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Projection of Macroeconomic Impacts on The Toll Plazas Waiting Time Queueing: A Case Study In Brazil

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SUMMARY:- This study aims to understand the flows of vehicular traffic in a toll plaza impacted by macroeconomic events. The study provides the traffic demand of commercial and small vehicles on a Brazilian highway until the year 2020. This Highway plays an important role for the oil industry and the development of the region depends mostly on it. The population, the region's Gross Domestic Product and oil production are considered as explanatory variables. The data used is divided by the toll plaza, vehicle type and area of influence. A simulation model for discrete events is used based on the actual scenario and future events. The model concludes that the amount of commercial vehicles will rise significantly, generating an increase in the queue waiting time of the toll plazas, going up to nineteen minutes. To reduce the stakeholders impact the study suggests some steps for planning the highway in the medium term.

Keywords:- logistics bottleneck; simulation; macroeconomic development; transportation planning; linear regression.

I. INTRODUCTION

The country´s economic development needs a quality infrastructure that allows a flow of vehicles and people and also allows developing less accessible areas, facilitating their access to major cities and ports. This dynamics leads to improve production flow, either for domestic consumption or export.

The National Transportation Agency (ANTT) regulates road and rail transport in Brazil. Aiming to improve the infrastructure through the concession highways program, granted to private initiative fifteen sections, covering, actually, 5.240 km. The BR-101 in the State of Rio de Janeiro is one of these concessionaires, connecting Niterói to Campos dos Goytacazes. The highway has 320 kilometers and is mostly single track (261 km, or 82%) marked by a heavy volume of traffic, according mainly in the Campos Basin, where is the largest oil reservoirs in Brazil with approximately 77% of total reserves (ANP).

The discovery of new oil fields in the pre-salt area in the Campos Basin and the consequent increasing population in the region indicate that vehicular traffic will have significantly impact in the coming years, what motivates calculate how much will be the increase in demand for vehicles on this road. This analysis will allow to propose actions to reduce negative impacts on the highway concerning the exponential growth of vehicles using the road.

This study considers several factors, such as increased production of oil and natural gas (discovery of large reserves in the pre-salt region, which could increase 160% by 2020). The increase of private vehicles is another issue that this study takes into account. It is happening because of the constantly income growth of the population. The vehicle demand can vary greatly over a day, month or year, according to the economic activities.

The north of Rio de Janeiro region has 700,000 inhabitants, equivalent to 11% of the state Gross Domestic Product (GDP) [1]. The most important city of this region is Campos dos Goytacazes, which has 0.67% participation of Brazilian GDP in 2010.

The next section brings a brief of the review of the literature. After that, a methodology that is used is detailed. Finally, the last sections bring the modeling study, followed by results, conclusions and suggestions for future studies.

II. LITERATURE REVIEW

2.1 Demand Forecasting

Demand forecasting is used to plan a lot of factors as described for the reconstruction plan of a highway in Lithuania, where it should identify how bottled will be the highway in a few years [2]. To this prediction it is necessary to analyze various factors of influence, such as the history of the annual daily average volume (AADT), changes in the economy and the number of people and vehicles, average distance traveled by a vehicle, industrialization rate in the region and fuel price.

A multiple linear regression is applied to predict the average daily traffic volume in Santa Catarina, between 2002 and 2008. The following variables were considered: annual rice production in southern Santa Catarina, annual production of ceramic in Southern Santa Catarina, population in Southern Santa Catarina, GDP, Selic rate, industrial production of Santa Catarina, exchange rate and domestic household expenditure. The Minitab 6.1 software presented the set of variables that best explains the movement of vehicles and their respective coefficients [3].

A determination of the demand for a highway, can exist in two forms: first when you have a new infrastructure will need to generate demand expectations and second when the infrastructure already exists and can be used historical data to forecast. In the second case the forecast will have greater consistency with reality. Is necessary to identify the expected demand for the coming years and determine how vehicles will access this highway, ie, how will be the arrival distribution [4].

The number of road accidents concerning Turkish highways consider as variables: GDP per capita, population, number of vehicles and percentage use of modal (road, rail and air transportation). For this analysis the methods of multiple neural networks and nonlinear regression are used [5].

To predict the number of accidents some variables are designed by simple linear regression and only the percentage of utilization of each mode is designed in three different scenarios from 2007 to 2020, keeping the other constant. Scenario I assumes that there will be no investment in railways, its share falling from 3.0% to 2.6%. The second preview a railroads growth of 15% per year, from 3.1% to 18.8%. Finally, scenario III considers a slight increase in investment by railroads from 2.9% to 10.1%. The study concludes that the transfer of passengers from road to rail, scenario II, significantly reduces the number of traffic accidents in Turkey.

2.2 Simulation of toll plaza

Simulate dynamic systems is an advantage over analytic models, since give more information about what is happening in the system over time, which helps in decision making [6].

A toll plaza acts as a bottleneck to the flow of vehicles on highways, since the capacity of the square is usually smaller than the capacity of highway [7]. Service time in the cabins is directly related to the fare (easier change reduces the time), payment (cash or electronic billing), flow, type of vehicle (cars and trucks) and pre-collectors along the queue. Simulating an operation of the toll plaza can conclude that simple attitudes as the adoption of tariffs that facilitate change can increases the efficiency of manual collection, as shown in the study of concessionaires Rio Grande do Sul [7].

To plan the best number of cabins in a toll plaza in Porto Alegre, is simulate their flow in some distinct periods, considering the busiest period, the lowest and intermediate. Thus one can conclude what is the peak usage and idleness. The number of cabins was tested from 3 to 25 (current quantity in the toll plaza). From 20 cabins, the queue time for peak-hour is less than 2 minutes, considering one direction of the highway. Analyzing the volume from the opposite direction at the same time the need for the same queue time is 7, totaling 27 cabins. The total number of cabins is flexible and can be used for both directions [8].

A toll plaza is simulate evaluating the optimal number of cabins according to three variables: current traffic, use of automatic cabins dynamically (can be used when there are large queues in manual cabins) and encouraging motorists to increase use of automatic cabins. The study concludes that an increase of 10% in traffic can generate large queues [9].

