What is wrong with the implementation of auto pollution policy in Zimbabwe?
A system dynamics perspective.

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Thesis submitted in partial fulfillment of the requirements for the Degree of Master of Philosophy in System Dynamics.

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Bergen, Norway **June 2011**

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Abstract

Zimbabwe has in recent years experienced rapid growth in the national vehicle population. Since 1994, the vehicle population has increased by a total of over 150%. Many of these are poorly maintained low-cost second hand vehicles that do not meet strict emission standards of the countries of their origin. Zimbabwe has become a dumping ground for used cars because people rely heavily on importing second-hand vehicles as they cannot afford new vehicles sold in the country. As a result vehicle emissions have remained prevalent and have become a major source of pollution in the country's urban cities.

In 2002 an Environmental Management Act was introduced which replaced the old environmental policies. The policy prohibits pollution from vehicles and to ensure this, the Act created an Environmental Management Agency (EMA) which appoints a Standards and Enforcement Committee responsible for monitoring air quality standards through stationery monitoring which focuses on industrial emissions from factories and mobile monitoring for vehicles. However, despite clear intentions and regulations, implementation of the Act has remained minimal as literally no action was taken since the inception of the Act to this date to monitor and control mobile emissions. We therefore seek to address issues on what could have gone wrong with the implementation and what we could do to improve the process. Auto pollution is expected to keep rising as cheap cars flood the market rendering the Environmental Management Act ineffective.

System dynamics simulation and policy implementation analysis are used to answer the research question. The study designs a model that links auto pollution in Zimbabwe and the flow of sub-standard cars into the country, the duration of their use in Zimbabwe and the resulting effect as compared to the use of new cars sold in the country. It analyzes the current policy and develops options for improvement of the same policy.

1. Introduction

This study addresses the growing problem of auto pollution in Zimbabwean urban cities particularly due to changes in air quality which is caused by rapid proliferation of motor vehicles. It assesses the effectiveness of the implementation process of Environmental Management Act (EMA) in Zimbabwe during the period 1994 and 2010 and the prospects of effective implementation from 2011 to 2020 using system dynamics. This chapter provides the background to the study, the history of environmental policy in Zimbabwe and the growth of vehicle population.

Motor vehicle exhaust is the major source of air pollution in most urban centres both in industrialised and industrializing countries (Khare and Shama, 2002), and Zimbabwe has not been an exception. This has been due to extensive growth in road traffic over the years which has led to very high vehicular exhaust emissions which have been recognized as major contributors of air pollution in the world for over 40 years (OECD, 2008). The high demand for energy caused by these increase in traffic fleets is considered to be the most notable cause of air pollution in cities (Agrawal, Raj et al. 1980); Stephen 1981; Melgarejo et al. 1986; Barrat 1990; Fuleka et al., 1983; Ho and Tai 1988; Dube 1992; Musonza 1996; Musekiwa 1998; Zendera 2001; Zvimba 1999). Worldwide motor vehicle population has experienced a five-fold increase over a period of 30 years adding to the problem of auto pollution (Reinjenders 1992). However, Africa's problems with air pollution and exhaust emissions are not as significant compared to the industrialized countries of Europe and North America (United Nations, 2001). Despite this, the continent is regarded as more prone to any effects of exhaust emissions due to limited resources which hamper the continent's ability to carry out preventative measures to lessen these effects (Chapman 1993).

In Zimbabwe, ambient concentrations of nitrogen oxides (NOx) and particulate matter (PM_{10}) exceed World Health Organization (WHO) Air Quality Guidelines (AQGs) (Kuvarega and Taru, 2008). In 2002 the average level of PM_{10} measured at Loius Mountbatten School was 59.70 mg m−3, and was higher than the United Kingdom-European Union (UK-EU) guideline limit of 50 mg m−3. The average level of $PM_{2.5}$ measured at the same site also exceeded WHO guidelines of 15 mg m−3 (Ibid). As a result of this, the urban air quality is characterized by the presence of a mix of pollutants that pose threats to public health which is one of the problems affecting the urban population. Even though air pollutants which include these nitrogen oxides are mainly attributed to both vehicular and industrial sources but due to legislations and the relocation of industries from urban cities, industries are not a major problem for some of the cities in the country.

In 1993 there were no concerns of vehicular emissions in the country and air pollution was not a problem (Moyo, O'Keefe et al. 1993). Industrial processes, energy, agriculture, waste disposal, forestry, savanna burning and land-use were reported as the main sources of air pollution inventory back then (Zimbabwe Ministry of Environment and Tourism 1994), yet just fifteen years later Harare now faces severe danger of deterioration in air quality just like in other cities in the world. At present, over 5 million city inhabitants are exposed to pollutant emissions from more than a million vehicles.

1.1 Vehicle emissions and auto pollution in Zimbabwe

The transport sector dominates in urban centers and contributes up to 90% of emissions.[i] The sector consumes about 60% of liquid fuels in Zimbabwe, and grew at an annual rate of about 4.8% between 1985 and 1990 and at an annual rate of about 12.3% during the period 1990 to 1993 (Zimbabwe Ministry of Environment and Tourism 1994).

There are two explanations for the increase in emissions from transport: the first is the dependency on the internal combustion engine for transport; the second is the sharp increase in vehicle-kilometers travelled, which seems to be an unavoidable characteristic of economic development. A vehicle's full life cycle contributes to air pollution. This refers to emissions that are related to vehicle manufacturing, operation, refueling and disposal. Vehicles cause both primary and secondary pollution. Primary pollution is emitted directly into the atmosphere; secondary pollution results from chemical reactions between pollutants in the atmosphere.[ii] The composition and concentration levels of the pollutants depend on the distance travelled, type of the fuel, the vehicle age, and the composition of the fleet. The focus for this study is on exhaust emissions of five pollutants, which are sulfur dioxide (SO_2), carbon dioxide (CO_2), particulate matter (PM), carbon monoxide (CO) and nitrogen oxides (NOx). NOx and PM are produced by the inefficient burning of fuel in vehicle engines and ineffective filtering of exhaust gases, and SO_2 results from the sulfur content of fuels.

The fast increasing numbers of imported second-hand cars which do not meet regulations in their countries of origin and poor road networks in Zimbabwe have lead to traffic congestion in cities around the country with impacts on fuel wastage and auto pollution. Most of the vehicles in use are not roadworthy, due to lack of maintenance caused by the shortage of spare parts and foreign currency in the country particularly over the last 8 years. The vehicles do not have catalytic converters and therefore they have a high potential to emit pollutants into the atmosphere. To worsen the situation, Zimbabwe still uses leaded gasoline which contains 0.6 to 0.8 mg of lead per liter even though unleaded gasoline is available on the market. Leaded gasoline causes commensurate rises in airborne-lead concentrations. As a result of this continual influx of road unworthy cars, auto pollution has been on the rise in the country.

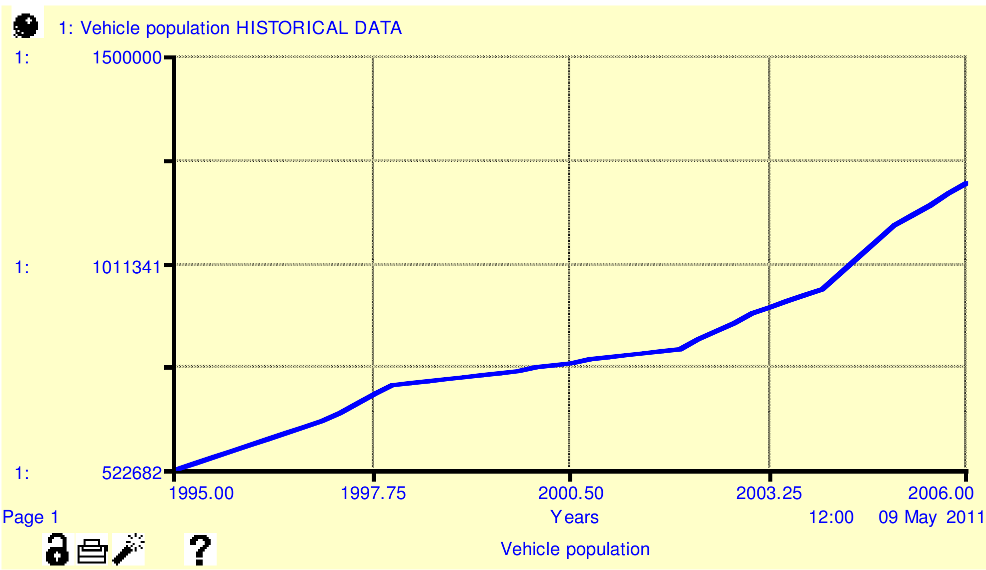


Figure 1: Zimbabwe vehicle population. (Reserve Bank of Zimbabwe, Monetary Policy Review Statement, July 2005)

Figure 1 above shows the total vehicle population between 1995 and 2005. The population of registered vehicles in Zimbabwe doubled between 1992 and 1998 (National Strategy Studies, 2010) and during the past 10 years from 2000 to 2010 the doubling has continued.[iii],[iv]

1.2 Environmental Law

Attempts to control mobile emissions began in the United States, Japan and northern-Europe around 1970. Until about a decade ago, direct public health impacts were the focus of auto emission policies which were designed to reduce emissions of major pollutants which posed high risk to health (OECD, 2008). Of these pollutants, the most serious was lead, an additive that raised octane levels in gasoline. Today gasoline is lead free in most of the developed world and is being steadily phased out in everywhere else. In Zimbabwe, like in most African countries, leaded gasoline is still available on the market and it is the most widely used due to economic reasons.

Various laws have been passed, amended and replaced in Zimbabwe over the last 40 years with the aim to reduce or eliminate atmospheric emissions. However no proper evaluation has been carried out yet to establish the success of these laws. There is therefore need to assess and analyze the progress achieved in implementing specific goals and policies with regard to auto pollution. This is relevant in order to ascertain the success of the existing policy, find ways to improve the strategies and formulate an alternative towards a cleaner atmosphere. This research is meant to highlight that part of the environmental policy implementation process, that is, how the policy was implemented and with what results. While we have given more attention on the status of auto pollution in Zimbabwe and on details of the implementation process, no attention has been given to policy formulation and how the policy changes.

To combat pollution in a more effective way an Environmental Management Act (Chapter 20: 27 No 13/2002 EMA) was introduced in 2002. When the Act came into operation in 2004, it brought in a holistic approach to environmental management in Zimbabwe after many years of a fragmented and less coordinated legal and policy framework. EMA takes a broad definition of the environment to include economic, biophysical, technological, social and political aspects, thus embracing the concept of sustainable development. However, despite this broad perspective to environmental management, a lot remained unfulfilled particularly on atmospheric control as no implementation was carried out to monitor and control mobile or exhaust emissions which then resulted in the continued growth in the inventory of exhaust gasses to this date. In 2007 the Government issued the Environmental Management (Atmospheric Pollution Control) Regulations based on the polluter pays principle. According to the regulation:

> No owner or operator of a transport conveyance shall operate it in such manner or condition as to cause air pollution in contravention of prescribed emission standards for the class of transport conveyance concerned. Any operator of a transport conveyance who pollutes the environment by contravening the emission standards referred to, commits an offence and shall
>
> (a) on conviction for a first offence, be liable to a fine,
>
> (b) on conviction for a second or subsequent offence, be liable to a fine or in default of payment, to imprisonment for a period not exceeding six months.

To ensure the above, the Act, created an Environmental Management Agency (EMA) which came into existence in February 2005. EMA succeeded the Department of Natural Resources, the Water Pollution Control Unit, the Hazardous Substances Control Unit and the Air Pollution Control Unit. EMA appoints a Standards and Enforcement Committee responsible for monitoring air quality standards through stationery monitoring which focuses on industrial emissions from factories and mobile monitoring of vehicles. EMA has authority to impose an environment levy on any person or class of persons whose activities impact on the environment or any person who emits any substances which cause air pollution. However, despite these regulations, implementation of the Act has remained minimal as literally no action has been taken since the inception of the Act to monitor and control mobile pollution. EMA failed to take into account the implementation possibilities based on the availability of expertise and the availability of appropriate technology to test mobile emissions. The possibilities of limiting a high influx of sub-standard second hand cars into the country as a measure to control emissions have also been overlooked over the years.

Attention has been given to stationery monitoring of air pollution rather than mobile monitoring. The City of Harare has eight pollution monitoring stations, which are: Mbare, Southerton, Highfield, Mabelreign, Mufakose, Town House, Hatfield and Beatrice Road Infectious Diseases Hospital. In 2001, suspended particulates and sulphur dioxide could not be monitored at Southerton station due to breakdown of the power point and all the other pollutants could not be monitored throughout the whole year due to lack of transport (Kuvarega and Taru, 2008). This shows that stationery monitoring of atmospheric gasses has been ongoing for some time but there has been no monitoring of mobile emissions in the past even though the new law clearly forbids pollution from vehicles.

There exists a knowledge gap on issues of program design, resource and administrative capacity and outcomes of environmental policy implementation in Zimbabwe. What could have led to non-performance of the policy? Is it ineffective implementation methods? As noted by other scholars non-performance of environmental legislation can be a result of ineffective methods of implementation of the legislation or inadequate resources, (Shava, 2003).

1.3 Literature review

Studies have been conducted in the past on air pollution in Zimbabwe (Kuvarega and Taru, 2008; Dube, 1992; Musonza, 1996; Musekiwa, 1998; Zendera, 2001; Zvimba, 1999). These studies have focused on air pollution in general and not specifically vehicular emissions and neither has any study been conducted from a system dynamics perspective. The politics of environmental policy making in Zimbabwe has also been given attention (Keeley and Scoones 2000). This study will add knowledge to the policy implementation of EMA revealing its actual versus intended outcomes on controlling auto pollution.

<u>Policy implementation</u>

Policy implementation means to carry out, accomplish, fulfill, produce or complete a policy (Hill and Hupe 2002). Implementation presupposes precise policies as specific responses to specific problems in society because there must be something out there prior to implementation. After a public decision has been made it then must be applied in real world situations. Implementation is the process whereby programs or policies are carried out. It includes translation of policy prescriptions into goals and actions that address the procedures needed to sustain the policy's intended objectives (Sabatier 1991). These definitions of implementation share an emphasis on the successive development of policy from intent through structuring of action to the level of policy impact generation (Nagel 1994). This study uses Van Meter and Van Horn (1975) definition of policy implementation which is taken as encompassing actions by both public and private individuals or groups and these actions are directed at the achievement of objectives set forth in prior policy decisions.

Implementation until the early 1970s was neglected whilst more emphasis was given to policy formulation and decision making. This was based on the assumption that as long as a good policy is formulated nothing can go wrong with implementation as the administrative arm would simply carry it out following the outlined procedures, (Hargrove, 1975; Thomas & Grindle, 1990). This however, is not always the case especially in developing countries where implementation is central to politics as observed by (Grindle 1980). Pressman and Wildavsky's (1973) study on programme implementation on unemployed inner-city residents of Oakland, California revealed that the way job creation programmes were being carried out was not the same way as anticipated by policy makers and it was argued that the problem was in the manner implementation was carried out (Pressman ; Howlett and Ramesh 2003). This then triggered interest in implementation studies and its importance in the policy cycle.

During the implementation stage, policy can be said to continue to be shaped as policy making continues through the decisions by those involved in the implementation. This question on how to separate implementation from policy formation influenced what is known as the top-down/bottom-up debate. Implementation process is complex as it occurs across time and involving multiple actors. These theories have taken into account a number of variables and others have built models that try to take into account all the identifiable variables. Many of these implementation theories show variations between policy issues or types of policy issues and between institutional contexts (Hill and Hupe 2002). Both top-down and bottom-up theories of policy implementation have focused on what policy makers and policy administrators can do and should do in order to ensure effective implementation and positive policy outcomes.

The top-down approach assumes that the policy process can be viewed as a series of chains of command made by political leaders and articulated in a clear policy preference which is then carried out by the administrative machinery that serves the government. On the other hand, studies conducted from a bottom up perspective argue that the success or failure of many programs often depends on the commitment and skills of the actors directly involved in implementation programs (Lipsky 1980). The bottom-up approach directs attention to the formal and informal relationships which make up the policy subsystem involved in implementing the policy.

Numerous studies have shown that monitoring, coordination, flexibility and political stability improve implementation (Van Meter and Van Horn 1975; Brinkerhoff 1996; Lane and Ersson 2004). Policy outcomes are influenced by bureaucratic complexity and intra bureaucratic coordination (Morton 1996) and other scholars emphasize the interconnections between cultural values of the administrative body and economic problems in non-western bureaucracies (Riggs 1964; Emmerson 1983; Doner 1992). Their models of policy implementation expand on administrative structures, institutional constraints and the type of political regime implementing the policy, economic problems and resource availability have also been addressed in some of these models (Thomas and Grindle 1990). Lane and Ersson (1996) state that corruption and poverty trap are the main challenges to effective policy implementation in developing countries as these countries are politically unstable. However failure to implement a policy effectively wastes scarce resources, undermining any prospects for sustainable development which will lead to an eventual less capacity to cope with any evolving problems that require government attention and the cycle of policy implementation failure continues.

Development issues are pertinent to contemporary Africa and what is central to development effort is the need to formulate and implement robust policies. Achieving sound pollution control is one of the many aspects of policies for sustainable development. In this regard, implementation studies are a crucial part of the development process because implementation research describes assesses and explains. It often seek to ask "What is happening, what is desired and why is it happening as it is?" (Werner 2004). As policy makers and program managers are expected to use state resources to efficiently and effectively promote social goals, implementation research can be used to provide information which supports the decisions which they make. Evaluation in the form of implementation research assists those involved in the designing and operation of the programs.

Implementation and system dynamics

System dynamics regards implementation as important right from the beginning of the modelling process and it also includes guidelines for implementing system dynamics models effectively even though little evidence can be found that the guidelines are being followed. Although system dynamics literature has focused on the implementation of improved policies, until recently it had not fully explored how system dynamics can be used to implement strategies that result from either system dynamics of other analytical measures (Snabe and Größler 2006). Only a limited published work in system dynamics show a clear structure of the policy implementation (Wheat 2010). Some projects particularly those that focus on cognitive and behavioural aspects including alignment of mental models (Andersen, Richardson et al. 1997), emphasize modelling efforts which centre on strategy forming and not strategy implementation (Snabe and Größler 2006), whereas system dynamics can also be effective beyond formulation into implementation. Implementation in system dynamics has been an issue right from the beginning (Forrester 1968) and was further emphasized in 1994 when policy implementation was stated as the last step of the modelling process (Forrester 1994).

Implementation is a problem that should be dealt with right from the beginning of the project (Coyle 1977). Sterman (2000) highlights that implementation should not be regarded as the end of a project but rather as the beginning of a new model cycle. He goes on to point out implementation to be amongst the challenging areas for system dynamics in the future. More work in system dynamics has addressed questions on how and if implementation concerns are part of the modelling process, in principle and practice (Wheat 2010). It has been suggested that the process of incorporating implementation to the modelling process should be achieved by adding new structures with stocks and flows as a way of illustrating features of policy implementation as opposed to changing parameter values to address 'what if' questions (ibid). This is the where this study is located arguing that system dynamics application in implementation is expected to deepen and broaden the application from the ordinary way in defining the process of implementation by way of creating a new policy structure that establishes the implementation challenges.

1.4 Research objective

This main objective of this study is to come up with findings that address the following:

Determine and establish what went wrong with the implementation of the Environmental Management Act from 2002 to present, such that it failed to control auto pollution and assess whether the policy is likely to succeed in reducing auto pollution until 2020.

1.5 Research questions

In addressing the above objective the following questions were used in the study to inform and guide the research process:

1. What happened to auto pollution inventory in Zimbabwe from 2002 to 2010 after EMA had been enacted?
2. What was desired to happen to pollution levels during that same period?
3. Why did it happen as it did instead and why did the EMA policy not work?
4. What can happen from 2011 onwards in terms of auto pollution levels?

1.6 Overview

This study comprises seven sections. Section 1 introduces the main themes of research, explaining the research problem. It also gives a general background to auto pollution. Section 2 reviews both historical and the status quo of auto pollution in Zimbabwe. Section 3 provides a conceptual map to the approach adopted in this study, reviewing a variety of literature which has informed the analysis. The system's behaviour is analyzed using a dynamic simulation model based on the principles of system dynamics (SD) methodology and theories of policy implementation. The fourth is the analysis section. Section five discusses the policy. Section six outlines the implementation challenges. The last section of the study concludes and recommends a way forward towards meeting the goals and cleaner air in Zimbabwe.

2 Dynamic problem

2.1 The problem

The dynamic problem is an increase in levels of vehicular emissions into the atmosphere form 1994 to 2010 in Zimbabwe. These emissions comprise of five pollutants, which are sulfur dioxide (SO_2), particulate matter (PM), carbon monoxide (CO), carbon dioxide (CO_2) and nitrogen oxides (NOx). The behavior of the pollutants is illustrated in figure 2 below.

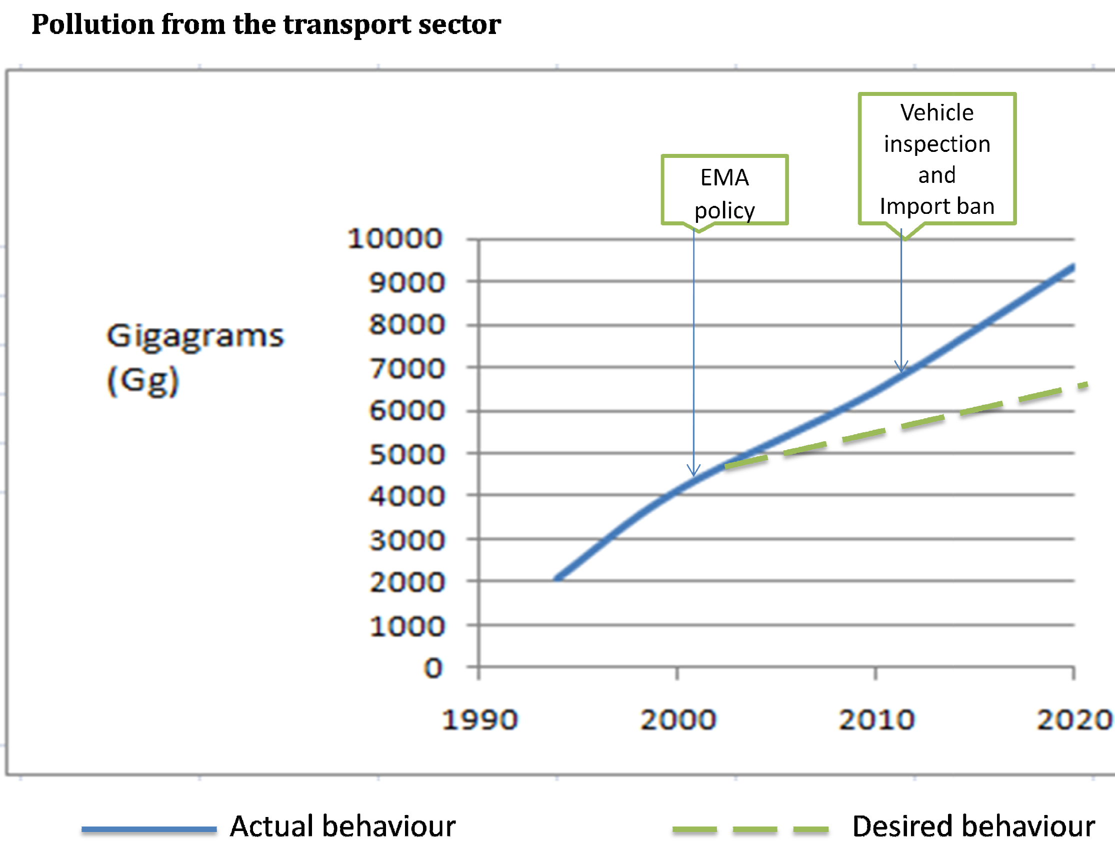


Figure 2: Trend of auto pollution from 1994 to 2010 and forecasts to 2020 (National Strategy Studies (2010))

There is a sharp growth between 1994 and 2000, a steady increase from 2000 to 2010 and a further steady increase from 2010 to 2020 as estimated. These emissions in Zimbabwe were expected to increase by a total of 38% between 1994 and 2010 from a total of CO_2 equivalent of 2054.20Gg to 6 441.57Gg. This corresponds with growth of motor vehicles between 1992 and 1999 which was 12.2% per annum (National Strategy Studies Report, 2010).

2.2 The public issue

Increases in the level of auto pollution represent threat to public health. This is because emitted particles reside much longer in the atmosphere and epidemiological studies indicate an association between exposure to particulate matter and a number of health effects (WHO, 2002). Toxicological studies show that the size and the chemical composition of the particles determine the extent of the health effects (Morris, 2001; WHO, 2002; Mugica et al 2002). Pollutant gasses when inhaled, they can penetrate into the lungs causing the respiratory system to inflame. These particles can have high metal concentrations such as lead which is associated with leaded fuel combustion which affects mainly the nervous system and the vascular system particularly in children. (Folio et al., 1982; Valerio et al., 1988; Mugica et al., 2002). During a ten year period from 1982 to 1992 Harare urban population increased by a total of 80% (Bassett, Chokunonga et al. 1995). This shows a rapid urban population growth which leaves more people exposed to vehicle emissions and currently close to 5.4 million urban city inhabitants face health risks as a result of vehicle emissions.

3 Hypothesis

Among the philosophies of System dynamics is the premise that "system behavior predominantly results from system structure" (Roberts 1978; Jan 2003). To understand how auto pollution has developed over time, this study develops a model to simulate the causes surrounding the accumulation of gasses into the atmosphere.

The main hypothesis of this study is that, implementation of the Environmental Management Act has been rendered ineffective to control auto pollution due to the influx of used vehicles into the country. The model therefore links three spheres which are believed to be connected, which are; auto pollution, vehicle population, political and administrative decisions and it has a simulation time which runs from 1994–2020.

3.1 Hypothesized causal relationship:

There has been neglect over the years of an encompassing approach to environmental issues in Zimbabwe. Environmental policies in the country basically focus on improving environmental performance and human activities such as transportation, land use and industrialization but ignore the importance of other related issues which also have an impact on the environment such as economic growth, the rate of growth of the transport industry and the quality of vehicles allowed to operate in the country. As a result, in the long run, government control on air pollution hardly makes any different in pollution patterns. This is because it does not restrain or put limitations to the expansion of the car industry and its market in terms of the quality of the cars which they are allowed to sell. Instead, government benefits from the remuneration of tax certificates brought about by the growth of the car industry when new owners register their vehicles for the first time.

The car industry, in general, expands during urban development (European Conference of Ministers of Transport, 2007; Davison, 2004; Button 1993; (Stares and Liu 1996). The result is that auto emissions increase as urban development expands and more people are attracted into the city as a result of employment opportunities. Rural to urban migration is a major characteristic of emerging economies (Todaro and Smith, 2009; Harber and Davies, 1998 (Tostensen 2002), therefore as people gain employment, the gross domestic product (GDP) per capita increases. When people have more purchasing power they tend to desire material goods which make their lives more comfortable. Considering that the public transport is not very reliable in Zimbabwe, this creates a great need for private vehicle ownership.

System behaviour demonstrates that urbanization tends to benefit economic growth and a boost in the vehicle industry but it will reach saturation point when excessive pollution encourages outmigration from urban to rural or stagnation in the urban population. An urban settlement, in Zimbabwe, is defined as a settlement of 2500 people or more whereas in other sub-Saharan countries an urban center is constituted by 5000 people (Munzwa and Wellington 2010). During the colonial period, movement between the rural and urban centers was restricted and controlled and the premise of family and household separation and division created by labour migration hindered any permanent residence in urban centers by the local population. When the controls were lifted at independence in 1980, urban population grew by large numbers because of the rural- urban pull that existed at the time. Urban areas were attractive due to job opportunities and social facilities as compared to the rural areas (Zinyama et al., 1993; Wekwete, 1992). The urban centers have since grown into cities and towns and currently Zimbabwe has 18 major towns. Between 1992 and 2002 the city of Harare's population grew by a total of over 60 percent from 1 184 169 to 1 903 510 people (Munzwa and Wellington 2010). The total urban population in the country grew from 3.2

million in 1994 to 5.4 million in 2010 and is estimated to be 11 million by 2050 (Ministry of Environment and Tourism, 1994). This trend in urban population growth has been observed to be accompanied by transport shortage (GoZ, 1991; Reserve Bank of Zimbabwe, Monetary Policy Review Statement, 2005), and environmental problems such as pollution and degradation (Moyo, Robinson et al. 1991), amongst other problems like traffic congestion.

New cars which are assembled in the country are very expensive to the majority of the working class. As a result there is a high demand for cheap imported second hand cars which have flooded the market.

The emission capacity of vehicles increases with the age of the vehicle resulting in the accumulation of atmospheric gases. This means that cars pollute more as they get old without proper maintenance and also cars that were manufactured a long time ago lack the capacity to pollute less due to inadequate controls which existed back then. Studies conducted by the Australian federal office of road safety (1996) have shown that cars which are 10 to 25 years old dominate the pollution scene particularly for hydrocarbon (HC) and carbon monoxide (CO). These findings are illustrated below. New cars emit less on average provided that they are maintained well. New model vehicles have better emissions performance because of enhanced technology. Improvements in computerised engine control, fuel injection systems, particle filters and catalytic converter have resulted in a huge difference to the quality of air.

