REDUCING CO_2 EMISSIONS DUE TO A SHIFT FROM ROAD TO CABOTAGE TRANSPORT OF CARGO IN BRAZIL

Irineu de Brito Junior

Universidade de São Paulo – Escola Politécnica – Eng. de Produção

Av. Prof. Almeida Prado,Travessa 2, Nº 128, São Paulo – Brasil - 05508-070

55 11 3091-5363

ibritojr@usp.br

Celso Mitsuo Hino

Universidade de São Paulo – Escola Politécnica – Eng. Naval e Oceânica

Av. Professor Mello Moraes, 2231 - São Paulo - Brasil - 05508-030

55 11 3091-5340

cmhino@usp.br

Paulo Gonçalves

Faculty of Economics - University of Lugano

Via Buffi 13, CH-6904 Lugano, Switzerland

41 58 666-4479

paulo.goncalves@usi.ch

Luiz Eduardo W. A. Andrade

Universidade de São Paulo – Escola Politécnica – Eng. de Sistemas Logísticos

Av. Prof. Almeida Prado,Travessa 2, Nº 128, São Paulo – Brasil - 05508-070

55 11 3091-5363

lew@usp.br

Charliston Moreira

Universidade Federal de Minas Gerais - Escola de Engenharia – Transportes e Geotecnia

Av. Antônio Carlos, 6627, Belo Horizonte – Brasil - 31270-901

55 31 3409-1893

charliston.moreira@gmail.com

Gustavo Costa

Universidade de São Paulo – Escola Politécnica – Eng. Naval e Oceânica

Av. Professor Mello Moraes, 2231 - São Paulo - Brasil - 05508-030

55 11 3091-5340

adolfao@gmail.com

Luis Gustavo Nardin

Universidade de São Paulo – Escola Politécnica – Lab. de Técnicas Inteligentes

Av. Prof. Luciano Gualberto, 158 – trav. 3 – São Paulo – Brasil – 05508-970

55 11 3091-5397

luis.nardin@usp.br

Hugo T. Yoshida Yoshizaki

Universidade de São Paulo – Escola Politécnica – Eng. de Produção

Av. Prof. Almeida Prado,Travessa 2, Nº 128, São Paulo – Brasil - 05508-070

55 11 3091-5363

hugo@usp.br

David José de Magalhães

Universidade Federal de Minas Gerais - Escola de Engenharia – Transportes e Geotecnia

Av. Antônio Carlos, 6627, Belo Horizonte – Brasil - 31270-901

55 31 3409-1893

davidmagalhaes.bh@gmail.com

Abstract: *This work aims to evaluate the existing Brazilian National Plan for Logistics and Transport (PNLT) impact for reducing* CO_2 *emissions in the domestic cargo transport. A formal system dynamics model is built that captures the causal relationships influencing the modal shift from road to cabotage transport of cargo in Brazil. Scenarios are charted to understand the impact of PNLT policies and the implications for the transport infrastructure. The simulation shows that pressure to reduce* CO_2 *emissions is beneficial in the acceleration process of modal shift.*

Keywords: *Cargo transport, Modal shift, Greenhouse gases emission, System Dynamics.*

1 Introduction

Problem: Significant CO_2 emissions in the transportation sector and political pressure to reduce emissions.

Importance: In the global agenda, transport is a great contributor (huge potential for impact). According to the International Energy Agency (IEA), the transportation sector is responsible today for about 19% of the world energy consumption and for about 23% of the CO_2 emissions and it projects that such participation will continue to increase in the future. The IEA concludes that, considering the actual tendencies, the energy consumption and CO_2 emissions in the transportation sector will globally increase approximately 50% by 2030 and more than 80% by 2050.

Challenges: High inertia from road transportation. Its high attractiveness also makes it difficult to change. On the other hand, the Intergovernmental Panel on Climate Change (IPCC) informs that in order to avoid the worst climate change impacts, the global CO_2 emissions should be reduced by at least 50% until 2050 in comparison with the emission level observed nowadays. In order to achieve this goal, the transportation sector will play a significant role because even with significant CO_2 emission reductions in other sectors, if the transportation sector fails to reduce its CO_2 emissions significantly until 2050, it will be very difficult to accomplish the established goal.

Contribution of this paper: This work investigates policies that have the ability to influence the modal shift from road to cabotage transport. In particular, the model explicits the comparative advantages of road and cabotage transport to capture the dynamics of the shift in transportation modes over time. Regarding specific governmental policies, we consider PNLT goals and explicitly provide a trajectory that clarifies how they can be achieved within the required time horizon. This allows capturing the effects that PNLT policies will have on the reduction of CO_2 emissions after implementation and evaluating the potential reductions of CO_2 emissions in the transportation sector and their contribution to the PNMC objectives. Therefore, our work evaluates PNLT policies and their impact on CO_2 emissions in the Brazilian national transportation sector using a formal system dynamics model.

The main purpose of the model is to analyze the modal shift from road to cabotage over time, driven by the level of investment in the modes capabilities and governmental pressure to reduce CO_2 emissions. As a final result, we want to understand the dynamics of modal shift in cargo transport and its impact on CO_2 emissions. In addition, our model provides a common framework through which (i) policy makers can understand the system and perform policies analysis, (ii) other related sectors can be incorporated and modeled (Abbas and Bell, 1994).

The remaining of this document is composed as follows. The next section presents additional detail on the political context of the transport sector in Brazil and some of its challenges. Section 3 provides an overview of the concepts used in this work. Section 4 describes the formal system dynamics model and the data used. Section 5 presents the base case behavior of the model, specific scenario and policy analyses. Finally, in section 6 we provide a discussion about the possible impacts of PNLT in the reduction of CO_2 emissions and its contribution to the PNMC objectives, as well as some conclusions.

2 Brazilian Transportation Context

In December 2008, the Brazilian National Policies on Climate Change (PNMC) (Brazil, 2009) was presented aiming (i) to encourage the development and improvement of actions in order to mitigate the emission of Greenhouse Gases (GHG) in Brazil, (ii) to collaborate with the global effort to reduce GHG emissions, and (iii) to create internal conditions for dealing with the impacts of global climate change. The goals presented in the PNMC were expected not only to reduce the emissions of GHG, but to bring some socioeconomic benefits and some other environmental gains, such as:

- Reduce the rate of annual deforestation in the Amazon region by 80% by 2020;
- Increase the domestic consumption of ethanol by 11% per year over the next ten years;
- Double the area of planted forests to 11 million hectares in 2020, of which 2 million would be planted with native species;
- Replace one million old refrigerators per year in the next ten years;
- Increase the recycling of municipal solid waste by 20% by 2015;
- Increase the electric power supply cogeneration, mainly through the use of sugar cane bagasse, to 11.4% of total electricity supply in the country by 2030;
- Reduction of non-technical losses in electricity distribution in the rate of 1,000 GWh per year over the next ten years.

The regulatory act no. 7390 (Brazil, Act 7390/2010) related to the PNMC, signed on December 9th 2010, estimates that Brazil will reach the year 2020 emitting at most 3.3 billion of tons (Gt) of CO_2 (carbon dioxide) equivalent (sum of all the GHG emissions converted to CO_2) per year. However, in order to achieve the Brazilian volunteer commitment instituted in Law no. 12187 (Brazil, Law 12187/2009) from 2009, the regulatory act requires the implementation of some actions that will allow the reduction of CO_2 emission between 1,168 and 1,259 million of tons (Mt) per year, which indicates that Brazilian emissions should be at most 2.1 Gt of CO_2 per year in 2020. According to the Brazilian Ministry of the Environment (MMA), the regulatory act in conjunction with other governmental actions provides a new base to the implementation of the United Nations Framework Convention on Climate Changes (UNFCCC) in Brazil.

The PNMC regulation act implies the establishment of a threshold for CO_2 emission levels, which requires the incorporation of specific goals for twelve sectors of the national economy. In order to meet these goals, each sector will need to present an action plan by the end of 2011. In 2005, according to the inventory submitted to the UNFCCC, Brazil emitted 2.19 Gt of GHG in CO_2 equivalent measures. In 2009, the emissions decreased to 1.77 Gt of CO_2 equivalent. However, according to the MCT, in order to maintain the GHG emission levels, Brazil will need to reduce the emissions in sectors such as transport, industry and agriculture, other than combating the deforestation.

In the transportation sector, the evaluation of CO_2 emissions must consider the ratio between the increase in cargo demand and the increase in Growth Domestic Product (GDP) to project a trend for the following years. Figure 1 depicts a graph which presents a ratio between those two indices provided by the European Environmental Agency (EEA). Observing the graph, it can be seen that the cargo demand, measured in tons per kilometer (tkm), has been increasing at a higher rate than the GDP.