A toll plaza simulation consider as variables: service capacity, vehicle arrival pattern, number of available gates and driver behavior. The principal results are the number of vehicles queued at the square when traffic jam occurs on departure and the average vehicle speed when crossing the square. The time of each vehicle in system is the difference between the arrival and departure. Four types of manual payments are considered: small vehicles who pay cash and no need change or toll ticket pre-paid, small vehicles that need change, heavy truck and trailer or bus. Each payment method presents its own service time and generate different queues [10].

III. METHODOLOGY

The concessionaire has five toll plazas, distributed along the track and located according to the criteria of the agency. The following table presents consolidated data for commercials and passengers vehicles for each, 2009-2012. Data for 2009 are annualized for comparison purposes, since the database presented values only from February to December, when toll collection started.

Toll Plaza	km-km	2009*		2010		2011		2012	
		Commercial Vehicles	Passanger Vehicles	Commercial Vehicles	Passanger Vehicles	Commercial Vehicles	Passanger Vehicles	Commercial Vehicles	Passanger Vehicles
São Gonçalo	300,0 - 320,1	960.414	5.899.684	1.076.258	6.491.903	1.165.635	7.176.612	1.222.605	7.602.021
Rio Bonito	253,0 - 300,0	570.524	1.396.801	1.583.703	3.847.039	1.747.367	4.118.825	1.785.839	4.390.132
Casimiro de Abreu	193,0 - 253,0	1.060.677	2.596.829	1.601.788	4.083.883	1.779.910	4.386.437	1.823.825	4.778.789
Conceição de Macabu	124,0 - 193,0	1.310.222	2.230.919	1.415.358	2.445.934	1.530.438	2.595.549	1.582.082	2.795.100
Campos dos Goytacazes	38,2 - 124,0	936.358	1.099.203	1.045.527	1.223.820	1.124.800	1.245.551	1.165.952	1.331.201

* Original data: February to December, annualized.

Table 1.Traffic vehicles at toll plaza 2009-2012.

The data of annual average traffic volume preceding the count of vehicles through the concessionaire belong to the National Department of Infrastructure and Transport (DNIT). The National Plan Count Transit (PNCT) began in 1975 as volumetric automated counting that quantifies the volume of vehicles that travels through particular stretch of highway. The extent of the BR-101 has six counters.

The history of traffic volume for BR-101 between 2000 and 2001 is presented for six specific mileage points, namely: 26.5; 78.0, 267.0, 308.0, 393.7 and 534.0. The equivalences considered at the table since the measuring DNIT points are not exactly the points where the toll plazas were installed. It takes into account the proximity of mileage and consistency in the measured subsequently by the concessionaire volumes, which resulted in the same use of a mileage for Casimiro de Abreu, Rio Bonito and São Gonçalo. Along the same lines, the mileage 267.0, 308.0 and 534.0 were not used in any equivalence.

For the first two squares is necessary to use a percentage adjustment because the volume of vehicles in São Gonçalo is superior and mainly affected by the tourist route.

KM (DNIT)	Toll Plaza	
	Name	KM
26.5	Campos dos Goytacazes	40.5
78.0	Concição de Macabu	123.0
393.7	Casimiro de Abreu	129.5
393.7	Rio Bonito	252.5
393.7	São Gonçalo	299.1

Table 2.Equivalence DNIT vs. toll plazas.

Data obtained from DNIT is consolidated by mileage and don´t show differentiation between commercial and passenger vehicles. In the study, the percentage considered for each of the two types is measured by the average percentage concessionaire due to the period 2009-2012. Daily volumes are annualized. Casimiro de Abreu and Rio Bonito are using the same data as São Gonçalo, but they have their traffic volume reduced to 80% of total according to the percentage of passenger vehicles and the volume measured by concessionaire in the following years. The total volume of commercial vehicles is reduced to 70%, following the same criteria.

KM (DNIT)	Toll Plaza Equivalence	2000		2001	
		Commercial Vehicles	Passengers Vehicles	Commercial Vehicles	Passengers Vehicles
26,5	Campos dos Goytacazes	785	901	810	930
78,0	Conceição de Macabu	1.102	1.899	1.187	2.046
393,7	Casimiro de Abreu*	922	2.655	1.047	3.015
393,7	Rio Bonito*	948	2.626	1.077	2.981
393,7	São Gonçalo	650	3.987	738	4.527

* Daily volume adapted. Consider 80% of total volume for passengers vehicle and 70% for commercial vehicles.

Table 3.Traffic volume 2000-2001.
Source: DNIT.

Projection from 2002 to 2008 is an approximation of the data, considering a constant growth rate of 2% per year for Campos dos Goytacazes and Conceição de Macabu, 4% for Casimiro de Abreu and 5% for Rio Bonito and São Gonçalo, commercial and passenger vehicle. This growth is designed to be conservative and approximate DNIT data and official data from the concessionaire.

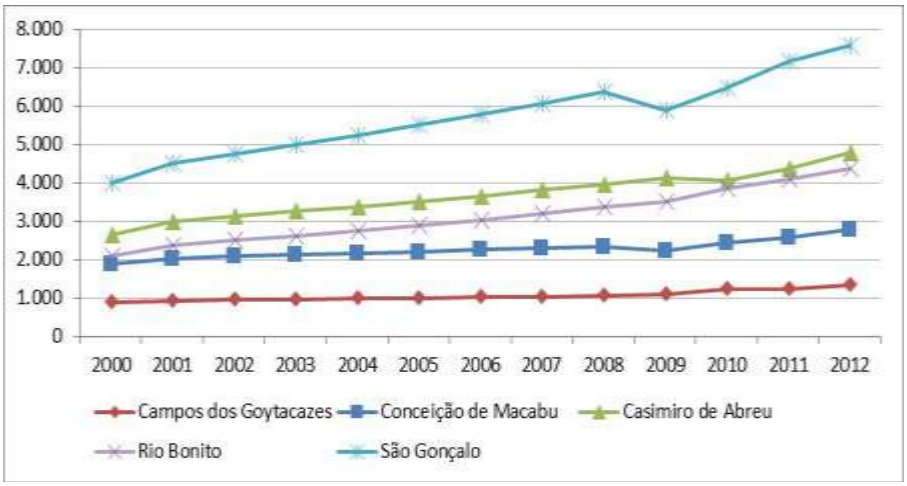

Figure 1.Passenger vehicles in toll plazas (2000-2012).