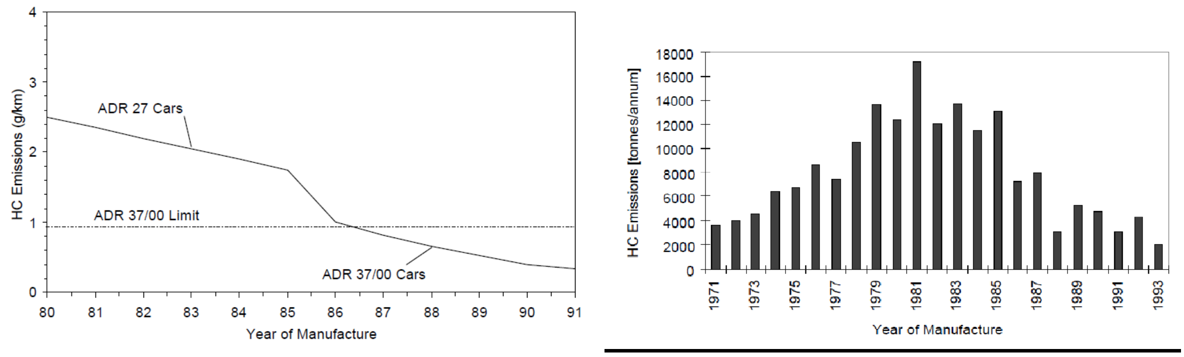


Figure 3: Model year versus pollution capacity. Source: Australian federal office of road safety (1996)

Sectoral distribution of emissions in 1994.

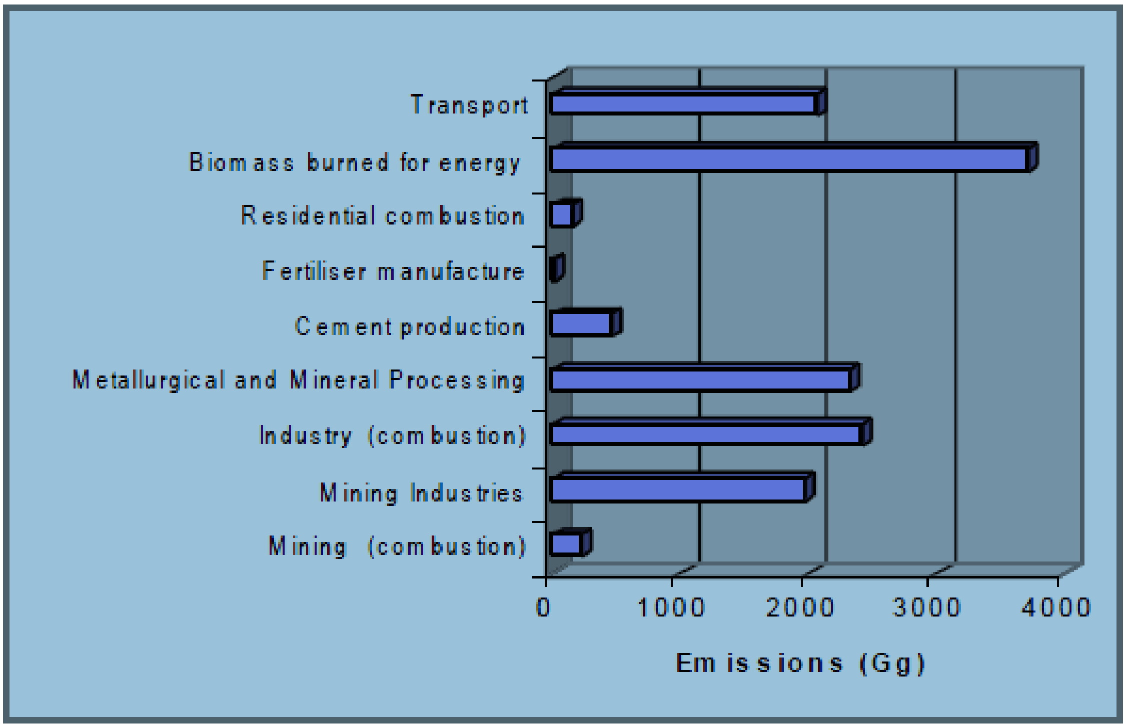


Figure 4: Distribution of emissions by sector. (National Strategy Studies (2010))

Figure 4 gives a bigger picture of emissions in the country with the transport sector contributing the fourth largest emissions in 1994 but if we consider the urban areas separately, the sector produces 90% of the emissions because mines and a majority of the industries are located outside cities.

3.2 Model assumptions

It is important to indicate the main determinants of rising auto pollution concentration levels because actions to influence these factors become a major policy consideration. This section therefore explains the reasons behind the choice of variables. Only the model is presented here. Model equations are listed in Appendix 1 and a file with the full model is submitted in addition to this paper.

The main drives on the demand for vehicles are urban population growth and GDP per capita. Many economic studies have hypothesized that a growth in vehicle demand is directly related to the growth of GDP (Stares and Liu, 1996; Organisation for Economic Co-operation and Development, 2001; International Monetary Fund; 2006), however there are constrains in the system that will bring vehicle demand to saturation.

Economic growth and GDP per capita

The rate of vehicle ownership expansion in emerging markets and developing economies has important implications for transport and environmental policies. Economic development has historically been strongly associated with an increase in the demand for transportation and particularly in the number of road vehicles. This relationship is also evident in the developing economies today (Dargay, Gately et al. 2007). Historical results for 1970-2002 show that vehicle ownership in most countries grew twice as fast as per-capita income, and in a few countries more than twice as fast (Dargay, Gately et al. 2007). When income levels increase to the range of $10,000 to $20,000, vehicle ownership increases only as fast as income. At very high levels of income, vehicle ownership growth decelerates and slowly approaches the saturation level (Ibid). In OECD countries, motor vehicle ownership has reached saturation levels as shown by low annual growth rate of motor vehicle fleets between 1984 and 1988 for example in the United Kingdom growth rate was 0.75 percent per annum and 0.5 percent per annum in the United states (Lovei 1998).

There is a positive correlation between Gross Domestic Product (GDP) per capita and vehicle ownership. The GDP in Zimbabwe was fast increasing during the period from 1999 to 2003 then fell drastically in 2004 until 2010 when it was expected to increase gradually.[v] During the same period when GDP per capita was at its peak, the vehicle population also increased sharply in Zimbabwe and it is still a long way from reaching saturation level. In most African countries, vehicle fleets have shown high growth for example 26 percent in Kenya (Fiaz 1990), with an annual growth rate of 3.6 percent between the period 1980 to 1996 (Archondo-Callao 2000), and is likely to keep growing. A study of vehicle fleet in sub-Saharan countries by Archondo-Callao (2000), confirmed this relationship between gross national product (GNP) and vehicle fleet. The study illustrates in a linear regression equation with correlation coefficient (r^2) of 0.99 for Zimbabwe, an exponential growth rate of 4.4 percent for the vehicle fleet per year and 2.9 percent per year for GNP for the period 1980 – 1996 as shown in figure 5 below.

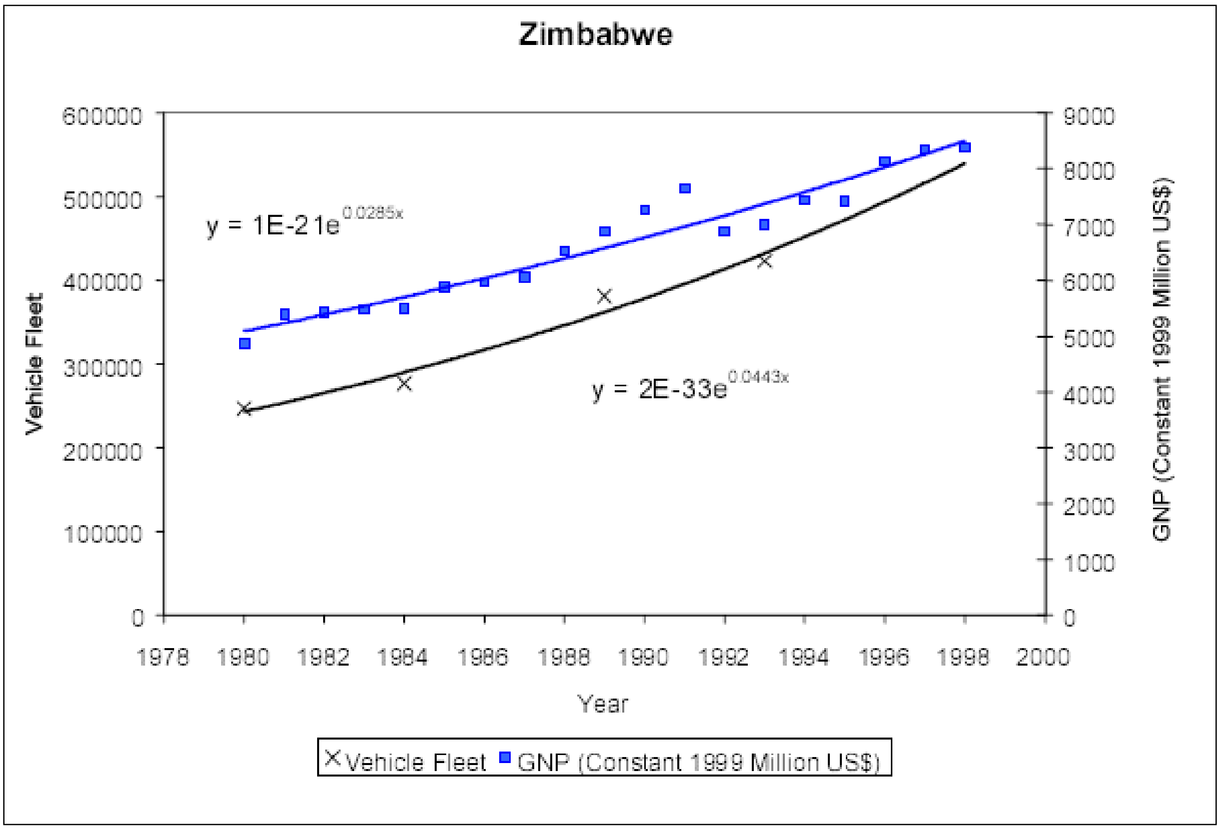


Figure 5: Correlation between GNP and vehicle fleet. Archondo-Callao (2000: 2)

Vehicle recycling and the rhetoric of environmental protection

"Environmental dumping" has been the main issue of concern raised by free trade in used cars with the main markets being: Jamaica, Sri Lanka, Cyprus, Russian and Peru and Japan remains the largest source of used car exports (Kojima and Lovei 2001). The automobile industry has been targeted by the European Commission as one of the five business areas in which it seeks reductions in the amount of waste destined for landfill (Volpato, 2000). In 1997 a legislation was proposed in the European Union (EU) which focused on total recycling of at least 85% of a vehicle's weight by 2005 and total recycling of at least 95% of the vehicle's weight by the beginning of year 2015 (Ibid). Car manufactures had already started recycling vehicles in 2000. The main issue in the proposed legislation was the obligation of manufactures to refund the negative market value which results from the difference between the recycling costs and the value of the car to be dismantled, therefore, the total additional costs for the industry can be huge. However, the issue was filled with risk because there were many incidences that could negatively influence the market value of cars to be scraped and a more restrictive policy for demolition methods or waste dumping was needed to bring additional charges to carmakers (Volpato, 2000). In 2002 the EU implemented the End of Life Vehicle Directives which means that the car industry has a challenge to design environmentally friendly cars that can be recycled. As a result of dumping costs there is a risk that the final value of a car drops below the value of the recycled material.

This regulation represents a weakness for the European automobile manufactures as compared to the Japanese and American because it increases charges for the European manufactures and therefore exporting used cars to least developed countries becomes a better option than recycling. There are no recycling limitations in Japan and the United States which are imposed when designing a car. This is because in the United States the population concentration is relatively low and therefore the goal of reducing waste dumping is not very urgent (Volpato, 2000). The US government does not implement end of life vehicle regulations like the ones in Japan and EU and the regulation only requires car batteries to be recycled (Kumar and Yamaoka 2007).

Regulations for car service inspection in Japan are predominantly restrictive and expensive putting used cars off the market very fast. As a result Japan makes huge exports of eight to nine year old used cars to foreign markets particularly developing countries, exporting the recycling problem as well (Volpato, 2000). Japan also imposes an emissions standard which forces vehicle owners to replace old vehicles with new cleaner models or retrofit old vehicles with approved nitrogen oxide control devices. In 2005 the Japanese Car Recycle law was implemented due to the increasing cost of raw materials and the unavailability of landfills sites for waste disposal. The goal of the law is to increase the recycling rate by over 95 percent by 2015. However the law ignores the end-customer and the capability of recyclers (Kumar and Yamaoka 2007), as can be observed on what occurred when the End of Electrical Product was implemented in Japan, and goods were found dumped on the street or exported to other countries. In Japan, a car's useful life is around 11 years on average which is shorter than in the US, where the median life of the 1990s and 1980s model is 14 and 12.2 years respectively (Kumar and Yamaoka 2007).

Majority of the Zimbabwean second-hand vehicle imports are of Japanese origin mainly because steering wheels are on the right hand side generating a natural market. Over one million used cars are exported annually, worldwide with price and quality variation and a substantial lack of buyer information compared to new cars (Thompson 2001). Used cars gain a large share of the total car market in Zimbabwe.

Lead quantity in gasoline

The global history of the use of lead in gasoline can be categorized into two parts: first there was "the rise of lead" from the 1930s to the 1970s, and second, was the "gradual removal of lead from gasoline" from the 1970s to the present (Lovei 1998). The total quantity of lead added to gasoline went down by 75 percent worldwide between 1970 and 1993. It dropped to less than 100 000 tons from more than 375 000.[vi] In 1995 African countries constituted two-thirds of countries worldwide which belonged to the highest range of gasoline lead content and in Europe no countries were found to be in the same range (Ibid). Reasons which led to the shift from using lead additives include the development in the technology to manufacture cars that allows the manufactures to equip their cars with catalytic converter in reaction to mounting concerns on the environment brought about by vehicular emissions and the growing concern about the health impact of lead as a result of new medical evidence (Lovei 1998).

Conversely, gasoline lead content grew significantly in most developing countries during the 1970s and 1980s for example from 0.58 to 0.84 gram per litre in Uganda (Lovei 1998). In 1996, South Africa was the only country in Africa which had a market share of unleaded gasoline (Ibid). Zimbabwe is amongst the countries with high lead quantity of about 0.6 to 0.8 mg/litre and this poses a great risk to public health and the environment due coupled with outdated vehicle fleet.

There is a connection which can be identified between the income of countries and their achievement in phasing out leaded gasoline but also such an accomplishment is greatly influenced by a government's political commitment to solve the problem as well as policies that are aimed to assist in the process of phasing out lead (Lovei 1998), hence the importance of this research to assess government's commitment to save the environment based on their implementation strategies.

Car usage and road network

Road traffic contributes to environmental degradation as the traffic volume increases (Button, Ngoe et al. 1993). As car ownership is expanding, the implications in many poorer nations is the increased pressure on road networks coupled with large import bills for fuel and vehicles (Button, Ngoe et al. 1993). As already indicated above that the growth of vehicle ownership is occurring simultaneously with rapid urbanization, the harm is predominantly severe in cities (Bayliss 1981). The rise of vehicle fleets also negatively affects the facilities to maintain vehicles by putting strains on the administrative structure that is required to monitor and regulate the road system itself.

Traffic congestion is caused by overloaded road network. Rush hour in Harare is characterized by relative traffic congestion into the city. The public road network in Zimbabwe comprises of 76,000km of roads in total (African Development Bank Group, 1999). The public road network is split into three categories: State Roads which amount to 24 percent, which is under the Department of State Roads and links district and provincial centers, Rural District Council Roads which amounts to 69 percent serving the commercial farming areas, and Urban Council Roads amounting to only 7 percent. Table 1 below shows the three categories and amongst them, urban council roads have the second highest paved roads but it has the least total road network.

Public Road Network (1994)

Road Type	State	Rural District Council	Urban Council	total	percent (%)
Earth	3,728	13,823	0	17,551	23
Gravel	6,445	36,779	1,153	44,377	58
Surfaced	8,261	1,755	4,134	14,150	19
Total	18,434	52,357	5,287	76,078	100
Percent (%)	24	69	7	100	

Table 1: Road network. African Development Bank Group (1999: 8)

From 1985 investment in road maintenance has been declining if we look at the the net present value of budget allocations on road maintenance. From 1994/95 the amounts allocated to road maintenance only represent less than one third of the amount requested (African Development Bank Group, 1999). Therefore, the roads have not been properly maintained or improved by constructing new road to ease the traffic jam during rush hour which results in idling and more pollution.

Zimbabwe is a deforested and water-stressed country. 60% of the deforestation rate is attributed to land clearing for agriculture and up to 40% of deforestation can be attributed to firewood demand (Nziramasanga, 2004). 45.3% or about 17,540,000 hectares of Zimbabwe is forested.[vii] Estimated levels of deforestation for the period 1990–1995 were recorded to be more than 10 times the corresponding afforestation rates. Between 1990 and 2005, the country lost a total of 36.8% of its forest cover and woodland habitat[viii], still more, the rate of forest loss accelerated by a total of 16 % between 2000 and 2005 when political and economic crisis gripped the country. This increased the rate of deforestation from 1.41% per annum between 1990 and 2000 to 1.64% per annum between 2000 -2005.

In most areas the demand for dry wood outstrips supply because the population densities are high. This means that fuelwood contributes as a major source to deforestation. Positive environmental gains can only be observed if proper intervention measures that reduce the fuelwood demands are implemented (Nziramasanga, 2004). As a result, the rate of absorption is far too less as compared to the rate of emission. It has been argued that low income causes high discount rate (Clark 1991; Perrings 1991). This explains the observation that "very poor regions seem to degrade renewable resource stocks far below economically optimal level".(Moyo, Robinson et al. 1991; Chapman 1993)

The environmental policy is aimed at reducing mobile emissions through a number of regulatory strategies, yet the rate of emissions still remains higher than the rate at which the emissions can be absorbed by plants creating an accumulation of auto pollution. Figure 6 below shows a simple stock and flow diagram with an inventory of auto pollution which increases through vehicle emissions and reduces by absorption. The problem indicated by the graph in figure 2 in section two results from an accumulation of the stock which is caused by a higher rate of flow into the stock as compared to a lower rate of flow out of the stock.

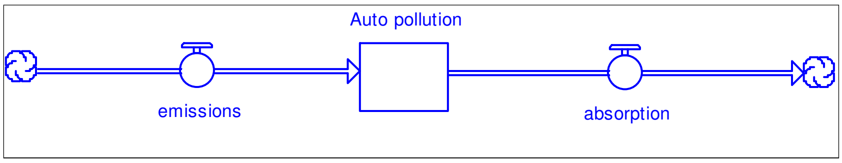


Figure 6: Simple Stock-and-Flow structure of the auto pollution problem

A causal map was developed as shown in below to illustrate a causal loop relationship of the auto pollution dynamics and to understand the relationships amongst the variables.

3.3 Causal loop diagram

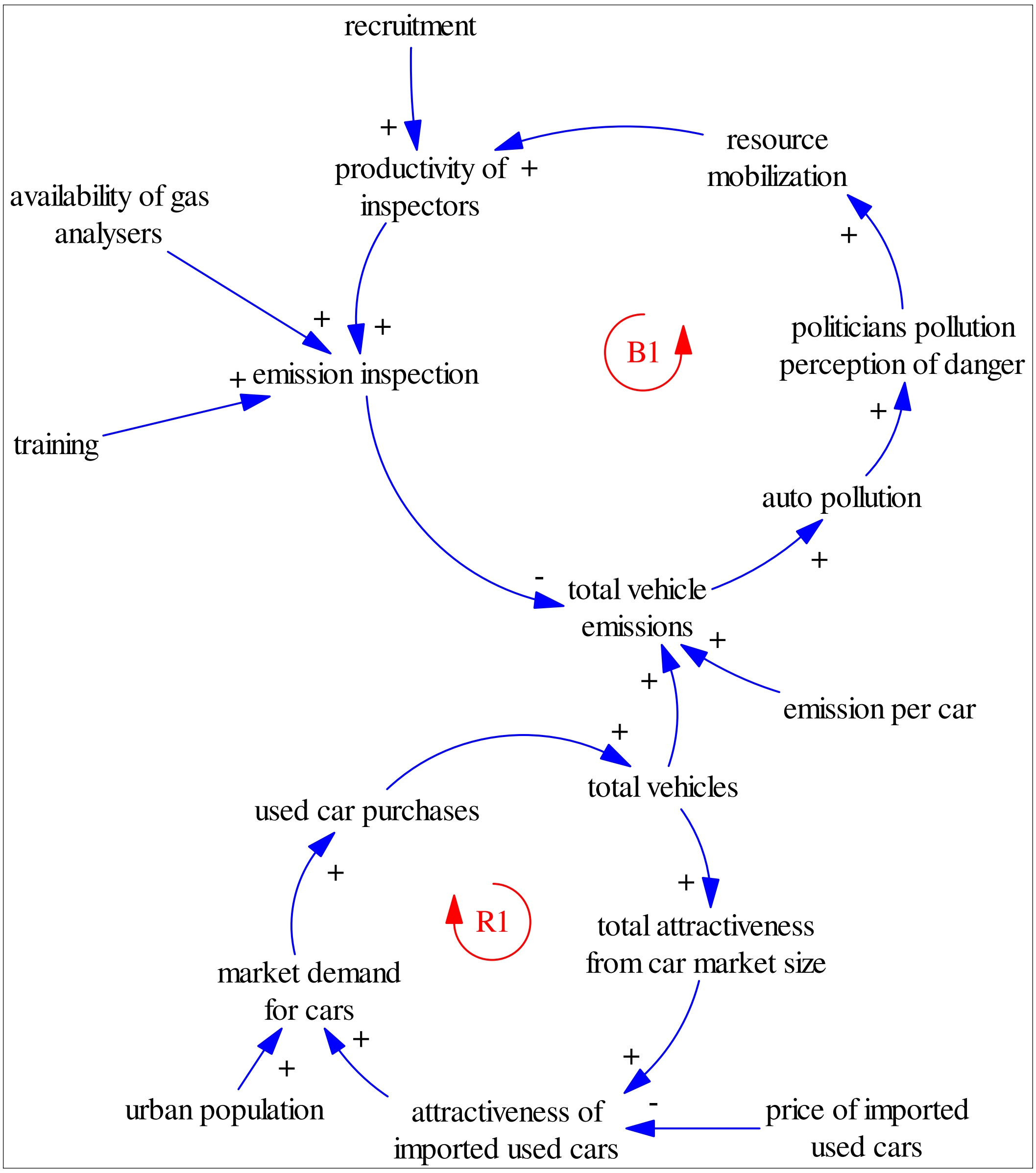


Figure 7: Problem CLD, Vehicle population and pollution control

The pattern of auto pollution relates to urban population growth, urban traffic size, vehicle quality and environmental policy implementation. Urban development attracts and encourages rural to urban migration, increasing the urban population and large urban population causes further urban expansion. Growth of urban population together with attractiveness of imported used cars influence demand for cars. Price of imported used cars plays a major role in determining the attractiveness of used cars. Used cars are sold at less than half the price of a new car which is of the same model raising their level of attractiveness on the market.

Demand for the car industry plays a significant role for car sales. The higher the demand the higher the sales and when demand falls so do the sales. As car sales change so does the total vehicle population. The sale rate of each type of vehicles either used or new is also a product of its market share and this market share though not shown in the causal loop diagram determines the attractiveness of each product relative to the other product. As a result when the total fleet changes, total attractiveness of both types of cars which is a sum of used and new cars attractiveness, also changes. The larger the vehicle population, the greater the attractiveness of the whole industry and depending on the market share of each product the attractiveness of each product will be determined. This development resembles the balancing feedback loop R1 as shown on Fig. 7. Attractiveness rises and falls as the vehicle population changes and other factors like availability of the cars. Loop R1 is found inside the market share module of the main model.

When there are more used cars in operation, there will be more vehicle emissions depending on the emission capacity of each car. The influx of second hand cars means that the average age of the vehicles is very high and the older the vehicle is, the more it pollutes (Kahn 1996; Van Wee, Moll et al. 2000). As levels of auto pollution change policy makers might be influenced to take necessary action that corrects the problem and the extent of their willingness to commit to solving the problem depends on the magnitude of the severity of the issues at hand. Political will then influences the resources which are committed to a project. The availability of such resources plays a role in determining the productivity of the policy implementer. This is because for each policy implementer or environmental officer there should be made available exhaust testing equipment and proper training in order to complete the job. Productivity then translates into actual job performance which is mobile exhaust testing. Mobile exhaust testing is expected to eventually have a significant negative influence on emissions. This relationship is indicated by the feedback loop B1.

From the beginning of the simulation period in 1994 no specific strategy had been carried out to reduce auto pollution in particular. In 2002, even though EMA was enacted actual implementation of the policy still remained nonexistent. As a result, feedback loop B1 has not been fully effective in bringing down pollution levels to date.

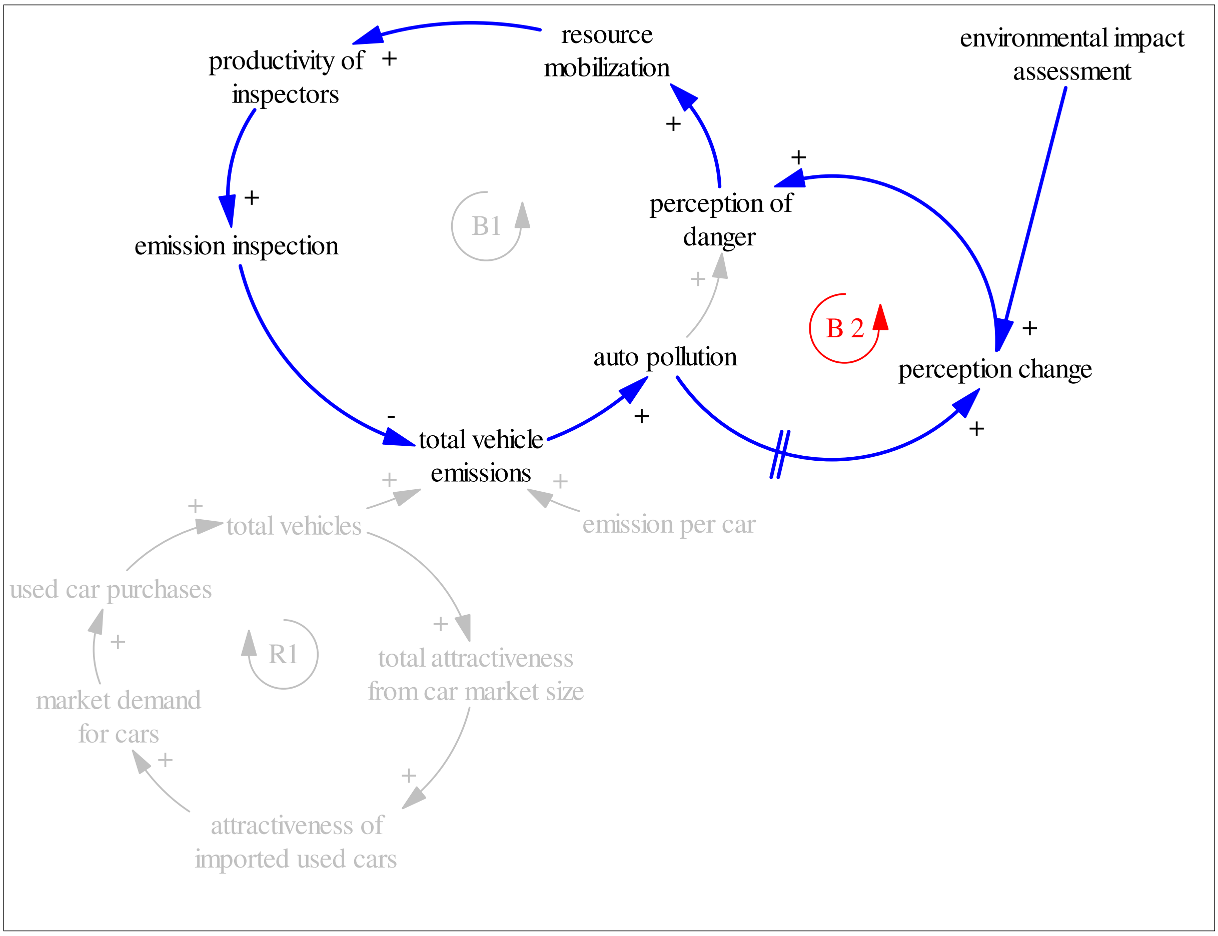


Figure 8: Perception change (EMA policy adoption in 2002)

It takes time before the levels of emissions influence a change of perception amongst the policy makers. Before policy makers make a commitment to allocate resources to alleviate a problem there has to be perception change that leads to policy adoption. Their perceptions determine the extent of political commitment to solve the problem and reduce emissions which influences the amount of pressure they put on their administration. This relationship is denoted by feedback loop B2 in figure 8 above. This loop symbolizes the adoption of EMA in 2002 after the problem of auto pollution had been on the rise since 1994.