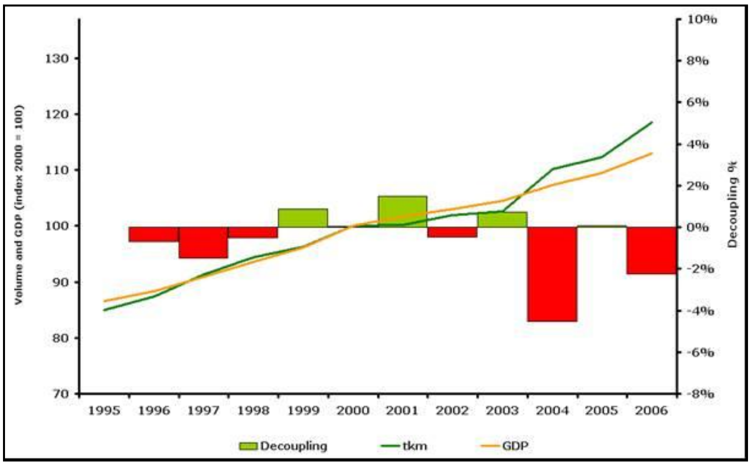

Figure 1 – CO_2 emissions in the transportation sector.
Source: EEA, 2010

In addition, the graphs also show that the economic growth (GDP) generates more cargo demand (tkm), which causes an increase in the CO_2 emissions. The emission levels, on the other hand, depend on the cargo transportation modes. Table 1 presents the participation of each Brazilian transportation modes in the CO_2 emission in 2006 and the transportation modes participation in the Brazilian transport matrix. Therefore, if the economic growth and the transport matrix are maintained, the CO_2 emission levels will not be reduced and the goals proposed by the Brazilian National Policies on Climate Change will not be achieved.

Table 1 – CO_2 emissions in the transportation sector (Brazil, MCT, 2009).

Mode	CO_2 tons/year	Participation(%)
Road	83,302,000	88.31
Air	6,204,000	6.58
Waterway	3,558,000	3.77
Railroad	1,260,000	1.34
Total	**93,324,000**	**100.00**

Table 2 – Brazilian cargo transportation matrix (Brazil, MMA).

Mode	Cargo Percentage
Air	0.4%
Pipeline	4.19%
Waterway	13.59%
Road	61.09%
Railroad	20.73%

Aiming to change this situation, in 2007, the Brazilian Ministry of Transport elaborated the Brazilian National Plan for Logistics and Transport (PNLT), which was developed in a partnership with the Brazilian Ministry of Defense via the Center of Excellence in Transportation Engineering. Among the main PNLT objectives, we may highlight the following:

- Elaborate the planning process in the transportation sector, based on a geo-referenced information system containing all the key data in the sector, either at the bid involving all transportation modes, or at the demand;
- Consider the costs of the entire logistics chain between the origins and destinations of transport flows;
- Change, with a better balance, the current cargo transportation matrix of the country, with more intensive and appropriate use of railroad and waterway modes, taking advantage of their energy efficiencies and productivity in moving streams of higher density and distance of transport;
- Promote environmental conservation, aiming to respect the restriction areas and control of land use, be it the issue of production of goods, be it in the deployment of infrastructure.

However, the PNLT does not include a provision aiming at reducing GHG emissions among its main goals. This reduction is expected to be achieved by changing the percentage of the cargo transportation matrix (presented in Table 2) within a 15 to 20-year time horizon. Such expected changes are presented below and summarized in Figure 2:

- Increase the participation of railroad from the current 25% to 32%;
- Increase the participation of waterway from 13% to 29%;
- Evolution of pipeline and air modes to 5% and 1%, respectively;
- Decrease the participation of the road mode from 58% to 33%.

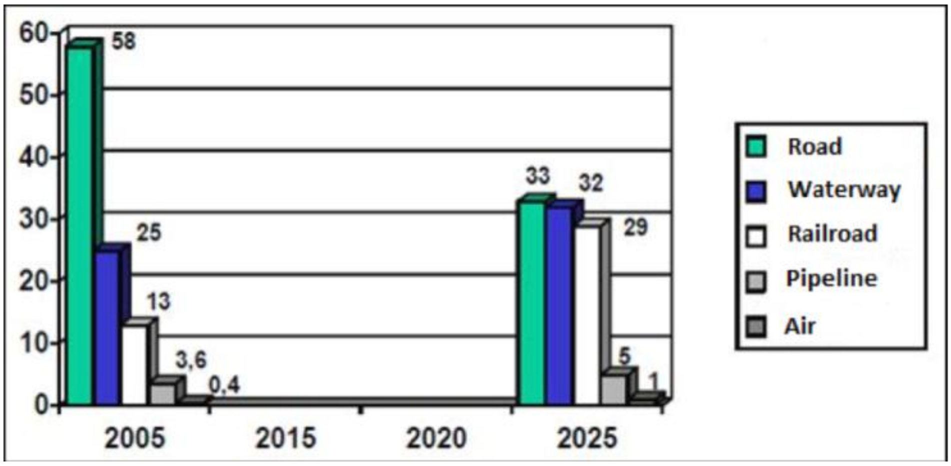

Figure 2 – Progress of the Brazilian cargo transportation matrix (Brazil, PNLT, 2009).

Although this figure shows a desired goal, it does not detail how this can be done and the scope of this work is to provide a trajectory that helps getting it done.

On the other hand, the PNMC refers to the PNLT in the transportation sector analysis, but it does not recognize the effects that PNLT policies will have on the reduction of CO_2 emissions after implementation.

3 Overview of subjects

This section presents a brief summary of the emission of greenhouse gases and its relation to the transportation sector, and a literature review on the use of system dynamics to simulate transport networks.

3.1 Greenhouse Gases Emissions

The greenhouse gases (GHG) occur naturally in the atmosphere and help to sustain life on the planet, since they retain the natural heat of the sun. IPCC reported in (IPCC, 2001) that without this retention of heat the temperature on Earth would be approximately 33 degrees Celsius lower than the one experienced today, thus impeding life as we know it nowadays. The most important gases that occur naturally and are associated with this effect are water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Besides these, there are other greenhouse gases that do not occur naturally, being produced only syntactically; these gases are the chlorofluorocarbons (CFCs), the hydro fluorocarbon (HFC), the per fluorocarbon (PFCs) and sulfur hexafluoride (SF_6) (IEA, 2010).

In recent years, GHG emissions have grown at an annual rate of 3 to 4%, and CO_2 emission in 2007 was approximately 28.8 billion tons (Gt). Globally, the transportation sector is the second largest emitter of CO_2, contributing approximately with 6.5 Gt in 2007 (IEA, 2010), and this volume results mainly from burning fossil fuels derived from petroleum. Moreover, it is projected that the transportation sector will continue to have a substantial representation in the GHG emissions in the world, as illustrated in Figure 3.

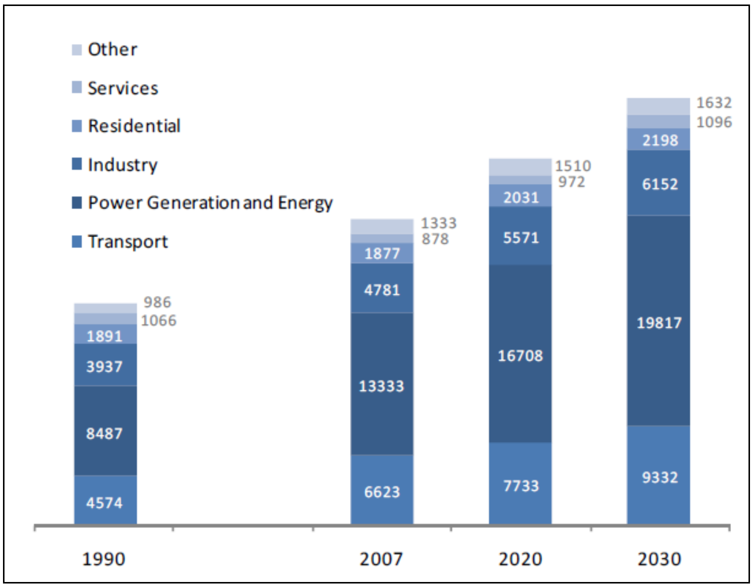

Figure 3 – Projected global CO_2 emissions related to energy (Mt) (IEA, 2010).

Despite its great contribution to GHG emissions, the transportation sector is considered one of the most resistant to reducing greenhouse gases emissions. Some reasons for this resistance can be considered the result of a market failure, as users of light vehicles are not made aware of the economic and environmental impacts of their actions, and the primary means of cargo transportation is the road mode.

These characteristics of the transportation sector associated with projections of increasing its contribution to GHG emissions require some government actions, if not for the reduction of GHG emissions, at least for its stabilization.

According to (Apogee, 1998), strategies to mitigate GHG emissions in the transportation sector can be grouped into three categories, which were focused on reducing travel in vehicle efficiency and fuel used.

The strategies associated with reductions in travels try to reduce GHG emissions by reducing vehicle miles per person. The reduction in fuel consumption occurs with the elimination of travel, reduction in distance traveled, or replacement of personal vehicles usage by alternative modes that use less energy.

The second category focuses on strategies for reducing GHG emissions through improved fuel consumption efficiency. Since CO_2 emissions are directly proportional to the amount of fuel consumed, improvements in fuel consumption efficiency would proportionately reduce GHG emission per kilometer. These strategies may also be performed through the use of incremental vehicle technologies, advanced technologies and operational practices. For example, it is estimated that incremental improvements in combustion and transmission using existing technologies could reduce GHG emissions by up to 20%.

The third category of strategies focus on reducing GHG emissions through the use of fuels that have low volume of carbon emissions as compared to conventional fossil fuels. All fuels have a carbon concentration which reflects the amount of CO_2 emitted per unit of energy consumed in combustion; therefore, the use of fuels with lower carbon helps reduce emissions (Yeh, Sperling, 2010). Even though the fuels with low carbon concentration offer an opportunity to reduce GHG emissions without substantially reducing the demand for transportation, they face a combination of barriers to their implementation related to infrastructure and economic issues.

If all transport technologies and fuels could be developed and implemented, they would bring GHG emissions from the transportation sector below the levels measured in 2000 by 2030. However, although the vehicles, fuels and technologies are attractive in the short term, they are insufficient to achieve the reduction targets of 80% by 2050 (McCollum and Yang, 2009).

