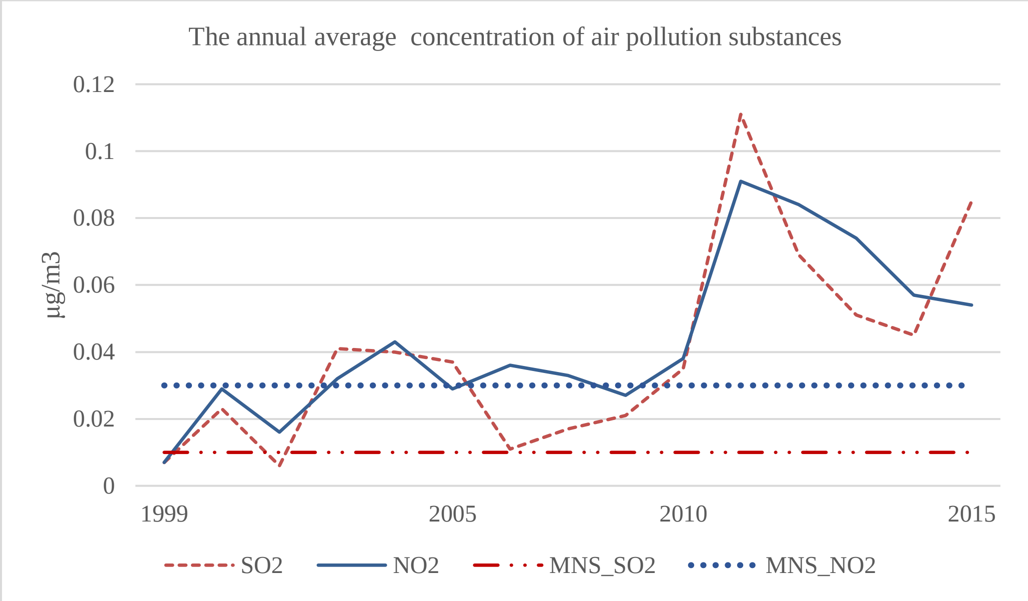


Figure 5.2 Air pollution substances

There are 12 ambient air quality monitoring stations in Ulaanbaatar city. These stations have been measuring ambient concentrations regularly. It measures every 5-30 minutes for 24 hours continuously. Data is processed and transmitted. Also there is wireless and data logger which collects all data for 6 months[4)].

The MNS of the average air quality for SO_2, considering a year, is 0.01 μg/m^3, and for NO_2, it is 0.03 μg/m3. The annual concentration levels of SO_2 and NO_2 have exceeded MNS since 2010. The annual average concentrations of SO_2 have increased from 0.007 μg/m3 in 1999 to 0.085 μg/m3 in 2015, which is 12 times higher. The annual average concentrations of NO_2 have increased from 0.007 μg/m3 in 1999 to 0.054 μg/m3 in 2015, which is eight times higher (see Figure 5.2)[2)].

One of the main reasons for vehicle emission is fuel quality. Thus, the fuel additive (Lubricon A-112M) which is an enzyme-based additive used in bunker fuel vehicles, was tested. It keeps the inside of the engine clean, thereby reducing the emissions of nitrogen oxides (NOx), suspended particulate matter (SPM), and hydrocarbons (HC)[33)].

Moreover, it has 20% less sulphur content than diesel following the result of Laboratory of Petroleum Product Analysis Mongolia[34)]. Also, to make the vehicle emission predictions of using fuel additives and applying Euro 4 standard.

The use of fuel additive in emission factor measurement was conducted for the first time in Mongolia. In an effort to assess the effectiveness of the Euro 4 standard and vehicle fuel additive, and also to support the update of current EF databases, emission data from two passenger cars (both diesel and gasoline) were collected and analyzed. This emission prediction model is worth supporting in national emission inventories and assessing the performance of air quality policies.

5.2 Methods

Lubricon A-112M (fuel additive) is a new product that was first introduced in late 2016, in Mongolia. In the past, EF measurement was not tested on this type of product in Mongolia. In this study, two vehicles with gasoline and diesel engines were selected. The emission factor (EF) measurement was conducted under three conditions: (1) using ordinary fuel, (2) using fuel additive once, and (3) using fuel additive for six months. Then, vehicle emissions were predicted by comparing the EF measurement results.

5.2.1 Emission factor measurement

Two types of vehicles were used in this study. The first one was a 1300-cc gasoline-engine-powered Hyundai, an Accent passenger car, which was manufactured in 2005. The Gross Vehicle Weight rating (GVWR) was 1580 kg. The second one was a 2600-cc diesel-engine-powered Hyundai Grace micro-bus, which was manufactured in 2003; GVWR was 3045 kg. Accent and Grace are typically used for taxi and public transport in suburbs of Ulaanbaatar, Mongolia. It is also suitable for age classification and engine category (gasoline and diesel). By age classification, 3.7% of the total vehicles are 0-3 years old, 23.7% are 4-9 years old, and 72.6% are over 10 years old.

This study was conducted under three conditions: Accent1 and Grace1 used ordinary fuel, Accent2 and Grace2 used fuel additive once, and Accent3 and Grace3 used fuel additive for six months. We assumed that which product needed time to adapt to the engine, and also, it would reduce emission when used for a long time. For this reason, the fuel additive was for six months by these vehicles (see Table 5.3).

Table 5.3 Measurement condition

Vehicle type	*Measurement condition*
Accent1 Grace1	Gasoline Diesel
Accent2 Grace2	Using fuel additive once Gasoline + Fuel additive Diesel + Fuel additive
Accent3 Grace3	Using fuel additive for six months Gasoline + Fuel additive Diesel + Fuel additive

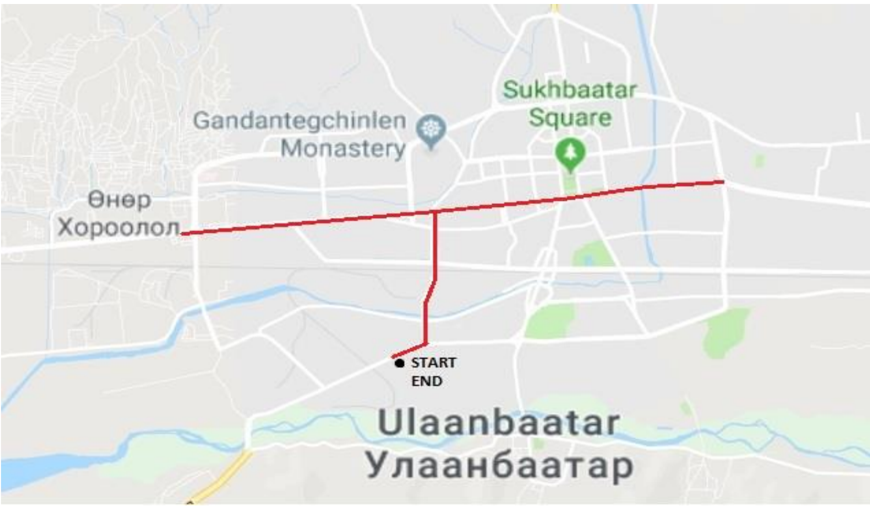


Figure 5.3 Measurement route (first day)