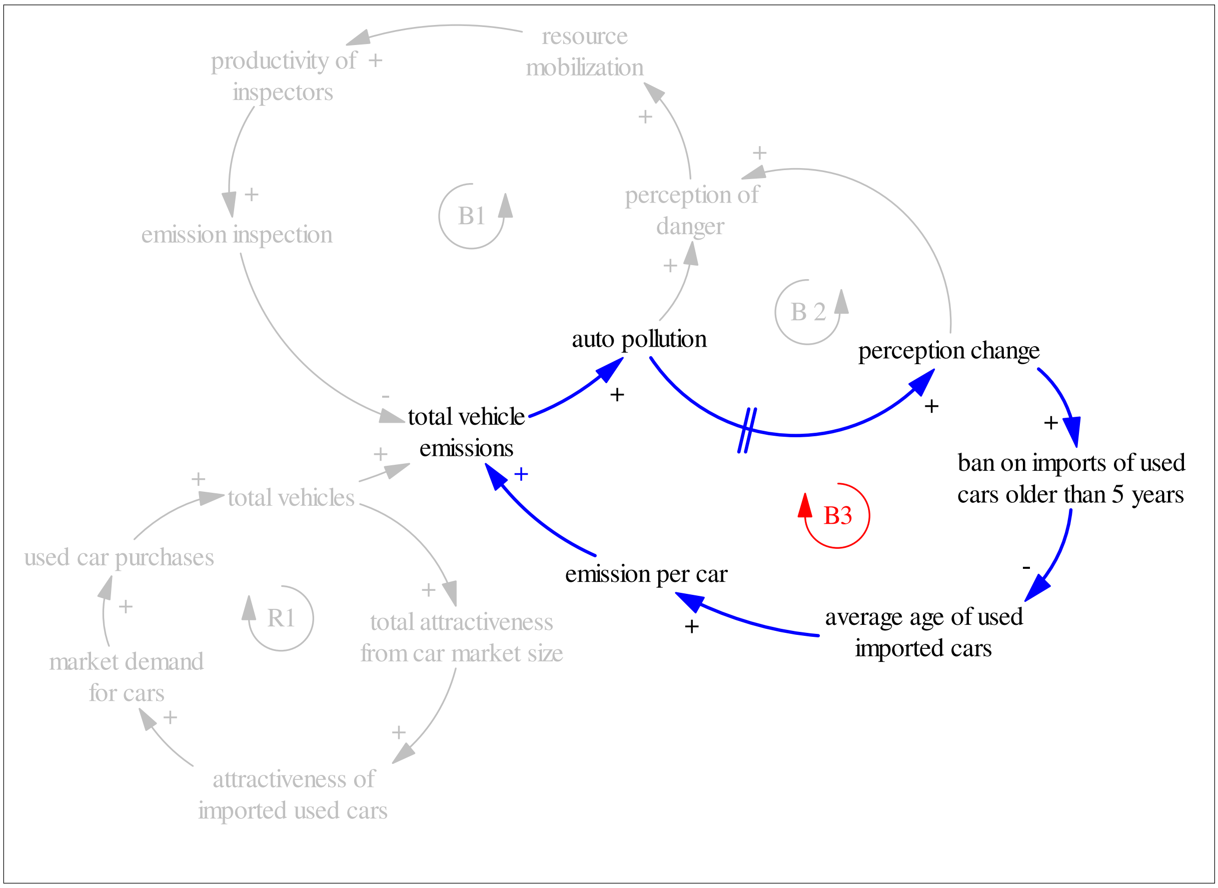


Figure 9: Import ban of cars older than 5 years.

Changes in auto pollution influence perception change amongst the policy makers and it influences how policy makers review and formulate regulations based on professional and expert advice. The government intends to ban the importation of used vehicles older than 5 years effective from 30 June 2011. This could work given the example of Hungary which set the limit of imported vehicles at 10 years in 1991, then reduced it to 8 years, 6 years and finally 4 years in 1997 (Kojima and Lovei 2001). The Minister of environment, in consultation with the Standards and Enforcement Committee EMA and with the approval of the Minister responsible for finance may by notice in a statutory instrument, impose an environment regulations on persons whose activities impact on the environment. The introduction of import ban to augment mobile testing was a result of such processes. This ban is expected to have some long-term positive effect on auto pollution because it is expected to effectively reduce the average age of used cars which are imported into the country. When the average of used cars goes down emission per car is expected to also change reducing the total annual emissions as shown by feedback loop B3 in figure 9 above.

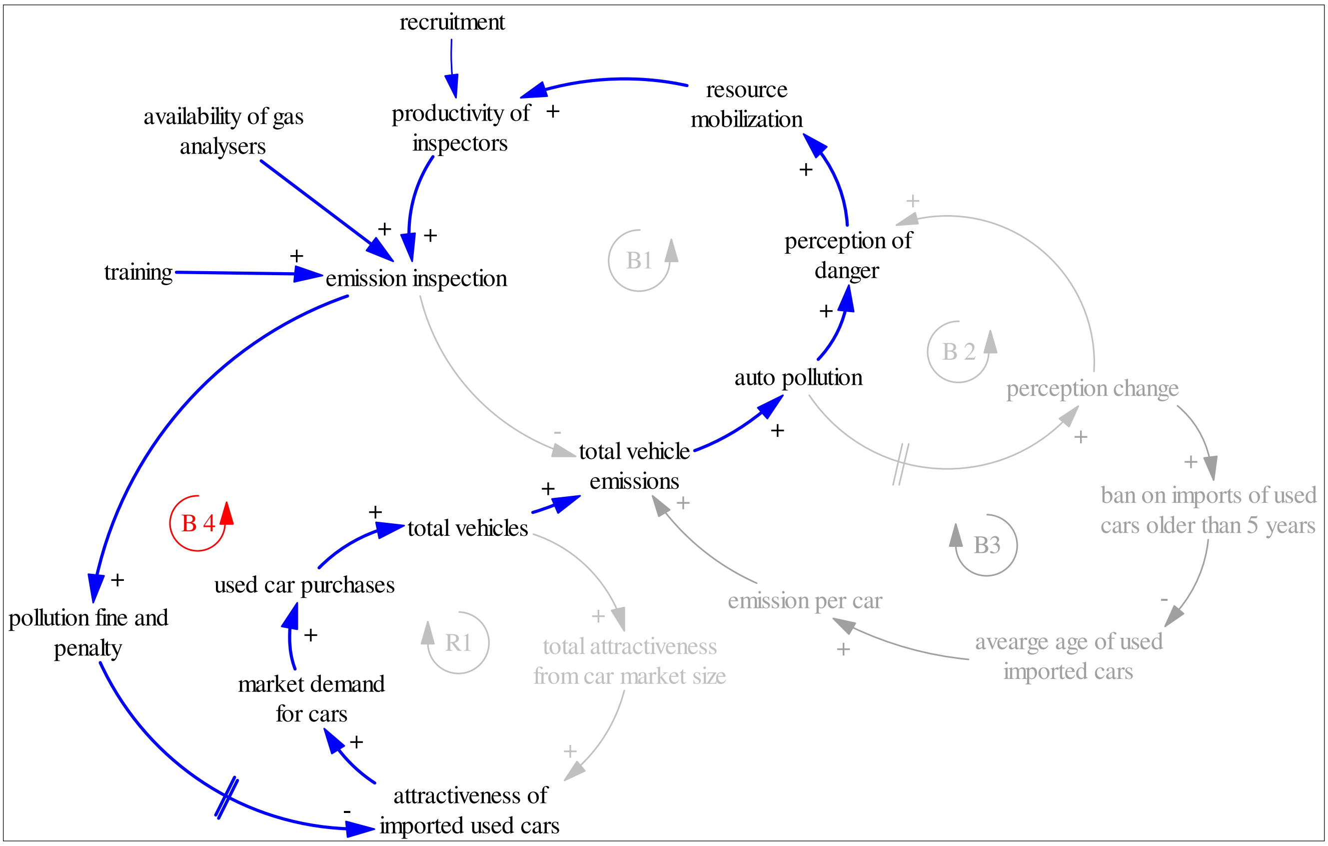


Figure 10: Mobile exhaust testing

EMA is expected to commence on mobile emission testing from mid year 2011. A few environmental officers have undergone training for exhaust emission testing in South Africa. The agency has also purchased 18 mobile testing machines in preparation for this mission. Any operator of a vehicle found polluting will be fined and repeated offenders will face imprisonment for up to three months. Given a delay time of approximately 2 years it is expected that these fines will deter drivers from polluting thereby reducing the attractiveness of used imports lowering the demand for cars and eventually reducing emissions as indicated by feedback loop B4 in figure 10 above.

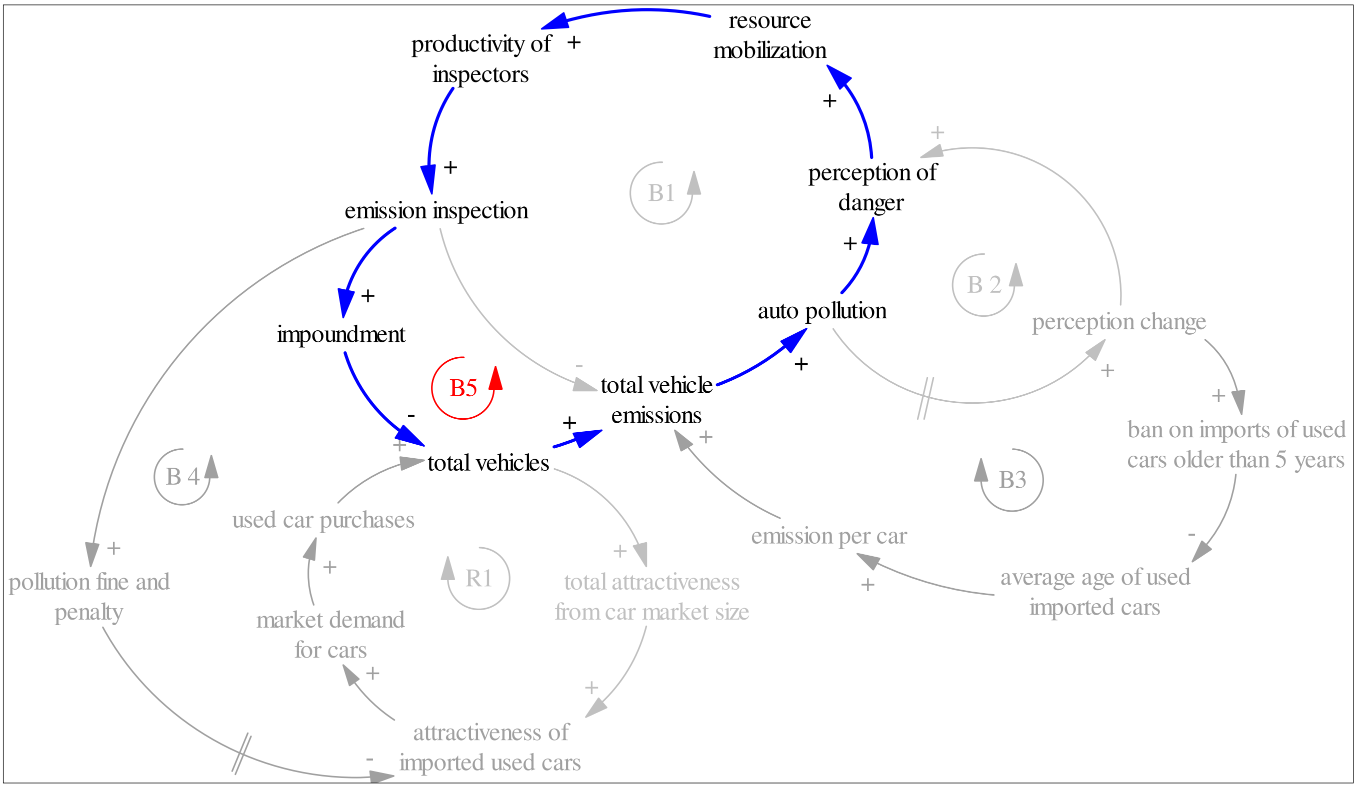


Figure 11: Vehicle impoundment

Mobile testing is also aimed at impounding vehicles which are considered road unworthy and thereby reducing the total number of vehicles. This will eventually reduce emission because the aim is to impound only cars which pollute the most. This process is depicted by feedback loop B5 above.

3.4 Model structure

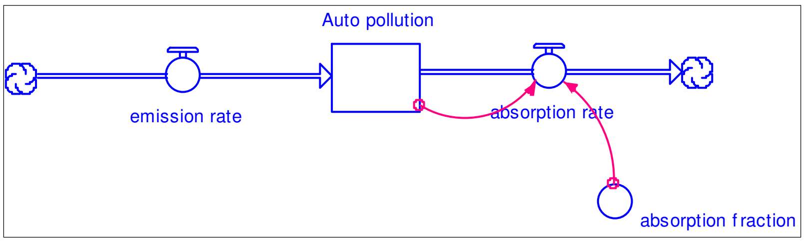


Figure 12: Auto pollution Stock and flow diagram

Auto pollution increases through vehicle emissions rate and reduces through absorption rate. The absorption rate is determined by an absorption fraction which also takes into account the effect of deforestation on absorption. Emission rate is a result of a multiplication of total vehicles and the total emissions per vehicle (Figure 12).

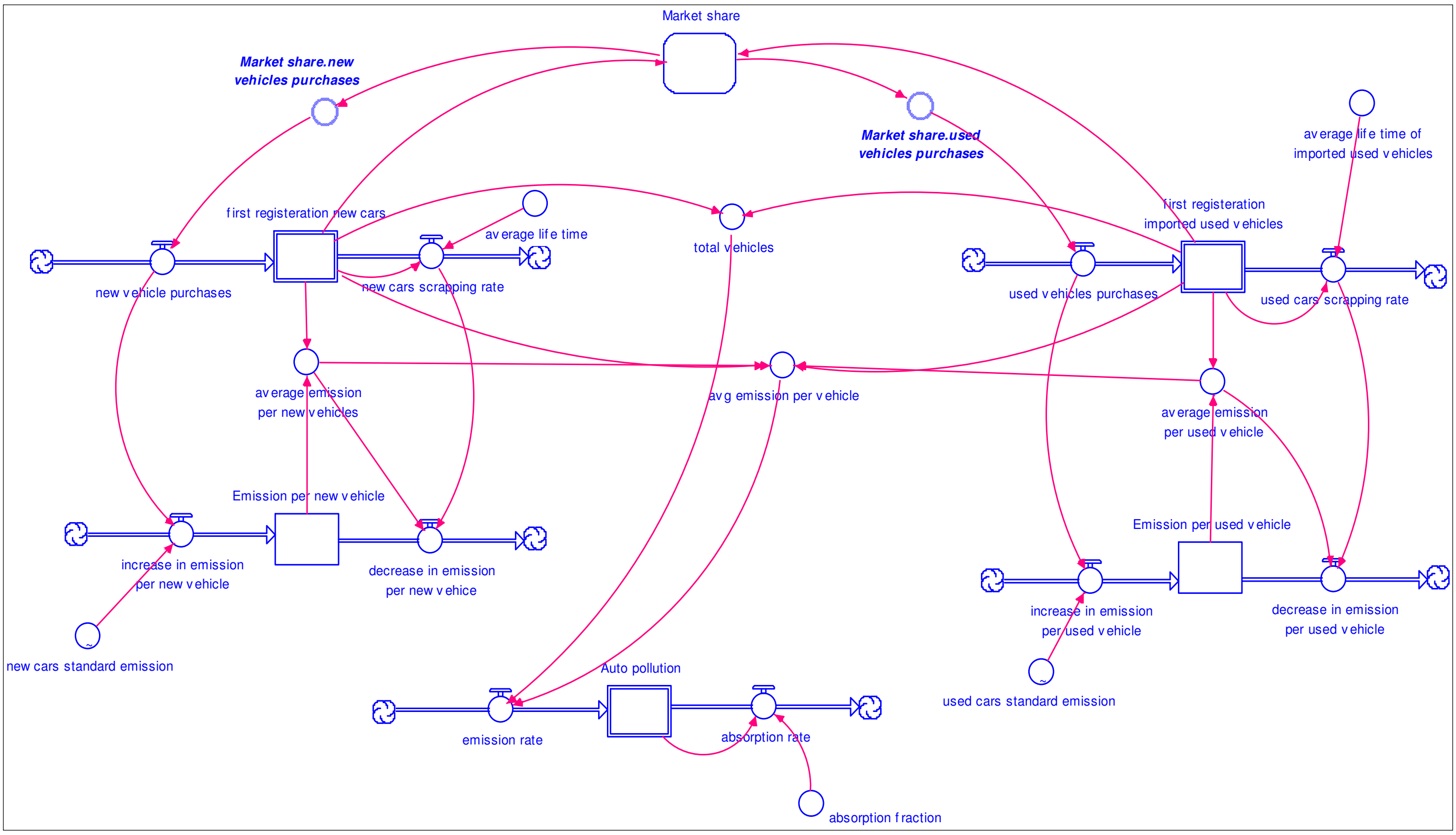


Figure 13: Problem model including the vehicle population

Total vehicles come from an addition of first registrations of new cars and first registration of used imports. First registrations of new vehicles increase through purchases of new vehicle. New purchases are driven by demand from the car market multiplied by the market share of new vehicles which is represented by the market share module. This stock reduces through scrapping which is determined by an average life time of new cars. On the other hand used imported vehicles also increase the same way, by demand multiplied by the market share of used imports which are represented by the market share module and the stock reduces by scrapping which is determined by an average life time of used cars. Total emission per vehicle is a function of both the first registration new cars and imported used cars multiplied by an average emission of both stocks (Figure 13).

Average emission per vehicles is a weighted average of emission per vehicle and the total vehicles. Emissions increase based on the number of used old cars on the road compared to new cars. Emission per new vehicles changes through an increase in emission per new vehicle and this is also true for emission per used imports which changes through an increase in emission per used vehicles. Increase in emission is determined by purchases of new cars and the standard emission rate per each type of vehicle, that is, whether new or used imports. Emission per vehicle reduces through an outflow of decrease in emission per vehicle. Decrease in emission is determined by the scrapping rate and the average emission per either new or used imports. As a result total emissions per vehicle change consistently depending on the structure and composition of the vehicle stocks and the subsequent influence on each stock of emission per car as follows:

((first_registeration_new_cars*average_emission_per_new_vehicles)+(first_registeration__imported_used_vehicles*average_emission_per_used_vehicle))/(first_registeration_new_cars+first_registeration__imported_used_vehicles)

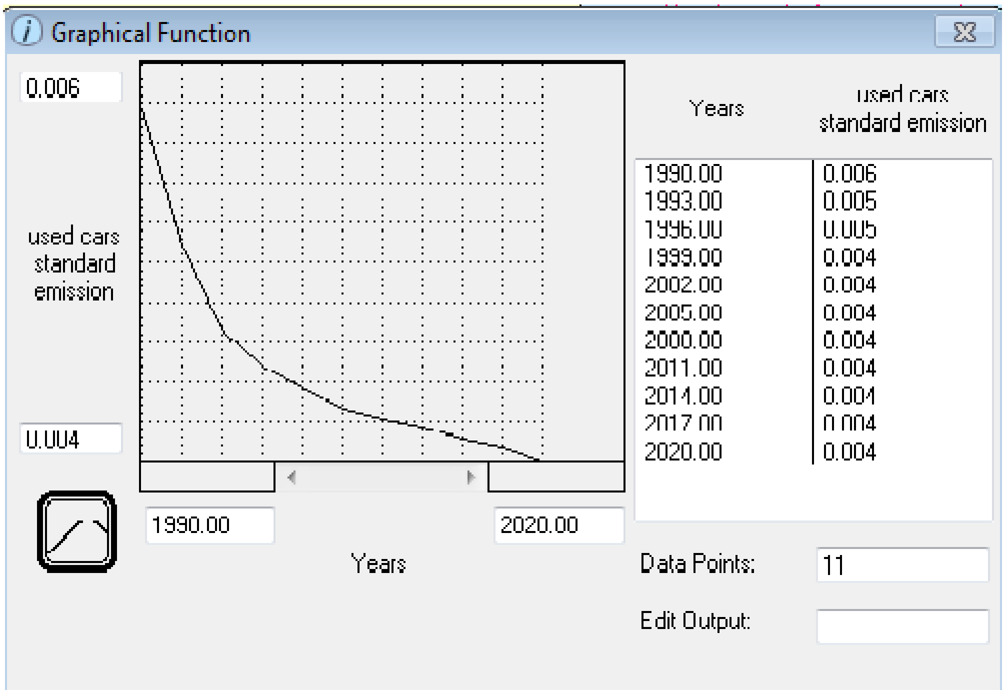


Figure 14: Used cars standard emission

The variable used car standard emission (Figure 14) is based on the literature that old models pollute more compared to later models as mentioned earlier in this chapter.

Clicking on the market share module structure in Figure 13 above reveals the structure below.

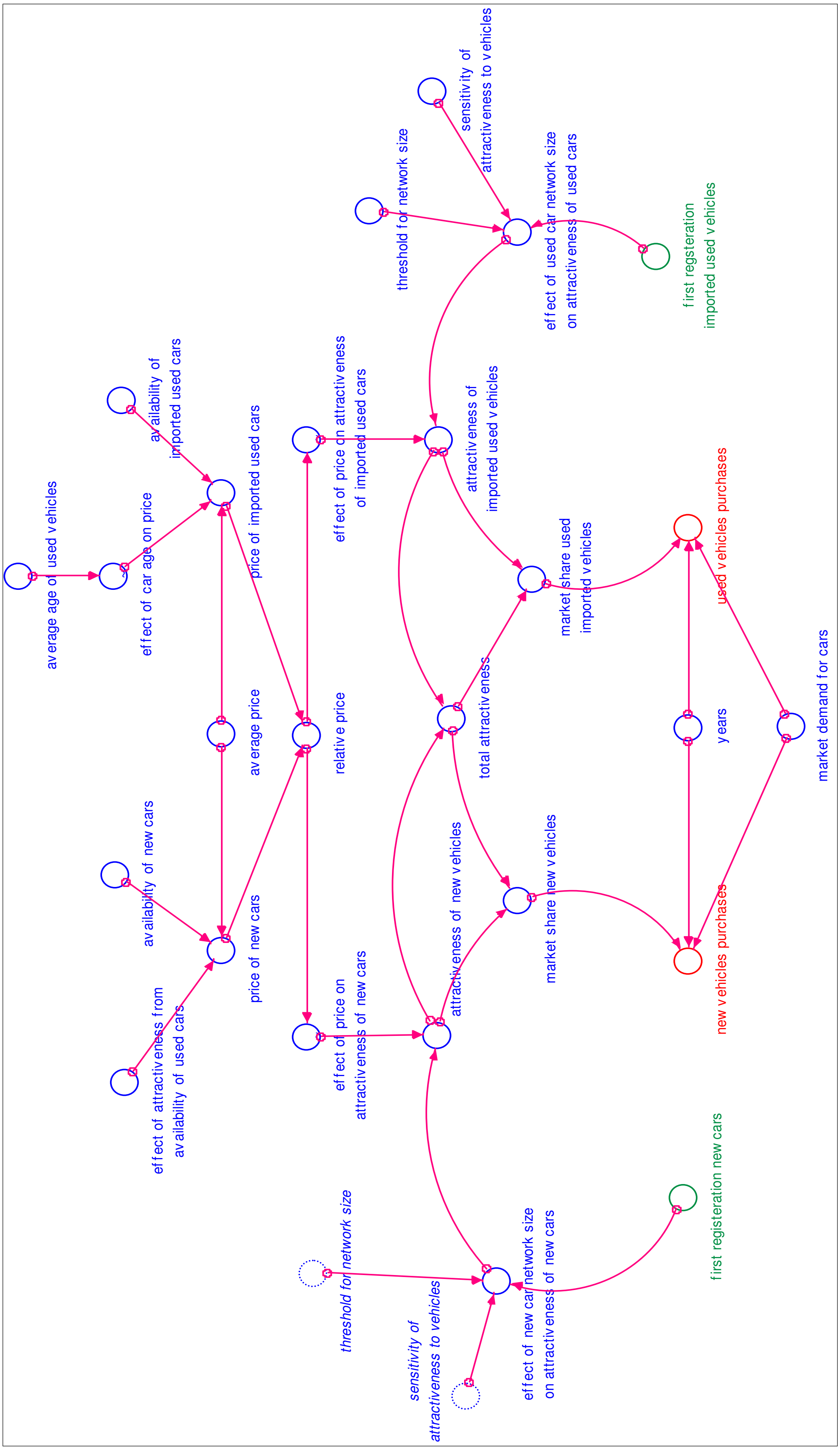


Figure 15: Vehicle fleet composition (Market share module)

As mentioned earlier the vehicle fleet is divided into two stocks: first registration new cars and first registration imported used vehicles. The choice between purchasing an imported used vehicle versus a new vehicle depends on the price of the vehicle which is determined by the age of the vehicle. Cars older than 15 years cost almost half price compared to a new car. This ultimately influences the attractiveness of each stock. Attractiveness determines the eventual market share of each product compared to the other product leading to sales or purchases (figure 15). Variables marked in green are inputs from the main model. Market demand for cars is driven as illustrated below.

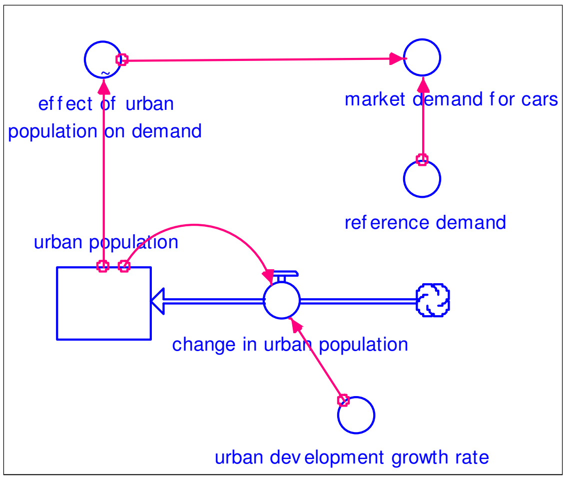


Figure 16: Demand for cars

Urban population is the main influence on the market demand for vehicles in the urban cities which will result in purchases of either new or used cars.

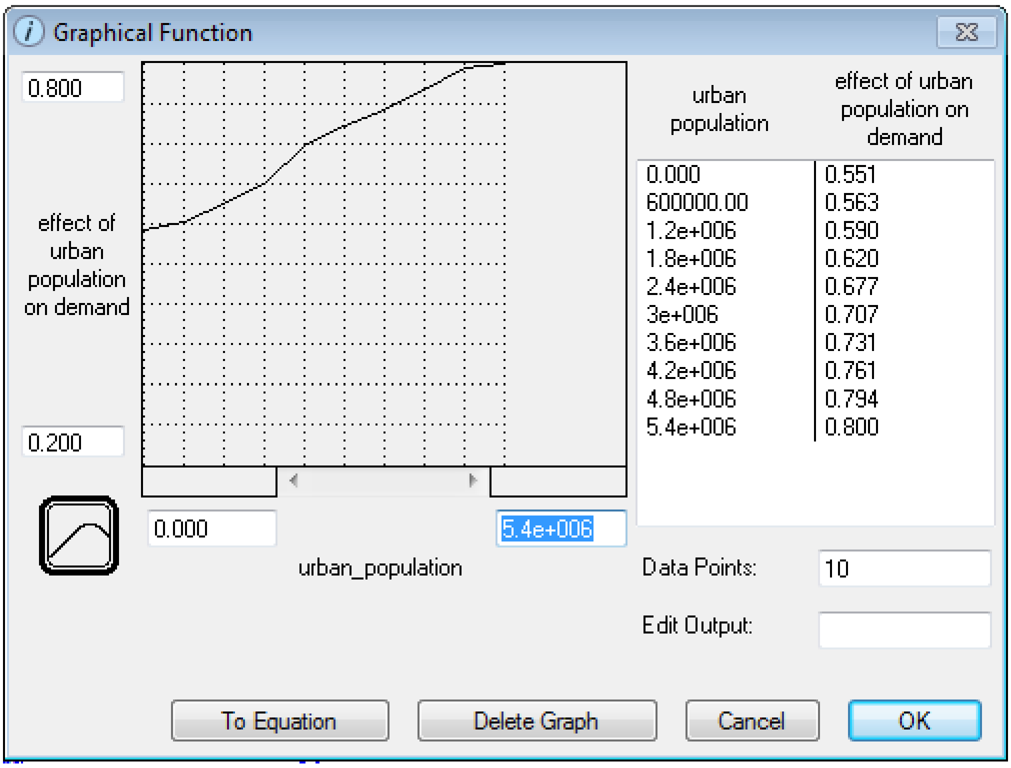


Figure 17: Effect of urban population on demand

Urban population can only have an influence on demand after it has reached a certain level rather than from the onset because when the population is small there is less competition and transport shortages.