Calculation of CO_2 emissions by the energy sector, which includes the transportation sector, can be made using two different methodologies: top-down and bottom-up (IPCC, 2006).

The top-down methodology, or reference approach, estimates CO_2 emissions taking into account only the amount of the energy consumed in the country, but not considering how the energy is consumed. Emissions are estimated from a balance involving domestic production of primary fuels, net imports of primary and secondary fuels and the internal variability of the stocks of those fuels. The advantage of top-down method over other methods is its non-dependence in detailed information regarding the use of fuel by the end user.

The bottom-up methodology, or by sector approach, identifies and quantifies the emissions of all GHG separately and takes into account not only the amount of fuel consumed, but also the type of equipment used and their respective efficiency. In this approach, emission sources are divided into stationary sources and mobile sources, and typical emission factors are developed for each source. However, these factors vary widely depending on the technology and the country it is being considered; they are developed based on sample information and the engineering knowledge each country has about the different technologies. Therefore, one cannot generalize the emission factors, i.e. factors should be developed in accordance with the reality of each country. Because of this greater detail, this methodology facilitates the study of policies and projects to reduce emissions, but it is difficult to apply because it is extremely complex to obtain data related to sources of fuel combustion and GHG emissions.

The IPCC classifies the gases emissions in some key categories. The key categories considered in this study are: *1A3b - Fuel Combustion Activities - Transport - Road* and *1A3d - Fuel Combustion Activities - Transport - Water-borne Navigation* (IPCC, 2006 Volume 1 Chapter 4 Table 4.1).

3.2 System Dynamics in Simulation of Transportation Networks

The sustainable development of an effective urban transport system is a key point in reducing the consumption of energy resources and building an urban society that enjoys a better quality of life. The concept of sustainable urban transport involves four aspects: economic sustainability, environmental sustainability, social sustainability and sustainable transport (Wang, et al., 2008). The study of the dynamic relationships between economic development and environmental preservation can provide the scientific basis for planning the coordinated development of (an urban) society (Duan and Yang, 2008). However, because of the complexity and scope of transport systems, traditional simulation methods are not suitable for its analysis. Complex systems like this have been successfully simulated and analyzed using system dynamics that was first proposed by Forrester and later used in urban systems modeling (Wang, et al., 2008).

Such transportation simulation systems involve many agents, with multiple feedback loops among them; furthermore, they consider different time intervals for response among users, developers, operators and managers. The system dynamics model not only offers a different perspective, with a whole system approach to transport planning, but also demonstrates to managers the importance of these feedback loops and lag responses. The system dynamics approach also provides specialized tools that help managers understand the underlying structures of systems and cause and effect relationships within them. Furthermore, the approach allows for model calibration to data and generation of optimal policies (Shepherd and Emberger, 2010).

In addition, the time-dependent aspect allows the system dynamics model to simulate performance patterns not as a result of extrapolation of trends, but through the continuous application of rules and relationships that modify simulated conditions and on which subsequent understanding and decision analysis may be based (Abbas and Bell, 1994).

Moreover, the modeling process of transportation systems requires that its model captures the consequences of investment policies since its main aim is to aid policy-makers in reaching an optimum design policy with plausible solutions to a lot of transportation problems (Abbas and Bell, 1994).

Some proposed system dynamics models played an important role in helping the evaluation of policies in order to reduce emissions. One is the TREMOVE (EEA, 2011), which was designed to evaluate the effect of different transport policies on emissions of pollutants from European countries.

Another model designed to support policy decisions about transport and its impact is GLADYSTE (Global Scale System for Dynamic Simulation Model Transport Emissions) that extends the coverage of TREMOVE to the globe (Purwanto et al., 2010). In this model, the CO_2 emissions in cargo transportation is mainly determined by the quantity shipped, the transport mode used and the power consumption characteristics of each mode. Because these components interact, environmental impact can be changed through policies that expand the network of each mode (Wang et al., 2010).

In GLADYSTE model, the transportation system and environmental impacts are simulated through four modules that are interconnected. The first module refers to the demand for motorized transport, taking into account the supply-demand balance. The second module considers the outputs of the first one, generating the fleet needed to meet the demand. In the environmental module, fuel consumption and pollutant emissions are calculated from the fleet, and the average speed of each transport mode to meet the demand. Finally, the module of the impacts calculates the costs of externalities, taxes and subsidies. (Purwanto et al., 2010).

System dynamics was also used in a study conducted on behalf of the Community of European Railway and Infrastructure Companies (Doll et al, 2008) to analyze the impact of transport on CO_2 emissions, which simulates the environmental impact caused by a partial shift of the railway demand to road. The model simulates the reference transport demand in four different segments of market and the final output of the model consists of the CO_2 emissions in various scenarios.

4 Model Description

The main purpose of the model is to analyze the modal shift from road to cabotage over time, driven by the level of investment in the modes capabilities and governmental pressure to reduce CO_2 emissions. As a final result, we want to understand the dynamics of modal shift in cargo transport and their impact on CO_2 emissions.

A modal shift occurs when one transportation mode has a comparative advantage in a similar market over another. Comparative advantages can take various forms, such as costs, capacity, time, flexibility or reliability. Depending on what is being transported, the importance of each of these factors varies. In this work, the most important factor for the achievement of modal shift is directly related to the capability of each transportation mode; the assumption is appropriate since, in the long term, this may cause the greatest impact within the premises of the study.

Figure 4 illustrates the model diagram developed to study the impacts of modal shift over the CO_2 emissions.

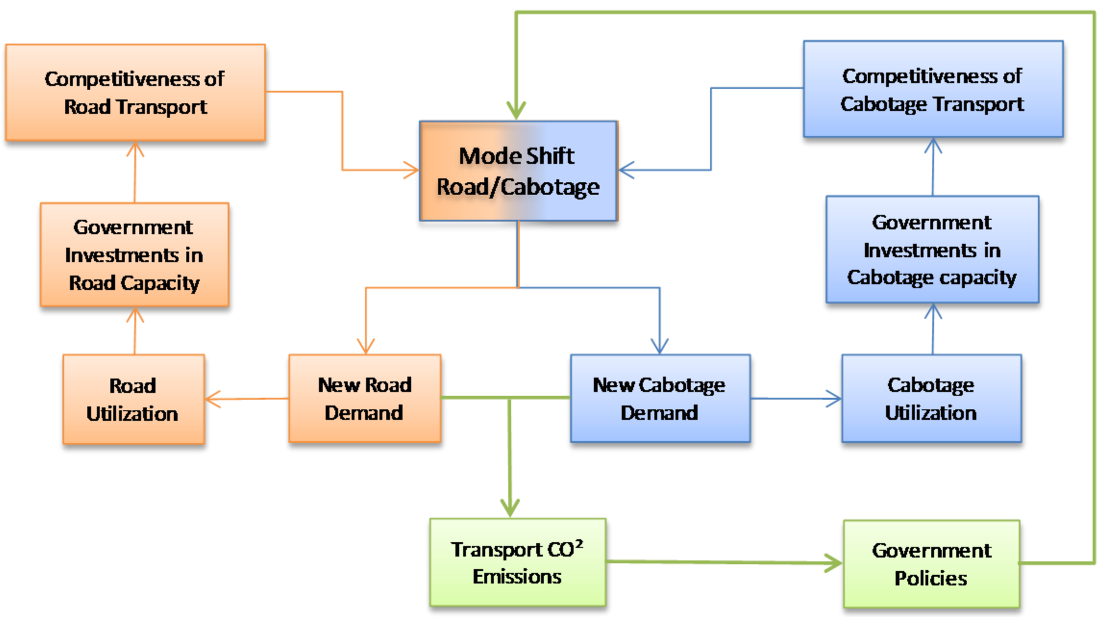

Figure 4 – System Dynamics model diagram.

The diagram can be divided in 4 parts:

- Transport Capacity
- Transport Demand
- Modal Shift
- CO_2 emissions

The following figures show each of these four parts. All the equations units, inputs and outputs are detailed in Annex A.

Transport Capacity

Figure 5 shows the increase in Road and Cabotage, relating the modal shift, increasing demand and investment to increase transport capacity

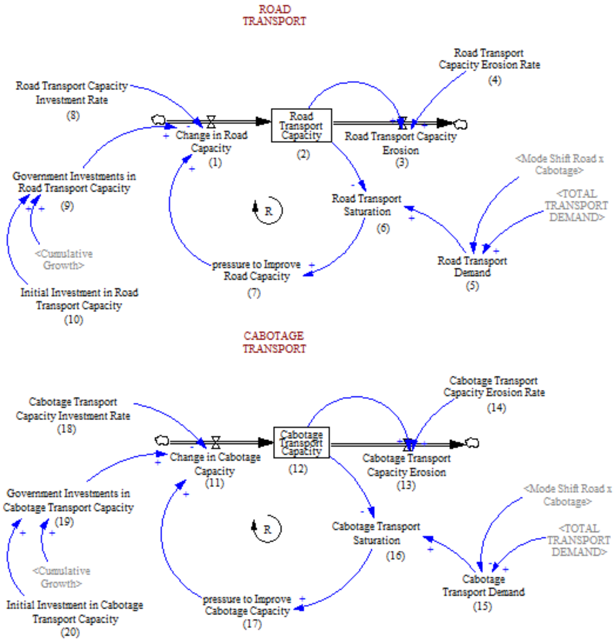

Figure 5 – Road and Cabotage Transport Capacity.