The figure above shows growth trend over the 12 years represented. Casimiro de Abreu and Rio Bonito, in the first year of toll collection (2009) recorded a significant drop in volumes, which is justified by the bypass used by drivers. To align the data and provide more efficient predict about the future flow in toll plazas, the discordant data for 2009 are fixed, keeping the projection of the years 2002 to 2008.
São Gonçalo presents each year the largest volumes of passenger vehicles because it is the only one on the tourist route in the state, connecting Rio de Janeiro to Região dos Lagos.

The commercial vehicle traffic (Figure 2) also shows decline in volumes from 2009 to Casimiro de Abreu and Rio Bonito, following the same logic of passenger vehicles. A growing trend is observed in all locations. Casimiro de Abreu has the largest volume in 2012.

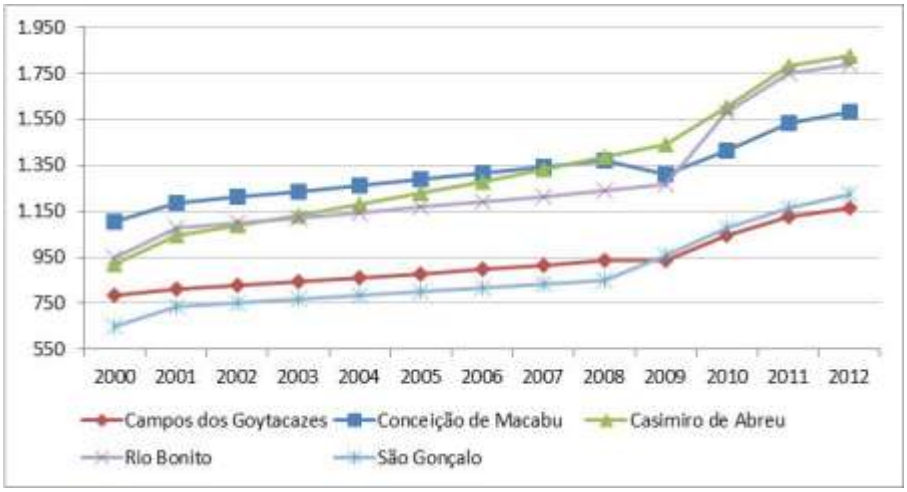

Figure 2.Commercial vehicles in toll plazas (2000-2012).

Highway demand forecasting is important for country's development because it translates the vehicles behavior in a given region. After identified the percentage increase traffic in a route is possible to plan how to reduce the number of accidents, traffic jam, increase safety and so on. These actions must be taken to absorb the impact of this increase.

All surrounding cities to BR-101 were considered in the analysis, since its impact on the volume of vehicles on the highway is clearly justifiable. These municipalities are: Campos dos Goytacazes, Conceição de Macabu, Quissamã, Carapebus, Macaé, Rio das Ostras, Casimiro de Abreu, Silva Jardim, Rio Bonito, Tanguá, Itaboraí, Niterói and São Gonçalo.

Besides these, are also considered influential cities near highway and that in order representation of the total GDP of the State of Rio de Janeiro, reach 92.4% of accumulated GDP. Cities considered influential that are not bordering the BR-101/RJ are: Rio de Janeiro, São João da Barra, Cabo Frio and Maricá.

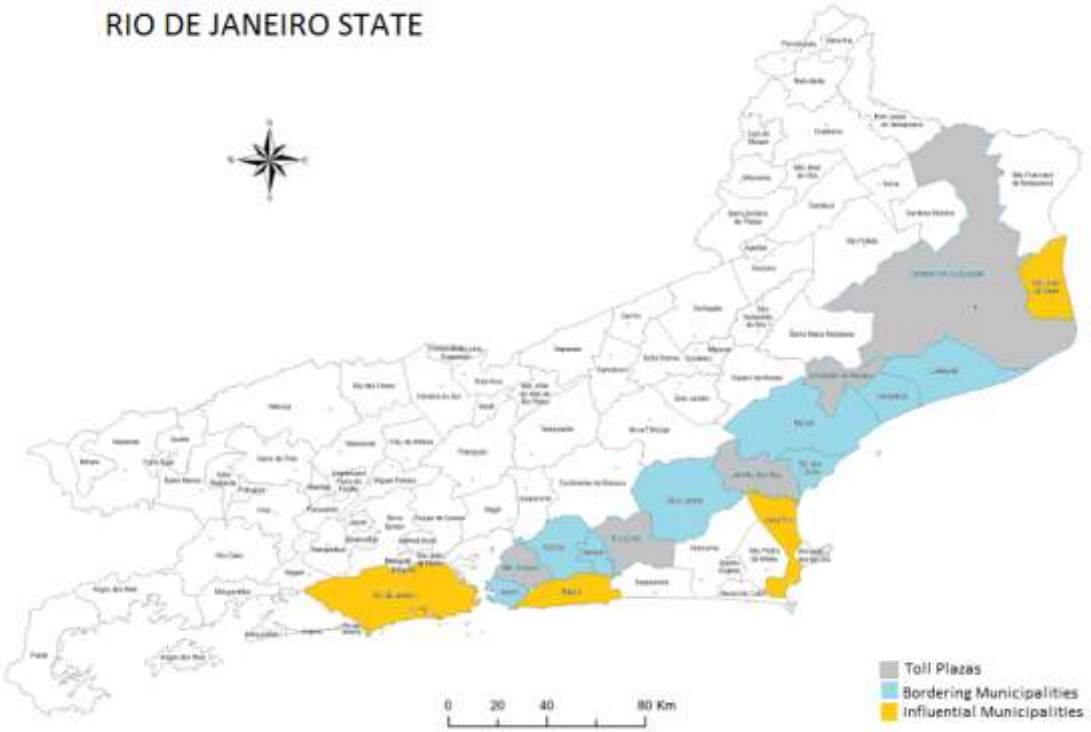

Figure 3. Bordering, influential and toll plazas municipalities.

Municipalities are consolidated to project the traffic. Thus, is defined an area of influence for each toll plaza, what means that will be analyzed which municipalities directly impact each one. The choice of cities is made based on two criteria: vicinity of location and author's knowledge about the region. Figure above shows the influential municipalities for each toll plaza.