Figure 5.4 Measurement route (second day)

Aiming to study the amount of emitted PM and NO_x from engines while vehicles were running, and thus, made a comparative assessment using ordinary fuel and fuel additive (Lubricon A-112M). The addition rate was 1,000:1 (1000 ppm = 1 g/L).

An on-board emission measurement system that could only measure NO_x for the vehicle with a gasoline engine, but could measure both NO_x and PM for the vehicle with a diesel engine was used in this study. This measurement system measures the exhaust gas concentration (ppm) and exhaust flow from the exhaust pipe simultaneously.

The measurement system is necessary to be installed on a vehicle. Nevertheless, local car-mechanics, such as auto repair, maintenance factory, and so on, had neither knowledge nor experience of installation of the measurement system at first time. So JICA experts cooperated and trained workers of "Forward motors" auto repair center. Now they have experience and knowledge to install this measurement system. Each test vehicle was conducted on two different days to allow measurements. Further, two days were required to install and remove the emission measurement system from the vehicle. It took four days to complete a single measurement.

Two different routes were used for measurements (see Figure 5.3–5.4). These two routes passed through main roads with high traffic volume. Traffic census of taken on the main road showed 470 million vehicles a year in Ulaanbaatar. By vehicle type, 92% of all vehicles was a passenger car. Buses and trucks made up 8% of all traffic census. People usually prefer their own private car to public transport because the public transport is not well developed in Mongolia[18)].

Using the measured results, emission (g) was calculated. Moreover, with the system installed in the target vehicle, the emission under all conditions (acceleration, deceleration, constant speed, and stop) was measured. The on-board emission measurement system was different and more advanced than the general portable exhaust gas analyzer. The concentration of NO_x and PM, fuel consumption, and GPS location were measured at intervals of 0.5 s. Because sensors that could be installed in an engine exhaust pipe to take measurements were available, using a separate instrument was not required for taking samples. Therefore, samples were not kept in static volume as it was possible to take quick measurements. To accumulate the reading data to a collector that can be connected and operated by a computer interface (see Figure 5.5–5.7)[4).

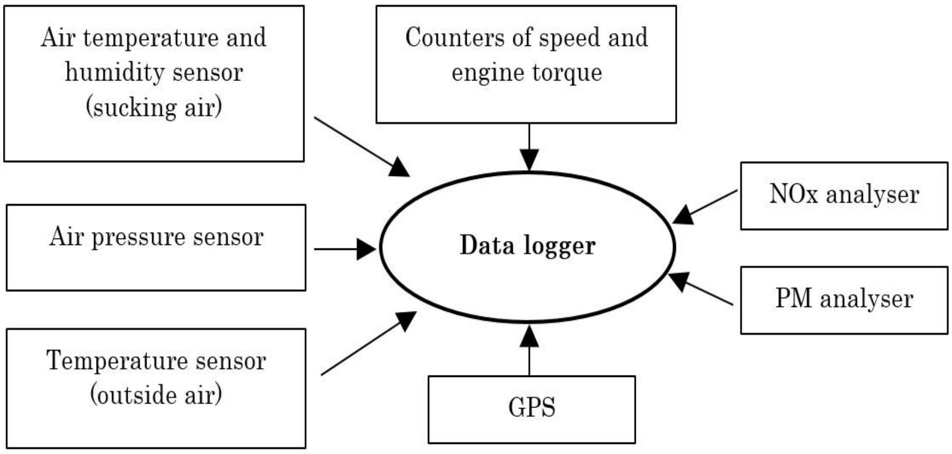


Figure 5.5 On-board emission measurement system scheme

Figure 5.6 MEXA-720 NO_x analyzer

Figure 5.7 MEXA-130S PM analyzer

5.2.2 Emission prediction

Aiming to assess the effectiveness of using fuel additives and applying the new gas exhaust standard in Mongolia. The results obtained in real situations (current situation) with those in the mixed scenario in which fuel additive was used and the new gas exhaust standard was applied, were compared.

Mixed scenario = Fuel additive (2016) + Euro 4 standard (2020)

In this scenario, the Lubricon A-112M fuel additive was used in 30% of all vehicles from 2016, and the Euro 4 standard was used for all vehicles, except those over 10 years old, from 2020. The average reduction rate of fuel additive EF measurement results were used for emission component in the scenario. Also, the vehicle emission prediction model which mentioned chapter 4 was used this study.

5.3 Result and discussion

5.3.1 Emission factor measurement

The results show that there is no big difference when using fuel additive for the vehicle with gasoline engine once or for long time. However, it is more effective to use fuel additive for long time to reduce NO_x emission for the vehicle with a diesel engine.

When using fuel additive for vehicle with diesel engine once, the emission level of NO_x decreased by an average of 4% and when using fuel additive for six months, it decreased by an average of 30% (see Tables 5.4 and Figure 5.8–5.10).

For the vehicle with a gasoline engine, when using fuel additive, the emission level of NO_x decreased by an average of 1.69 to 1.87 times (26%–37%). For the vehicle with a diesel engine, when using fuel additive, the emission level of NO_x decreased by an average of 1.04 to 1.51 times (4%–30%), and the emission level of PM decreased by 1.52 to 2.06 times (20%–26%), (see Table 5.5). The emission level of NO_x tended to decrease as the vehicle speed increased (20–60 km/h), but for the PM, it tended to decrease with the increase in speed, only when using the fuel additive (until 40 km/h), (see Table 5.4 and Figure 5.8-5.10). For the vehicle with a gasoline engine, the average reduction rate was 31% for NO_x, and for the vehicle with a diesel engine, the average reduction rate was 17% for NO_x and 23% for PM (see Tables 5.5).