Main equations:

Road Transp Capacity = Change in Road Capacity - Road Transp Capacity Erosion (1)

Cabotage Transp Capac = Change Cabotage Capacity - Cabotage Transp Capac Erosion (2)

Cabotage Transport Demand = Mode Shift Road x Cabotage * Total Transport Demand (3)

Road Transport Demand = (1-Mode Shift Road x Cabotage) * Total Transport Demand (4)

Table:

Table 3 shows Transport Saturation and Pressure to improve capacity. Obtaining this value function is difficult; an approximation to the values from the table is a representation of empirical observations of professionals in the area.

Table 3 – Transport Saturation and Pressure to improve capacity.

Transport Saturation	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	> 1
Pressure to improve capacity	0	0	0	0.01	0.04	0.1	0.25	0.54	1	1.8	3	5

Transport Demand

Figure 6 shows the increase of Transport Demand in function of economic growth.

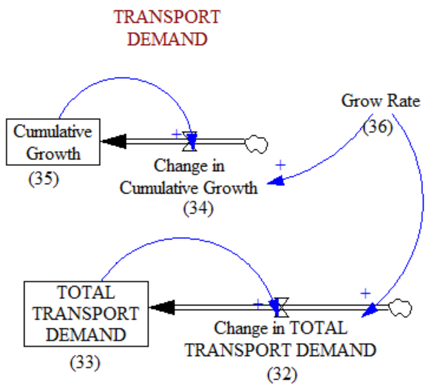

Figure 6 –Transport Demand.

Main equations:

Change In Total Transport Demand = Total Transport Demand * Growth Rate (5)

Total Transport Demand = Integ (Change In Total Transport Demand) (6)

Modal Shift

Figure 7 shows the change in the modal according to the government policies and differences in competitiveness. The curve value study was based on the study of Yoshizaki et al. (2007).

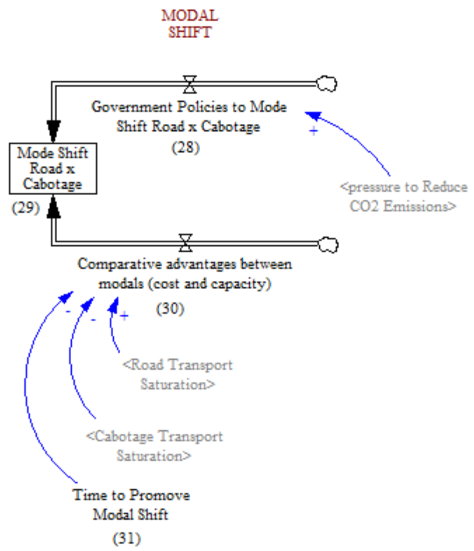

Figure 7 – Modal Shift.

Main equation:

Mode Shift Road x Cabotage =
Integ ("Comparative advantages between modals (cost and capacity)"+Government Policies to Mode Shift Road x Cabotage) (7)

Tables :

Table 4 lists the government policies with the pressure to reduce CO_2 emissions. These values are assumptions adopted for the study, because it is currently difficult to predict those parameters.

Table 4 – Government policies X pressure to reduce CO_2.

Pressure to reduce CO_2	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Government Policies	0	0	0.001	0.002	0.004	0.006		0.01			0.02

Table 5 shows the ratio of the difference between the use of modals and generating competitive advantages. Obtaining the curve value study was based on the study of Yoshizaki et al. (2007) and Costa et al, 2009.

Table 5 –Government policies X pressure to reduce CO_2.

Difference between modals	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Comparative advantages	0	0.0415	0.078	0.11	0.137			0.19			0.2

Source: Yoshizaki et al. (2007) and Costa et al, 2009 (adapted).

GHG emissions

Figure 8 Totals CO_2 emissions based on the modal emissions (road and cabotage).

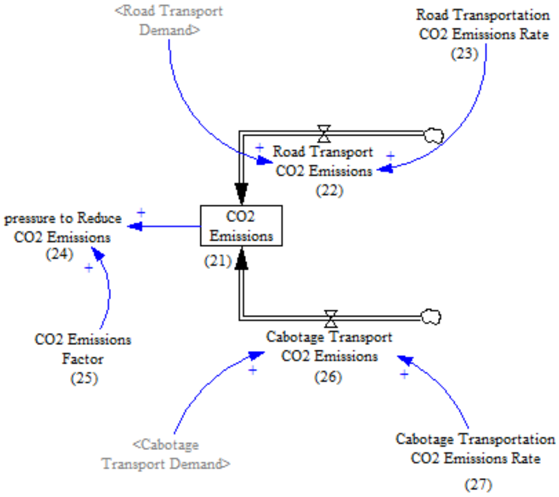

Figure 8 – CO_2 emissions.

Main equations:

$$CO_2 \text{ Emissions} = \text{Integ (Cabotage Transp } CO_2 \text{ Emissions} + \text{Road Transp } CO_2 \text{ Emissions)} \quad (8)$$

$$\text{Road Transp } CO_2 \text{ Emissions} = \text{Road Transp Demand} * \text{Road Transp } CO_2 \text{ Emissions Rate} \quad (9)$$

$$\text{Cabotage Transp } CO_2 \text{ Emissions} = \text{Cabotage Transp Demand} * \text{Cabotage Transp } CO_2 \text{ Emissions Rate} \quad (10)$$

Table:

Table 6 lists the CO_2 emissions with the pressure to reduce CO2 emissions. These values are assumptions adopted for the study, because those parameters are currently difficult to predict.

Table 6 –Government policies X pressure to reduce CO_2.

CO_2 Emissions (Gt)	0	500	1800
Pressure to reduce CO_2	0	0.5	1

Obs: Based on the worst case, existing and growing pressure to understand the implications on PNLT and the transport infrastructure in Brazil.

Cargo Transportation in Brazil

One of the greatest challenges of this work was to obtain a representative set of data of cargo transportation in Brazil. Although the Brazilian governmental regulatory agencies regulate the transport activities in Brazil, such as the National Land Transport (ANTT) and the National Waterway Transport (ANTAQ), they do not have a centralized database with a matrix with origin and destination of national transport. Even the Ministry of Transport does not have a centralized database that serves as a source for determining the required variables values. Therefore, the development of this work is based on information obtained from professional private companies operating in road and cabotage modes.

The full list of model variables is presented in Annex A as well as their initial values used in this work.

4.1 Demand Estimation

The estimated demand used in this work was based on data obtained from PNLT and from the enterprise Log-In Logística Intermodal (Log-in, 2010) that operates in the cabotage transport in Brazil. In 2009, this company hired a consultancy to assess the potential of cargo that would shift from the road transportation mode to the cabotage mode. According to this study, in 2009 93 million tons of cargo were handled per month. Excluding bulk handling, intra-state transportation and the states not competitive for the maritime mode, a potential of 2.5 million tons of cargo per month was estimated for movement by cabotage (Figure 9).

Considering an average weight of 16.5 tons per container, the market potential of cabotage was estimated at 2.5 million ÷ 16.5 = 151,000 TEUs (Twenty-Foot Equivalent Unit). The estimated volume achieved by this mode in 2009, estimated at 24,000 TEUs per month, so the total potential market that year was 151,000 + 24,000 = 175,000 TEUs per month. The results of this study are summarized in Figure 9.

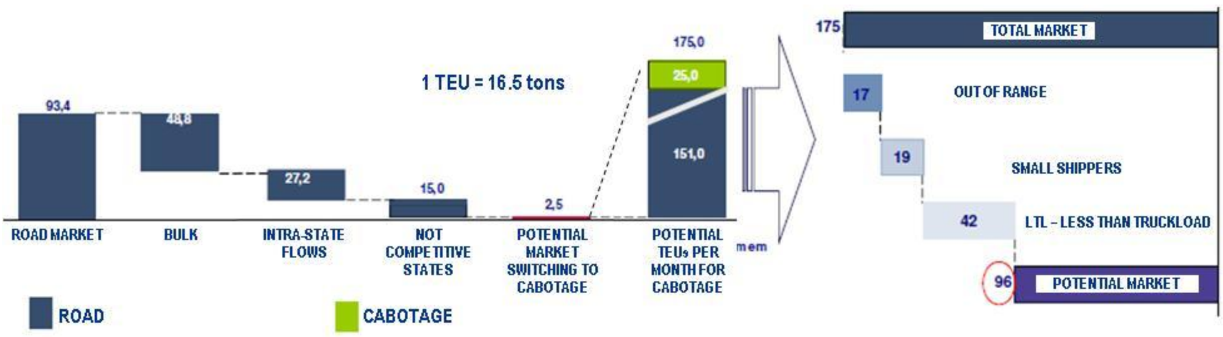

Figure 9 – Potential cabotage market in 2009 (Log-In, 2010).

In the same study, the potential market for cabotage by 2018 was projected considering a linear growth of Brazilian GDP of about 3% per year as from 2010. Figure 10 illustrates the estimated market growth of cabotage transportation mode resultant from this study.