A single municipality may impact the demand for more than one plaza, as Macaé, which impacts in the areas of influence of Campos dos Goytacazes, Conceição de Macabu and Casimiro de Abreu because it is the main hub for oil in the region.

Toll Plaza	Campos dos Goytacazes	Conceição de Macabu	Casimiro de Abreu	Rio Bonito	São Gonçalo
Influential Municipalities	São João da Barra, Quissamã, Conceição de Macabu and Macaé.	Campos dos Goytacazes, Quissamã, Carapebus and Macaé.	Macaé, Rio das Ostras, Cabo Frio and Silva Jardim.	Silva Jardim and Tanguá.	Maricá, Tanguá, Itaboraí, Niterói and Rio de Janeiro.

Figure 4.Influential municipalities per toll plaza.

Considering the city of Rio de Janeiro as impactful in São Gonçalo toll plaza changes the profile of this toll plaza in relation to the others, since this city represents 47% of state's GDP and its economic activities are distinct from the common to the other toll plazas flow. The volume of commercial vehicles is very representative when compared to the others and the highlight is for passenger vehicles.

Analyzing the region where is located the highway we note that several factors may influence the annual traffic flow. Production oil in Campos Basin is one of the prominent factors because require logistics services as such: handling equipment, office supplies, potable water, food and others.

Oil and natural gas to be withdrawn in wells are transported to the terminals thru pipelines, the cleaner and lower costs transport for large volumes, or by vessels. Natural gas is processed in units of Natural Gas Processing and oil is processed on refineries. After that the derivatives goes back to the terminal to supply the market.

Oil production in the state of Rio de Janeiro grew by 69% from 2000 to 2009 (higher production history). In the last two years there has been a significant drop, caused by global crises. This is because 29% of the oil produced in the country in 2011 was exported, mainly to the United States, which imported 27% of this total (ANP).

The oil import has shown a decrease over the last few years, proving a lower dependence of Brazil in relation to external production. From 1999 to 2012 the cumulative decline represented 33% (ANP). On the other hand, the export of oil has increased and in 2010 was recorded the peak of Brazilian exports.

Projections for oil production concerning pre-salt areas, is estimated over 300,000 barrels of oil per day in 2013, 1 million in 2017 and 2.1 million in 2020 (Petrobras). This area represents an increase of 135% in the volume of oil comparing 2011 to 2020. For this study is considered oil production by 2020, including estimates for the pre-salt and post-salt area. The projection of the volume of oil in pre-salt area, considered as influencing factors: historical production and U.S. GDP, representing external demand.

Initially a multiple linear regression was performed, considering the Brazilian GDP, U.S. GDP and historical oil production as explanatory variables. This model is not supported by the variables because they are not independent, which results in multicollinearity. The coefficient of determination (r^2=87%) measures the percentage of variance contained in the data which has been explained. The correlation between variables is greater than 98%.

For these reasons, the calculation of projections is performed using simple linear regression, the most suitable time series mathematical method, considering as explanatory variable only U.S. GDP. Data used are from 2001 to 2012. GDP is lagged in one year because there is one year gap impact in oil production is planned, since it is not so flexible. Thus, when the previous year, increased or decreased the U.S. GDP the volume of oil is impacted this year.

Through software R, the multiple linear regression to estimate oil production presents a coefficient of determination (r^2=84%) meaning that 16% is the variability that is considered in the model. F statistic is 51.47 and t-test is 7.2, what means confidence interval between 95 and 99%. In this case all explanatory variables are accepted.

In 2020, oil production reaches a higher production that means 36% more than the 2012. Production scheduled for the pre-salt uses a linear and annual growth, according to the milestones set out by Petrobras. The figure below shows that in 2020 the production of the post and pre-salt area will be equivalent, totaling 1.5 billion barrels per year (4.2 million barrels/day). The sum of this amount is almost three times greater than 2012 total.

Data projection consider a scenario without global financial crisis, showing a growth trend in oil consumption in Brazil and worldwide. As an assumption, all oil produced in 2020 will be consumed (national or international market).

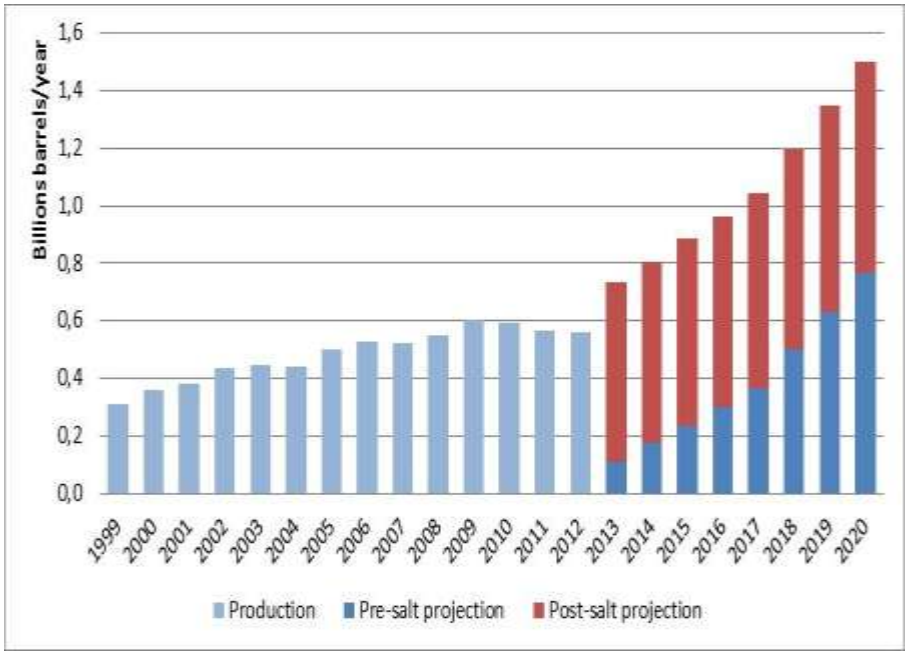

Figure 5.Oil production and projection in Rio de Janeiro State (1999-2020).