Table 5.4 Regression coefficient of EF measurement

Regression coefficient		EF measurement of vehicle type		
		Accent_1	Accent_2	Accent_3
Nox_Accent	a	-0.005	-0.015	-0.013
	b	0.000	0.000	0.000
	c	1.925	0.313	0.919
	d	0.835	0.731	0.714
		Grace_1	Grace_2	Grace_3
Nox_Grace	a	0.008	-0.011	-0.004
	b	0.000	0.000	0.000
	c	10.691	6.509	4.890
	d	-0.175	0.340	0.198
PM_Grace	a	0.002	-0.001	-0.003
	b	0.000	0.000	0.000

	c	0.363	0.045	-0.100
	d	-0.015	0.040	0.070

Table 5.5 Average reduction rate

	Average reduction rate of Accent1 and Grace1 (times)		(percent)	
Gasoline	*NO_x*	*PM*	*NO_x*	*PM*
Accent1/Accent2	1.87	-	37%	-
Accent1/Accent3	1.69	-	26%	-
Average	1.77	-	31%	-
Diesel	*NO_x*	*PM*	*NO_x*	*PM*
Grace1/Grace2	1.09	1.52	4%	20%
Grace1/Grace3	1.51	2.06	30%	26%
Average	1.3	1.8	17%	23%