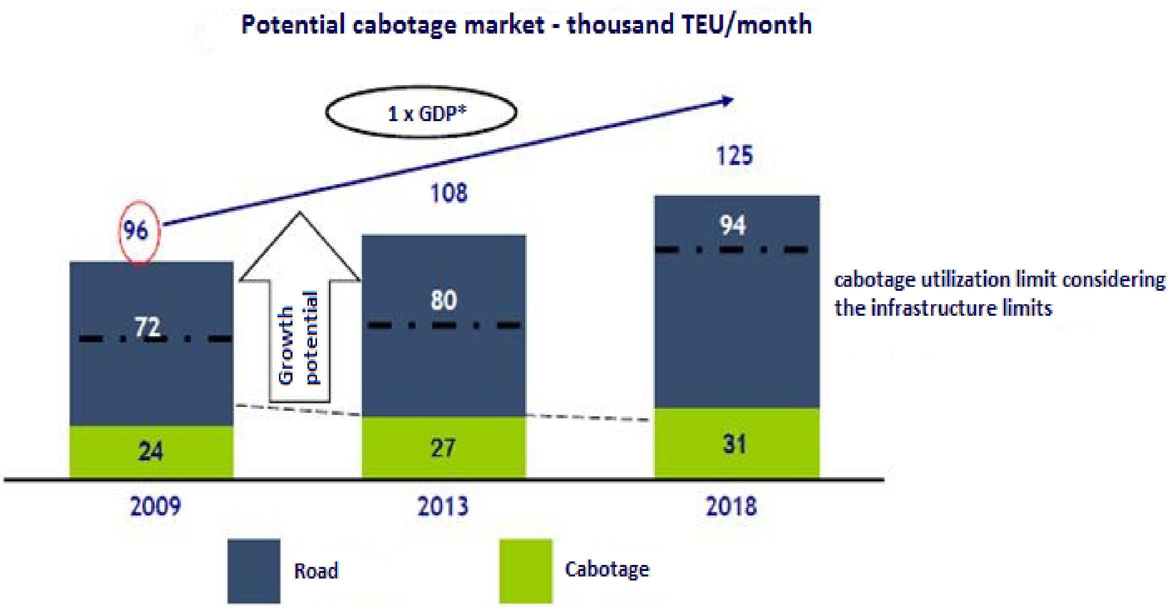

Figure 10 – Projected growth of the market from 2010 to 2018 (Log-In, 2010).

From the study contracted by Log-In (Log-in, 2010), it was possible to identify the relationship between the demand for transport and the cabotage transportation mode participation when not considering any kind of pressure for reducing CO_2 emissions. Such relationship is presented in Equation (11).

$$D_C = 0.27\, D_T \qquad (11)$$

where, D_C is the demand for cabotage and D_T is the total demand for transportation

The total demand for transportation has a relationship with the level of economic activity of a country, and one of the indicators used to estimate the growth in demand is related to the Gross Domestic Product (GDP), as shown in Figure 1. Thus, in order to determine the demand trend curve, the current TKU (ton per kilometer) should be obtained and its growth estimated in function of the GDP growth. The PNLT considered for calculating the GDP by region and a matrix of origin and destination obtained by simulation as there are no official data. This method of demand generation is not used in this work and macro values are considered here for the whole country and not per region. Therefore, the transport mode production participation values from 2006 are adopted in this work, as shown in Table 7 (CNT, 2009).

Table 7 – Transport mode production participation (CNT, 2009)

Mode	Million (TKU)	Participation (%)
Road	485,625	61.1
Railroad	164,809	20.7
Waterway	108,000	13.6
Pipeline	33,300	4.2
Air	3,169	0.4
Total	**794,903**	**100**

The PNLT considers the planning horizon from 2005 to 2025; therefore, the total annual demand should be estimated for the same period. In order to perform such estimation, a value of 1.5 was considered. This value was obtained with long-experience logistics professionals working in the cabotage transport mode.

The projection of demand is presented in Table 8. The demand for road and waterway are calculated according to the PNLT transport matrix presented in Table 2 without considering the pressure for modal shift. In turn, the demand for cabotage is calculated using the 0.27 factor presented in Equation 11.

Table 8 – Projected Demand.

Million TKU (Road and Cabotage)						
YEAR	TOTAL DEMAND TKU	TKU % Grow Rate	% Road PNLT	Road TKU	% Cabotage PNLT	Cabotage TKU
2010	719,910	6.8%	79.0%	568,729	21.0%	151,181
2011	768,864	6.8%	77.3%	594,075	22.7%	174,788
2012	821,147	6.8%	75.5%	620,239	24.5%	200,907
2013	876,985	6.8%	73.8%	647,215	26.2%	229,770
2014	936,620	6.8%	72.1%	674,990	27.9%	261,629
2015	1,000,310	6.8%	70.3%	703,551	29.7%	296,759
2016	1,068,331	6.8%	68.6%	732,875	31.4%	335,456
2017	1,140,977	6.8%	66.9%	762,933	33.1%	378,044
2018	1,218,564	6.8%	65.1%	793,691	34.9%	424,873
2019	1,301,426	6.8%	63.4%	825,104	36.6%	476,322
2020	1,389,923	6.8%	61.7%	857,119	38.3%	532,804
2021	1,484,438	6.8%	59.9%	889,673	40.1%	594,765
2022	1,585,380	6.8%	58.2%	922,691	41.8%	662,689
2023	1,693,185	6.8%	56.5%	956,085	43.5%	737,100
2024	1,808,322	6.8%	54.7%	989,755	45.3%	818,567
2025	1,931,288	6.8%	53.0%	1,023,583	47.0%	907,705

This method of calculating demands results in a very high percentage of participation of cabotage mode in waterway in the early years. In the absence of more detailed data for validation of the values obtained, this work disregards the first 5 years of the table and uses only the values from 2010.

4.2 Capabilities Estimation

The estimated capacity of each transportation mode considers that the current demand is being met by a utilization factor, which was estimated by the Alliance Company logistics professionals as being 0.8. Table 9 shows the estimated capacities of each transportation mode at the beginning of the planning horizon.

Table 9 – Estimated capacities

Capacities in TKU Millions		
Year	Road	Cabotage
2010	710,911	188,976

The capacity of each transportation mode has some dynamic characteristics of loss and replacement that affect the available capacity to meet the demand. Analyzing these characteristics with logistics professionals, a relationship between growth and investment was identified on roads and vehicles for the road transportation and on vessels and ports for the cabotage transportation. On the other hand, the capacities are decreasing with the obsolescence of the vehicles on road transportation and vessels on cabotage.

Considering only the information provided by the PNLT, a government investment of R$ 74,194 million in the road mode and R$ 25,162 million is required in the cabotage mode (ports only) in order to increase the capacity of those transportation modes.

Fleet obsolescence rates are difficult to estimate since they must consider the average age of the vehicles fleet on road transportation and their participation in meeting the demand of this transportation mode. The same applies to the fleet of vessels in the cabotage mode. Since these relationships cannot be derived due to lack of available data, the obsolescence rate used in this work was 1% per year for the two transportation modes.

Table 10 shows the values of cost and obsolescence for each transportation mode.

Table 10 – Obsolescence and cost of replacement.

	Road	**Cabotage**
Cost for replacement (R$/TKU)	0,1213	0,0297
Rate of obsolescence (1/Year)	1%	1%

4.3 CO_2 Emissions

The GHG emitted

from each key category (1A3b – Road transportation and 1A3d – Water-borne Navigation) is considered separately in this work. Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are emitted from both road and cabotage transportation modes. The key category analysis is performed for each of these gases separately because the methods, emission factors and related uncertainties differ for each gas.

After the calculation of each gas emissions, their values are converted to CO_2 equivalent, which is the emissions measurement standard, by multiplying the quantities calculated by the conversion factors for each gas (CO_2 = 1, CH_4 = 23 and N_2O = 296) (U.S. Department of Energy, 2009) and summing them up as depicted in Equation (12).

$$CO_{2eq} = CO_2 + (23 * CH_4) + (296 * N_2O) \tag{12}$$

Based on the equation of CO_2 eq. Figure 11 below shows CO_2 per kg emissions in each modal for every 1,000 tkus transported.

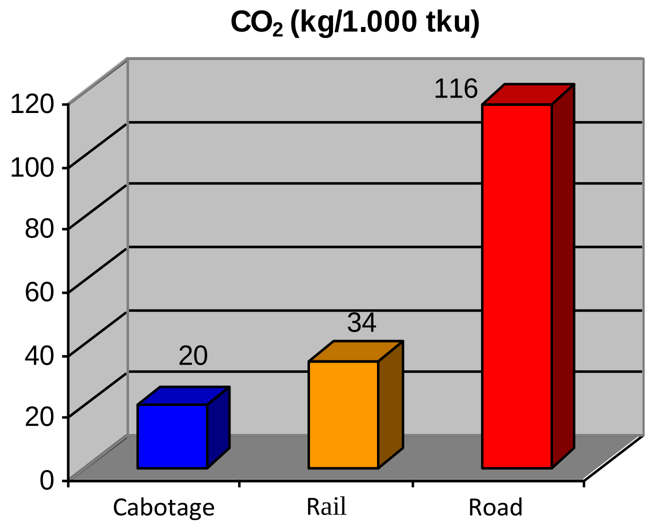

Figure 11 – CO_2 emissions by transport mode). Brazil, Ministry of Transportation (2009)

4.4 Scenarios

The model has been built with the VENSIM software based on the approach of System Dynamics Modeling. The model simulates the transport demand in one market segment, specifically the transport of general cargo, via road transportation and coastal shipping (cabotage).

The model was used to simulate five different scenarios the variable values of which are defined in Table 11. The first scenario provides a pessimistic case (worst case), where no modal shift is expected. Scenarios 2 and 3 represent moderate cases, while scenarios 4 and 5 are considered optimistic cases. The parameters that will be changed in all the scenarios are the level of investment in the capacity of road transport and cabotage and the presence or absence of pressure to reduce CO_2.