IV. FORECASTING DATA TRAFFIC

The data modeling for forecasting vehicular traffic on the highway BR-101/RJ consider each vehicle type (passenger and commercial) undergoes different influences.

4.1. Passengers vehicle

The passenger vehicles are light vehicles, primarily for the carriage of people. Traffic is directly related to the size of the local population and their behavior.

The north of Rio de Janeiro region oil exploration has direct impacts on the population, increasing the number of employees working on the platforms and operational bases of several companies. In addition, services that are related to this population also present growth as schools, hospitals, supermarkets and shops.

The projection of passenger vehicles per toll plaza is calculated according to the sum of the population of the municipalities involved in each. Initially, the GDP of these municipalities is also considered as an influencing factor, but not statistically valid. A justification for this fact is that the index is represented in monetary values and may be affected by movements in dollar. Thus a fall in dollar would represent a drop in traffic of the highway, which is not consistent.

The estimated population growth is taken from the method of Demographic Components of IBGE, which interpolates the known data to estimate the years that official surveys are not done. This method is annual reviewed, and its fundamental principle is the subdivision of a larger area (a state, for example) whose estimate is already known in n smaller areas (municipalities of this state). As reference for this study, official data of the Brazilian population are the 2000 and 2010 Demographic Census and 2007 Population Count [11].

The influence area of São Gonçalo has great disparity as to others due to the contribution from Rio de Janeiro and São Gonçalo. Those cities represent the 1st and 2nd place respectively in the share of the state's population [11]. All areas show growth trend between 2000 and 2012.

4.2. Commercial vehicle

Commercial vehicles are used for freight transportation. The behavior of this traffic is greatly influenced by the activities of the local economy. To measure these activities in the region we use GDP, a worldwide indicator that represent the sum (in monetary value) of all final goods and services produced in a specified region during a given period (month, quarter, year). Intermediate consumption goods are not considered, avoiding duplicity in a production chain.

This study details GDP per municipality and its three major sectors of economic activity: agriculture, industry and services. The projection for 2011 and next years (official data are from 1999 to 2010), is made independent for agricultural GDP and industrial GDP since each activity has different influence factors. The service GDP follows the same percentage than industrial GDP since the movements of the services accompanying industrial activity.

To evaluate the influence that GDP exerts on the toll plaza the sum of the GDP is considered individually for the three sectors of the economy and for a group of influence municipalities.

Agricultural GDP is not identified by a similar behavior over the years because there is no seasonality or clear relation to other factors. There is a trend of growth over the twelve years presented, however, the existence of peaks does not allow evaluating a unanimous flow between the toll plazas. In this case the prediction (2011-2020) is accomplished through the ARIMA model, more suitable for forecasting stationary stochastic processes and isn't derived from any economic theory, only the analysis of past data [11].

The projection of agricultural GDP (2011-2020) uses different models for each area of influence, according to the ARIMA model that best suits, as presented on table below.

Toll Plaza	Campos dos Goytacazes	Conceição de Macabu	Casimiro de Abreu	Rio Bonito	São Gonçalo
Projection of Agricultural GDP	ARIMA (1,1,0)	ARIMA (0,1,1)	ARIMA (1,1,1)	ARIMA (1,1,0)	ARIMA (1,1,1)

Table 4. ARIMA models for projection of agricultural GDP.

Figure below presents that Campos dos Goytacazes, Conceição de Macabu and Rio Bonito maintain a constant forecast data, while Casimiro de Abreu and São Gonçalo present trend of linear growth over the years.

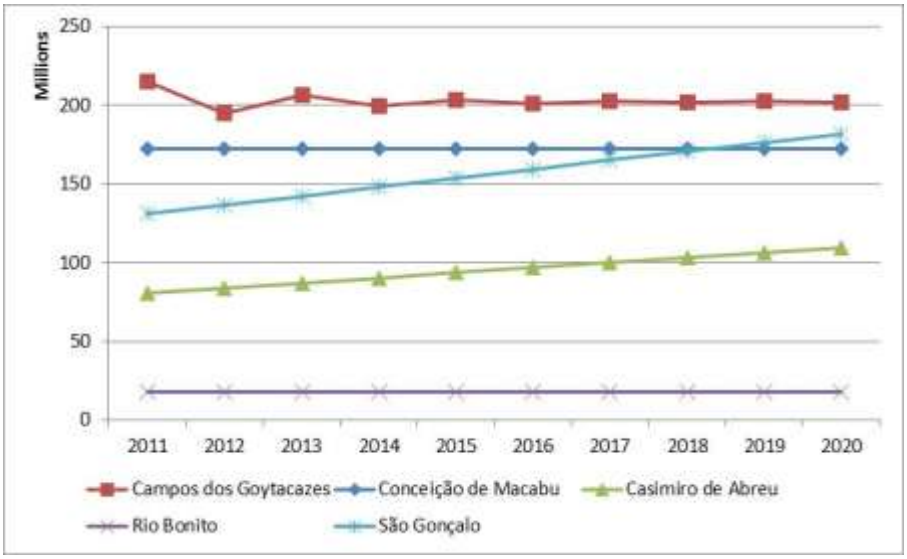

Figure 6.Projection of agricultural GDP per area of influence (2011-2020).

Another influence issue is the industrial GDP, influenced by mineral extraction, manufacturing, construction and production and distribution of electricity, gas, water, sewage and cleaning. North of Rio de Janeiro region is greatest impacted by mineral extraction, basically oil production in the Campos Basin. From this historical GDP all areas present growth trend, especially Campos dos Goytacazes, Conceição de

Macabu and São Gonçalo. The last one presented a significant increase from 2008 to 2009, while the others presented fall in this period, what can be justified by the financial crisis experienced in many countries [12].

To project this index, annual production in the State of Rio de Janeiro is used (including forecasts for the pre-salt exploration from 2013) and the annual average price of oil export in real (R$). This last indicator compares the output in monetary terms, including the analysis of the possible exchange variations and oil prices in the international market. Accordingly, the fall in oil prices in 2009 justify the fall of the industrial GDP this year for Campos dos Goytacazes, Conceição de Macabu and Casimiro de Abreu, most affected areas with respect to oil production, since a large percentage of its GDP is influenced of oil production. Comparing the price of Brent barrel in dollars (US$) and real (R$) shows a high in 2008, falling in 2009 and growing thereafter. In 2012 the relationship between the currencies was higher than the last two years and the period between 2002 and 2004 also showed the highest exchange.