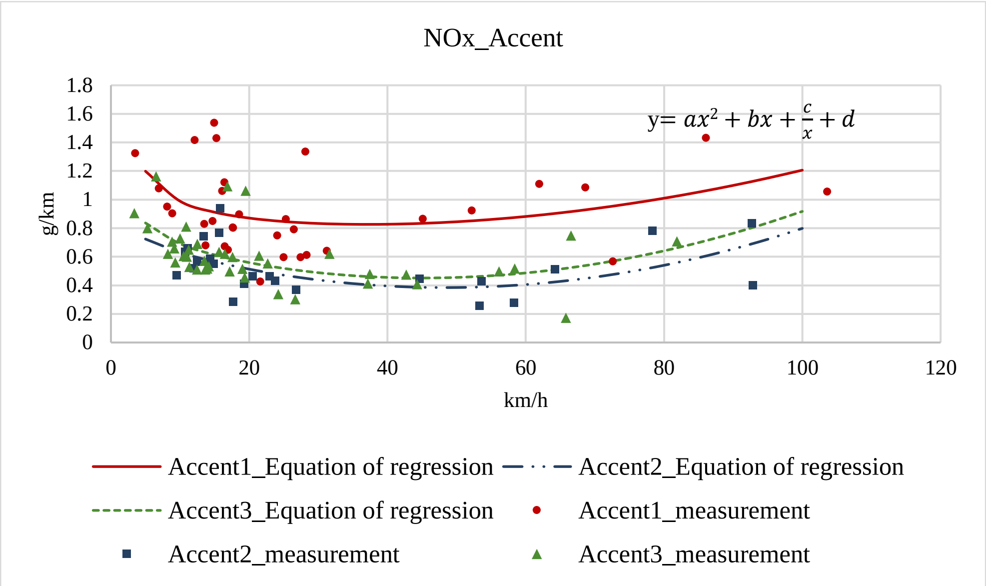


Figure 5.8 EF of NO*x* vehicle with gasoline engine

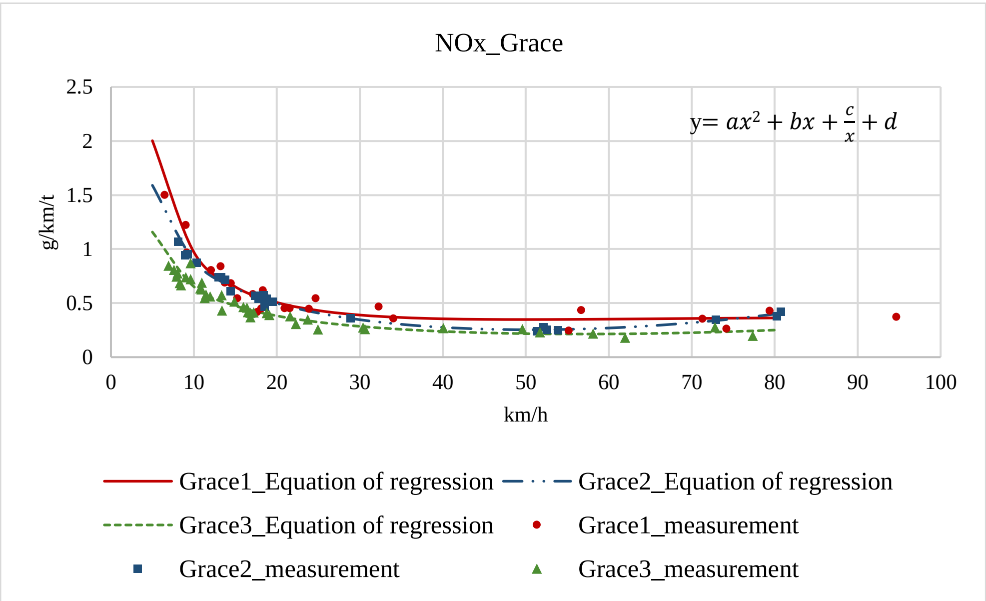


Figure 5.9 EF of NO_x vehicle with diesel engine

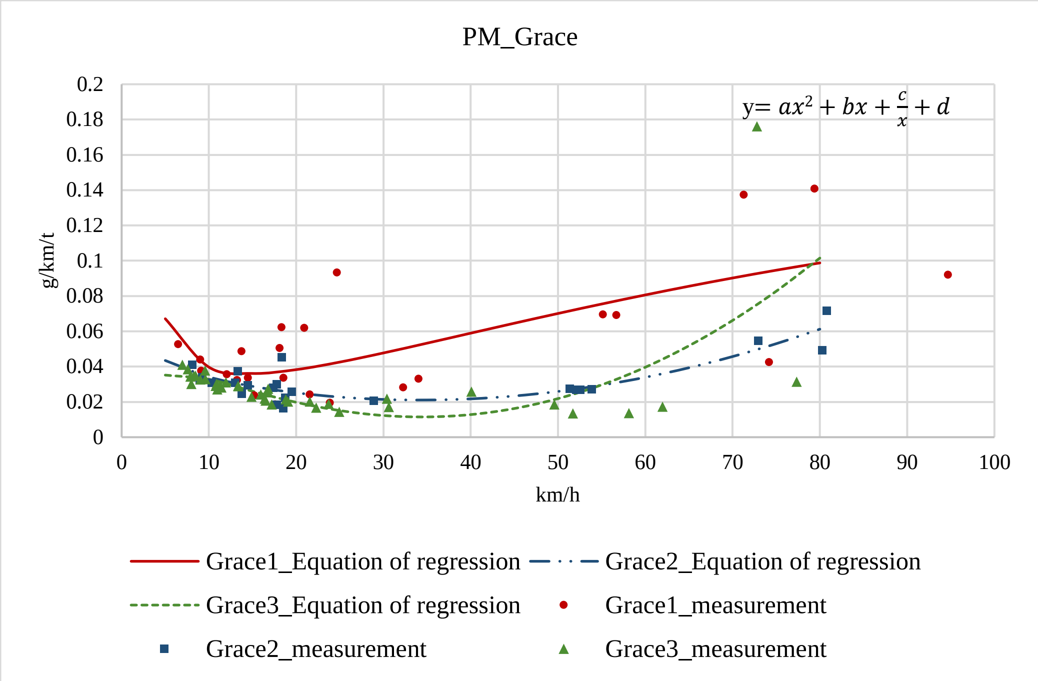


Figure 5.10 EF of PM vehicle with diesel engine

5.3.2 Emission prediction

Vehicle emission in two types of situation: the real situation and a scenario were predicted. The real situation means the current situation. The scenario means a situation where actions should be taken to reduce vehicle emission.

In comparing the real situation with the scenario, the emission levels of NO_x and PM reduced by approximately 8% and 13% until 2020. After that, the emission levels of NO_x and PM reduced by 6%–22% and 16%–30%. Thus, it means that the emission levels of NO_x and PM reduced by 8% and 13%, respectively, when using fuel additive, and 6%–22% and 16%–30% when applying the Euro 4 standard (see Table 5.6, Figure 5.11, 5.12).

For HDV, in comparing the real situation with the scenario, the emission levels of NO_x and PM reduced by 7%-38% and 13%-42%. However, the emission level of LDV was similar in the real situation and in the scenario. This scenario was more effective to HDV, but for LDV, it was not. The emission levels of NO_x and PM in LDV reduced by approximately 10% and 13% when using the fuel additive. Because the EF level in the real situation was similar to that of the Euro 4 standard, there was no big difference when applying the Euro 4 standard to vehicles 0-9 years old. If we apply this standard to vehicles over 10 years old, there will be a big difference in LDV emission. In other words, for HDV, the emission levels of NO_x and PM reduced by approximately 7% and 13% when using fuel additive, also 17%–38%, 21–42% when applying the Euro 4 standard until 2040 (see Figure 5.13, 5.14). This scenario was more efficient for the vehicle with a diesel engine and HDV.

Table 5.6 Emission prediction

years	NO_x		PM	
	Real situation	Scenario	Real situation	Scenario
2016	4743.0	4333.6	330.8	286.9
2017	4550.0	4157.3	316.1	274.2

2020	4650.3	4465.9	308.5	268.1
2021	4785.9	4462.5	315.4	264.5
2022	4865.5	4347.7	319.9	254.0
2024	5088.7	4142.7	332.5	233.9
2025	5384.4	4375.5	353.4	249.8
2026	5709.3	4617.7	376.8	267.7
2028	6552.2	5267.3	432.3	310.1
2030	7564.2	6043.0	500.3	362.0
2031	8145.7	6464.1	542.4	394.8
2032	8922.2	7088.7	591.6	433.6
2034	10682.9	8491.6	705.5	522.9
2035	11512.1	9110.7	768.7	571.5
2036	12436.1	9711.5	839.9	626.2
2038	14718.4	11424.0	1010.0	756.7
2040	17272.4	13389.1	1190.1	886.9