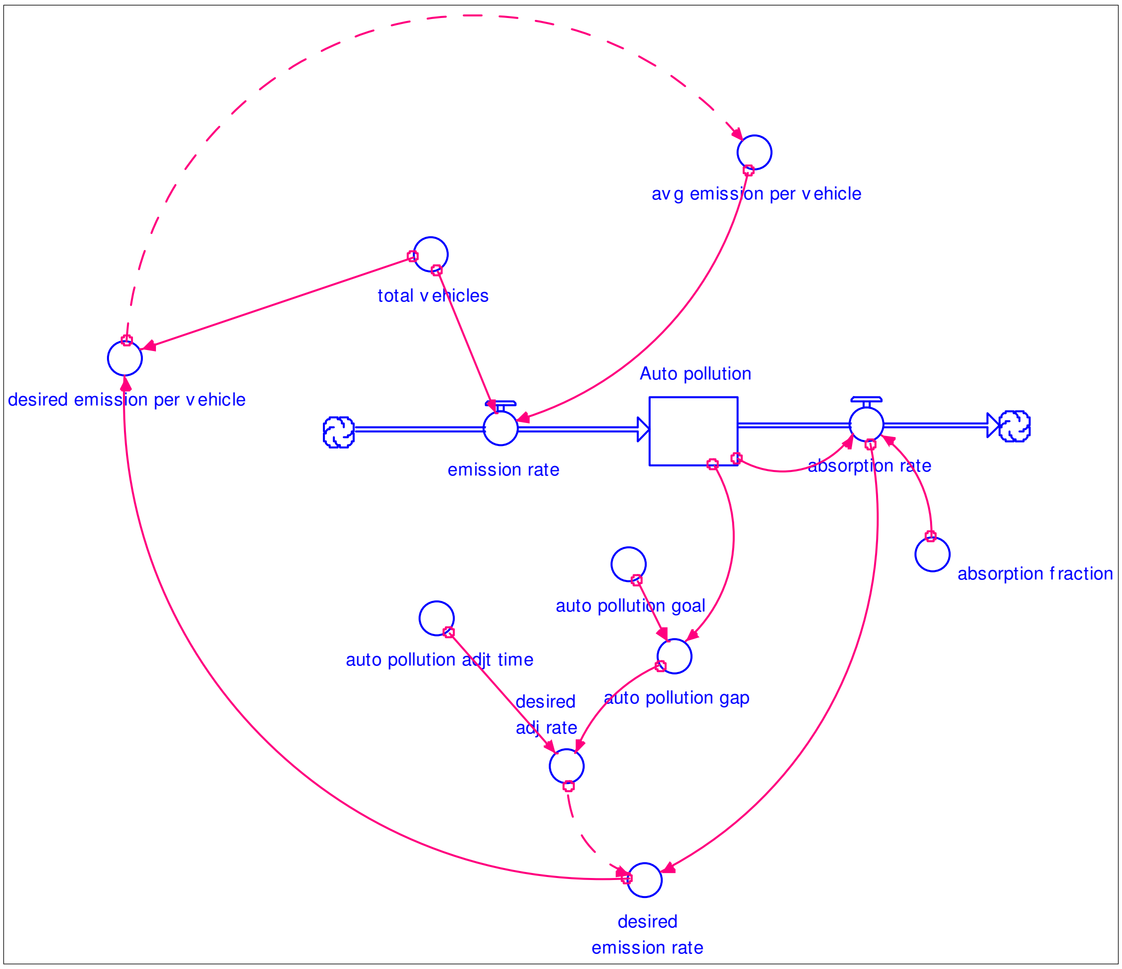


Figure 18: Hypothetical desired emission per vehicle

The ideal situation is to reduce the pollution level to an ideal level by means of creating desired emissions rate. If we create a goal for auto pollution given an adjustment time to reach that goal, there is a gap that exists between the goal and the status quo (Figure 18). Therefore a desired adjustment rate will close this gap at a specific quantity per time period within the adjustment time. If we divide the desired emission rate by total cars the aim is to make the desired emission per vehicle the same as the average emission per vehicle. The logic behind the desired emission per vehicle is to create a situation where emission is reduced to the same level as the absorption rate because we take the absorption rate minus the rate to adjust to reach the auto pollution goal and we divide this by total vehicles as follows:

$$desired\_emission\_rate/total\_vehicles$$

The dashed link from desired emissions per vehicle to average emissions per vehicle is wishful thinking; this link requires an operational structure in order for the link to be implemented in the model. It represents how the ideal situation would have been. This is because if the actual and desired emissions were the same, the policy goal would be reached. As a result this dashed wishful thinking link is not really operating in the system. It has been disabled by the following equation:

if(time<2030)then

(((first_registeration_new_cars*average_emission_per_new_vehicles)+(first_registeration__imported_used_vehicles*average_emission_per_used_vehicle))/(first_registeration_new_cars+first_registeration__imported_used_vehicles))

else(desired_emission_per_vehicle) {Gg/vehicle/year}

Setting the time to 2030 means that the link can only be operational from that time but our simulation runs to 2020 meaning that the link does not get to operate in the model. The only way to implement this wishful link is by coming up with desired imported used vehicles.

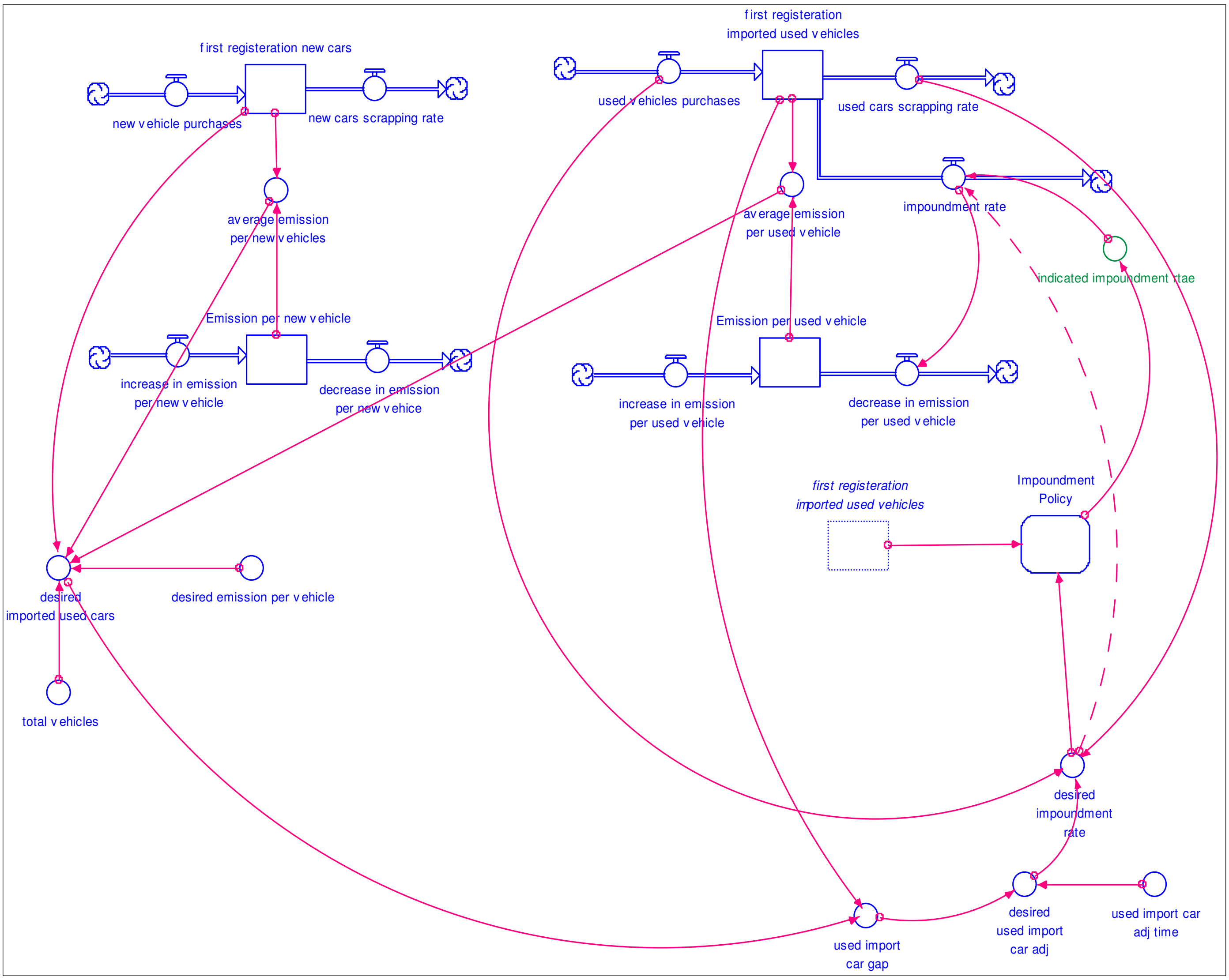


Figure 19: Desired imported used cars

The next step in the policy implementation is to manage the stock of imported vehicles by defining a goal for the first registrations of used imported vehicles which is the desired imported used vehicles. This goal is defined by 5 variables: total vehicles, new vehicles, average emission per new vehicles, average emission per used vehicles and desired emission per vehicle.

Before 2011 imported vehicles are defined by just subtracting new vehicles from the total fleet. After implementation begins in 2011 we would desire to have a stock of imported vehicles that is governed by desired emission per vehicle as:

if(time<2011)then(total_vehicles-first_registeration_new_cars)

else:

$$(desired\_emission\_per\_vehicle * total\_vehicles) - (first\_registeration\_new\_cars * average\_emission\_per\_new\_vehicles)/average\_emission\_per\_used\_vehicle)$$

$$= desired\ total\ emissions - (first\_registeration\_new\_cars * average\_emission\_per\_new\_vehicles)/average\_emission\_per\_used\_vehicle$$

$$= desired\ total\ emissions - actual\ emissions\ for\ all\ new\ vehicles/\ average\_emission\_per\_used\_vehicle$$

$$= desired\ emissions\ for\ all\ imported\ vehicles/average\ emission\ per\ used\ vehicle$$

$$= desired\ imported\ vehicles\ \{\text{vehicles}\}$$

With a goal comes a gap between the desired imported vehicles and the actual stock. Given an adjustment time the gap will close each year until we reach the goal. We also need to remove impounded vehicles each year from the stock of imported used vehicles as an outflow once exhaust inspections begin because a certain fraction of the inspected vehicles are impounded each year. This outflow is defined by an indicated impoundment rate which is a fraction of the inspected vehicles from the impoundment policy. Adding the imported vehicles adjustment rate to the net-flow that adds to the imported vehicles stock would produce a desired impoundment rate. If the impoundment rate equals the desired impoundment rate pollution level would go down as expected by the policy (Figure 19). But this scenario depends entirely on the implementation progress, that is, mobile inspections. Desired impoundment rate goes into the impoundment policy module and comes out of the module as the indicated impoundment rate into the impoundment rate

In order to follow the actual implementation process we import the desired impoundment rate into the impoundment policy module for us to build the implementation structure. Out of this structure we will get the indicated impoundment rate which goes into the main model and the pollution fine and penalty rate which will reduce the attractiveness of buying used vehicles. To find the structure that actually produces the indicated impoundment rate and the penalty rate we take the emission rate and multiply it by the fraction of inspected vehicles impounded. We also multiply the inspection rate by the fraction of inspected vehicles that are fined for polluting to get the penalty rate. The fraction of inspected vehicles that are impounded has been estimated to be 2% because only heavy polluting vehicles will be impounded and other less or average polluting cars will get a fine. The fraction of fined vehicles has been set at 50% because the majority of Japanese cars in Zimbabwe are mainly exported out because they fail to meet the pollution standards and become expensive to maintain in Japan. By using the fraction of inspected vehicles that are impounded we can get the desired inspection rate. This will be again wishful thinking if our desired emission rate was to become the emission rate. But the inspection rate actually depends on the number of trained inspectors and their productivity which is based on the actual inspections per inspector. Desired inspection rate divided by desired productivity gives us desired trained inspectors (Figure 20).

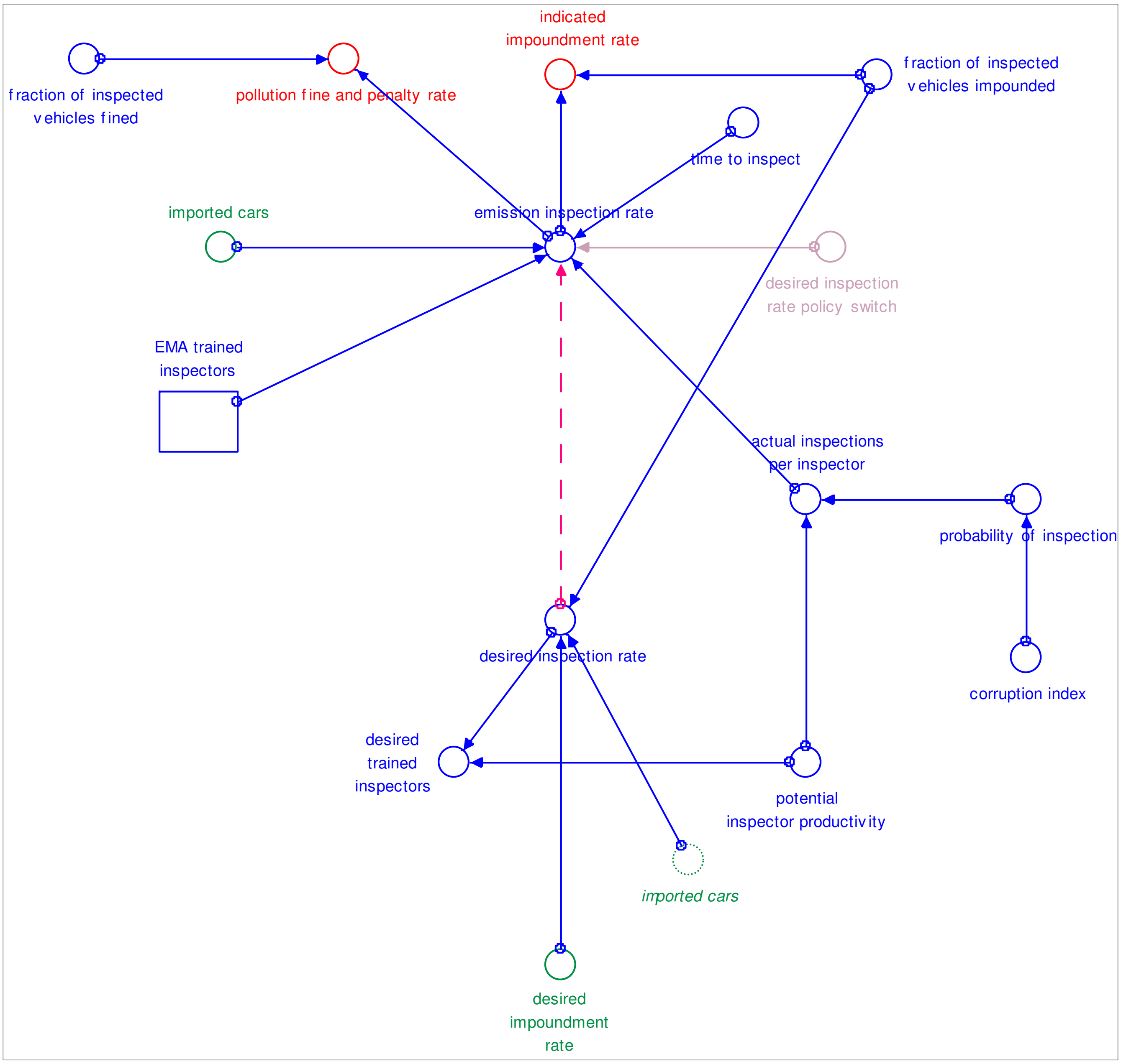


Figure 20: Desired inspection rate.

It costs money to hire and retain trained inspectors so there should be a budget for wages before we make the desired number of inspectors our goal for inspectors. So we take an average wage and multiply it by the desired trained inspectors to get a desired wage budget. The wage budget which comprises of all inspectors multiplied by the average wage as the initial value can be altered by giving the budget an adjustment time to which it can change because it requires some effort for the budget to change. The change occurs by adjusting the budget to the desired wage budget and out of the wage budget divided by the average wage comes out the number of inspectors that are budgeted for as the goal for inspectors (Figure 21).

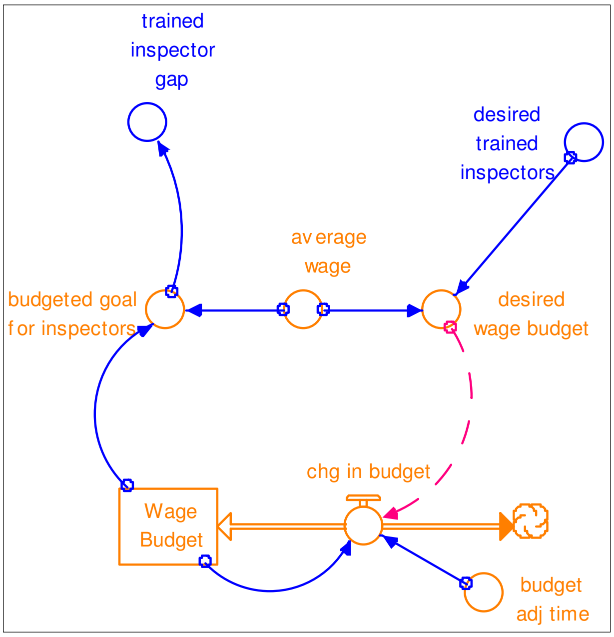


Figure 21: Budgeted number of inspectors

We can then compare this goal for budgeted inspectors to the actual and based on this comparison we then recruit in such a way that we try to close the gap between the goal and actual within a specific time. By doing so, we come up with recruitment structure for the inspectors (Figure 22).

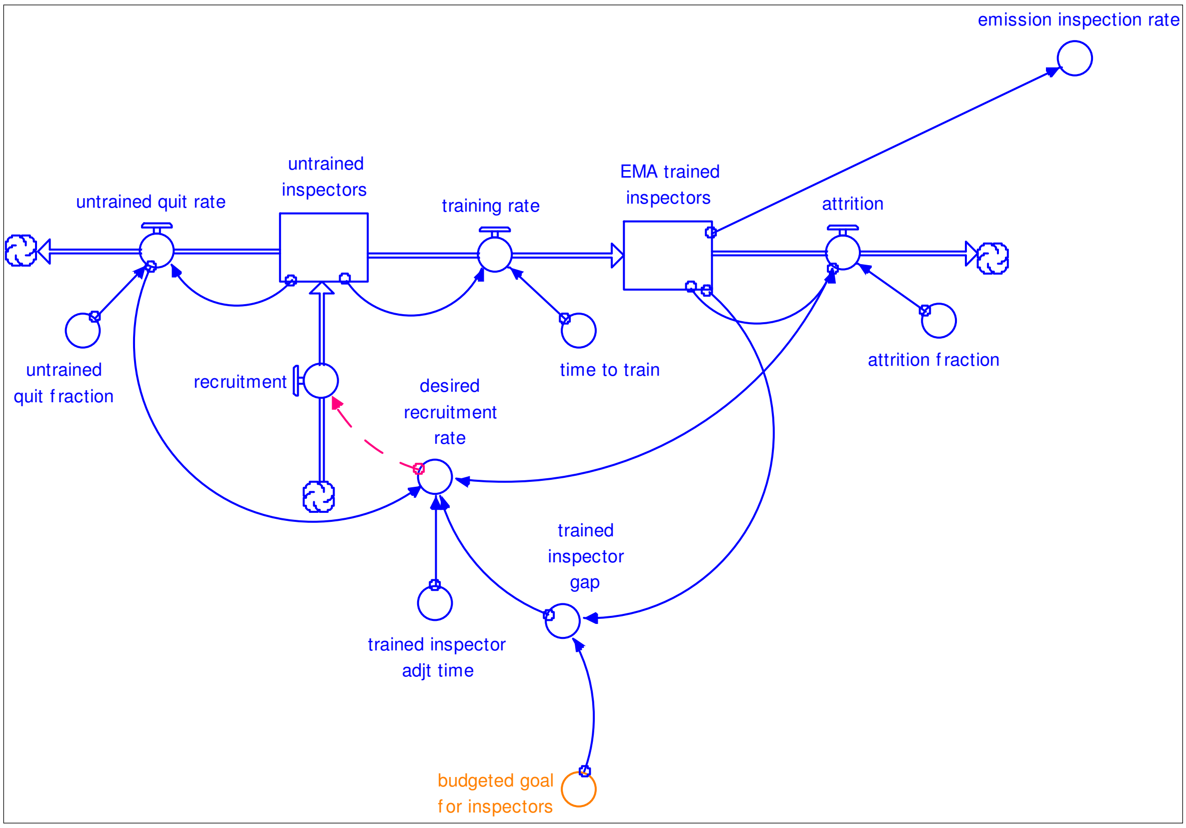


Figure 22: Recruitment structure

Considering that EMA is a relatively a new organization, there was no mobile emission inspection experienced staff within EMA at the time of its conception in 2004 which means that no mobile testing had been conducted before that. As a result this model consists of two stocks: untrained inspectors and trained inspectors (Figure 18). In April 2010 the agency deployed a team of environmental officers to South Africa for training and to obtain necessary equipment for mobile exhaust testing.

Firstly there is a stock of environmental officers who are not trained to conduct mobile exhaust emission testing. Untrained officers increase through hiring and the recruitment rate is determined by the desired recruitment rate and the total inspectors quit rate. We also assume an outflow of quit rate from the untrained inspectors which is based on a quit fraction. Since some of the inspectors have undergone training on exhaust testing which we have approximated to last for 1 month it means we now have a stock of trained inspectors. This stock of trained officers reduces through attrition based on a fixed attrition fraction. Eventually the stock of trained inspectors will feed into the emission inspection rate as shown earlier in Figure 20.

After training, vehicle inspections are expected to commence depending on the availability of testing equipment or gas analyzers which determine the probability of conducting tests. Control of mobile emissions involves mounting roadblocks to test vehicle emissions. The ability of EMA to make mobile checks and measure exhaust emissions is based on the availability of exhaust emission testing technology and the number of trained environmental officers. The distribution of trained environmental officers amongst the 18 urban areas in Zimbabwe determines the number of road control checks conducted in a year based on the rate at which new officers are recruited into the agency and the amount of time it takes to train them.

Probability for inspection is influenced by a corruption index. When corruption is high fewer inspections are carried out efficiently. The probability of conducting mobile tests influences productivity of inspectors. Excessive emissions will result in a fine or impoundment of a vehicle. Repeat offenders are supposed to be prosecuted and may face imprisonment not exceeding three months. Impounding reduces the size of the vehicle fleet thereby reducing emissions from the current fleet of old cars. Eventually we will end up with a certain fraction of the inspected vehicles being impounded each year.

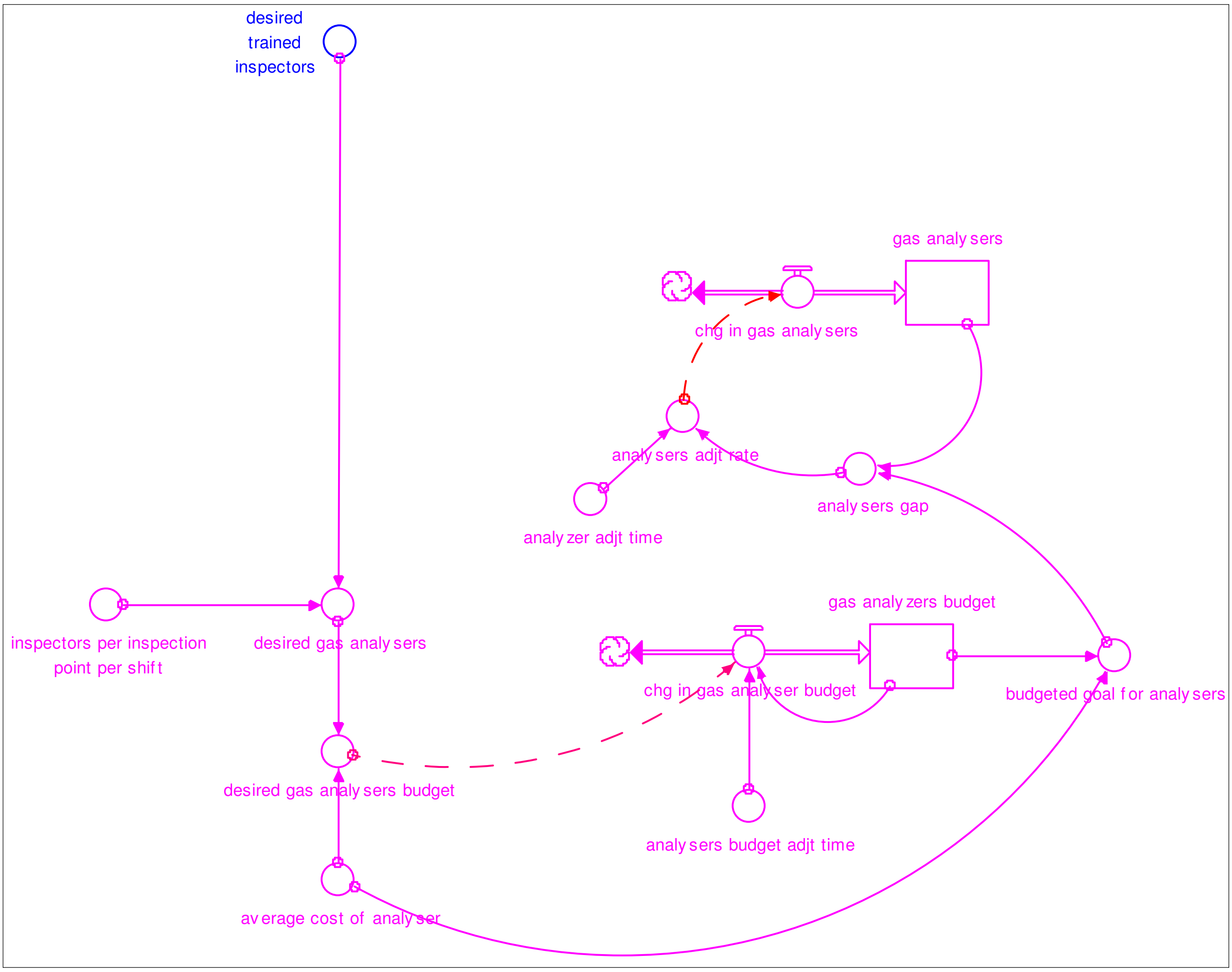


Figure 23: Gas analysers.

Gas analysers are determined by a goal for the budgeted analysers. These budgeted analysers are defined by analyser budget divided by the average cost of analysers. The average cost is estimated to be 5000 united states dollars based on their price range which is between $640 and $15 000[ix]. Given the average price we can come up with desired budget for gas analysers. Therefore, with time, the gas analyser budget will adjust to the desired budget eventually giving us the budgeted number of gas analysers (Figure 23).

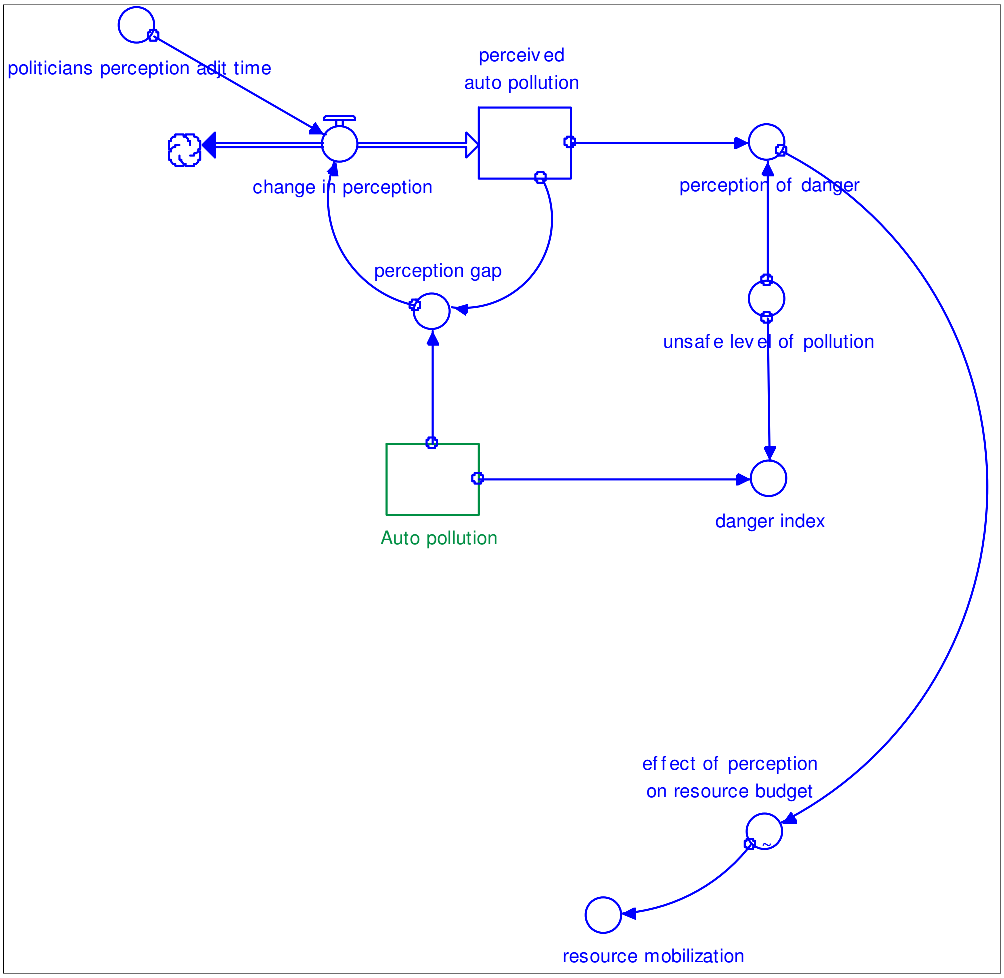


Figure 24: Auto pollution perception

Rising auto pollution levels influence perception change amongst the policy makers. When perceived pollution rises to a level that is close or above the unsafe pollution index which poses a risk to public health this might result in new laws being passed. The extent of political commitment is indicated by the amount of resources channeled towards exhaust testing either through either hiring more inspectors or buying more testing equipment. The introduction of import ban for cars older than five years with effect from 30 June 2011 to augment mobile testing was a result of such processes (Figure 24).

Perception of danger is a ratio which is defined by dividing perceived auto pollution by the unsafe level of pollution. This influences the extent of commitment by policy makers. When the danger is low politicians do not really see the need to act as compared to when the ratio is high (Figure 25).