The scenarios were created considering the possibility of covering the limits of the events that may occur. The pessimistic scenario would represent the worst case, in which the change of modal PNLT proposal would not occur; the moderate scenarios represent the modal shift at a rate as proposed in PNLT optimistic scenarios and evaluate a condition in which the modal shift is more pronounced.

Table 11 – Simulated scenarios using the system dynamics model.

#	Description	Road Investments	Cabotage Investments	Pressure to reduce CO_2
1	Pessimistic	x 1.5	x 0.5	no
2	Moderate	x 1.0	x 1.0	no
3	Moderate CO_2	x 1.0	x 1.0	yes
4	Optimistic	x 1.0	x 1.5	no
5	Optimistic CO_2	x 1.0	x 1.5	yes

As far as other parameters are concerned:

- Initial time: 2010;
- Final time: 2025.
- Time step: 0.03125 years.

5 Main results

The results of the system dynamics model are available in several dimensions:

- Modal shift: showing the transition and maturation of the change of modal.
- Comparative advantages.
- CO_2 emissions: shows the evolution of CO_2 emissions.

A significant result for analysis is the rate of change of modal. Figure 12 shows the behavior of this variable. This graph represents the modal share of cabotage in the total demand, as a consequence of model assumptions, the share of road transportation is provided by the complementary value of the percentage. We may note in the scenarios Moderate CO_2 and CO_2 Optimist that the presence of pressure to reduce CO_2 has a significant impact on the final value of participation of modes, besides providing a stronger growth in the last decade of the simulation. This difference in the last decade can be better understood with the values of comparative advantages.

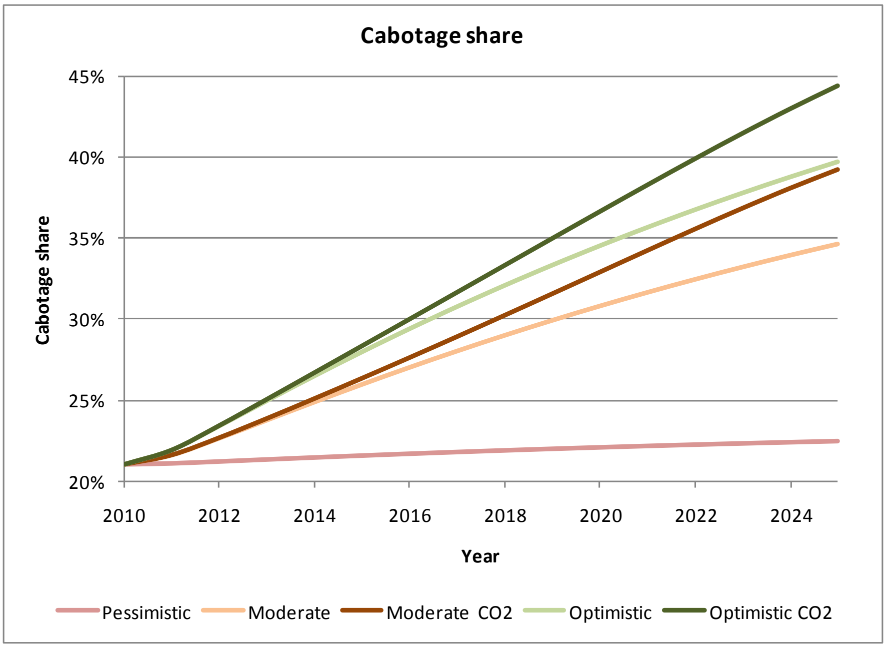

Figure 12 – Scenarios modal shift (cabotage share).

Comparative advantages are shown in Figure 13. This figure shows the synthesized form of the competitive advantage of modal cabotage on the roads; this advantage is represented by the fraction of the annual migration of a modal to another. In the pessimistic scenario, where there is no change of modal, one can see that the advantage of modal cabotage is not representative. In the Moderate and Optimistic scenario, we see a creation of an early lead and maintained that advantage over time. It is worth noting that the maintenance of competitive advantage over time did not cause a more representative modal shift than changes in CO_2 and Optimistic scenarios Moderate CO_2. This dynamic is shown in Figure 13.

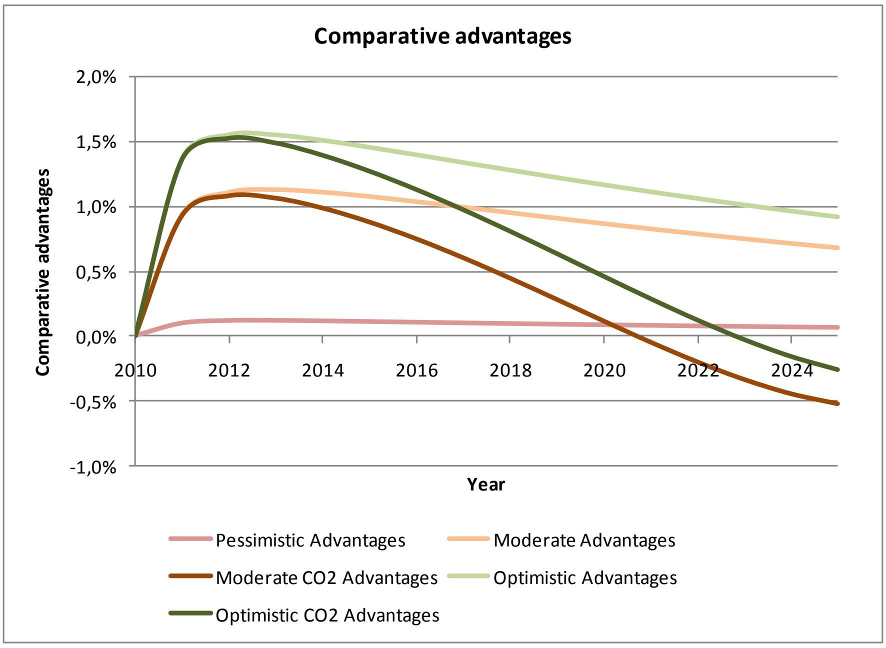

Figure 13 – Comparatives advantages between road and cabotage.

Figure 14 presents the scenarios Optimistic, Optimistic CO_2 Optimistic advantages and Advantage CO_2. In the graph, it is apparent that the competitive advantage of Optimistic scenario (green) the modal share of coasters does not remain. By contrast, CO_2 Optimistic scenario there is an increased modal share of cabotage even with the decline of competitive advantage; this is due to the presence of the factor of pressure to reduce CO_2 emissions.

Initially, a strong level of inertia makes the modal shift a slow and sometimes difficult to perceive process. Only a few users will experiment with modal shift, often as part of a publicly subsidized initiative (government providing the initial funding to develop infrastructures). Inertia implies that the modal shift is often much less significant than expected, leading to a situation of underperformance. The reasons behind the inertia are linked to accumulated investments and assets in the prior mode and terminals.

This observation is interesting because what we see in Moderate and Optimistic scenario is a process of maturation inertia and modal migration, despite this attempt to stabilize over the years, which slows the modal shift. With the presence of pressure to reduce CO_2, CO_2 scenarios Moderate and Optimistic CO_2 process of modal shift has a faster maturation.

Maturation occurs when the full potential of the modal is reached and a new equilibrium in modal share is reached, so their respective comparative advantages are of lesser variance.

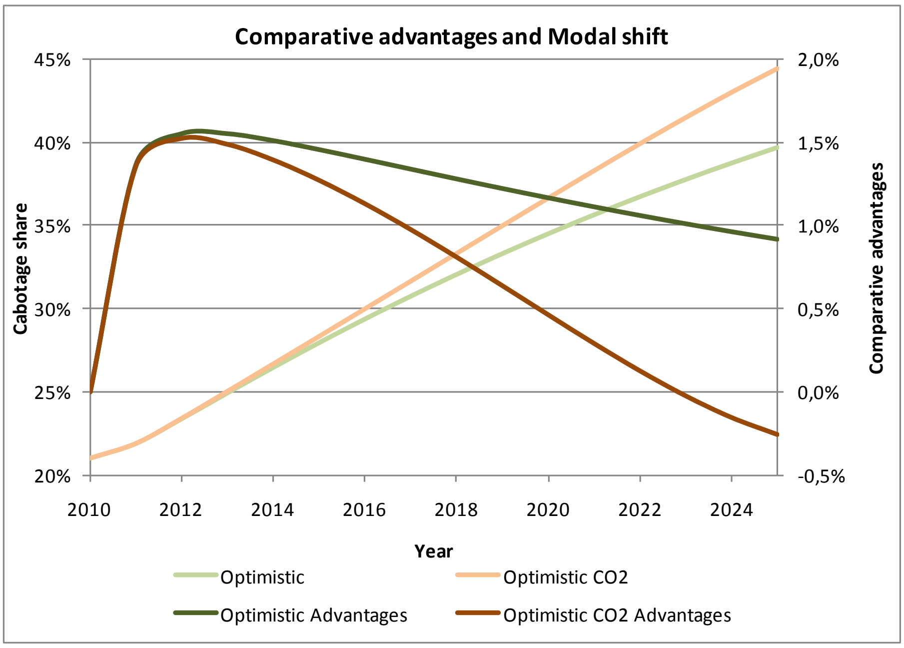

Figure 14 – Comparative advantages and modal shift.

Regarding CO_2 emissions, as in Figure 15 below, the Pessimistic Scenario (1) presents a worse than the other scenarios (13%) as compared to the Optimistic CO_2 scenario). The other scenarios show that the main factor in the reduction of CO_2 emissions is to invest in cabotage.