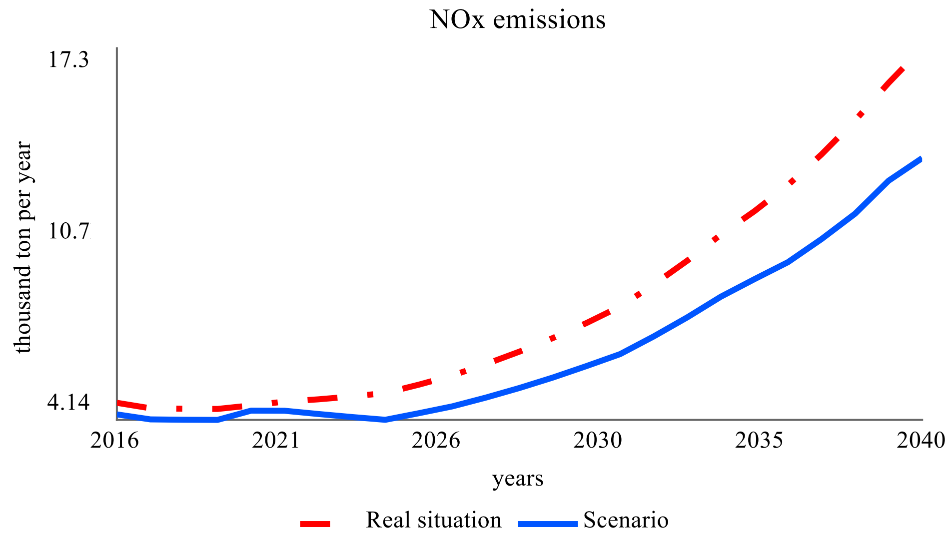


Figure 5.11 NO_x emission prediction

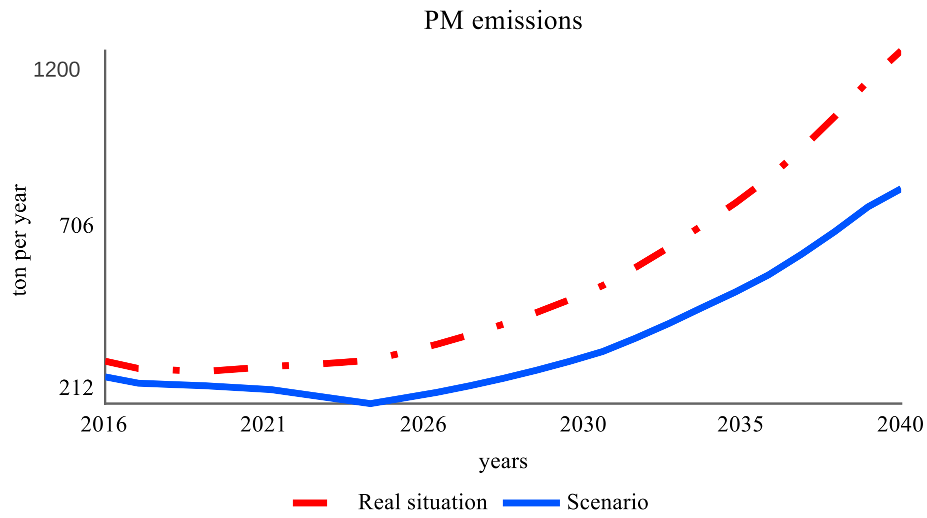


Figure 5.12 PM emission prediction

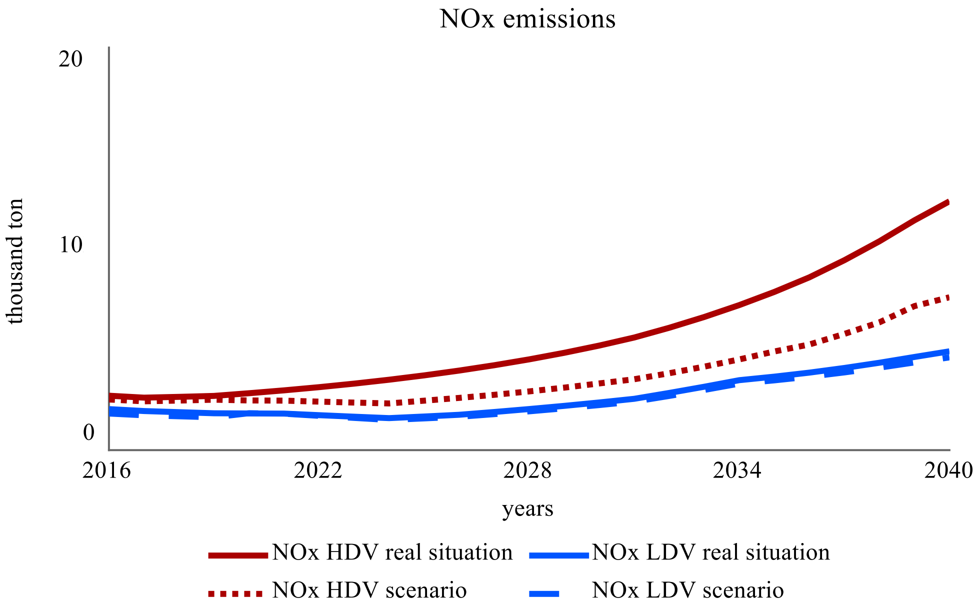


Figure 5.13 NO_x prediction by vehicle classification

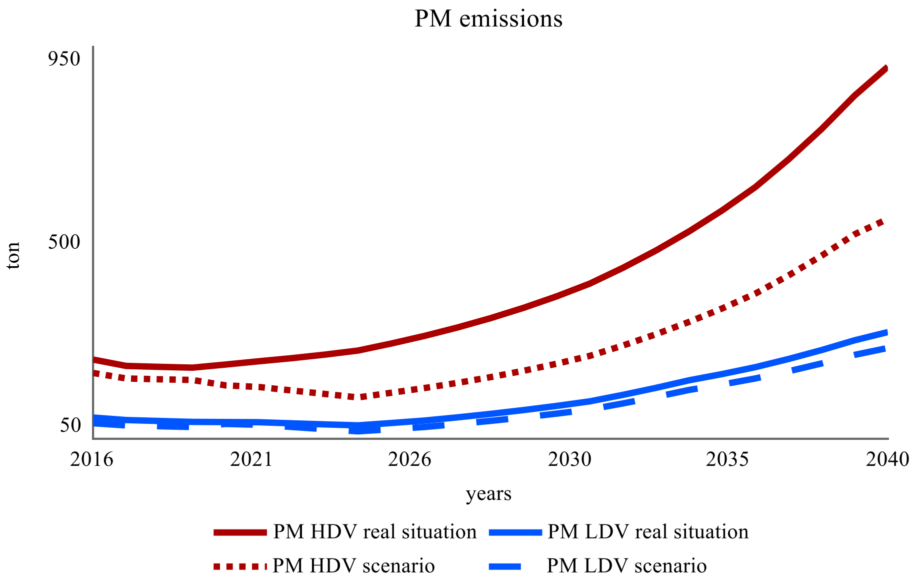


Figure 5.14 PM prediction by vehicle classification

5.4 Conclusion

Results were shown that Lubricon A-112M was more effective to use for the vehicle with a gasoline engine for NO_x reduction and for the vehicle with a diesel engine for PM reduction. The fuel additive was more efficient for NO_x reduction in the vehicle with a diesel engine when it used for long time. According to the study, the Euro 4 standard was more effective for HDV.

Not apply this scenario to vehicles over 10 years old, thus this study covered about 30% of the total vehicles. As to the measurement results, usually the EF level of vehicles over 10 years old exceeded Euro 4 standard. For example, in the passenger car, NO_x EF in the real situation was 10-70 times higher than Euro 4 standard (see Figure 5.15). Also, there was no vehicle EF standard, as it is new in Mongolia; therefore, we did not apply Euro 4 standard to all vehicles.

Currently, vehicles over 10 years old account for 70% of total vehicles. If this study covered 50%-60% of total vehicles, the result would be quite different and more efficient. To do this, we need a proper legal arrangement to control and reduce the population of old vehicles. In addition, legislation or technology alone cannot bring down emission levels significantly if the fuel quality does not improve. Currently, high-sulphur-content gasoline and diesel fuels are used in Mongolia. Therefore, the standard of vehicle fuel needs to be updated according to more suitable terms.