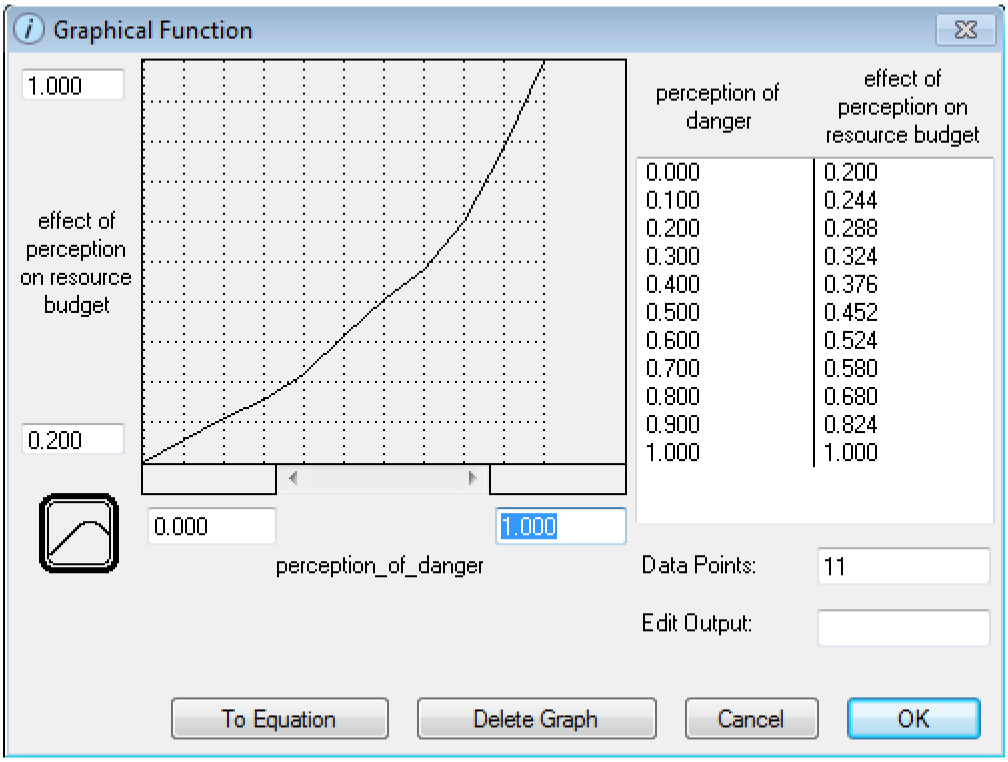


Figure 25: Effect of perception ratio on resource budget

Resource mobilization influences the time it takes to adjust each budget towards either the goal for inspectors or gas analyzers. When mobilization is 1 the adjustment time becomes shorter as compared to low mobilization (Figure 26).

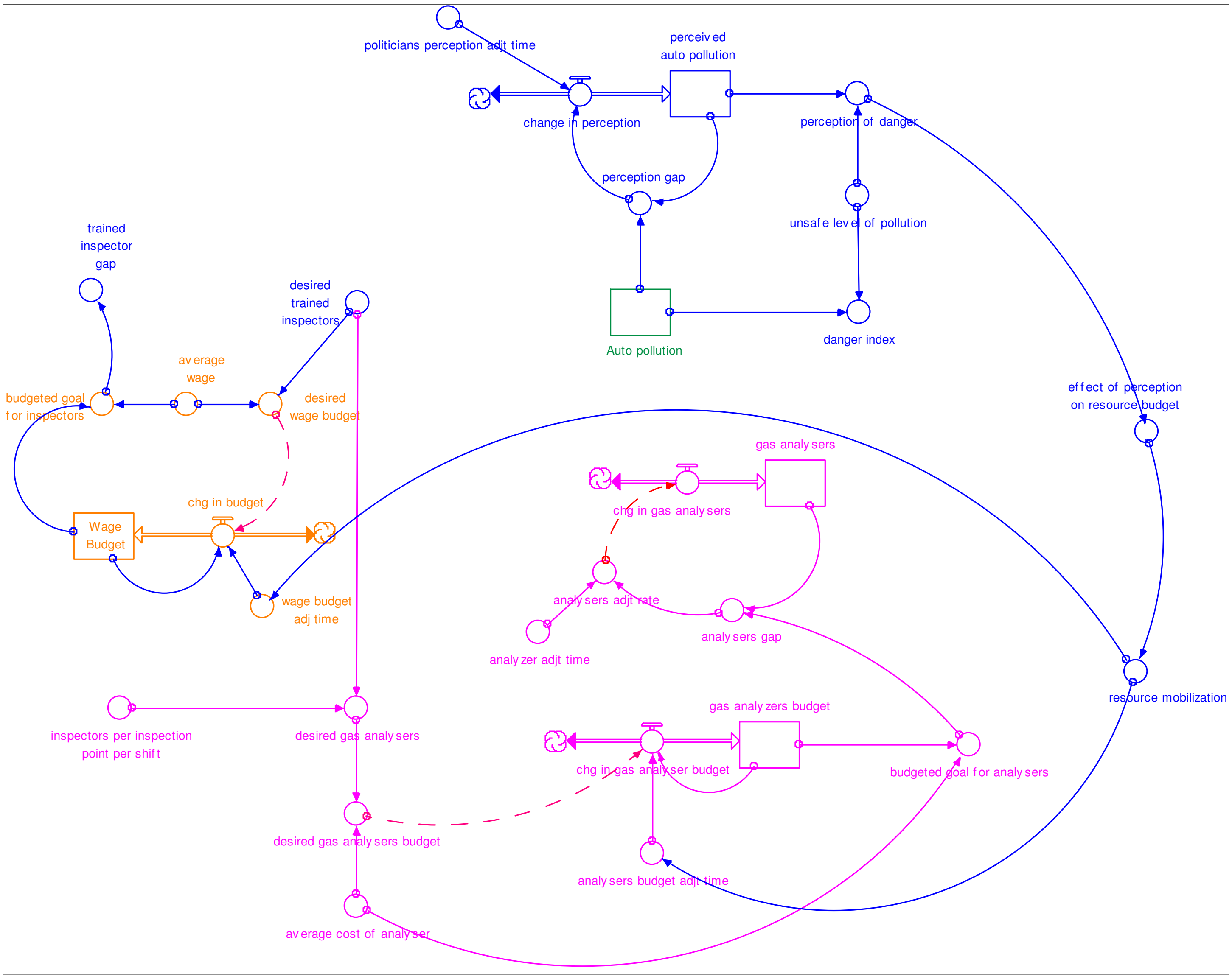


Figure 26: Effect of perception on resource budget

Summary

This section demonstrated the model building process from the hypothesis to the causal loop diagram and the stock and flow structure which all defined the problem dynamically. The chapter includes explanations on how the literature has been interpreted as connected to the problem. We now move further to validate the model.

4 Analysis

Model testing and validation

The main goal of validation is to make sure that a model depicts reality in order to gain confidence in the model's ability to act as a policy tool. On the other hand, there is no way to prove that a model is correct and model validity is a relative concept (Forrester and Senge 1978). However a theory or model stands when it has not been disproven and if there is shared confidence in its usefulness. Therefore model validation is a very important aspect of system dynamics modelling as it serves the purpose to create confidence. If we develop confidence in the model we give way for improvement in the way we understand our real world creating a testing ground for decisions and alternatives for use in the real world. Validity can only be properly assessed relative to a specific purpose (Ibid) and this model serves to explain policy implementation failure.

This chapter summarizes all the tests which have been conducted during the model building process and after the model was designed. The tests are divided into two categories; first we cover structure tests then second behaviour tests.

4.1 Structure tests

Structure verification test

Verifying the structure entails comparing model structure with the structure of the real system that the model is representing. This is done by making sure that our model does not contradict knowledge of the real system.

Each structure in the system has been based on established research. The growth in vehicle demand has been directly linked to the growth of GDP according to economic studies (Stares and Liu, 1996; Organisation for Economic Co-operation and Development, 2001; International Monetary Fund; 2006). The recruitment and training structure of EMA is based on the Agency's organisation's profile.

Parameter verification test

Model parameters are verified against observations of real life by comparing the parameters to see if they correspond conceptually to real life. Parameters in this model were based on thorough examination of information available on Zimbabwe's country profile from United Nations website and reports published by the Ministry of Environment and Tourism. Real data was used wherever possible to act as measuring sticks during the model building process. We also tried to carefully examine the vehicle registrations and inspection process in Zimbabwe through consultations with the Vehicle Registry Department in order to ascertain the actual data and process from the real system.

Extreme conditions test

We have incorporated knowledge about the extreme conditions in the model. Each rate equation in the model has been examined, tracing them back through auxiliary equations to stocks on which the rate depends. We have also considered the implications of negative values for each stock in order to determine the resulting effects on the rate equations. When a model operates according to predicted behaviour under extreme conditions it creates confidence that the model is operating as intended under normal conditions. During model building every new variable was tested according to its behaviour to both extremes. The equations for variables were adopted only in the event that they managed to give the behaviour that was being hypothesized or provided an opportunity to improve the hypothesis. Extreme condition tests were carried out several times several times as the main model was being connected to its modules.

4.2 Behavior tests

These tests are meant to evaluate adequacy of the model structure by analyzing the behaviour that is generated by the structure. Focus in paper has been given on testing how the system reacts from an equilibrium state through shock inputs. To emphasize the validity of our hypothesis major feedback loops where cut from the system. Details of cutting loop B1,B2 and B3 have been excluded in this paper as they are closely similar to the effects of other loops in the system. Details of sensitivity and extreme condition tests are contained in appendix 4.

4.2.1 Behaviour reproduction test

In this part of the paper, the model was initialised with historical data in all cases where the data was available. In cases where the data was not available estimates were based on the historic behaviour. Analyzing the historic fit of the model is part of the behaviour reproduction test. Behaviour reproduction tests however involve more than comparing the resemblance of the simulated and actual data on a point to point basis (Sterman 1984). As a result point by point comparison of historical data has been minimized in system dynamics whilst focus has been given to other tests which are included in this chapter. This is because

> "one can always fit any set of data to any degree of precision required"(Sterman 1984).

The other reasons include the fact that any real system produces behaviour that is subject to its relevant forces and purpose, particularly the noise or randomness which might not be specifically relevant the purpose of that particular study (Ibid). Despite this, test on historical fit was carried out in this study and there were small variations as observed from Figure 27 which were not considered to be of significant harm to building confidence in the model.

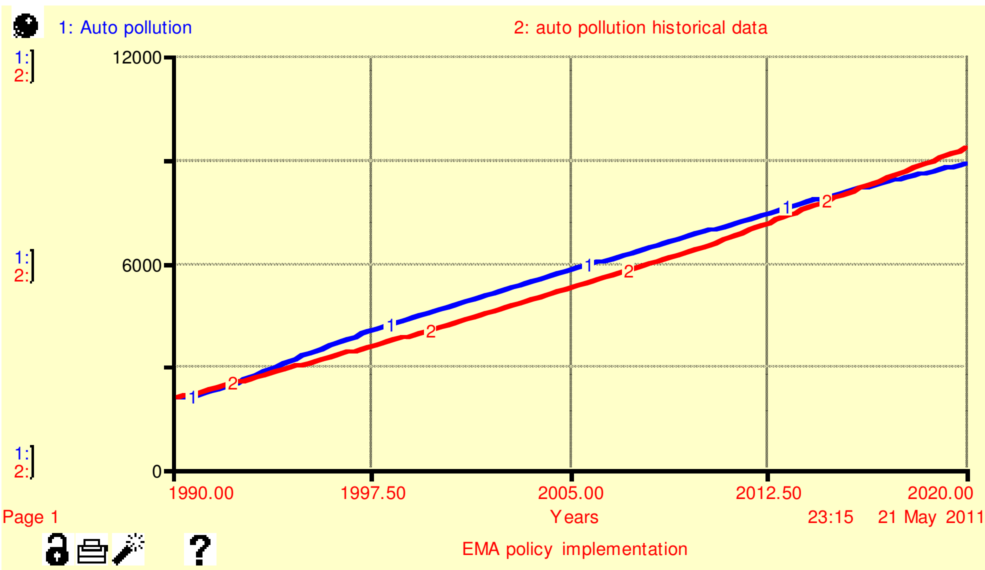


Figure 27: Behaviour reproduction

Choosing DT and integration method

DT was set to 0.01 and this provided stable results.

The steady nature of auto pollution suggested the use of Euler's integration method.

4.2.2 Equilibrium shock test

The model was initialized in equilibrium. Applying a shock of 200 Gg emissions each year should cause auto pollution to rise steadily. This initial disturbance will cause auto pollution to keep rising as observed in Figure 28 below.

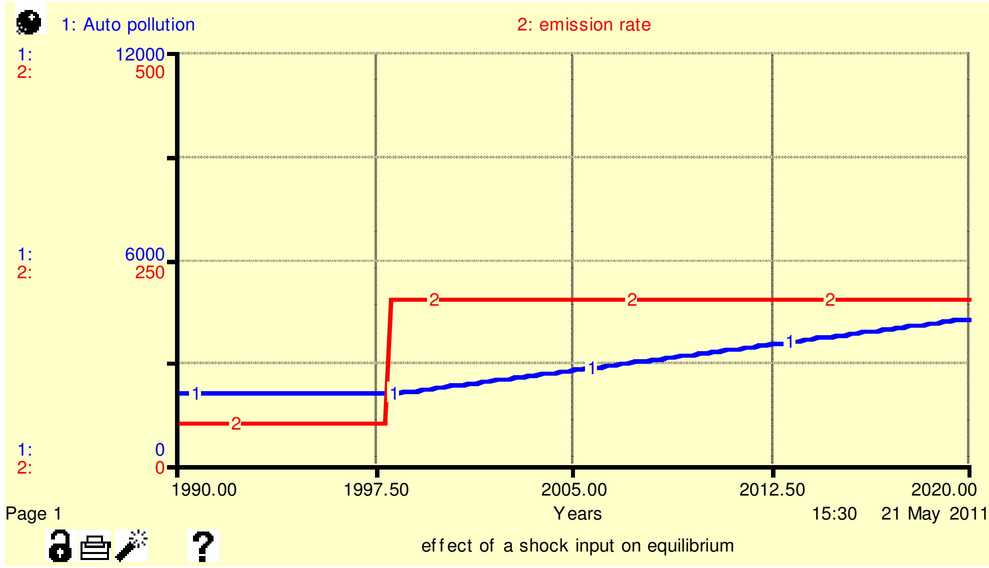


Figure 28: response to shock input

The initial change in auto pollution is the system's sudden response to the increase in inflow. The gradual increase occurs as there is more emission compared to absorption. As no action is taken to increase absorption, auto pollution continues to build up. The next step is to cut individual loops to observe how they contribute to disturbances in equilibrium.

4.2.3 Extreme policy test

The vehicle population Loop R1

According to the vehicle population Loop R1, the attractiveness of used imports based on their price increases a demand for cars resulting in more vehicles operating in the country. If this hypothesis is correct the influx of used imports should coincide with the rise in levels of auto pollution. The more the stock of used vehicles increase the more the auto pollution should rise as compared to any changes in the stock of new cars (figure 29).

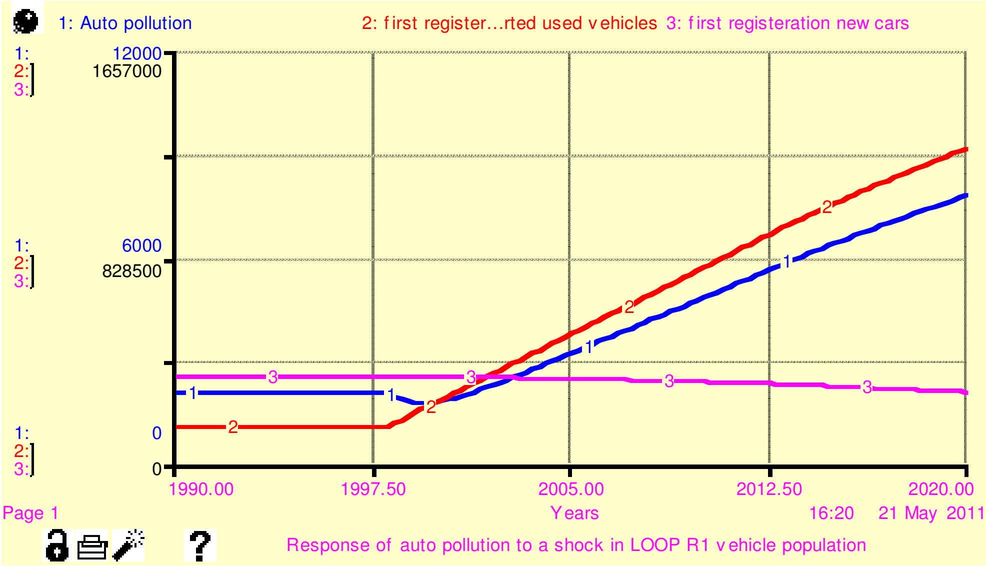


Figure 29: Relationship between vehicle population and auto pollution

In order to see the effect of the vehicle population Loop R1, we can cut this loop from the model after an initial state of equilibrium. Cutting Loop R1 can be done by making the inflows of the new and used vehicle stocks equal to the outflows of the same stocks. This should put the vehicle population into a state of constant equilibrium as observed in Figure 30.

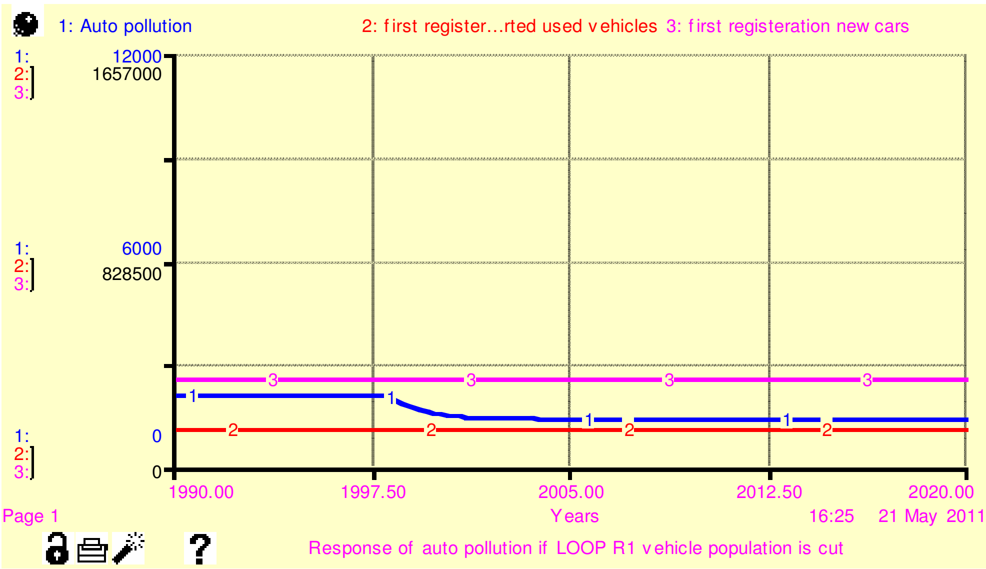


Figure 30: cutting Loop R1

After the state of equilibrium auto pollution falls until it stabilizes because absorption rate will exceed emission for a while thereby reducing pollution. This reduction only occurs until the two flows equalize because the vehicle population, even though constant, it is still emitting in small amounts which can be absorbed at the same rate. We can conclude from these observations that the vehicle population Loop R1 particularly the stock of used imports is at the centre of auto pollution problems. As long as Loop R1 is active pollution problems will occur whenever the stock of used imports increase.

Mobile exhaust testing Loop B4

We have hypothesized that conducting mobile exhaust testing will bring down auto pollution if implemented to full capacity. Switching on this policy switch from 2011 brings results similar to Figure 31 below. Auto pollution stops rising, levels off and remains constant. This observation supports our observation that ineffective policy implementation from 2002 caused auto pollution levels to keep rising because conducting mobile tests actually reduces auto pollution.

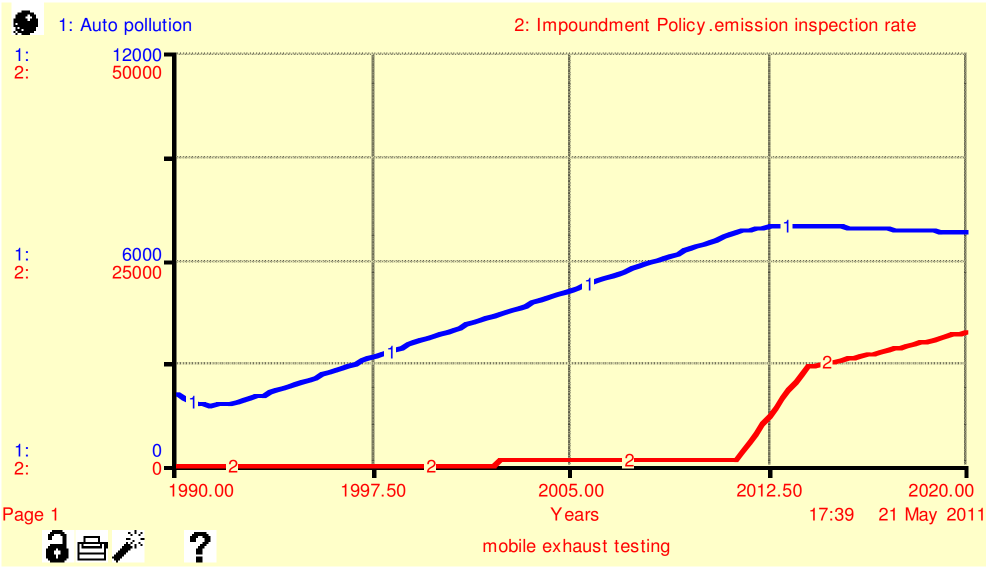


Figure 31: LOOP B4

If this policy switch is turned on from 2002, a huge reduction in auto pollution will be observed revealing what would have occurred had implementation begun in 2002 (Figure 32).

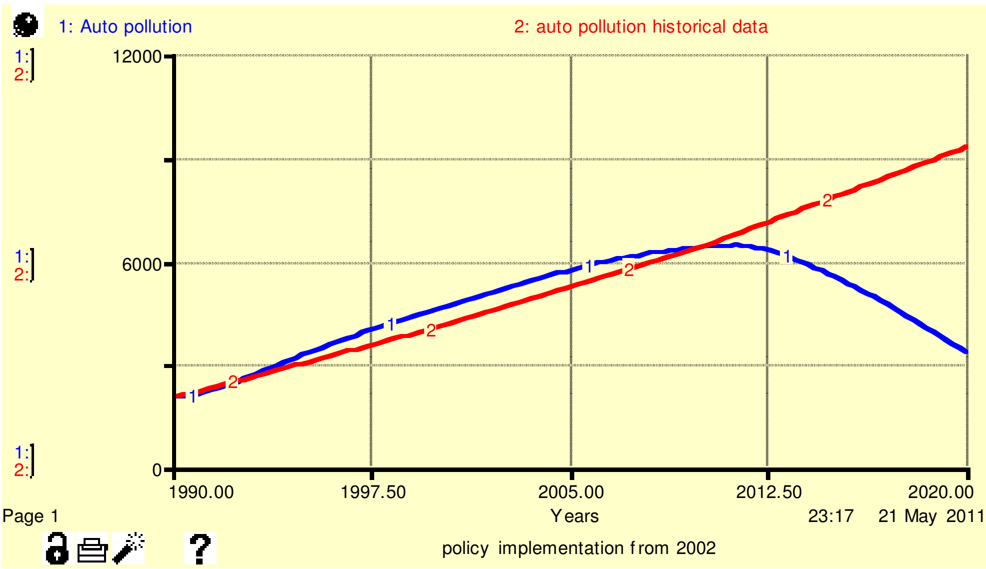


Figure 32: Mobile inspection from 2002

What was causing auto pollution to rise even though Loop B4 was part of the system is its inaction, that is, lack of practice despite the existence of the policy and the same is true for Loop B5.

Vehicle impoundment Loop B5

If we add vehicle impoundment from 2011 to the inspection as hypothesizes the resulting behaviour should be similar to Figure 33 below. Auto pollution begins to fall immediately as impoundment of the most polluting cars commence

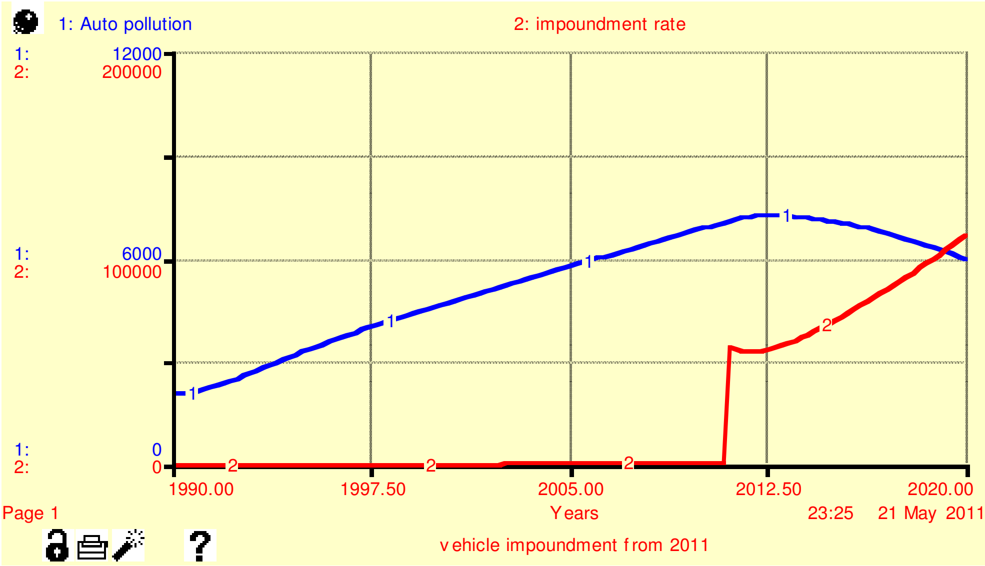


Figure 33: LOOP B5

Suppose policy implementation involving both inspections and impoundment had commenced in 2002, this would have been effective in bringing down auto pollution to equilibrium as observed below (Figure 34). This further proves our hypothesis that auto pollution rose as a result of inactive and ineffective policy implementation.

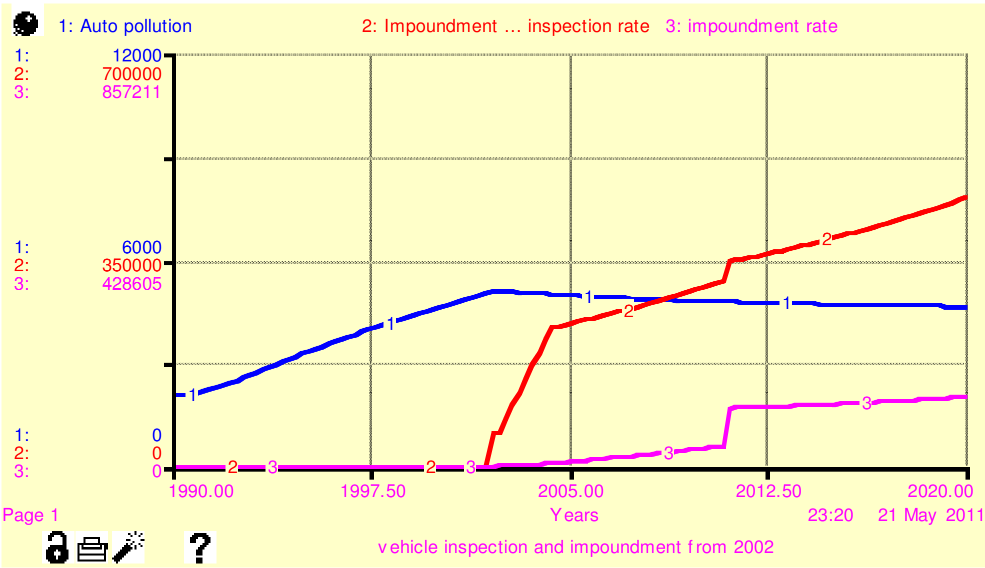


Figure 34: Effective implementation from 2002

If we make an experiment and activate Loop B3 right from the beginning of the simulation and ban the importation of all used cars by reducing the age of used cars to 0, there should be a remarkable reduction in auto pollution as observed in Figure 35.

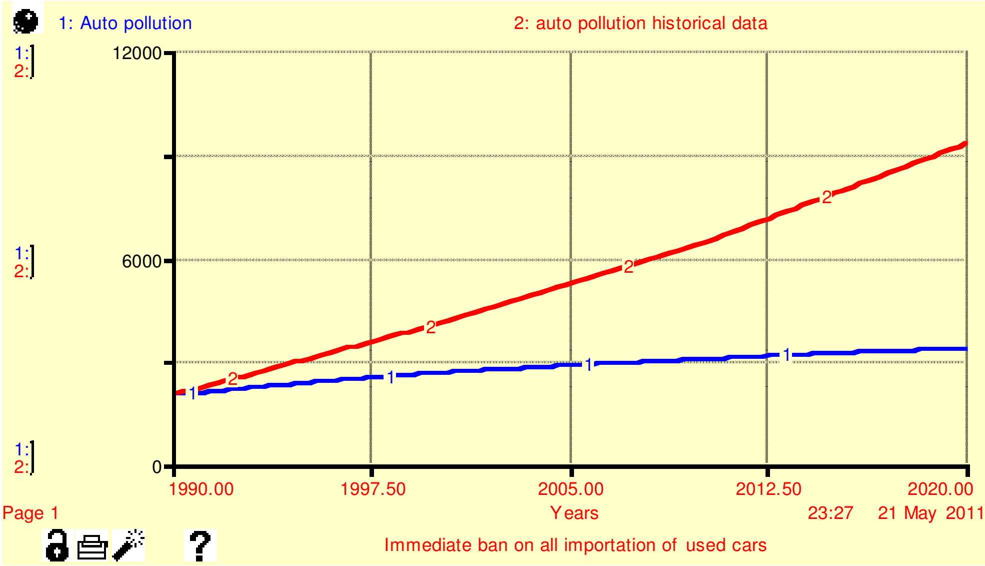


Figure 35: A ban on importation of all used cars from the start.

4.2.4 Sensitivity analysis

Sensitivity analysis is used to evaluate the behaviour of the model to assumptions that are uncertain concerning model formulations and parameter values (Moxnes 2005). We are going to achieve this analysis by varying model assumptions then observing how the behaviour of auto pollution changes.