According to World Economic Outlook (WEO) estimates the projection of the average annual price of oil barrel export is US$102.60/barrel (or R$210.33) in 2013 and US$87.00 (or R$182.70) in 2020. Values were converted according to the estimates of the rate of exchange facilities by the Brazilian Central Bank (BCB).

The annual oil production in the state of Rio de Janeiro, in monetary terms, considers the selling price, from US$4.2 billion (1999) to US$108.6 billion (2012). From 2013 to 2020, the projection indicates a trend of growth since local production is expected to grow and there is a slight drop in the price of a brent barrel, falling 15% in eight years. According to Petrobras projection for oil production in pre-salt, 2020 reaches US$273.8 billion.

The projection of industrial GDP, 2011-2020, for each area of influence uses a simple linear regression, considering the projection of annual production in the State of Rio de Janeiro and the annual average price of a barrel of oil export in real (R$). For this model is used the software R.

Toll Plaza	Campos dos Goytacazes	Conceição de Macabu	Casimiro de Abreu	Rio Bonito	São Gonçalo
Variability in Model	97%	96%	92%	75%	No coherent statistics
T-test	18.5	15.7	10.6	5.4	
Acceptance region	> 99,99%	> 99,99%	> 99,99%	95% < R < 99%	

Table 5.Regression for industrial GDP.

São Gonçalo didn't present a coherent statistics when analyzing the regression and the influence of oil production, since only less than 50% of the data are explained by the regression. Therefore, we can say that this toll plaza presents a distinct behavior, as influenced by municipalities with other features such as Rio de Janeiro,

the main city of the State. Based on this conclusion, São Gonçalo is excluded from the analysis since is not under direct influence of increased oil exploration in the Campos Basin.

From 2012 to 2013 industrial GDP projection presents a big gap, influenced by the beginning of pre-salt oil exploration, while between 2013 and 2017 a linear growth is observed. From 2017 there is a new trend, projecting GDP growth even higher than in the previous period, as explained by the increase of oil exploration.
The service GDP as well as industrial, also presents growth trend over the years for considered areas of influence. For the projection of service GDP is considered a relationship with the industrial GDP, since it is directly influenced by the increase of industrial activities in the region.

Influence areas of Campos dos Goytacazes and Conceição de Macabu exhibit a similar behavior for this relationship. An average of the last five years shows that service GDP corresponds to approximately 38% of industrial GDP. In Casimiro Abreu the average rises to 56%, which means that the amount collected through services in this region is most representative. The area of Rio Bonito diverges and the average is 630%. This value is much higher than others because the region is more focused on providing services than industrial activities. Years 2009 and 2010, shows an atypical behavior for regions of Campos dos Goytacazes, Conceição de Macabu and Casimiro de Abreu, with above average values presented in other years, which means an increase in services.

For the projection of this indicator is considered the average percentage of the last 10 years of the relationship between GDPs, as follows: 40% for São Gonçalo, 41% for Conceição de Macabu, 53% for Casimiro de Abreu and 652% for Rio Bonito.

V. RESULTS

5.1. Projections

5.1.1. Passengers vehicle

Data for Campos dos Goytacazes from 2009 to 2012 do not show a well-defined traffic flow, and between 2012 and 2020, the growth is 13%, representing an average growth of 1.7% per year. Conceição de Macabu in these years is greater than the rest of the series, marked by growth of 10% between 2009 and 2010 and 8% between 2011 and 2012. To project the following years the line is similar to the first period (2000-2008). The forecast (2012-2020) represents an increase of 9%, which means an average annual growth of 1.1%.
As identified in Conceição de Macabu, Casimiro de Abreu shows a linear increase between 2010 and 2012 with different angle from the previous period and later. In this case, 2009 was a continuation of the period 2002-2008, since this year started toll collection and was identified the bypass made by drivers for not paying the tax. The projection is based on a similar angle to the first period with an offset on the y axis. For the projection (2012-2020) the traffic increases 12%, representing an average annual growth of 1.4%.

For Rio Bonito actual and projected data present a nearly linear trend over the years. Similarly to the previous toll plaza, 2009 was far below presents the data recorded by the concessionaire in the years 2010-2012. The average annual growth for eight years is 2.5%.
The table below shows details from software R for all toll plazas.

Toll Plaza	Campos dos Goytacazes	Conceição de Macabu	Casimiro de Abreu	Rio Bonito
Variability in Model	97%	89%	95%	94%
T-test	18.9	9.6	14.9	13.7
Acceptance region	> 99%	> 99.99%	> 99.99%	> 99%

Table 6. Regression data from software R (passengers vehicles).

A linear growth trend for the next eight years is observed in all toll plazas. The higher average growth is presented for Rio Bonito, then Campos dos Goytacazes, Casimiro de Abreu and finally Conceição de Macabu. The difference between the first and the last one is significant (11%).