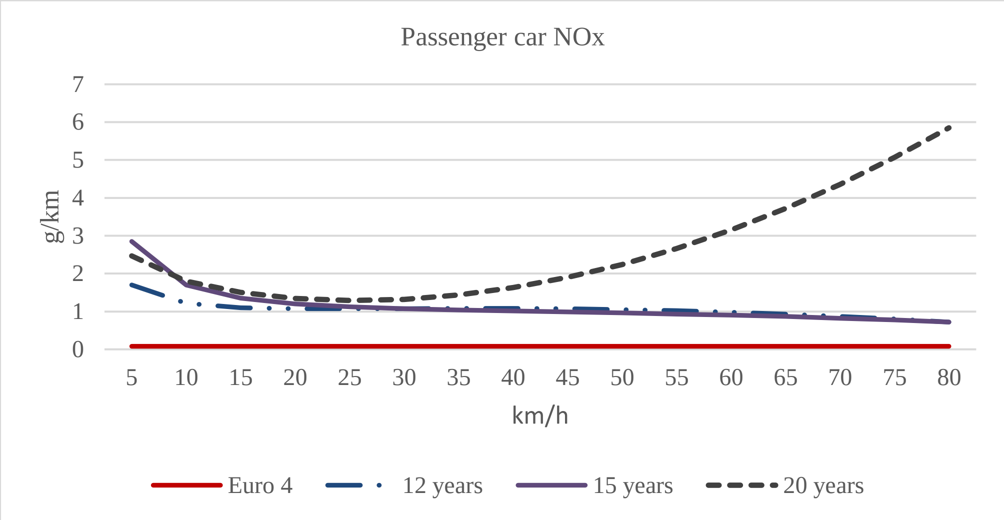


Figure 5.15 EF measurement of passenger car

Chapter 6. Summary and further study

6.1 Summary of each chapters

The total emission of main road was estimated by hour, day, year and analyzed for each vehicle type, age and link road. The annual emission of NO_x was 6905.7 t and PM was 301.7 t. In consideration to vehicle type, the truck and bus accounted 49% and 34% of NO_x emission and 30% and 15% of PM emissions respectively. The passenger cars accounted 17% and 55% of NO_x and PM emissions. In consideration to vehicle age, vehicles with over 10 years accounted 96% and 82% of NO_x and PM, with 4-9 years accounted 3% and 17%. At present emission factor standard based on both new and used vehicles in Mongolia has not been developed yet, but the research of emission factor of vehicles has been begun from 2014. Furthermore, it needs to expand the number of measurements and create a database. The measurements included emission concentrations of NO_x and PM, so it is required to equipment to measure emission factor of other pollutants (CO, CO_2, HC etc.). There are 7 main bridge roads which cross the Tuul river and Dund-gol river in Ulaanbaatar city. Four of them were the highest traffic census and highest emissions. The vehicle emission factors were higher than developed countries, especially truck and bus. The emission factors are depended on many factors which are vehicle fuel, speed, traffic condition, weather, vehicle service, vehicle age etc. Nowadays traffic congestion is serious problem in Ulaanbaatar. The vehicle population has been increased faster than the length growth of paved road last decades. The emission factor will increases when the vehicle speed is lower. This is also one reason for the vehicle emission. There is only 24 VDS camera and they do not work regularly because of organization budget. The data of traffic census is very important to road and traffic planning, also for environmental study.

The vehicle emission prediction model was developed from 2015 to 2040, using system dynamics which is a methodology for studying and managing complex systems that change over time. The age-based cohort model for vehicles is a useful tool for prediction and for assessing regulatory mechanisms for vehicle emissions. This model also gives us the chance to identify which vehicle cohort would contribute the most to the annual emissions. The HDVs and vehicles in service for more than 10 years accounted for a significant proportion of the total pollution. In comparing 2015 with 2040, the total vehicle population was increased by 3.9 times, the total vehicle emission level was increased by 4.3 times. The real situation and two kinds of scenario were compared: scenario 1, the Euro 4 standard for all vehicles was applied from 2015, and the Euro 5 standard for all vehicles from 2020. Scenario 2, which was same as scenario 1 but all vehicles except over 10 years. The result of scenario 1, by converting to the Euro standard, the emission level in the real situation showed that NO_x was 1/3, PM was 1/7-1/37, and CO was 1/3-1/5 from 2015 to 2040. As a result for the scenario 2, the emission level in the real situation was reduced NO_x by 0.8%-22%, PM by 10%-38%, and CO by 4%-27% respectively from 2015 to 2040. The data of VKT is essential component to vehicle emission calculation. Furthermore, it is necessary to record every vehicle’s annual amount of odometer numbers in vehicle inspection for creating VKT database. In consideration the measurement results, the emission factors in Mongolia were higher than the emission standards in developed countries, and differ for the same vehicle category depending on the vehicle age. This was why an emission factor for each age group and category of vehicle was selected. The high emission factors of vehicles in Mongolia are due to the lack of a vehicle emission standard and fuel quality. Sulphur content of supplied fuel in Ulaanbaatar city is approximately 200 ppm for gasoline and 1200 ppm for diesel. On the other hand, in Japan, Europe, and U.S.A, low sulphur fuel supply such as 50 ppm (Euro-4) or 10 ppm (Euro 5) is indispensable to ensure function of emission reduction system.

The vehicle fuel additive (Lubricon A-112M) was tested to improve fuel quality. Results were shown that for the vehicle with a gasoline engine, when using the fuel additive, the emission level of NO_x decreased by an average of 1.69 to 1.87 times (26%–37%). For the vehicle with a diesel engine, when using the fuel additive, the emission level of NO_x decreased by an average of 1.04 to 1.51 times (4%–30%), it depended on vehicle speed. Lubricon A-112M was more effective to use for the vehicle with a gasoline engine for NO_x reduction and for the vehicle with a diesel engine for PM reduction. The fuel additive was more efficient for NO_x reduction in the vehicle with a diesel engine when it used for long time. Here, aiming to assess the effectiveness of using fuel additives and applying the new gas exhaust standard in Mongolia. In this scenario, the Lubricon A-112M fuel additive was used in 30% of all vehicles from 2016, and the Euro 4 standard was used for all vehicles except those over 10 years old, from 2020. The emission level of NO_x and PM was reduced by 8% and 13% when using fuel additive, and approximately 6%–22% and 16%–30% respectively when applying the Euro 4 standard from 2020 to 2040. For HDV, the emission level of NO_x and PM was reduced by 7% and 13% when using fuel additive, and approximately 7%–38% and 21%–42% when applying the Euro 4 standard from 2020 to 2040. According to the study results, the Euro 4 standard was more effective for reducing HDV emission in Mongolia.

6.2 Main findings

For the emission inventory, it is necessary to create and expand the database of VKT, traffic census, emission factors in Mongolia, for making the emission estimation more accurate and exact. For that, the number of emission factor measurements needs to be expanded and conducted by every vehicle type and age. The database of traffic census will be created, if VDS cameras operation is provided regularly. Also, if they record every vehicle's annual amount of odometer numbers in vehicle inspection, the database of VKT will be created.

For the emission prediction model, it is based statistical data of vehicle population. There has not been any study about vehicle emission prediction before. The main reason to develop models for vehicle emission prediction is the emission calculation, prediction. Also, the consequences of different scenarios can be evaluated before management decisions are taken. For my experience, vehicle emission prediction dynamic model is suitable for long term management plans. This model was aimed at researchers in the field of transport-related air pollution and policymakers. The vehicle population growth which did not include human population growth and economic growth was estimated using statistical data.