Vehicle age

In line with our hypothesis, that, implementation of the EMA has been rendered ineffective to control auto pollution due to the influx of used vehicles into the country, cutting loop R1 showed that the model was sensitive to the average age of vehicles at their first registration with the vehicle registry. Average ages of 1, 5, 10, 15 and 20 were tried. The difference in their on auto pollution was very huge indicating high sensitivity to vehicle age at first registration (Figure 36).

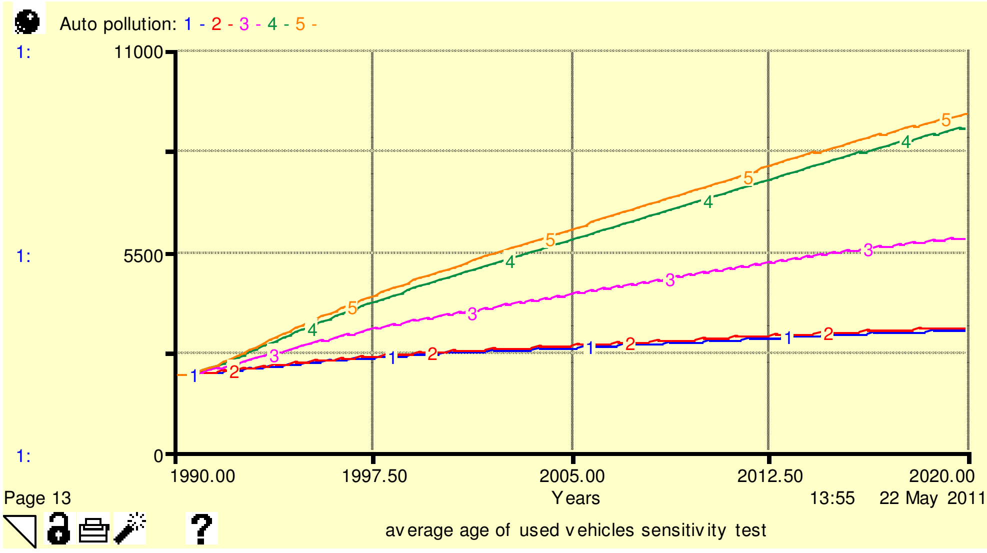


Figure 36: Auto pollution sensitivity to changes in vehicle age

Recruitment fraction

The same test was also run on recruitment fraction of untrained mobile inspectors. This also produced huge differences. Initiating the recruitment process from 2011 the behaviour of the system changes completely. The fraction has been set to range from 0.02, 0.1, 0.2, and 0.3 to 0.4. Raising the recruitment fraction has the effect of increasing the number of inspectors who are available for training. This will eventually raise the inspection rate leading to more impoundment of the worst polluters and reducing auto pollution (Figure 37).

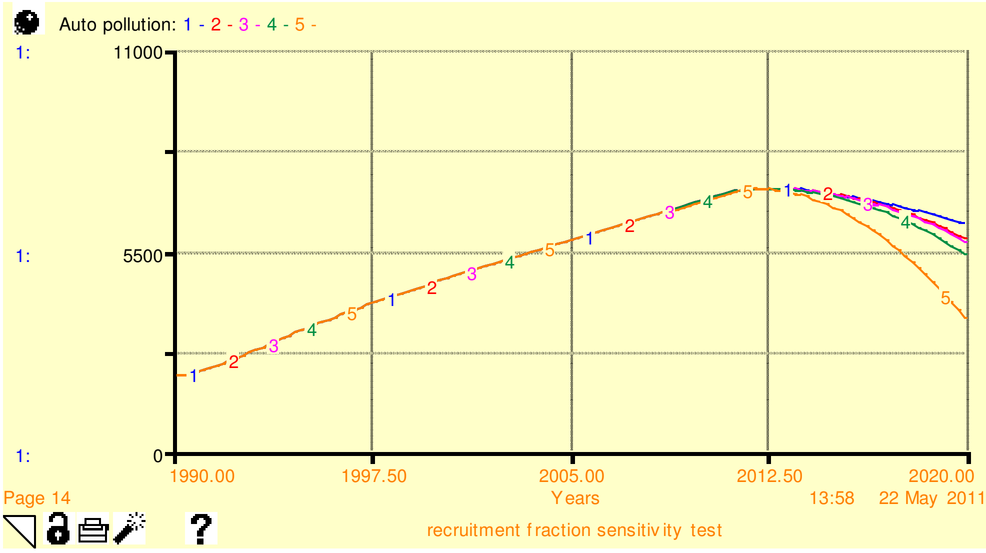


Figure 37: Auto pollution sensitivity to changes in recruitment fraction

Used import adjustment time

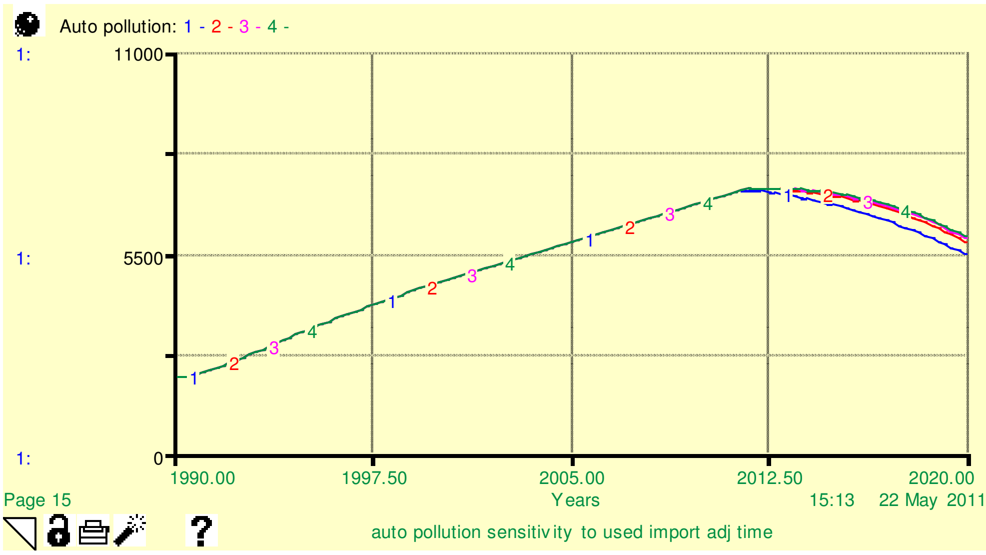


Figure 38: Auto pollution sensitivity to used import adjustment time

Suppose implementation starts from 2011, varying the adjustment time to reduce the used import car gap to its desired values has small significance to auto pollution unless the adjustment time is 2 years and below. We ran a sensitivity analysis of adjustment times ranging from 2, 8, 14 and 20 and the above results were produced as in Figure 38. The same is true for changes in trained inspector adjustment time below.

Trained inspector adjustment time

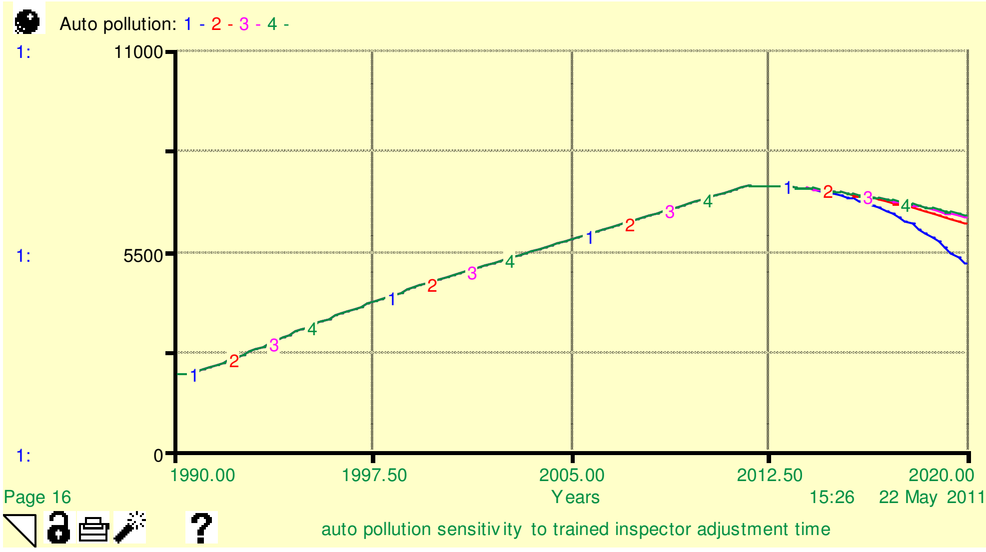


Figure 39: Auto pollution response to changes in trained inspector adjustment time

Varying the adjustment time to reach the desired trained inspector rate only produced significant results if the time is below 1 year. Adjustment times ranging from 0.5, 2, 3.5 and 5 years were tried with the above results (Figure 39).

4.2.5 Testing table functions

This section goes through some of the table functions used in this paper providing justification on how these functions influence the system. Curves from a table function reflect assumptions within a parameter that requires to be tested like any other assumption. Details are provided on the tests that were undertaken on two table functions: the effect of price on the attractiveness of used vehicles and the effect of urban population on demand. Three graphs are presented in each test and the third graph in the sequence represents the graph used in the model.

Effect of price on the attractiveness of imported used cars

Three different price ratio curves were tested in figure 40 below. A slight difference was observed on auto pollution by changing these three curves. The model used the third curve because it was observed to give a true reflection on how consumers perceive the car industry leading to demand and purchases. When the relative price is too high consumers would rather spend their money on a new product than a used product. Tendencies to opt for used products is only driven by price differences (Dobson 1997).

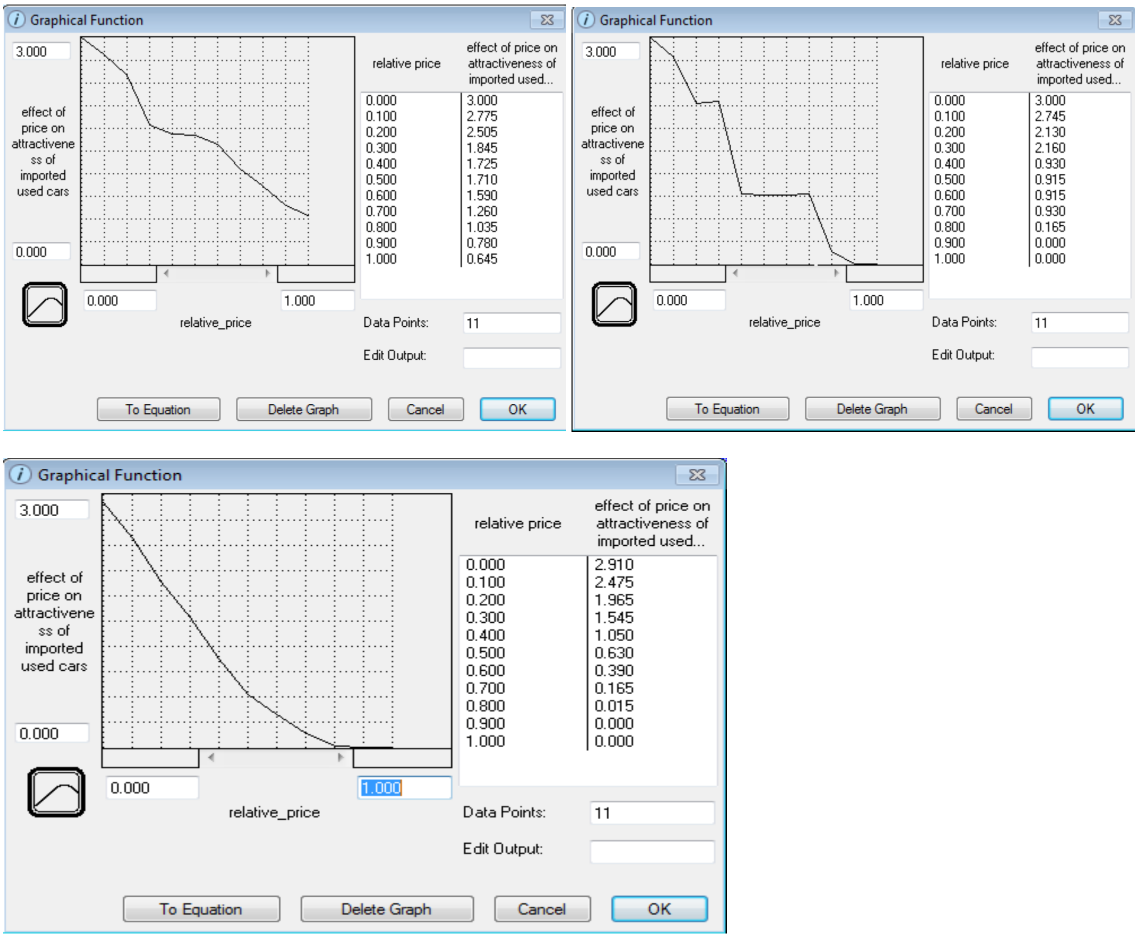


Figure 40: Different curves for the effect of price on the attractiveness of imported used cars.

<u>Effect of urban population on car industry demand</u>

The effect of urban population on market demand for cars has a significant effect on auto pollution. Three different curves were tested (Figure 41) and the third curve was used in the model. The graphical function used in the model was based on the findings that the car industry, in general, expands during urban development (European Conference of Ministers of Transport, 2007). It takes the urban population to rise to certain levels before its influence on demand because low population does not have much impact on pollution levels. The difference in these curves is so huge to the reference mode such that the results of the first graph have been included in figure 41. The third graph provided the behaviour that matched our hypothesis.

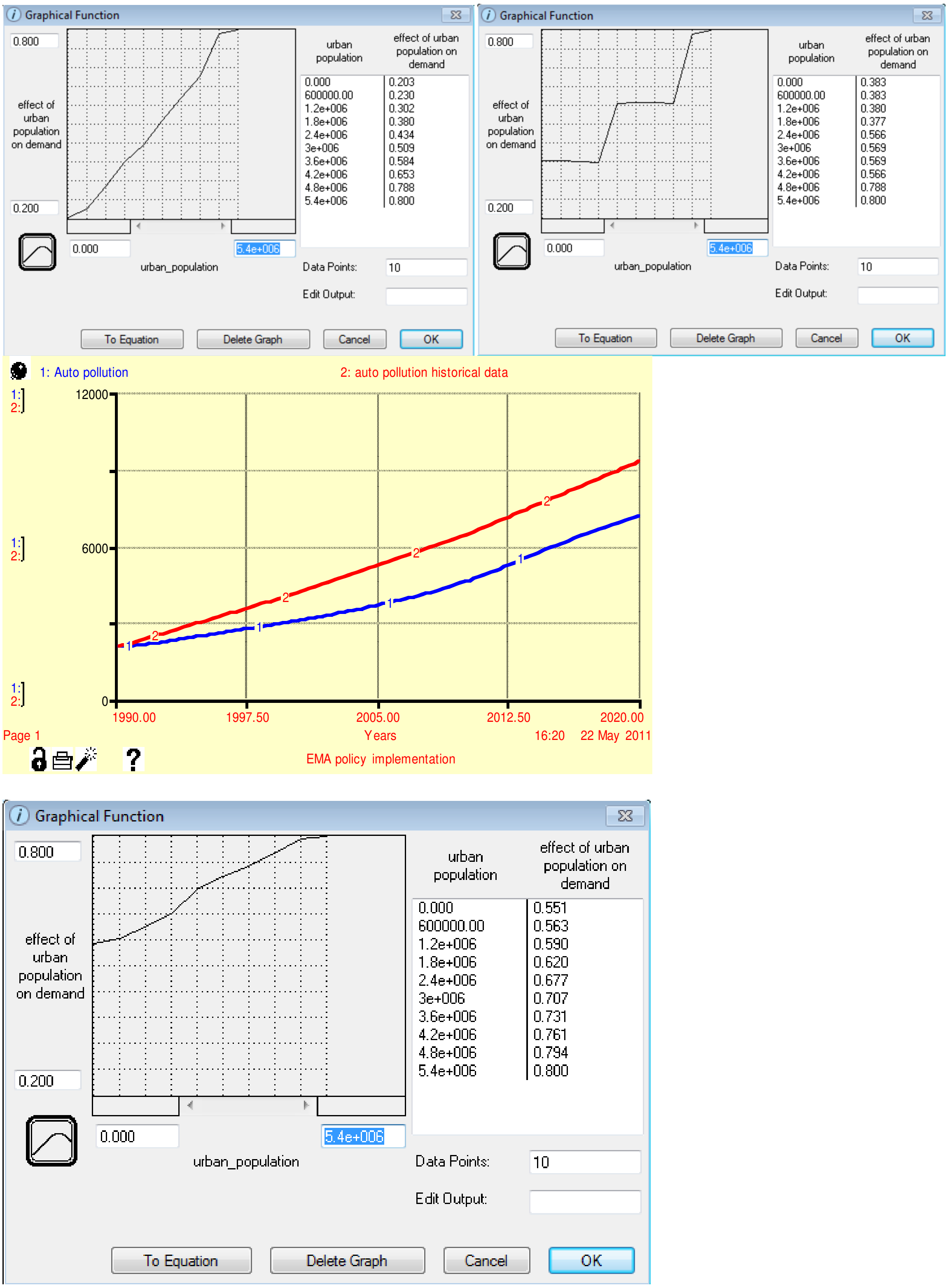


Figure 41: Different curves for the effect of urban population on demand and the results

5 Policy

This chapter does not bring in a new policy to the model but rather analyzes and tests the variations that could have been brought about by the current policy under different strategy decisions. We will tests all the desired links in the model versus the actual links in order to answer the questions of "what if" as described in the research questions. We start by determining the behavior that was expected to be ushered in by the EMA policy in 2002 then we show what actually occurred and assess what went wrong. We are going to show "What is happening, what is desired and why is it happening as it is?

5.1 Desired emission per vehicle

We have added and made a connection representing the desired emission per vehicle in the system which represents the situation we wished for as a result of the new policy. The actual average emission per vehicle is producing results that were not intended after the policy was introduced. This desired and wishful link symbolizes and produces the behavior that is desired in auto pollution levels. Figure 42 below is shown as a reminder of the link to which reference is being made. This link is crucial in assessing the success of this policy from 2002 to present if we want to compare the prevailing situation versus the desired.

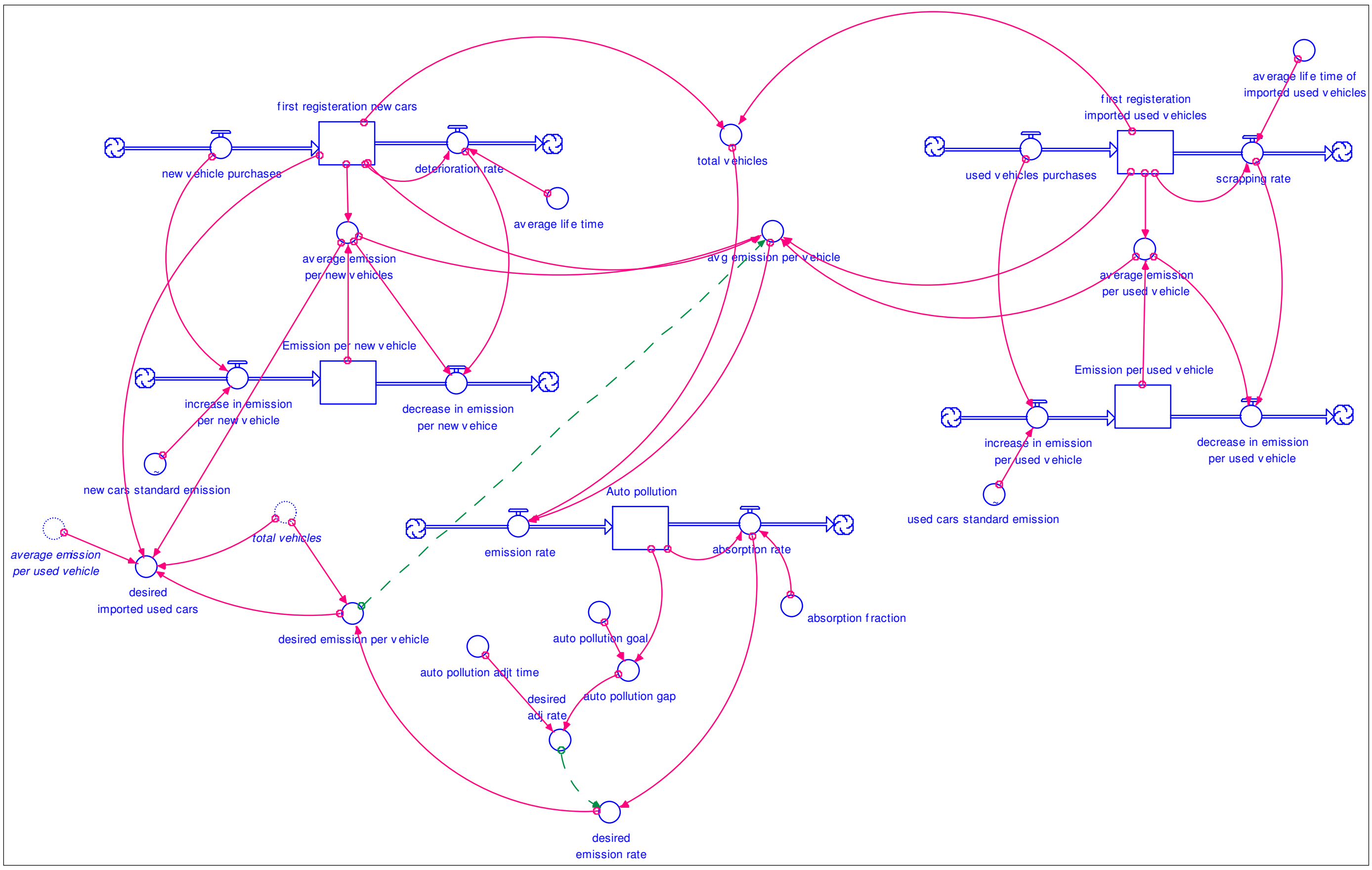


Figure 42: Desired emission per vehicle presumed link

Together with this link, a policy switch has been created that turns the connection on and off. A comparison of the resulting behavior by just connecting this link is remarkable. Auto pollution falls drastically and starts reducing gradually (Figure 43). What causes this to happen is an immediate response to emission reduction by creating a goal for the auto pollution which becomes the target for auto pollution. What were missing in the actual policy implementation were both a goal and a strategy to reach that goal.

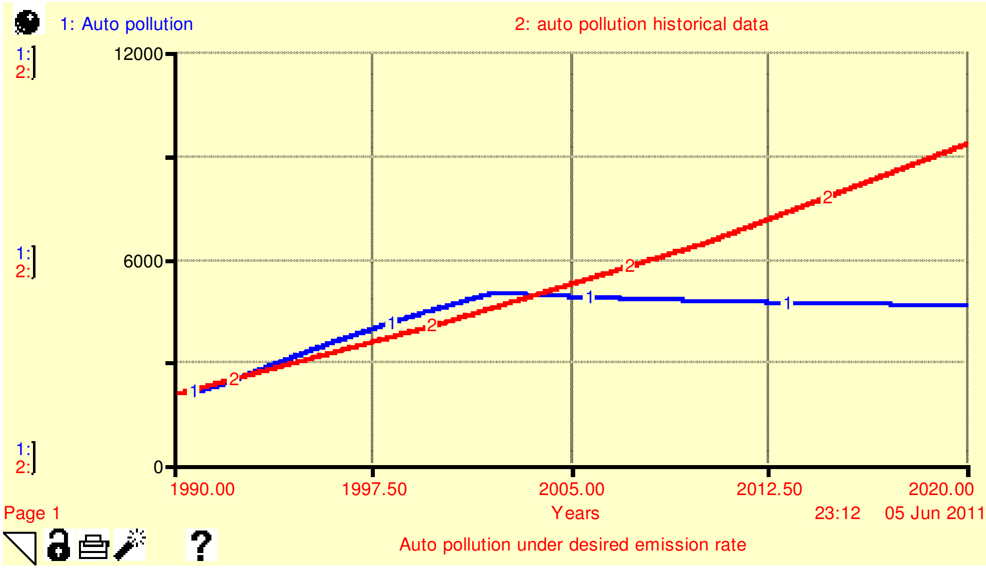


Figure 43: Auto pollution under desired emission rate versus auto pollution historical data

The comparison between the actual and the desired outcomes gives us enough information to ascertain the progress of this policy in achieving intended results. This assessment leads to one conclusion which reaffirms our hypothesis concerning the policy implementation being ineffective to date.

5.2 Desired recruitment rate

The second hypothetical link connects a goal for the trained inspectors to recruitment (Figure 44). Formulating a goal gives a target to reach and to adjust to within a specific time. If EMA as an agency had not taken 6 years from 2004 to 2010 to start sending inspectors to South Africa for training, the problem currently faced would have been reduced. A more ideal situation would have been to define a goal for inspectors depending on the available wage budget and start recruiting immediately.

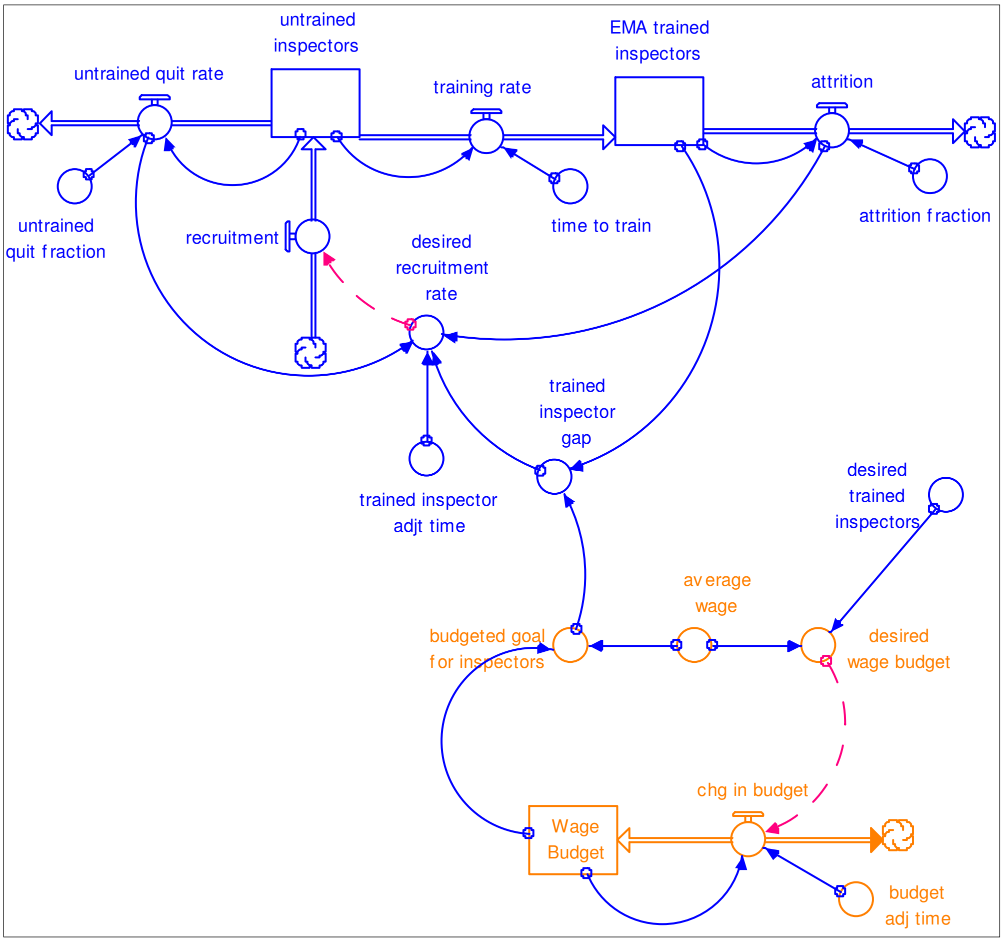


Figure 44: desired trained inspector adjustment rate

Assuming that no other action has been taken to date to increase the number of inspectors we go on to assess the results that are expected to be brought about by this assumption. In scenario 1 (Figure 45) we show how auto pollution will change from 2011 onwards based on the current recruitment without a budgeted goal as initiated by EMA in 2010. In scenario 2 (Figure 46) we consider and show how auto pollution would change also from 2011 onwards if we build a goal that is budgeted for and activate the desired recruitment rate.