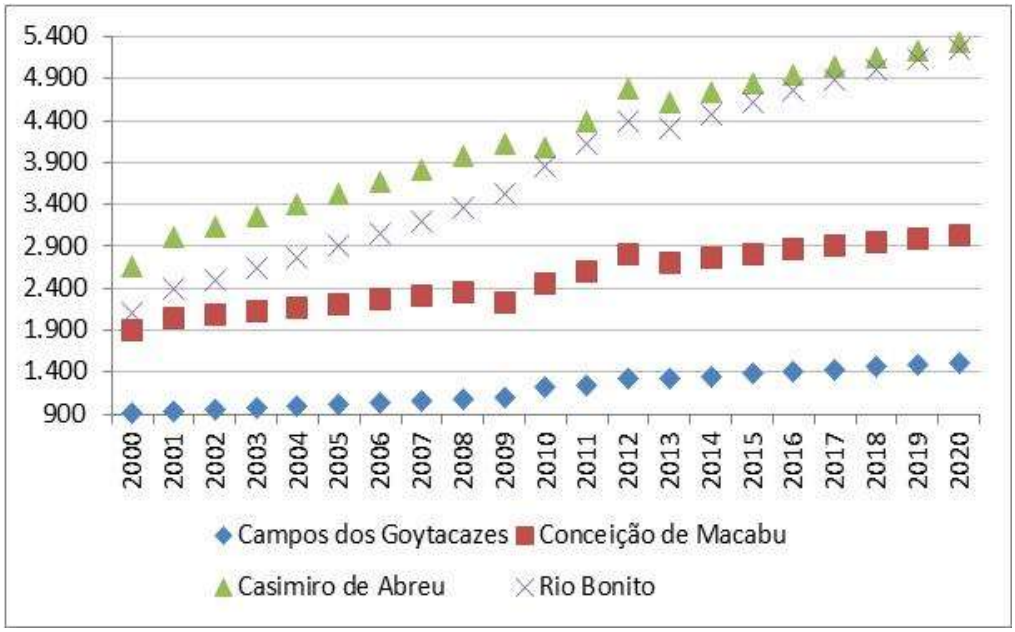

Figure 7.Actual data and projection of passenger vehicles (2000-2020).

5.1.2. Commercial vehicles

This projection initially considers as influence factors historical data from the toll plaza and agricultural, industrial and service GDP. The analysis justifies the most suitable forecasting models for each toll plaza. The table below shows regression data from software R that helps the analysis.

Campos dos Goytacazes considers only industrial or service GDP, where the second one shows best results. From 2012 to 2020 data grow is 54%, 6.7% per year. To Conceição de Macabu the growth recorded between 2012 and 2020 is 44%, annual average of 5.5%.

Regression for Casimiro de Abreu projected growth (2012-2020) of 78% or 9.7% per year. The projection for Rio Bonito shows an increase of 58% between 2012 and 2020, 7.2% per year.

Toll Plaza	Campos dos Goytacazes	Conceição de Macabu	Casimiro de Abreu	Rio Bonito
Variability in Model	95%	93%	96%	82%
Explanatory variables	Service GDP	Industrial and Service GDP	Industrial and Service GDP	Industrial GDP
F-Statistic	190.5	70.5	124.0	49.3
p-value	0	very low	0	very low
Acceptance region	> 99.99%	> 99.9%	> 99.9%	> 99%

Table 7.Regression data from software R (commercial vehicles).

All the areas have a similar projection of the data for the next eight years, where 2013-2016 have linear growth trend and the following period 2017-2020 presents a new growth trend. Actually occurs due to the prediction of oil exploration a factor that directly influences the industrial GDP and indirectly service GDP, most important variables in the regressions.

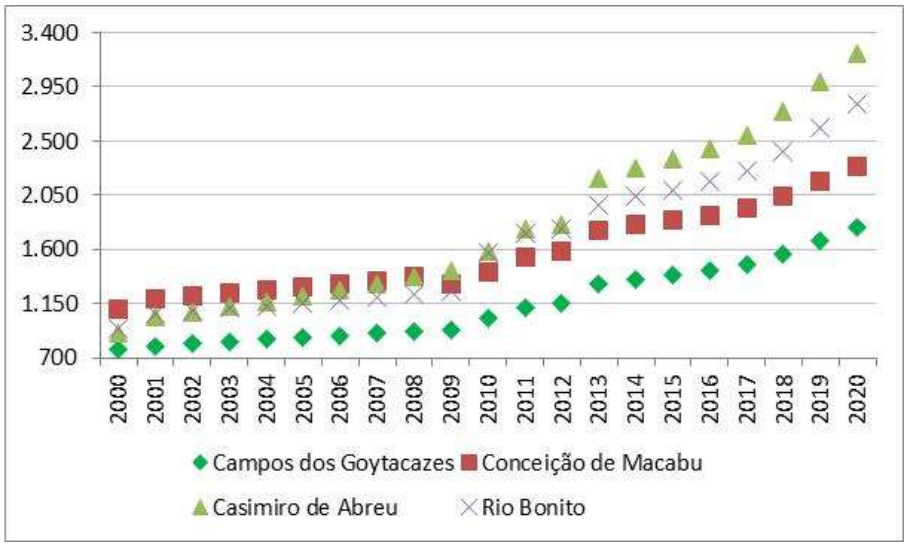

Figure 8.Actual data and projection of commercial vehicles (2000-2020).

Comparing results from passenger and commercial vehicles projections is easy to note a large difference between their growth from 2012 to 2020. Casimiro de Abreu, for example, shows the greatest disparity (12% for passenger and 78% for commercial). One reason for this difference is that the region had a significant increase in industrial GDP by increased oil production. Population growth was much smaller, slightly influencing the vehicles.

5.2. Simulation

Simulation will model the projection of traffic volume for the four toll plazas comparing 2012 and 2020 [9]. The simulation in software ARENA version 14.0 is based on Monte Carlo Model, with many repetitions to calculate the probability of a variable.

This simulation is characterized as macro simulation, evaluating data from operating system from the vehicle arrival rate, service time in the cabins and the system output. No more factors are considered, as driver changing lanes, congestion, hysteresis effect and other specifications.

The study considers data from 2020, the largest number of vehicles on the highway and a different flow for passenger (light vehicle, up to 2 tons) and commercial vehicles (heavy truck up to 6 axes). The total data volume represents both directions of the highway and so the simulation will consider the total number of cabins and only one direction of traffic.

The average service times for manual cabins (cash payment) supplied by two databases from a concessionaire in the state of Rio Grande do Sul for the year 2003: 24.99 seconds to light vehicles and 33.56 seconds to heavy trucks [7].

For electronic payment cabins is considered an almost invariable capacity of 1,100 vehicles/hour, by a suggested speed of passage of 30km/h [7]. According to the concessionaire there are always two cabins at the toll plazas of the highway intended for electronics payment and the others are exclusively for manual payment.
The highway concessionaire report informed that in the fourth quarter of 2012 the percentage of electronic toll collection was 47% in all toll plazas. For calculation purposes this percentage will be maintained as a constant in the simulation for the following years, both for passenger and commercial vehicles.

The simulation is based on the peak of each toll plaza and the percentages obtained from the concessionaire for the years 2010-2012. It is considered the factor k50, an indicator that represents the flow of vehicles in the 50th hour of highest traffic of the year, what means that there are 49 hours with a higher volume. Considering that the year has 52 weeks that episode occurs almost once a week. The arrival rate of vehicles is actually stochastic, however, for this study will be considered exponential rate, with the average for the peak-hour volume.