For the fuel additive, Lubricon A-112M was tested first time in Mongolia. Results were shown that Lubricon A-112M was more effective to use for the vehicle with a gasoline engine for NO_x reduction and for the vehicle with a diesel engine for PM reduction. The fuel additive was more efficient for NO_x reduction in the vehicle with a diesel engine when it used for long time.

For the scenarios of the first year, the vehicle emission of NO_x and PM was reduced by 4% and 16% approximately when Euro standard applied all vehicles except over 10 years old. Furthermore, vehicle emissions decreased significantly year by year during the scenarios because the vehicle population of 0-9 years old was increased. Therefore it is not effective to apply new emission standard without decreasing vehicle population with over 10 years old. On the other hand, sulphur content of supplied fuel in Ulaanbaatar city is approximately 200 ppm for gasoline and 1200 ppm for diesel. In Japan, Europe, and U.S.A, low sulphur fuel supply such as 50 ppm (Euro 4) or 10 ppm (Euro 5) is indispensable to ensure function of emission reduction system. If the introduction of low sulphur fuel will be conducted early, the emission reduction effect would be expected more. So the high sulphur content fuel is also one reason of the high emission factor in Mongolia. Considering that the first step of reducing vehicle emission is to improve the fuel quality, then reduce the vehicle population with over 10 years old. Finally, to apply new emission standard like Euro 4, 5.

6.3 Scenario of the fuel sulphur content reduction

Comparing to real situation and scenario in which fuel sulphur content was reduced. For gasoline fuel, sulphur content was reduced up to 100 ppm and 50 ppm. For diesel fuel, sulphur content was reduced up to 500 ppm and 50 ppm.

The emission factor measurement result of low sulphur content fuel (500 ppm, 100 ppm, 50 ppm) was not been in Mongolia. Therefore, Japanese emission factor list was used this study. Emission factors were selected by year (1996-2004, 2005) which depended on sulphur reduction fuel in Japan. Also, emission factors were selected by vehicle type and traffic speed (30 km/h). The vehicle emission prediction model which mentioned chapter 4 was used this study.

Sulphur reduction for vehicle fuel in Japan. For gasoline, regulation of sulphur 100 ppm or less based on Compulsive quality standard with liberalization of imports (Abolition of Specific Petroleum Sulphur reduction has progressed by the voluntary of oil 1995 Products Law) in 1996. Introduction of sulphur 10 ppm or less by the independent measure of oil industries (except for Okinawa, some detached islands and so on) in 2005. Regulation of sulphur 10 ppm or 100 ppm less by revised Law on the Quality Control of Gasoline and Other Fuels (LQCF) in 2008. For diesel, to set up JIS standard in 1953. Regulation of sulphur 500ppm or less based on Compulsive quality standard liberalization of imports (Abolition of “Specific Petroleum Products Law”) in 1997. Start of sulphur 50 ppm or less by the independent measure of oil industries in 2003. Introduction of sulphur 10 ppm or less by the independent measure of oil industries (except for Okinawa, some detached islands and so on) in 2005. Regulation of sulphur 10 ppm or less by revised LQCF in 2007 (Figure 6.1, 6.2)[35)].