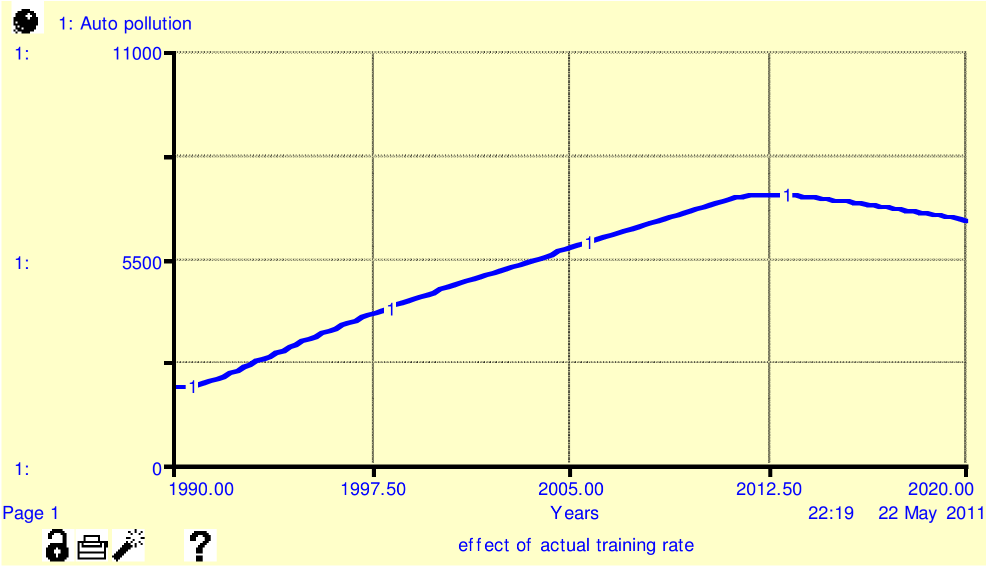


Figure 45: Actual recruitment rate

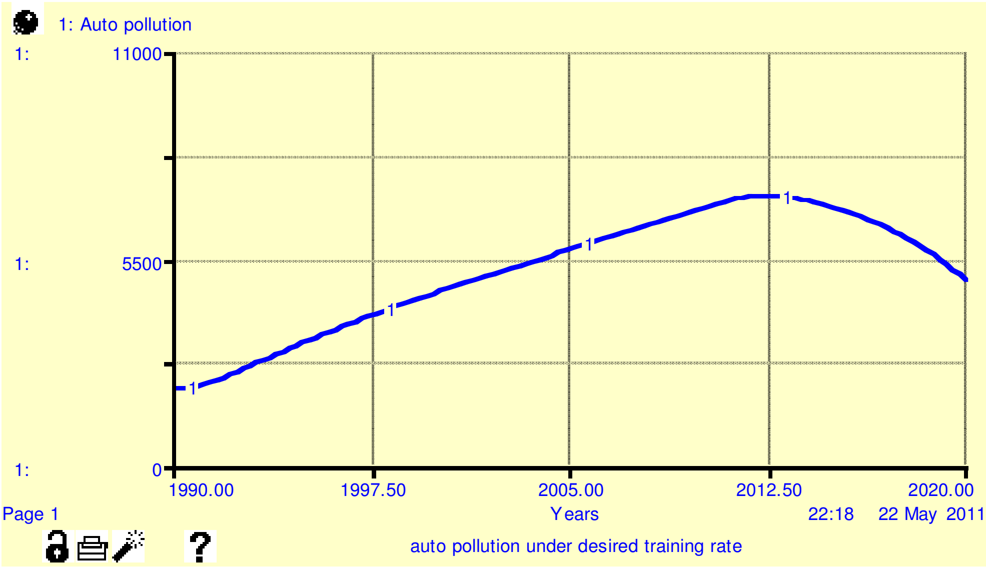


Figure 46: desired recruitment rate

It can be observed from the comparison that creating a budgeted goal for trained inspectors causes auto pollution to reduce more rapidly than without a goal.

5.3 Desired inspection rate

Desired inspection rate creates another option to consider instead of the actual inspection rate (Figure 47). If we hypothetically take the desired rate to replace the actual rate the results we would produce have a dramatic effect on auto pollution (Table 2).

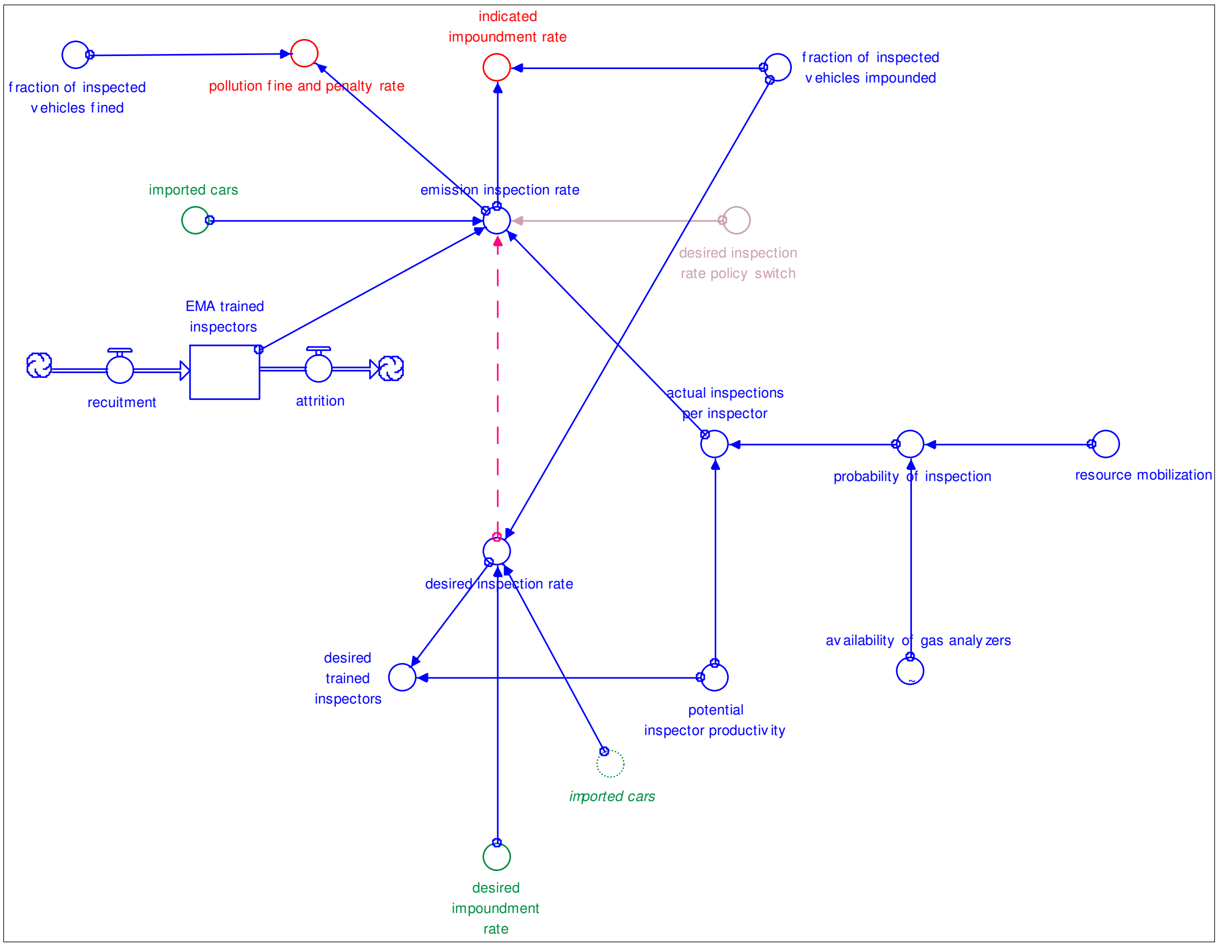


Figure 47: Desired inspection rate

22:45 22/05/2011 Table 1 (Untitled Table)

Years	emission inspection rate	desired inspection rate
2011	24,768.58	389,840.43
2012	34,580.02	486,206.75
2013	44,908.61	579,663.76
2014	55,285.37	670,845.93
2015	65,677.82	760,082.07
2016	76,109.11	847,518.55
2017	86,529.69	933,229.09
2018	96,888.45	1,017,253.98
2019	107,135.70	1,099,638.00

Table 2: Desired inspection rate compared to inspection rate

As observed above, only 24 700 vehicles are expected to be inspected in 2011 as compared to 389 000 in the same year out of a total of over 1.6 million cars. This means that EMA's current strategy needs to be revised if any significant impact on auto pollution is expected from the current policy.

5.4 Desired impoundment rate

Assuming that vehicle inspection is conducted at the current inspection rate as from 2011 gives us another option analyze. What if we create a goal for the stock of imported used vehicles which we call desired imported used vehicles? The gap which exists between these two variables represents excess vehicles which need to be removed from the road within an adjustment time of 10years. If we add this adjustment rate to the net-flow of imported used vehicle we can come up a total of road unworthy cars that should be impounded each year instead of relying entirely on the scrapping rate to reduce this stock (Figure 48).

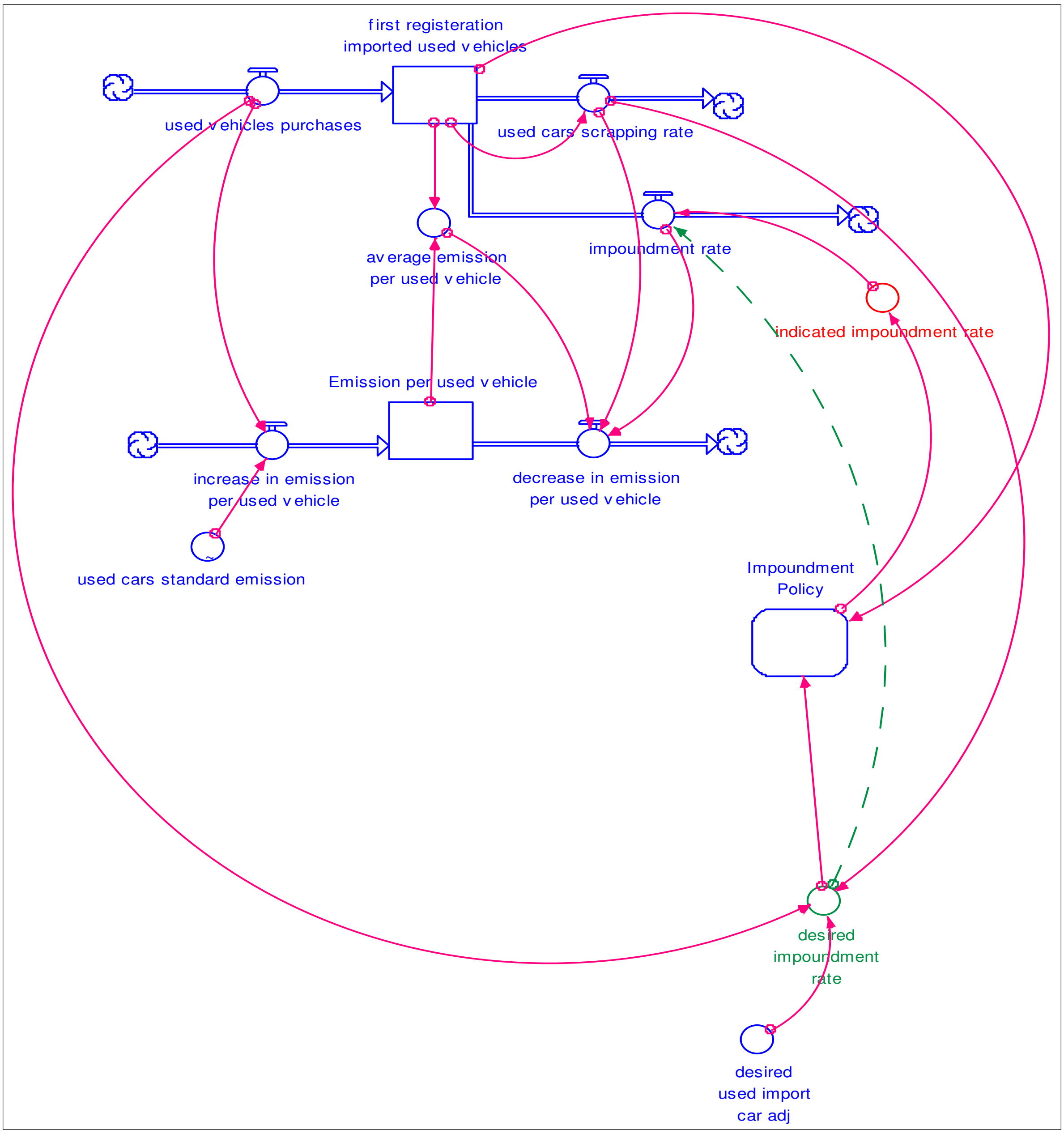


Figure 48: Desired impoundment rate

As shown in table 3 below the desired rate produces more impoundments as compared to the indicated rate. Therefore if EMA restricts itself to the indicated rate, not much significant results are expected from this policy from 2011 onwards. Instead auto pollution will continue to rise as estimated by the historical data's forecasts to 2020.

23:19 22/05/2011	Table 2 (Untitled Table)	
Years	Impoundment Policy.indicated impoundment rate	desired impoundment rate
2011	2,693.68	57,078.25
2012	3,399.77	56,406.17
2013	4,332.73	55,296.65
2014	5,495.51	54,169.15
2015	6,890.63	53,063.68
2016	8,520.88	51,982.50
2017	10,388.37	50,922.42
2018	12,494.59	49,880.81
2019	14,840.32	48,861.89

Table 3: Comparison between indicated impoundment rate and desired impoundment rate

5.5 Conclusions from policy testing

EMA policy implementation must be conducted using the most tactical option that creates the best results to control the problem. As observed from the different scenarios above there is a huge difference in policy outcomes depending on the aggressiveness of the implementation process. There are various options that are available for EMA the agency to capitalize on, in order to mitigate against the lost time when the law was not being enforced particularly for auto pollution. The agency needs to start by reorganizing its own structures and goals which match their budget and increase manpower before looking at the bigger picture. Mobilization of more resources is a mandate if any changes are desired on this problem because effective action requires more testing equipment.

Considering that all dynamics arise from feedback and the same information processed under different decision rules yields different decisions and results. Implementation failure is based on misperceptions of feedback and significant time delays in responding to the problem. This is amongst the reasons why the policy has failed to date. On the other hand the decision to cut on the importation of used vehicles is already facing heavy criticism from the public before it has even come into operation mainly because critics are overlooking the effects of the feedback loop. Since this decision was announced in October 2010 second hand vehicles have flooded the Beitbridge border post waiting for clearance into the country in order to beat the deadline on June 30, 2011. Zimbabwe Revenue Authority (Zimra) has indicated that the number of imported vehicles has gone up significantly as a result of the coming ban. Officials at the border post confirmed that 15 car carriers used to be handled per day which would translate to 101 vehicles but since January this year the numbers has increased to about 30 to 40 car carriers per day which gives about 250 cars per day. In January 2011 alone 3 150 second hand cars entered the country compared to 2 310 in January 2010

6 Challenges to environmental policy implementation

<u>Why would auto pollution be expected to keep rising from 2011 onwards?</u>

There is a lot of politics surrounding the environment (Carter 2007) which can be classified as following:

a) Public goods

Environmental resources are public goods, which mean that its consumption by one individual is not affected by another individual's consumption. This public nature of the environment has serious implications for policy makers because there is a temptation for individuals to ignore instructions to keep clean air under the assumption that others will follow the instructions. This result in free riding which brings about less than optimal provision of the public good which is clean air. This creates major challenges for implementation because EMA is a policy that requires close coordination in order to carry through.

b) Temporal and spatial variability

Environmental policies create winners and losers because the costs of environmental problems are unevenly distributed (Carter 2007). This is because the impact of environmental policy is usually long-term affecting generations in the future instead of the present, so the present generation must sacrifice for future benefits and politicians tend to be more concerned about short term issues like winning the next election.

c) Trans-boundary problems

Air pollution can be trans-boundary if it leads to climate change and ozone depletion because it does not respect national borders and requires action by the international community. If one nation takes no action to reduce global warming, other nations will also be affected by such inaction. Therefore cooperation is required between states and persuasion of reluctant states to participate in joint action and comply with international guidelines.

d) Complexity and uncertainty

The ecosystem is interconnected, complex and environmental problems are uncertain which policy making difficult. Many environmental problems cannot be addressed in isolation and policies that deal with single issues have unintended effects elsewhere (Carter 2007). For example industrial towns in Britain in the 1950s reduced local air pollution by building taller factory chimneys, only to be realised many years later that the action had exported the pollution to fall as rain acid in Scandinavia (ibid). In the same way fitting cars with catalytic converters reduces nitrogen oxide emissions which cause acid rain but this results in engine efficiency reduction which increases fuel consumption and subsequently increases carbon dioxide emissions which adds to global warming.

e) Administrative fragmentation

The government's administrative structure is commonly divided into several policy sectors such as education, health care and defence. Ministries such as finance, energy, industry, agriculture, transport and employment formulate policies that affect consumption, production and lifestyles that normally lead to negative impact on the environment. As a result, as these individual ministries pursue their sectoral objectives and the expansion of their services, they give little consideration to the environment. The transport ministry for example might embark on massive road construction whilst the responsibility for protecting the environment to a separate ministry. Bureaucrats tend to break down problems into separate unit but the interconnection of economic and ecological system has no respect for these administrative boundaries. Environmental problems need coordinated responses that move across sectors. An effective strategy for clean air requires the involvement transport, forestry, energy, livestock and industrial emissions ministries. Above all, the economic policy should be taken into consideration.

f) Regulatory intervention

In most cases the environment is usually damaged in the process of carrying out legitimate activities and as a result the government will need to intervene again to regulate these damaging activities.

Arguments against complying with air pollution regulations in the South.

Western countries and the United States developed at the expense of the environment and now that the effects of industrialisation on the environment have been discovered, measures to control further damage result in slowing or limiting the rapid growth of industrializing counties. Studies conducted in Africa in 1990–96 found that Mali, Kenya, Ghana, and Zimbabwe are greenhouse gas sinks (ENDA 1997). As a net sink, Zimbabwe is currently absorbing emissions from countries which are net emitters slowing down the pace of climate change. Given the present rate of emissions Zimbabwe will remain a net sink to sometime around 2040 (Ministry of Environment and Tourism, 2004) and the damaging effects of the greenhouse gases will not be experienced globally unless net emitters reduce their emissions.

In spite of whether or not Zimbabwe puts together all its efforts to make huge reductions in its own emissions, the global air pollution problems will still exist. Despite this fact, it is important for the country to address issues of air pollution because as mentioned earlier on African countries are more prone to the effects of climate change that results from pollution because of lack of resources to mitigate and cushion themselves against its effects. Zimbabwe is a land-locked country with no natural lakes and is prone to periodic droughts and a change in atmospheric gas composition could have negative consequences for the economy particularly the agriculture and tourism sector. The rural population relies on subsistence farming and depend on rain and irrigation for cultivation and low rainfall levels will lower the levels of water in catchment dams leading to water shortages. Low water levels in the Zambezi River can result in the reduction of recreational activities in the tourist resort areas of Victoria Falls and Kariba Dam and a poor ecosystem that cannot sustain the wildlife. For example the drought which occurred in 1991/92 caused the death of wildlife in national parks, particularly elephants. Global warming also poses a threat to human health particularly the threat of malaria to a much larger geographical area of the country as compared to the current malaria prone low-lying regions such as the Zambezi valley. Warmer climate will result in the migration of mosquitoes into higher areas where malaria is currently not an issue. All these possible effects of climate change could pose serious problems for the government which need to be address now before the problem escalates because prevention is better than cure. Even though Zimbabwe is an insignificant contributor to pollution, the impacts of warmer climate in the country are significant.

Other environmental programmes

There is lack of coordination on environmental management and control of atmospheric gasses. Zimbabwe signed and ratified the United Nations Framework Convention on Climate Change (UNFCCC) at the Earth Summit in Rio de Janeiro in 1992. Article 6 of the UNFCCC calls for parties to the convention to engage in the facilitation, promotion and implementation of public awareness and education on climate change and its effects. In an effort to achieve this, climate change awareness workshops have been conducted targeting grass root communities, schools and policy makers conducted by donors and the government. However focus of many of the workshops has been on enabling participants to conduct climate change studies targeting specific groups. Climate change awareness is taken to apply to research mainly and the unavailability of adequate resources has limited the awareness efforts to a very slow pace and financial assistance can only ensure continued progress in implementing climate change projects.

The government also introduced a "carbon tax" Revenue Authority which is payable by all motorists. The tax was adopted when the Finance Act and the Income Tax Act ware amended beginning from the first of January 2001 when the Government started collecting the carbon tax. This carbon tax is calculated depending on the engine capacity of the motor vehicle. The average tax on a light passenger car was US$5 per year in 2004. Payment is made when the vehicle owner gets the annual vehicle license renewal. The current estimates are that the country has over a million light vehicles only, thus an estimated US$5 million is collected from light passenger vehicles a year. If all categories of vehicles were to be included in this law, the government could collect at least US$8 million a year from the carbon tax.

This amount of money can be significant in addressing problems related to auto pollution. The adopted Environmental Management Act ushered in the establishment of an Environmental Fund that would help in the facilitation of environmental management, including air pollution projects. The carbon tax is potentially a source of funds to benefit the Environmental Fund.

Statistics are not yet available that indicates the number of fines or penalties, per year as a result of vehicle inspection. This is because has been no implementation of EMA in the field of auto pollution from its introduction to date.

7 Conclusion

Zimbabwe is at present entering a stage of industrialization characterized by motorization. As much as these bring benefits, there are also some disadvantages that become evident. With the increase in urbanization and the rapid growth of cities, urban transport is also growing. This increases the density of traffic coupled with the use of petrol and diesel vehicles. The result of this has been increase air pollution, due to increased emissions of gases such as carbon dioxide. In a move to limit emissions, the Government of Zimbabwe introduced the Environmental Management Act in 2002 which came with the establishment of the environmental management agency to administer the policy.

From our research, the modeling process and the validation of our model we managed to examine the implementation of EMA policy. We have developed options within the current policy that could be expanded on to address the problem of auto pollution. The model provided insights into how system dynamics modeling could be a useful tool in policy implementation.

We have opted not to design a new policy because there are a number of loop holes that could be manipulated in the current policy in order to get better results from the system. Creating desired flows and goals for stocks for recruitment, inspection and impoundment rates to counter the actual flows was found to have a huge influence in controlling pollution. This came after specific goals were established first for each stock of trained inspectors and imported used vehicles. Having to reach this goal in a specified time period speeds up the process unlike in situations where there are no goals that are set to reach.

As a result of this analysis our paper has provided insights into how EMA could improve their implementation strategies because different events within the system keep pushing it away from its point of equilibrium. Finally questions on how the system has been performing to date, how it could have performed and how it is expected to keep performing have been answered. Further research can seek to evaluate the cost effectiveness of vehicle mobile inspections, the effect of corruption on emission inspection and the nature of the administrative and political interaction in environmental management. This paper is believed to provide important basis for the development of these areas.

8 Appendices

Appendix 1: Equations

Auto_pollution(t) = Auto_pollution(t - dt) + (emission_rate - absorption_rate) * dt
INIT Auto_pollution = 2055
{Gg}
INFLOWS:
emission_rate = (total_vehicles*avg_emission_per_vehicle)*(1-equilibrium_swith)

{Gg/year}
OUTFLOWS:
absorption_rate = (Auto_pollution*absorption_fraction)*(1-equilibrium_swith)

{Gg/year}

Emission_per_new_vehicle(t) = Emission_per_new_vehicle(t - dt) + (increase_in_emission_per_new_vehicle - decrease_in_emission_per_new_vehice) * dt
INIT Emission_per_new_vehicle = new_cars_standard_emission*first_registeration_new_cars

{Gg/vehicle}
INFLOWS:
increase_in_emission_per_new_vehicle = new_vehicle_purchases*new_cars_standard_emission

{Gg/vehicle/year}
OUTFLOWS:
decrease_in_emission_per_new_vehice = new_cars_scrapping_rate*average_emission_per_new_vehicles

{Gg/vehicle/year}

Emission_per_used_vehicle(t) = Emission_per_used_vehicle(t - dt) + (increase_in_emission_per_used_vehicle - decrease_in_emission_per_used_vehicle) * dt
INIT Emission_per_used_vehicle = used_cars_standard_emission*first_registeration__imported_used_vehicles

{Gg/vehicle}
INFLOWS:
increase_in_emission_per_used_vehicle = used_vehicles_purchases*used_cars_standard_emission

{Gg/vehicle/year}
OUTFLOWS:
decrease_in_emission_per_used_vehicle = (used_cars_scrapping_rate+impoundment_rate)*average_emission_per_used_vehicle

{Gg/vehicle/year}

first_registeration_new_cars(t) = first_registeration_new_cars(t - dt) + (new_vehicle_purchases - new_cars_scrapping_rate) * dt
INIT first_registeration_new_cars = 350000

{vehicles}
INFLOWS:
new_vehicle_purchases = Market_share.new_vehicles_purchases
{vehicles/year}

OUTFLOWS:

new_cars_scrapping_rate = first_registeration_new_cars/average_life_time*(1-equilibrium_swith)

{vehicles/year}

first_registeration__imported_used_vehicles(t) = first_registeration__imported_used_vehicles(t - dt) + (used_vehicles_purchases - used_cars_scrapping_rate - impoundment_rate) * dt

INIT first_registeration__imported_used_vehicles = 150000

{vehicles}

INFLOWS:

used_vehicles_purchases = Market_share.used_vehicles_purchases

{vehicles/year}

OUTFLOWS:

used_cars_scrapping_rate = first_registeration__imported_used_vehicles/average_life_time_of_imported_used_vehicles*(1-equilibrium_swith)

{vehicles/year}

impoundment_rate = 1*(if(time<2011)then(0)else(desired_impoundment_rate))*(impoundment_rate_policy_switch)

+

Impoundment_Policy.indicated_impoundment_rate*(impoundment_rate_policy_switch)

{vehicles/year}

absorption_fraction = 0.73527

{1/year}

auto_pollution_adjt_time = 10

{year}

auto_pollution_gap = If(time<2002)then(0)else(Auto_pollution-auto_pollution_goal)

{Gg}

auto_pollution_goal = 4575

{Gg}

average_emission_per_new_vehicles = Emission_per_new_vehicle/first_registeration_new_cars

{Gg/vehicle}

average_emission_per_used_vehicle = Emission_per_used_vehicle/first_registeration__imported_used_vehicles

{Gg/vehicle}

average_life_time = 30

{year}

average_life_time_of_imported_used_vehicles = 23

{year}

avg_emission_per_vehicle = if(time<20030)then

(((first_registeration_new_cars*average_emission_per_new_vehicles)+(first_registeration__imported_used_vehicles*average_emission_per_used_vehicle))/(first_registeration_new_cars+first_registeration__imported_used_vehicles))
else(desired_emission_per_vehicle)
{Gg/vehicle/year}

desired_adj_rate = auto_pollution_gap/auto_pollution_adjt_time

{Gg/year}

desired_emission_per_vehicle = desired_emission_rate/total_vehicles
{Gg/vehicle/year}

desired_emission_per_vehicle_policy_switch = 0

desired_emission_rate = if(time<2002)then(0)else(absorption_rate-desired_adj_rate)

{Gg/year}

desired_imported_used_cars = if(time<2011)then(total_vehicles-first_registeration_new_cars)

else(((desired_emission_per_vehicle*total_vehicles)-(first_registeration_new_cars*average_emission_per_new_vehicles))/average_emission_per_used_vehicle)
{vehicles}

desired_impoundment_rate =
smth3(used_vehicles_purchases-used_cars_scrapping_rate,1)+desired_used_import_car_adj

{vehicles/year}

desired_used_import_car_adj = used_import_car_gap/used_import_car__adj_time

{vehicles/year}

equilibrium_swith = 0

impoundment_rate_policy_switch = 0

total_vehicles = (first_registeration_new_cars+first_registeration__imported_used_vehicles)

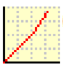
{vehicles}

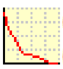
used_import_car_gap =
first_registeration__imported_used_vehicles-desired_imported_used_cars

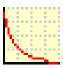
{vehicles}

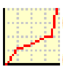
used_import_car__adj_time = 10

{year}

auto_pollution_historical_data = GRAPH(TIME)

(1990, 2055), (2000, 4108), (2010, 6442), (2020, 9353)

new_cars_standard_emission = GRAPH(TIME)

(1990, 0.00192), (1993, 0.00164), (1996, 0.00147), (1999, 0.00127), (2002, 0.0012), (2005, 0.00117), (2008, 0.00114), (2011, 0.00111), (2014, 0.00106), (2017, 0.00103), (2020, 0.001)

used_cars_standard_emission = GRAPH(TIME)

(1990, 0.00576), (1993, 0.00508), (1996, 0.00466), (1999, 0.00448), (2002, 0.00437), (2005, 0.00426), (2008, 0.00421), (2011, 0.00416), (2014, 0.0041), (2017, 0.00406), (2020, 0.004)

vehicle_population_HISTORICAL_DATA = GRAPH(TIME)

(1995, 522682), (1996, 575342), (1997, 632886), (1998, 721227), (1999, 739543), (2000, 760543), (2001, 786322), (2002, 807502), (2003, 839044), (2004, 856432), (2005, 859623), (2006, 1.2e+006)

Market share:

urban_population(t) = urban_population(t - dt) + (change_in_urban_population) * dt
INIT urban_population = 700000

{people}
INFLOWS:
change_in_urban_population = urban_population*urban_development_growth_rate

{people/year}

attractiveness_of_imported_used_vehicles = effect_of_used_car_network_size__on_attractiveness_of_used_cars*effect_of_price_on_attractiveness_of_imported_used_cars

attractiveness_of_new_vehicles = effect_of_new_car_network_size_on_attractiveness_of_new_cars*effect_of_price_on_attractiveness_of_new_cars

availability_of_imported_used_cars = 0.9

availability_of_new_cars = 0.33

average_age_of_used_vehicles = 15

{year}

average_price = 5000

{$}

effect_of_attractiveness_from_availability_of_used_cars = 2

effect_of_new_car_network_size_on_attractiveness_of_new_cars = EXP(sensitivity_of_attractiveness_to_vehicles*(.first_registeration_new_cars/threshold_for_network_size))

{1/year}

effect_of_used_car_network_size__on_attractiveness_of_used_cars = EXP(sensitivity_of_attractiveness_to_vehicles*(.first_registeration__imported_used_vehicles/threshold_for_network_size))

market_demand_for_cars = reference_demand*effect_of_urban_population_on_demand

{vehicles}

market_share_new_vehicles = attractiveness_of_new_vehicles/total_attractiveness

{1/year}

market_share_used_imported_vehicles = attractiveness_of_imported_used_vehicles/total_attractiveness

attractiveness_of_imported_used_vehicles/total_attractiveness

new_vehicles_purchases = market_demand_for_cars*market_share_new_vehicles/years*(1-.equilibrium_swith)

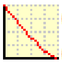
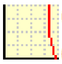
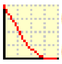
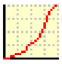
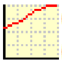
pollution_fine_and_penalty_rate = 0

price_of_imported_used_cars = average_price*(availability_of_imported_used_cars*effect_of_car_age_on_price)