The table below shows some assumptions done: number of manual payment cabins, peak-hour volume in 2020 and the average time service for manual and electronic payment.

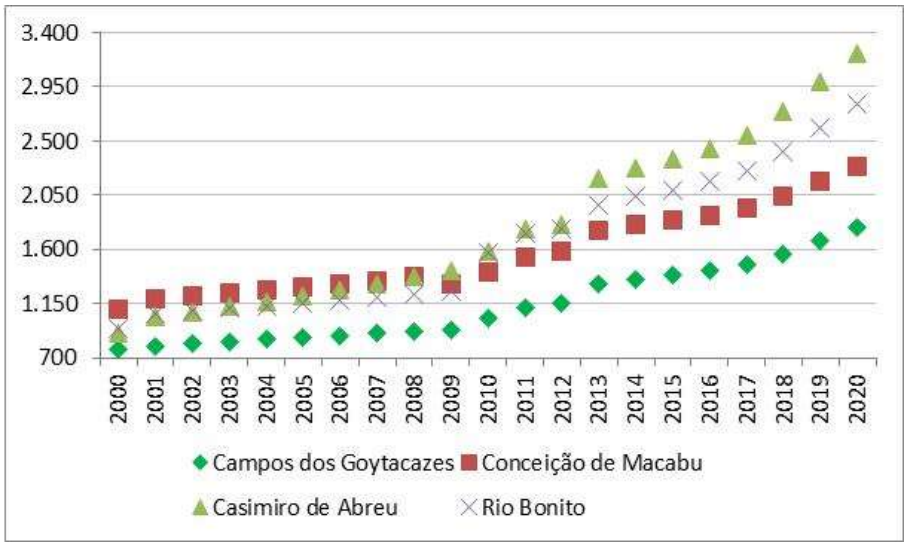

Table 8.Number of cabins, peak-hour volume and average service time by toll plaza (2020).

The driver chooses the cabin that has lower queue and service queue follows the FIFO rule ("first in, first out"), what means that the first driver in system will have first service.

From the simulation it's possible to predict what the impact of macroeconomic events in north of Rio de Janeiro region will have on traffic flow in each toll plaza. Next table presents the maximum and average time of each vehicle waiting until they reach the manual cabin, and the maximum and average number of vehicles in each queue, for 2020.

Table 9. Waiting times and vehicles queued for toll plaza (2020).

When comparing data from 2020 and 2012, Casimiro de Abreu and Campos dos Goytacazes show the largest increases in waiting time, both with over twelve minutes difference. Campos dos Goytacazes has an increase of 286% and Casimiro has the longest waiting time in 2020, up to nineteen minutes, which represents a difference of 174% compared to 2012. Conceição de Macabu presents a waiting time of eight minutes, followed by Rio Bonito, which had a smaller increase, less than thirty seconds.

The toll plaza of Rio Bonito, compared to Casimiro de Abreu, presents similar peak-hour volumes but the number of cabins is almost 60% higher, which justifies the nonexistent queue in Rio Bonito. Regarding the second, another factor that justifies its longest queue is the increased participation of commercial vehicles from 28% to 38% between the years 2012 and projection for 2020.

The occupancy rate of manual cabins, according to the software ARENA, is close to 100% where queues are registered. Only Rio Bonito has distinct occupations, with an average of 99% for eight cabins, one cabin for 85% and 0% for two cabins. The rate is not equal to all cabins because the system gives preference to the cabins that are unoccupied and not uniformly distribution.

For electronic payment simulation shows no queues, since the hourly capacity of these cabins is greater than the volume of vehicles on-peak hours.

VI. CONCLUSIONS AND RECOMMENDATIONS

Is possible to conclude about the projections for vehicle traffic in the highway that by 2020, from the assumptions used, the flow of passenger vehicles will increase from 1.1% (Conceição de Macabu) to 2.5% (Rio Bonito) per year for each toll plaza. For commercial vehicles impact of oil discoveries in the Campos Basin has a more significant growth between 5.5% (Conceição de Macabu) and 9.7% (Casimiro de Abreu). By identifying the characteristics and intensity of traffic is possible to know the saturation rate of the highway and predict its evolution and applying available resources in order to get the best return of these.

In fact, the scenario is even worse than described, since the total number of cabins is the sum of two-way directions, north and south, and the peak-hour volume is more concentrated in one direction. Thus, there is a greater volume concentration for a smaller number of cabins, which increases the time and the number of vehicles in the queue. This study cannot calculate because no data is available per directionto separate the volumes for both directions [8].

The simulation results show that the volume rising impact directly on the queue time that users face for manual toll payment. In order to control these impacts planning is necessary by the concessionaire, for example, increasing the number of manual cabins, more lines on arrival plazas, incentive the use of electronic payment and use more cabins for the direction of greater volume time.

Another possible suggestion is to turn on automatic cabins into manuals when there are long queues. In the case of Campos dos Goytacazes the increasing of 2 cabins will represent 67% more (and 18% for Rio Bonito, which has 11 manual cabins) [9]. This measure should be thoroughly evaluate, since users who pay for the convenience of not queuing are been injured.

Another important issue is about safety and quality of the highway, resulting in greater likelihood of accidents and pavement ware off. To avoid these impacts the concessionaire should anticipate infrastructure investments in such as construction of the third way in overtaking, monitoring traffic and more scales to determine the weight of the trucks. Moreover, it is important to increase staff and emergency equipment, awareness campaigns, and other policies.

Suggestion for future studies is to include further explanatory variables and simulate microscopically, ie, number of lanes, area type (town center, residential, rural, etc), miles of sideways, degree of competition from alternative transport (competition for cargo to other modals), changing lanes and hysteresis effect. These variables are able to offer a true insight into the traffic flow. In addition to this feature, it is important to simulate a longer period, ensuring that is realized the continuity of the operation, identifying peak and idle times of the cabins.

Also, another suggestion is to develop tools for analyzing the macroeconomic impacts in certain regions of the country, with the goal of mitigate the identified problems and improve the quality of road transport for all stakeholders.

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