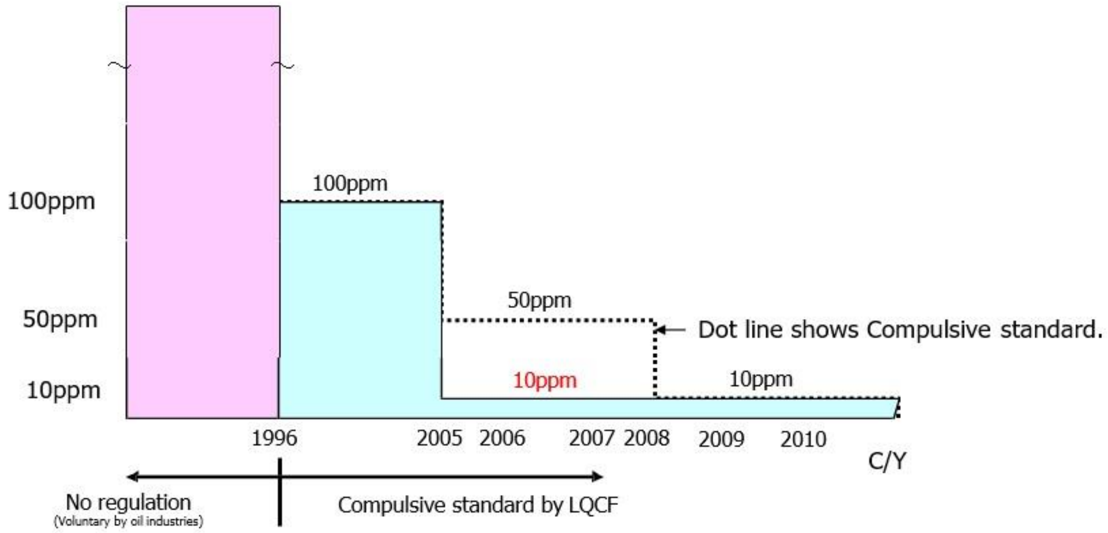


Figure 6.1 Sulphur reduction for gasoline in Japan

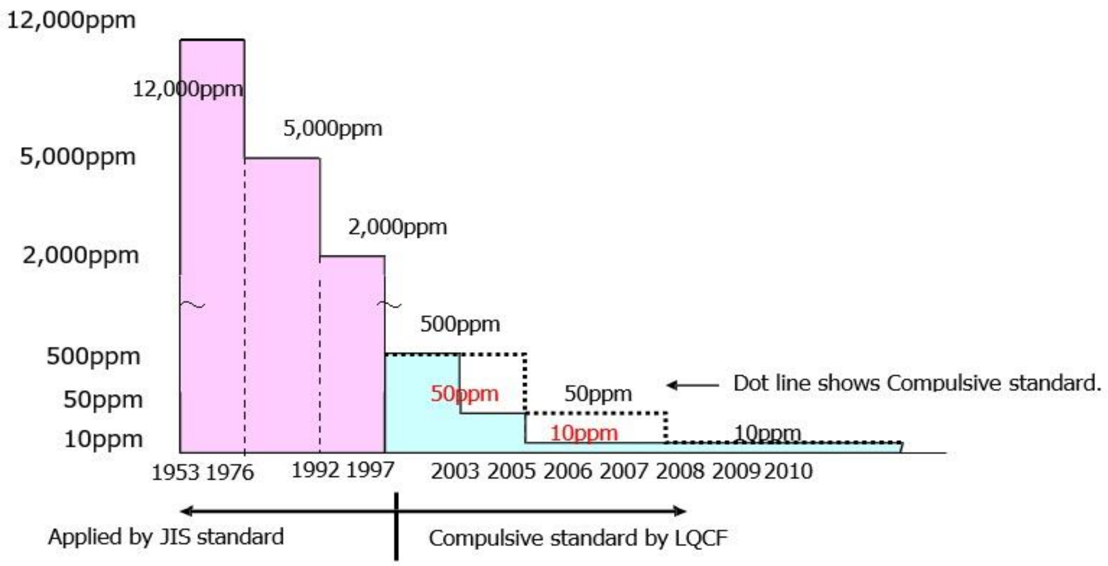


Figure 6.2 Sulphur reduction for diesel in Japan

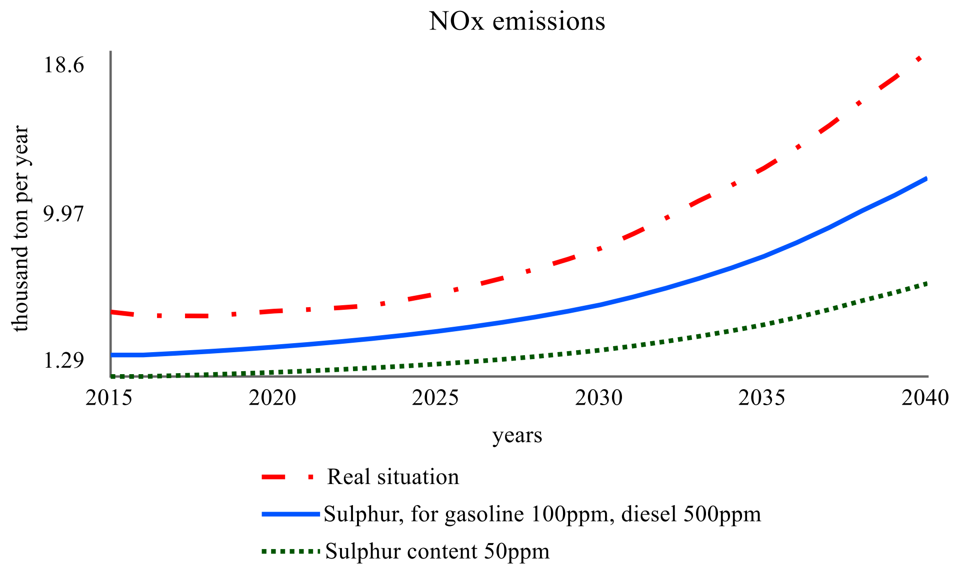


Figure 6.3 NOx emission prediction

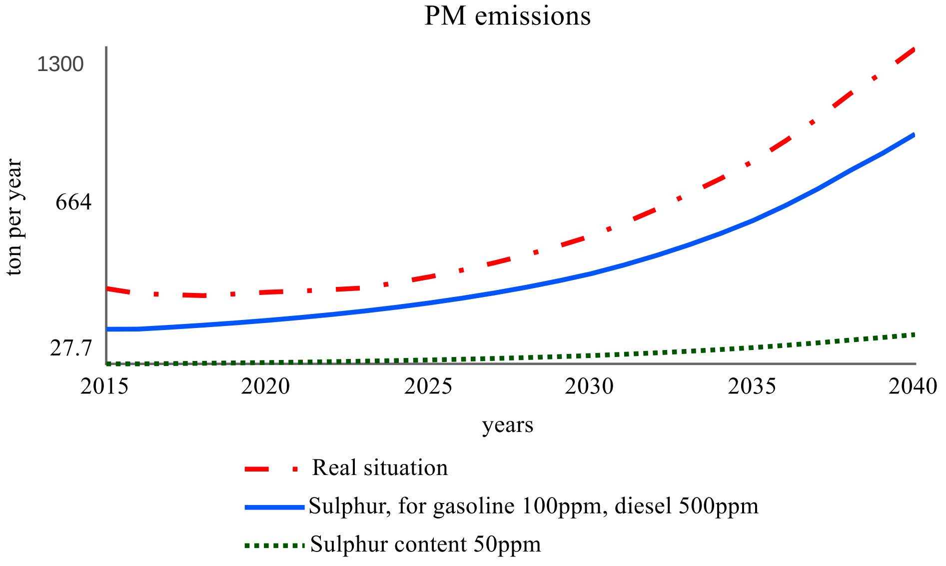


Figure 6.4 PM emission prediction

In comparing the real situation with the scenario, reducing sulphur content for gasoline 100 ppm and diesel 500 ppm, the emission level of NO_x and PM was reduced by approximately 38.6% and 31.4% until 2040. The emission level of NO_x was reduced by 35%-48%, PM 26%-49% from 2015 to 2040. Reducing sulphur content for vehicle fuel 50 ppm, the emission level of NO_x and PM was reduced by approximately 3.1 times and 9.3 times until 2040. The emission level of NO_x was reduced by 2.8-3.6 times, PM 8.6-11.9 times from 2015 to 2040 (Figure 6.3, 6.4).

This scenario was based on a Japanese EF measurement result. The level of EF depends on many factors as vehicle type, age, road condition, weather etc. These factors in Mongolia may be different from Japan, therefore, EFs also may be different. This scenario is just suggestion, not based on the real measurement result.

6.4 Limitation of this study and further improvement

Dispersion models estimate the circulation of pollutants in air to simulate the spatial distribution of emission concentrations and are widely used to calculate the spatial distribution of a pollutant concentration. Dispersion models have been categorized as statistical, deterministic, mathematical and physical modeling. Even if urban traffic induces turbulence and could be an important factor in pollutant dispersion, these are not taken into consideration. Wind direction, wind speed and atmospheric stability have, on the other hand, a major contribution on dispersion[36).]

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1. Batjargal, B. and Matsumoto, T.: Estimation and Prediction of Road Traffic Emissions in Ulaanbaatar. Journal of J.JSCE, Ser.G (Environmental research), Vol. 73, No. 5, pp. 183-190, 2017.
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Conference participation

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1. Bayasgalan Batjargal, Toru Matsumoto, Estimation and Prediction of Road Traffic Emissions in Ulaanbaatar, J.JSCE, Ser.G (Environmental research), Kobe, Japan, 6-8 September, 2017.