{$}

price_of_new_cars = average_price/(effect_of_attractiveness_from_availability_of_used_cars*availability_of_new_cars)

reference_demand = 120000
{vehicles}
relative_price = price_of_imported_used_cars/price_of_new_cars
sensitivity_of_attractiveness_to_vehicles = 0.9
threshold_for_network_size = 800000
total_attractiveness = attractiveness_of_new_vehicles+attractiveness_of_imported_used_vehicles
urban_development_growth_rate = 0.095

{1/year}
used_vehicles_purchases = market_demand_for_cars*market_share_used_imported_vehicles/years*(1-.equilibrium_swith)
years = 1
{year}
effect_of_car_age_on_price = GRAPH(average_age_of_used_vehicles)

(0.00, 2.00), (2.00, 1.73), (4.00, 1.50), (6.00, 1.27), (8.00, 1.06), (10.0, 0.85), (12.0, 0.68), (14.0, 0.48), (16.0, 0.32), (18.0, 0.18), (20.0, 0.05)
effect_of_fines_on_attractiveness_of_imported_used_cars = GRAPH(pollution_fine_and_penalty_rate)

(0.00, 100), (10.0, 85.0), (20.0, 65.5), (30.0, 50.0), (40.0, 36.0), (50.0, 24.5), (60.0, 17.0), (70.0, 9.00), (80.0, 3.00), (90.0, 0.5), (100, 0.00)
effect_of_price_on_attractiveness_of_imported_used_cars = GRAPH(relative_price)

(0.00, 2.91), (0.1, 2.48), (0.2, 1.96), (0.3, 1.54), (0.4, 1.05), (0.5, 0.63), (0.6, 0.39), (0.7, 0.165), (0.8, 0.015), (0.9, 0.00), (1, 0.00)
effect_of_price_on_attractiveness_of_new_cars = GRAPH(relative_price)

(0.00, 0.075), (0.1, 0.09), (0.2, 0.255), (0.3, 0.33), (0.4, 0.48), (0.5, 0.765), (0.6, 1.02), (0.7, 1.27), (0.8, 1.81), (0.9, 2.59), (1, 2.96)
effect_of_urban_population_on_demand = GRAPH(urban_population)

(0.00, 0.551), (600000, 0.563), (1.2e+006, 0.59), (1.8e+006, 0.62), (2.4e+006, 0.677), (3e+006, 0.707), (3.6e+006, 0.731), (4.2e+006, 0.761), (4.8e+006, 0.794), (5.4e+006, 0.8)

Impoundment Policy:

EMA_trained_inspectors(t) = EMA_trained_inspectors(t - dt) + (training_rate - attrition) * dt
INIT EMA_trained_inspectors = 0

{inspectors}
INFLOWS:
training_rate = untrained_inspectors/time_to_train

{inspectors/year}
OUTFLOWS:
attrition = EMA_trained_inspectors*attrition_fraction

gas_analysers(t) = gas_analysers(t - dt) + (chg_in_gas_analysers) * dt
INIT gas_analysers = 0
{analyzer}
INFLOWS:
chg_in_gas_analysers = analysers_adjt_rate
{analyzer/year}

gas_analyzers_budget(t) = gas_analyzers_budget(t - dt) + (chg_in_gas_analyser_budget) * dt
INIT gas_analyzers_budget = gas_analysers*average_cost_of_analyser
{$}
INFLOWS:
chg_in_gas_analyser_budget = if(time<2010)then(0)else((desired_gas_analysers_budget-gas_analyzers_budget)/analysers_budget_adjt_time)
{$/year}

perceived__auto_pollution(t) = perceived__auto_pollution(t - dt) + (change_in_perception) * dt
INIT perceived__auto_pollution = 0
{Gg}
INFLOWS:
change_in_perception = smth3(perception_gap/politicians_perception_adjt_time,10)
{Gg/year}

untrained_inspectors(t) = untrained_inspectors(t - dt) + (recruitment - training_rate - untrained_quit_rate) * dt
INIT untrained_inspectors = 0

{inspectors}
INFLOWS:
recruitment = desired_recruitment_rate

{inspectors/year}

OUTFLOWS:
training_rate = untrained_inspectors/time_to_train

{inspectors/year}
untrained_quit_rate = untrained_inspectors*untrained_quit_fraction

{inspectors/year}

Wage_Budget(t) = Wage_Budget(t - dt) + (chg_in_budget) * dt
INIT Wage_Budget = (EMA_trained_inspectors+untrained_inspectors)*average_wage
{$}
INFLOWS:
chg_in_budget = if(time<2010)then(0)else((desired_wage_budget-Wage_Budget)/wage_budget_adj_time)

actual_inspections_per_inspector = potential_inspector_productivity*probability_of_inspection

{vehicles/inspector/year}

analysers_adjt_rate = analysers_gap/analyzer_adjt_time
{analyzer/year}

analysers_budget_adjt_time = 3/resource_mobilization
{year}

analysers_gap = budgeted_goal_for_analysers-gas_analysers
{analyzer}

analyzer_adjt_time = 5
{year}

attrition_fraction = 0.02

{1/year}

average_cost_of_analyser = 5000
{$}

average_wage = 500
{$}

budgeted_goal_for_analysers = gas_analyzers_budget/average_cost_of_analyser

budgeted_goal_for_inspectors = Wage_Budget/average_wage

corruption_index = 0.5

danger_index = .Auto_pollution/unsafe_level_of_pollution

desired_gas_analysers = desired_trained_inspectors/inspectors_per_inspection_point_per_shift

desired_gas_analysers_budget = average_cost_of_analyser*desired_gas_analysers
{$}

desired_inspection_rate =
if(time<2011)then(0)else(MIN(.desired_impoundment_rate/fraction_of_inspected_vehicles_impounded,.first_registeration__imported_used_vehicles))
{vehicles/year}

desired_inspection_rate_policy_switch = 1

desired_recruitment_rate =
smth1(attrition+untrained_quit_rate,.08)+(trained_inspector_gap/trained_inspector_adjt_time)
{inspectors/year}

desired_trained_inspectors = desired_inspection_rate/potential_inspector_productivity

{inspectors}

desired_wage_budget = average_wage*desired_trained_inspectors
{$}

emission_inspection_rate = desired_inspection_rate_policy_switch*(MIN(
1*actual_inspections_per_inspector*EMA_trained_inspectors
+
desired_inspection_rate,.first_registeration__imported_used_vehicles))/time_to_inspect

{vehicles/year}

fraction_of_inspected_vehicles_fined = 0.5
{1/year}

fraction_of_inspected_vehicles_impounded = 0.02
{1/year}

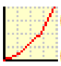
indicated_impoundment_rate =
emission_inspection_rate*fraction_of_inspected_vehicles_impounded
{vehicles/year}

inspectors_per_inspection_point_per_shift = 2
{inspectors}
perception_gap = .Auto_pollution-perceived__auto_pollution
{Gg}
perception_of_danger = perceived__auto_pollution/unsafe_level_of_pollution
politicians_perception_adjt_time = 10

{year}
pollution_fine_and_penalty_rate = emission_inspection_rate*fraction_of_inspected_vehicles_fined
{vehicle/year}
potential_inspector_productivity = 15000

{vehicles/inspector/year}
probability_of_inspection = 1-corruption_index
resource_mobilization = effect_of_perception_on_resource_budget
time_to_inspect = 1
{year}
time_to_train = .08

{year!}
trained_inspector_adjt_time = 5

{year}
trained_inspector_gap =
if(time<2011)then(0)else(budgeted_goal_for_inspectors-EMA_trained_inspectors)
{inspectors}
unsafe_level_of_pollution = 8000
{Gg}
untrained_quit_fraction = 0.1
{1/year}
wage_budget_adj_time = 3/resource_mobilization
{year}
effect_of_perception_on_resource_budget = GRAPH(perception_of_danger)

(0.00, 0.2), (0.1, 0.244), (0.2, 0.288), (0.3, 0.324), (0.4, 0.376), (0.5, 0.452), (0.6, 0.524), (0.7, 0.58),
(0.8, 0.68), (0.9, 0.824), (1, 1.00)

Appendix 2: Complete causal loop diagram

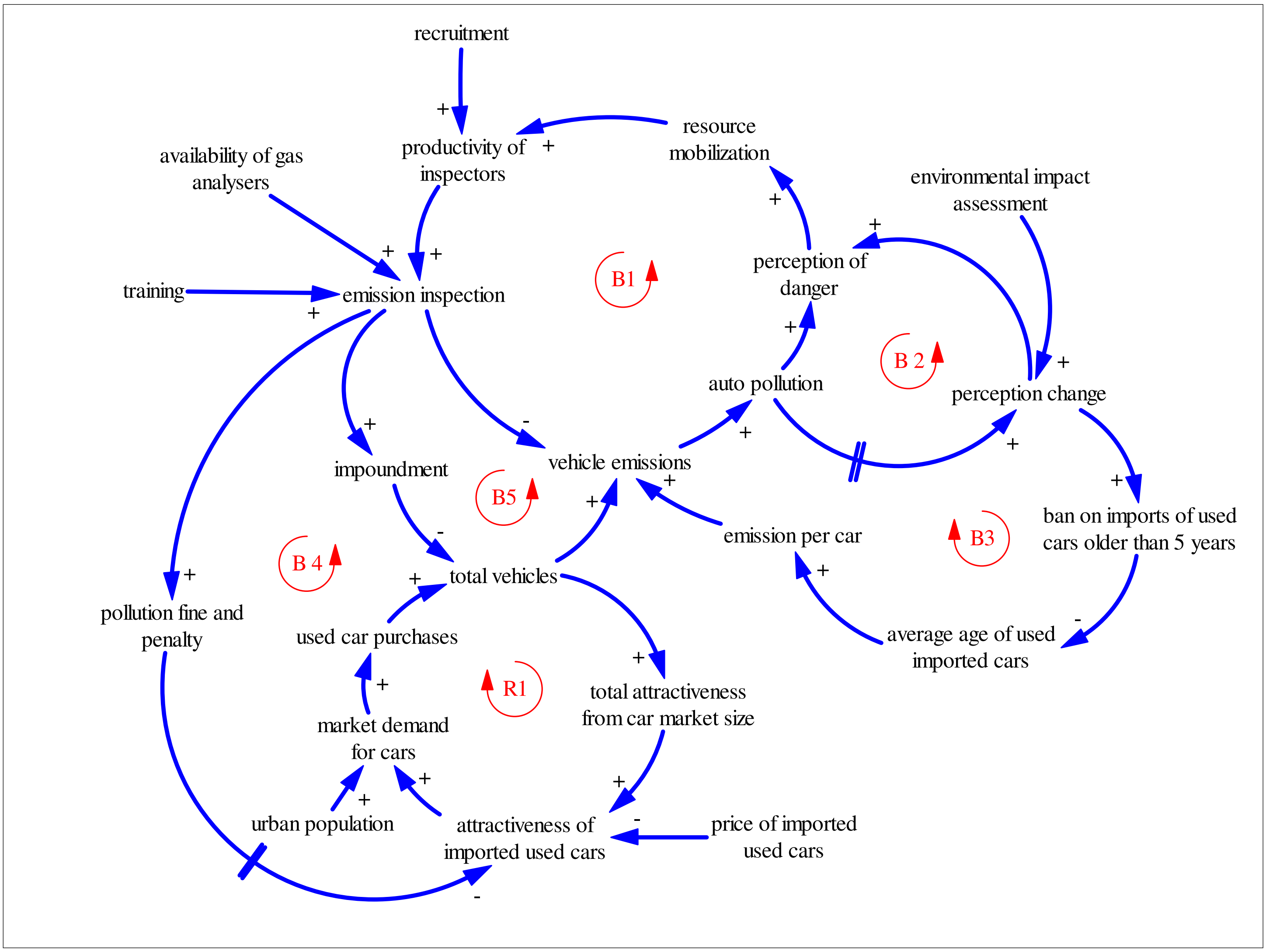


Figure 49: complete CLD

Appendix 3: Impoundment policy sensitivity tests

Wage budget adjustment time

A test was carried out on the effec of wage budget adjust time on EMA trained inspectors. The adjustment time produced dramatic differences. Most notably with an adjustment time of 6 months the system produces highest number of trained inspectors towards the desired inspectors. Times ranging from 0.5, 4, 7 and 11 years were tried (Figure 50). Reducing the wage budget adjustment time has the potential to reduce auto pollution because if there are more trained inspectors this would lead to more emission inspections and impondments.

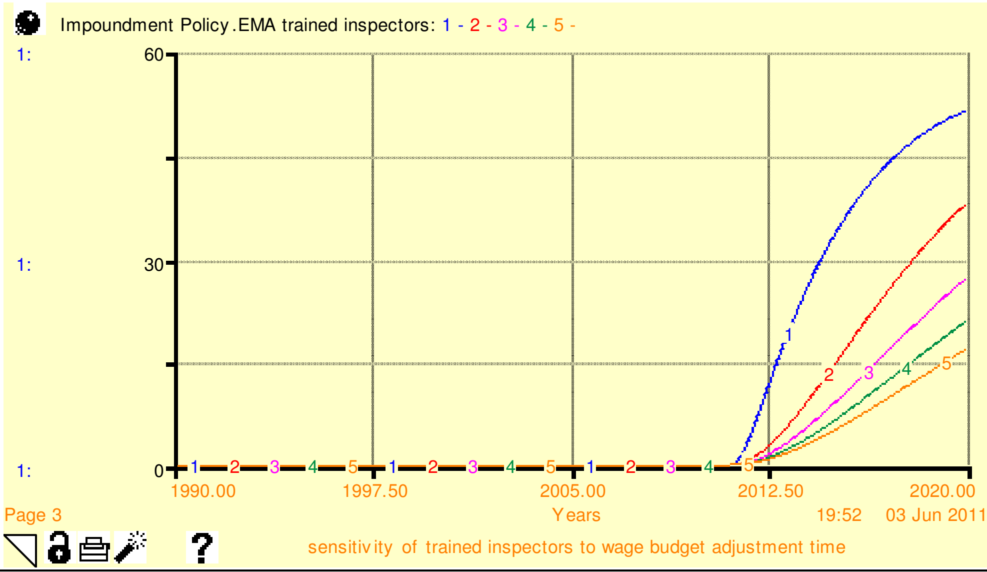


Figure 50: Sensitivity of trained inspectors to wage budget adjustment time

Analysers budget adjustment time

The same test was also run on the effect of analysers budget adjustment time on the stock of gas analysers. The results were also remarkable. The test ranged the adjutment times from 1, 3, 5 to 7 years. Reducing the time to less than a year matches the ideal situation of accuring more gas analysers that are proportinal to the number of trained inspectors (Figure 51).

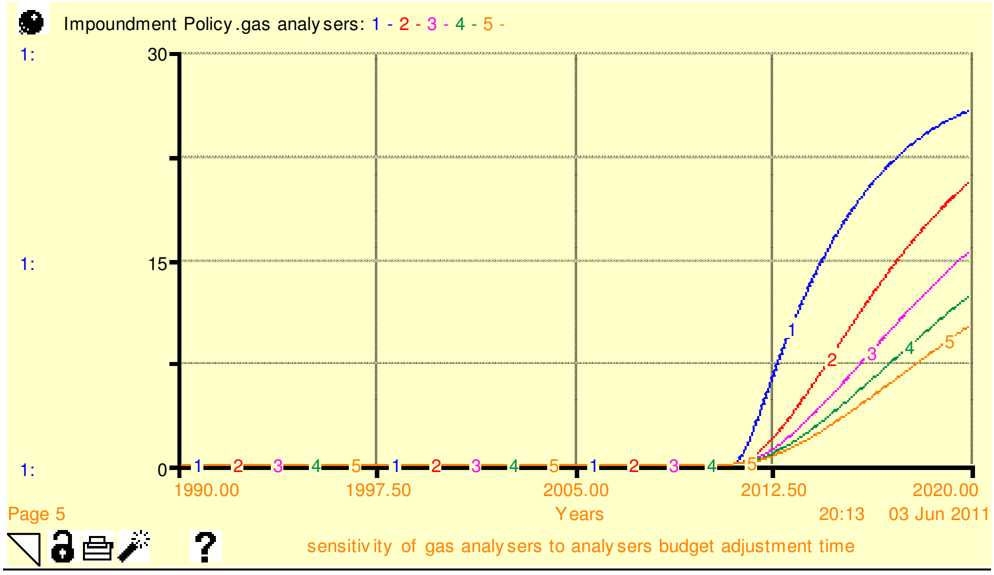


Figure 51: Sensitivity of gas analysers to analysers budget adjustment time

<u>Perception adjustment time</u>

Tests on perception adjustment time revealed that reducing the time to below 2 years increases perceived auto pollution faster in order to reach the same level as auto pollution. This would speed up the resource mobilization budget allocation process. When it takes a long time to perceive the levels of auto pollution it creats a long delay in the system waiting for the policy makers to respond to the problem. Adjustment times ranging from 2, 5, 8, 11 and 15 were tested with the following results in figure 52 below.

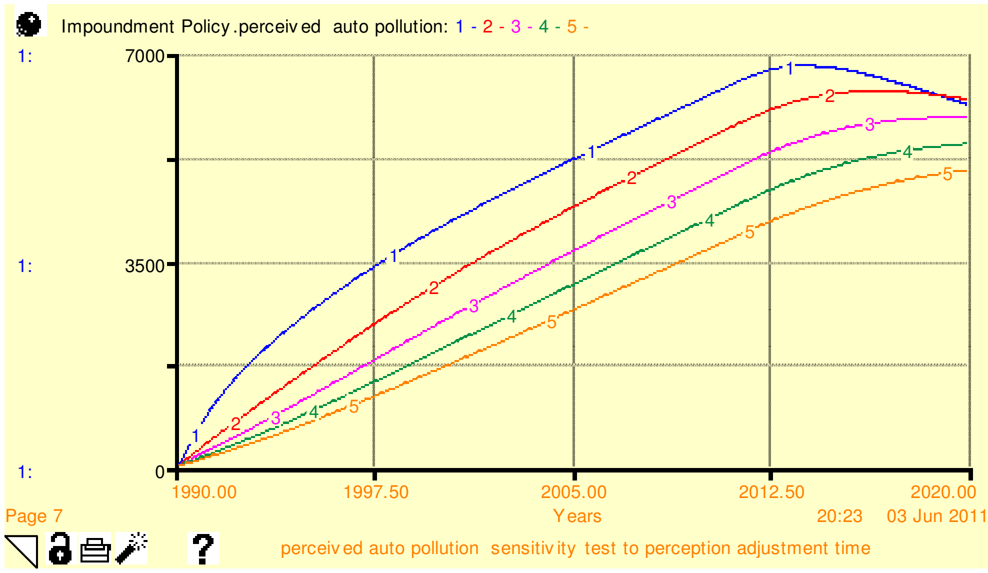


Figure 52: Perceived auto pollution sensitivity test to perception adjustment time

Appendix 4: Table function Test

Effect of perception

Three different perception ratio curves were tested in figure 53 below. A huge difference was observed on inspector productivity by changing these three curves. The model used the third curve because it was observed to give a true reflection on how perception changes leading to subsequent influence on resource allocation. When perception ratio is low policy makers do not see the need to change the nature of the current laws compared to when the ratio is close to 1.

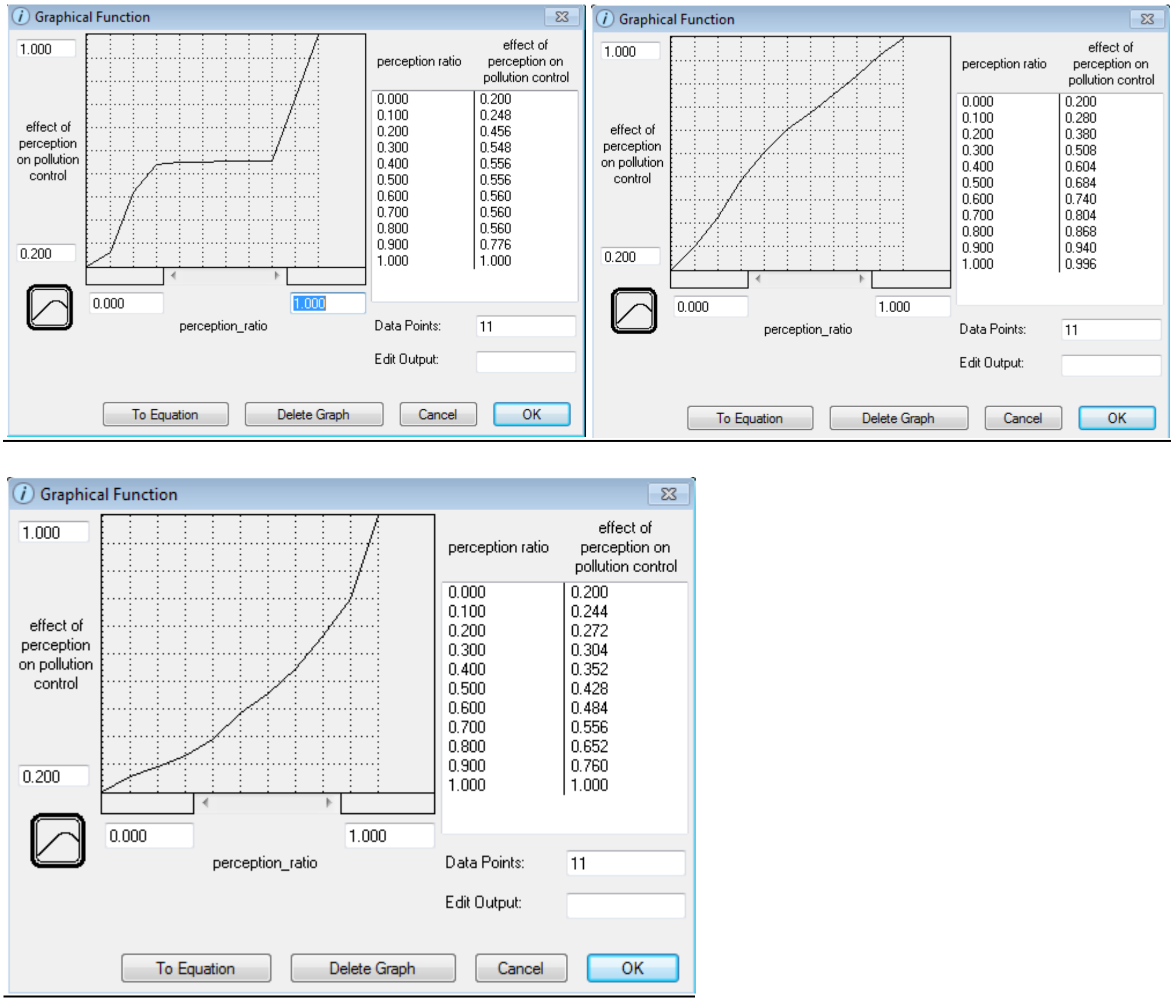


Figure 53: Effect of perception ration on resource mobilization

Availability of gas analysers

The effect of gas analyzers inspector productivity has a significant effect on inspection rate. Three different curves were tested (Figure 54) and again the third curve was used in the model. The graphical function used in the model was based on the assumption that an emission inspector can only by highly productive when he/she is fully equipped. The number of gas analyzers should therefore rise proportionally to the inspectors.

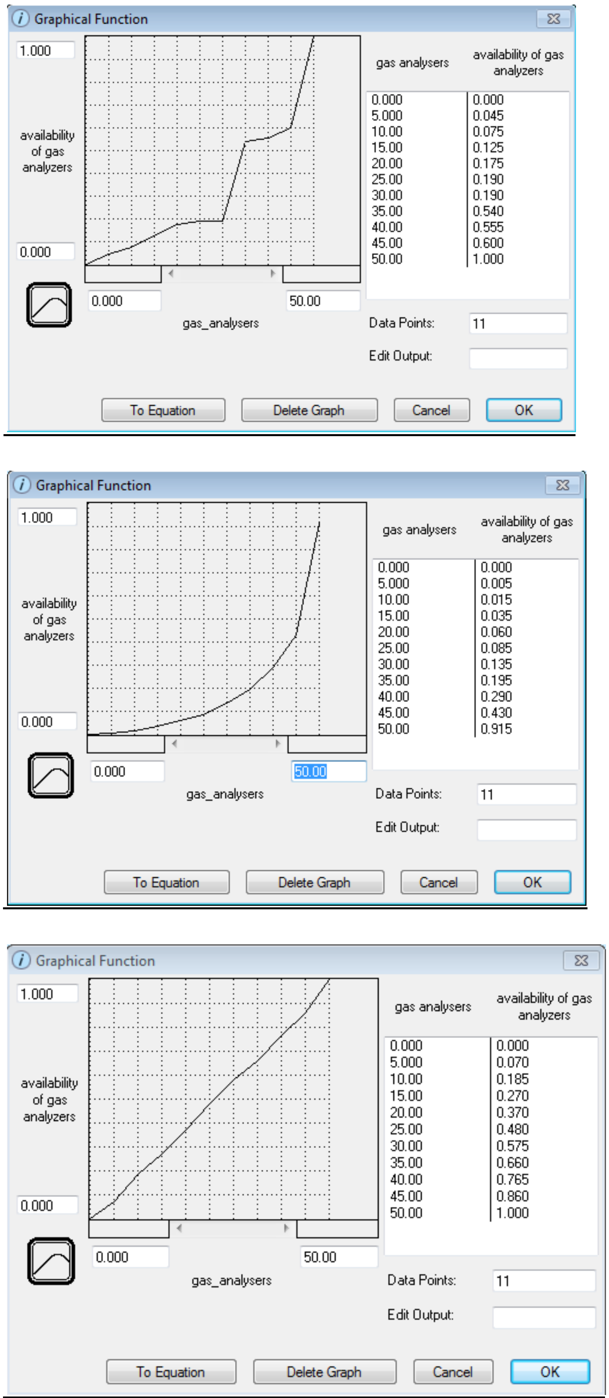
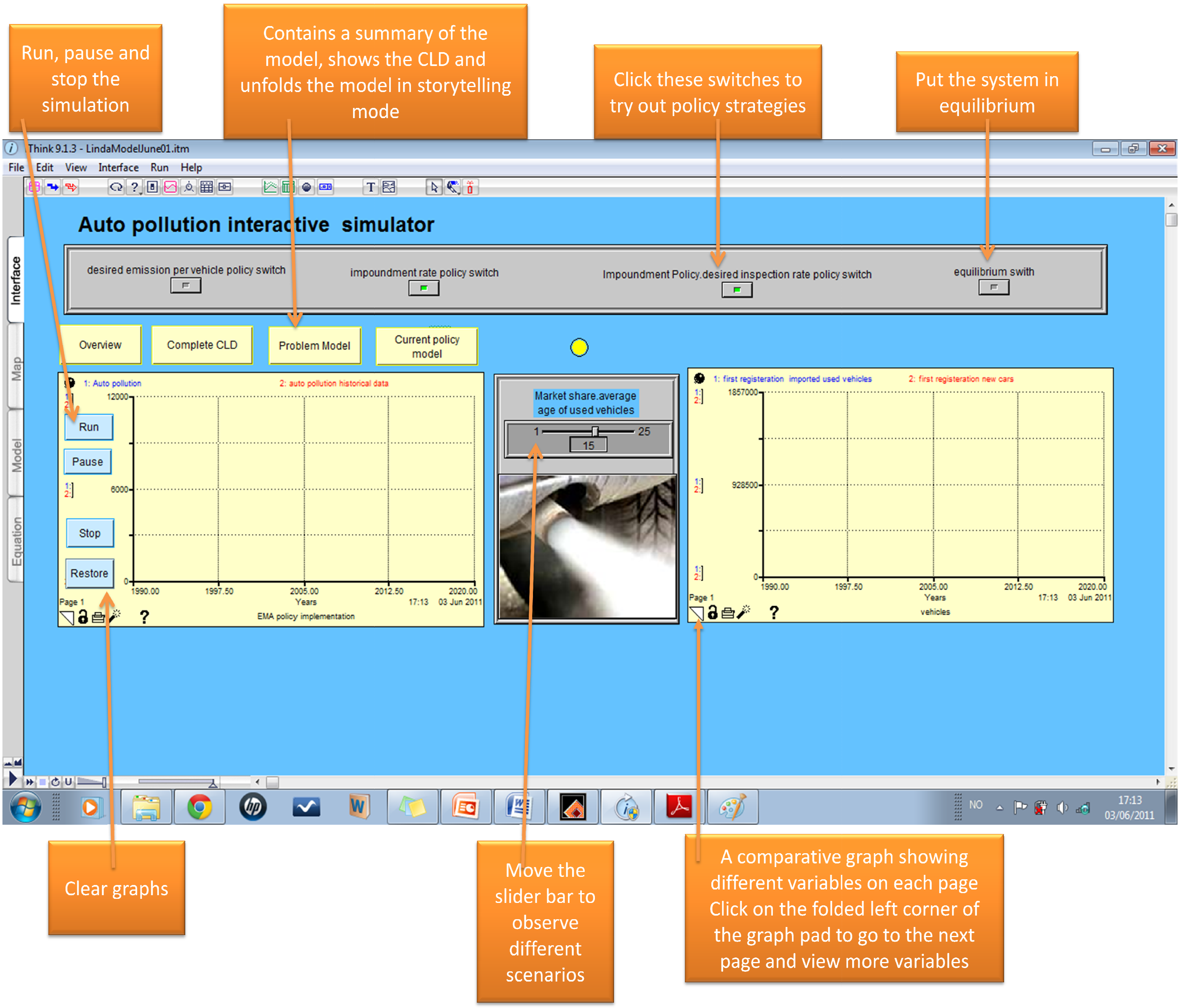


Figure 54: Effect of gas analysers on inspection

Appendix 5: A guide to the interface of the model



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