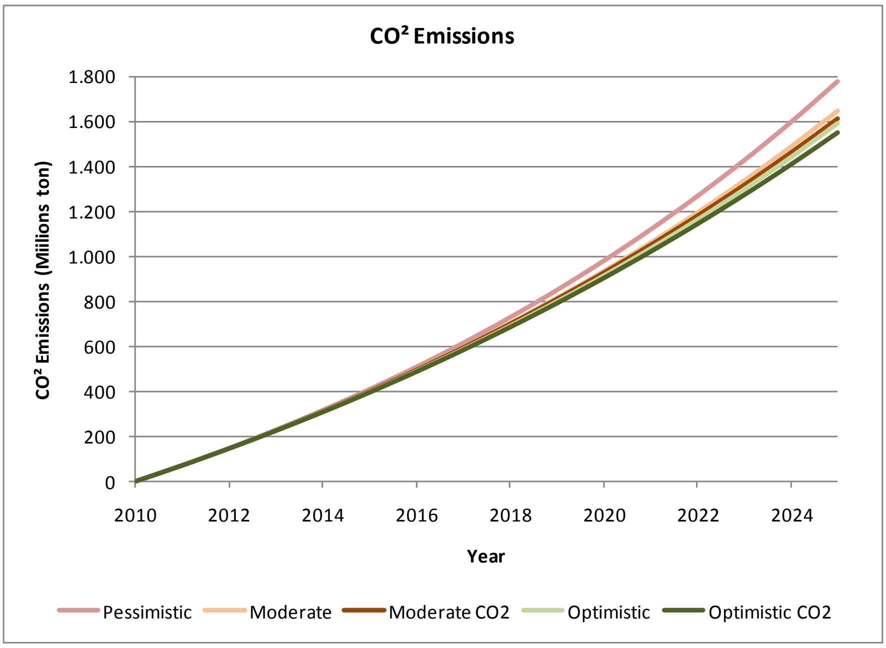

Figure 15 – CO_2 Emissions.

6 Conclusions

The objective was to evaluate the impacts of the implementation of the Brazilian National Plan for Logistics and Transport (PNLT) in the CO_2 emissions from transportation of domestic cargo in Brazil. To do so, a model based on system dynamics was used that allowed the analysis of the causal processes that occur in a modal shift in the matrix. Five scenarios were simulated that showed that the inertia for the maturation of the modal shift is long, which is actually observed in practice. These delay factors corroborate that this modal shift will occur is always beneficial. In the model, the impact of the implementation of a pressure to reduce CO_2 emissions in the simulation showed that this parameter is beneficial in the acceleration process of modal shift. This highlights the importance of public power as a motivator of the implementation of practices that do less damage to the environment.

References

Abbas, K.A. and Bell, M.G.H. System dynamics applicability to transportation modeling. Transportation Research Part A, 28(5), 373-390, 1994.

Apogee Research, Transportation and Global Climate Change: A Review and Analysis of the Literature. US Department of Transportation. Washington DC, 1998.

Brazil, Act 7.390/2010. Regulamentação da Política Nacional sobre Mudanças Climáticas, Brasilia, 2010.

Brazil, Law 12.187/2009. Política Nacional sobre Mudança do Clima – PNMC, Brasilia, 2009.

Brazil, MMA, Ministério do Meio Ambiente, I Inventário Nacional de Emissões Atmosféricas por Veículos Automotores Rodoviários, Accessed January 08, 2011. http://www.mineiropt.com.br/media/uploads/file/inventrio_de_emisses_veiculares_182.pdf.

Brazil, PNLT Ministério dos Transportes, Secretaria de Política Nacional de Transportes Plano Nacional de Logística e Transportes – PNLT, Brasilia, 2009.

Brazil, PNMC, Ministério do Meio Ambiente, Plano Nacional sobre Mudança do Clima (2009), Accessed January 08, 2011. http://www.meioambiente.gov.br/sitio/index.php?ido=conteudo.monta& idEstrutura=141&id Conteudo=7466&idMenu=11230.

Brazil, MCT Ministério da Ciência e Tecnologia, Inventário brasileiro das emissões e remoções antrópicas de gases de efeito estufa. Last modified November 24, 2009. Accessed January 08, 2011 http://homologa.ambiente.sp.gov.br/proclima/publicacoes/publicacoes_portugues/inventario_brasileiro_valores_preliminares.pdf.

CNT Confederação Nacional do Transporte Boletim Estatístico, March 2009, Accessed January 08, 2011 - http://www.cnt.org.br/portal/img/arquivos/Boletim%20Estat%C3%ADstico%20CNT%20-%202009.pdf

Costa, G A A ; Brinati, M A ; Hino, C. M. . Contribution margin model applied to the marketing planning of a container liner carrier, Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment v. 223, p. 63-90, 2009.

Doll, C.. Fiorello, D; Pastori, E; Reynaud, C.; Klaus, P.; Lückmann, P.; Hesse, K.; Kochsiek, J.Long-Term Climate Impacts of the In-troduction of Mega-Trucks Study to the Community of European Railways and Infrastructure Companies (CER), Brussels. Fraunhofer ISI (study co-ordinator, Karlsruhe) TRT (Milan), NESTEAR (Gentilly), Fraunhofer-ATL (Nuremberg), Fraunhofer-IML (Dortmund). Karlsruhe, July 2008.

Duan, A.; Yang, J. The research of the city transportation development ecological carrying capacity based on the system dynamics. Proceedings of 2008 IEEE International Conference on Service Operations and Logistics, and Informatics, IEEE/SOLI 2008 [S.I.], v. 1, p. 1449-1453, 2008.

EEA, European Environmental Agency, TREMOVE: an EU-wide transport model. Accessed January 08, 2011 http://ec.europa.eu/environment/air/pollutants/models/tremove.htm.

http://www.eea.europa.eu/data-and-maps/figures/trend-in-freight-transport-demand-and-gdp-3

IEA International Energy Agency, CO_2 Emissions from fuel combustion Highlights, 2010 Edition, http://www.iea.org/co2highlights/CO2highlights.pdf/. Accessed January 08, 2011.

IPCC, Guidelines for National Greenhouse Gas Inventories Volume 1 Chapter 4: Methodological Choice and Identification of Key Categories, IGES Hayama: Japan, 2006.

IPCC, Guidelines for National Greenhouse Gas Inventories Volume 2 Chapter 3: Mobile Combustion, IGES Hayama: Japan, 2006.

IPCC, Third Assessment Report, Climate Change 2001: A Scientific Basis. Cambridge, UK, 2001.

Log-in, Log-In Logística Intermodal S/A – Relatório para Investidores do 3T2010, November 2010, Accessed January 08, 2011. https://loginlogistica.com.br/Download/Arquivo/RI/CD_7884811F_101109%20Log-In%20Release%203T10%20port.pdf

Mccollum, D.; Yang, C. Achieving deep reductions in US transport greenhouse gas emissions: Scenario analysis and policy implications. Energy Policy 37 (2009), 5580–5596, 2009.

Purwanto, A. J. Hidalgo González I.; Fermi F.; Fiorello D.. Global Scale System Dynamic Simulation Model for Transport Emissions, (GLADYSTE). p. 24, 2010.

Shepherd, S. ; Emberger, G. Introduction to the special issue: system dynamics and transportation. System Dynamics Review [S.I.], v. 26, n. 3, p. 193-194, Jul-Sep 2010.

U.S. Department of Energy, Transportation Energy data book: edition 28–2009

Yoshizaki, H. T. Y. ; Chebat, D. ; Hino, Celso M . Análise da viabilidade de integração entre rotas de longo curso e de cabotagem utilizando um modelo matemático. In: Encontro Nacional de Engenharia de Produção ENEGEP 2007, 2007, Foz do Iguaçu. Anais do XXVII Encontro Nacional de Engenharia de Produção ENEGEP 2007. Foz do Iguaçu, 2007.

Wang, J. F.; Huapu Lu H; Peng H. System dynamics model of urban transportation system and its application. Jiaotong Yunshu Xitong Gongcheng Yu Xinxi/ Journal of Transportation Systems Engineering and Information Technology [S.I.], v. 8, n. 3, p. 83-89, 2008.

Wang, Y.; Jinling F.; Xuesong F.; Hidefumi I.; Yoshitsugu H. Estimation of CO_2 mitigation potential from freight transport based on system dynamics model - A case study of Beijing, China. Proceedings of the Conference on Traffic and Transportation Studies, ICTTS [S.I.], v. 383, p. 256-268, 2010.

Yeh, S and Sperling, D. Low carbon fuel standards: Implementation scenarios and challenges. Energy Policy 38 (2010), 6955–6965, 2010.

ANNEX A – Description of the System Dynamics model

Nº	Name	Unit	Input (nº) and [Unit]	Equation	Output (nº) and [Unit]	Initial Value
1	Change in Road Capacity	TKU/ (Year* Year)	▪ (9) Government Investments in Road Transport Capacity [Money/Year] ▪ (7) Pressure to Improve Road Capacity [Dmnl] ▪ (8) Road Transport Capacity Investment Rate [Money/(TKU/Year)]	(Government Investments in Road Transport Capacity*Preassure to Improve Road Capacity)/Road Transport Capacity Investment Rate	▪ (2) Road Transport Capacity [TKU/Year]	
2	Road Transport Capacity	TKU/ Year	▪ (1) Change in Road Capacity [TKU/(Year*Year)] ▪ (3) Road Transport Capacity Erosion [TKU/(Year*Year)]	Change in Road Capacity-Road Transport Capacity Erosion	▪ (3) Road Transport Capacity Erosion [TKU/(Year*Year)] ▪ (6) Road Transport Saturation [Dmnl]	710911
3	Road Transport Capacity Erosion	TKU/ (Year* Year)	▪ (2) Road Transport Capacity [TKU/Year] ▪ (4) Road Capacity Erosion Rate [1/Year]	Road Transport Capacity*Road Transport Capacity Erosion Rate		
4	Road Transport Capacity Erosion Rate	1/Year			▪ (3) Road Transport Capacity Erosion [TKU/(Year*Year)]	0.01
5	Road Transport Demand	TKU/Year	▪ (29) Mode Shift Road x Cabotage [Dmnl] ▪ (34) TOTAL TRANSPORT DEMAND [TKU/Year]	(1-Mode Shift Road x Cabotage) *TOTAL TRANSPORT DEMAND	▪ (6) Road Transport Saturation [Dmnl]	
6	Road Transport Saturation	Dmnl	▪ (5) Road Transport Demand [TKU/Year] ▪ (2) Road Transport Capacity [TKU/Year]	Road Transport Demand/Road Transport Capacity	▪ (7) Pressure to Improve Road Capacity [Dmnl]	
7	Pressure to Improve Road Transport Capacity	Dmnl	▪ (6) Road Transport Saturation [Dmnl]	2.9*Road Transport Saturation^4.73	▪ (1) Change in Road Capacity [TKU/(Year*Year)]	
8	Road Transport Capacity Investment Rate	Money/ (TKU/ Year)		0.121255	▪ (1) Change in Road Capacity [TKU/(Year*Year)]	
9	Government Investments in Road Transport Capacity	Money/ Year	▪ (10) Initial Investment in Road Transport Capacity [Money/Year] ▪ (35) Cumulative Growth [Dmnl]	Initial Investment in Road Transport Capacity*Cumulative Growth	▪ (1) Change in Road Capacity [TKU/(Year*Year)]	

Nº	Name	Unit	Input (nº) and [Unit]	Equation	Output (nº) and [Unit]	Initial Value
10	Initial Investment in Road Transport Capacity	Money/ Year		3842	▪ (9) Government Investments in Road Transport Capacity [Money/Year)]	
11	Change in Cabotage Capacity	TKU/ (Year* Year)	▪ (19) Government Investments in Cabotage Transport Capacity [Money/Year] ▪ (17) Pressure to Improve Cabotage Capacity [Dmnl] ▪ (18) Cabotage Transport Capacity Investment Rate [Money/(TKU/Year)]	(Government Investments in Cabotage Transport Capacity*Preassure to Improve Cabotage Capacity)/Cabotage Transport Capacity Investment Rate	▪ (12) Cabotage Transport Capacity [TKU/Year]	
12	Cabotage Transport Capacity	TKU/Year	▪ (11) Change in Cabotage Capacity [TKU/(Year*Year)] ▪ (13) Cabotage Transport Capacity Erosion [TKU/(Year*Year)]	Change in Cabotage Capacity-Cabotage Transport Capacity Erosion	▪ (13) Cabotage Transport Capacity Erosion [TKU/(Year*Year)] ▪ (16) Cabotage Transport Saturation [Dmnl]	188976
13	Cabotage Transport Capacity Erosion	TKU/ (Year* Year)	▪ (12) Cabotage Transport Capacity [TKU/Year] ▪ (14) Cabotage Capacity Erosion Rate [1/Year]	Cabotage Transport Capacity*Cabotage Transport Capacity Erosion Rate		
14	Cabotage Transport Capacity Erosion Rate	1/Year			▪ (13) Cabotage Transport Capacity Erosion [TKU/(Year*Year)]	0.01
15	Cabotage Transport Demand	TKU/Year	▪ (29) Mode Shift Roadx Cabotage [Dmnl] ▪ (34) TOTAL TRANSPORT DEMAND [TKU/Year]	(Mode Shift Roadx Cabotage) *TOTAL TRANSPORT DEMAND	▪ (16) Cabotage Transport Saturation [Dmnl]	
16	Cabotage Transport Saturation	Dmnl	▪ (15) Cabotage Transport Demand [TKU/Year] ▪ (12) Cabotage Transport Capacity [TKU/Year]	Cabotage Transport Demand/Cabotage Transport Capacity	▪ (17) Pressure to Improve Cabotage Capacity [Dmnl]	
17	Pressure to Improve Cabotage Transport Capacity	Dmnl	▪ (16) Cabotage Transport Saturation [Dmnl]	2.9*Cabotage Transport Saturation^4.73	▪ (11) Change in Cabotage Capacity [TKU/(Year*Year)]	

Nº	Name	Unit	Input (nº) and [Unit]	Equation	Output (nº) and [Unit]	Initial Value
18	Cabotage Transport Capacity Investment Rate	Money/ (TKU/ Year)		0.029731	▪ (11) Change in Cabotage Capacity [TKU/(Year*Year)]	
19	Government Investments in Cabotage Transport Capacity	Money/ Year	▪ (20) Initial Investment in Cabotage Transport Capacity [Money/Year] ▪ (35) Cumulative Growth [Dmnl]	Initial Investment in Cabotage Transport Capacity*Cumulative Growth	▪ (11) Change in Cabotage Capacity [TKU/(Year*Year)]	
20	Initial Investment in Cabotage Transport Capacity	Money/ Year		877	▪ (19) Government Investments in Cabotage Transport Capacity [Money/Year)]	
21	CO2 Emissions	Ton	▪ (26) Cabotage Transport CO2 Emissions [ton] ▪ (22) Road Transport CO2 Emissions [ton]	Integ (Cabotage Transport CO2 Emissions+Road Transport CO2 Emissions)	▪ (24) Pressure to Reduce CO2 Emissions [1/Year]	0
22	Road Transport CO2 Emissions	ton/Year	▪ (5) Road Transport Demand [TKU/Year] ▪ (23) Road Transportation CO2 Emissions Rate [ton/TKU]	Road Transport Demand*Road Transportation CO2 Emissions Rate	▪ (21) CO2 Emissions [ton]	
23	Road Transportation CO2 Emissions Rate	ton/TKU		0.6		
24	Pressure to Reduce CO2 Emissions	1/Year	▪ (21) CO2 Emissions [ton] ▪ (25) CO2 Emissions Factor [1/(ton*Year)]	CO2 Emissions Factor*(-4e-007*CO2 Emissions^2+0.0012*CO2 Emissions)	▪ (28) Government Policies to Change Mode Shift Road x Cabotage [1/Year]	
25	CO2 Emissions Factor	1/ (ton*Year)		1 (or 0)		
26	Cabotage Transport CO2 Emissions	ton/Year	▪ (15) Cabotage Transport Demand [TKU/Year] ▪ (27) Cabotage Transportation CO2 Emissions Rate [ton/TKU]	Cabotage Transport Demand*Cabotage Transportation CO2 Emissions Rate	▪ (21) CO2 Emissions [ton]	
27	Cabotage Transportation CO2 Emissions Rate	ton/TKU		0.1		
28	Government Policies to Change Mode Shift Road x Cabotage	1/Year	▪ (24) Pressure to Reduce CO2 Emissions [1/Year]	0.02*Preassure to Reduce CO2 Emissions^1.8671	▪ (29) Mode Shift Cabotage x Cabotage [Dmnl]	

Nº	Name	Unit	Input (nº) and [Unit]	Equation	Output (nº) and [Unit]	Initial Value
29	Mode Shift Road x Cabotage	Dmnl	▪ (30) Comparative advantages between modals (cost and capacity) [1/Year] ▪ (28) Government Policies to Mode Shift Road x Cabotage [1/Year]	Integ ("Comparative advantages between modals (cost and capacity)"+Government Policies to Mode Shift Road x Cabotage)	▪ (5) Road Transport Demand [TKU/Year] ▪ (15) Cabotage Transport Demand [TKU/Year]	0.21
30	"Comparative advantages between modals (cost and capacity) "	1/Year	▪ (6)Road Transport Saturation [Dmnl] ▪ (16)Cabotage Transport Saturation [Dmnl] ▪ (31)Time to Promove Modal Shift [Year]	(-0.2377*(Road Transport Saturation-Cabotage Transport Saturation)^2+0.4377*(Road Transport Saturation -Cabotage Transport Saturation))/Time to Promove Modal Shift		0.21
31	Time to Promove Modal Shift	Year		2	▪ (30) "Comparative advantages between modals (cost and capacity) " [1/Year]	
32	Change in TOTAL TRANSPORT DEMAND	TKU/ (Year* Year)	▪ (33)TOTAL TRANSPORT DEMAND [TKU/Year] ▪ (36) Grow Rate [1/Year]	TOTAL TRANSPORT DEMAND*Grow Rate	▪ (33)TOTAL TRANSPORT DEMAND [TKU/Year]	
33	TOTAL TRANSPORT DEMAND	TKU/Year	▪ (32)Change in TOTAL TRANSPORT DEMAND [TKY/(Year*Year)]	Integ (Change in TOTAL TRANSPORT DEMAND)	▪ (5) Road Transport Demand [TKU/Year] ▪ (15) Cabotage Transport Demand [TKU/Year]	719910
34	Change in Cumulative Growth	1/Year	▪ (35) Cumulative Growth ▪ (36)Grow Rate	Cumulative Growth*Grow Rate	▪ (35) Cumulative Growth	
35	Cumulative Growth	Dmnl	▪ (34)Change in Cumulative Growth [1/Year]	Change in Cumulative Growth	▪ (34) Change in Cumulative Growth [1/Year]	1
36	Grow Rate	1/Year		0.068		