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TEMPORAL ANALYSIS OF COMMERCIAL VEHICLE FLEET BEHAVIOR IN HIGH TRAFFIC HIGHWAY IN BRAZIL

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ABSTRACT

The traffic data obtained from counts of vehicles at toll booths on highways under concession provides rich historical information about the traffic characteristics on a specific highway. The analysis, during periods over ten years, brings to light true definition about information taken normally by subjectivity or intuition, in many cases. The paper aims to spot the behavior of traffic, assessing year by year the evaluation of volumes and type of vehicles for a period of fourteen years at toll booths of Presidente Dutra Highway - BR-116, between Sao Paulo and Rio de Janeiro (Brazil). It is presented growths and reductions in commercial vehicles, sorted by number of axles. There are characteristics to be highlighted, as the use of vehicles with six or more axles which use could have grown over this period and few reductions, most of times discrete, of conventional vehicles. This work also spots the question of growth of traffic rates, since the historical data make possible to obtain more reliable parameters for pavement design. Finally, it presents the range of traffic volumes that occur at the five President Dutra's toll booths and the relationship between traffic growth and the economic index Gross Domestic Product.

KEY WORDS: Axle load, traffic volume, traffic growth, vehicle characteristics.

INTRODUCTION

This paper aims to present the results of studies to evaluate the behavior of volume variation of commercial vehicle fleet in a highway in a long term condition.

For this study, it was considered vehicles counting obtained from the toll booths of Presidente Dutra highway, linking Rio de Janeiro and São Paulo cities in Brazil. This highway has four traffics lanes, most of its length and is under concession since 1996 under an agreement with CCR NovaDutra Company and Brazilian Government.

The traffic data were evaluated for their characterization in the temporal behavior; increase or decrease variation of the commercial fleet, and on the vehicles classification by number of axles.

The traffic data were collected in five toll booths located along the highway on the period from 1996 to 2009

It is also analyzed the data model relating those traffic information to an economic index with great importance. For this study it was chosen the Brazilian GDP – Gross Domestic Product used as rate of annual growth.

THE HIGHWAY

The President Dutra Highway – BR-116 is one of the most important roads in Brazil. It connects two of most important Brazilian cities, which are São Paulo and Rio de Janeiro.

The highway history starts a long time ago. It can be considered the milestone opening of Highway Rio – São Paulo in 1951, at that time it had already called the President Dutra Highway (1). Passed through several steps of paving, duplication and direction corrections, it was finished to the 402 km today known between the two metropolitan area spotted.

On March 1st, 1996 the highway was given to the concession to private operation, the first road in the country, to the NovaDutra Concessionaire that, on August 1st of that year, began to operate most of the toll booths.

In 2009, the Company had six toll booth areas. The map at Figure 1 shows the positions of each toll booth on the highway operating in 2009. The location and starting of operation year are presented on Table 1. The designation south means the traffic direction from north to south and north indicates direction from south to north.

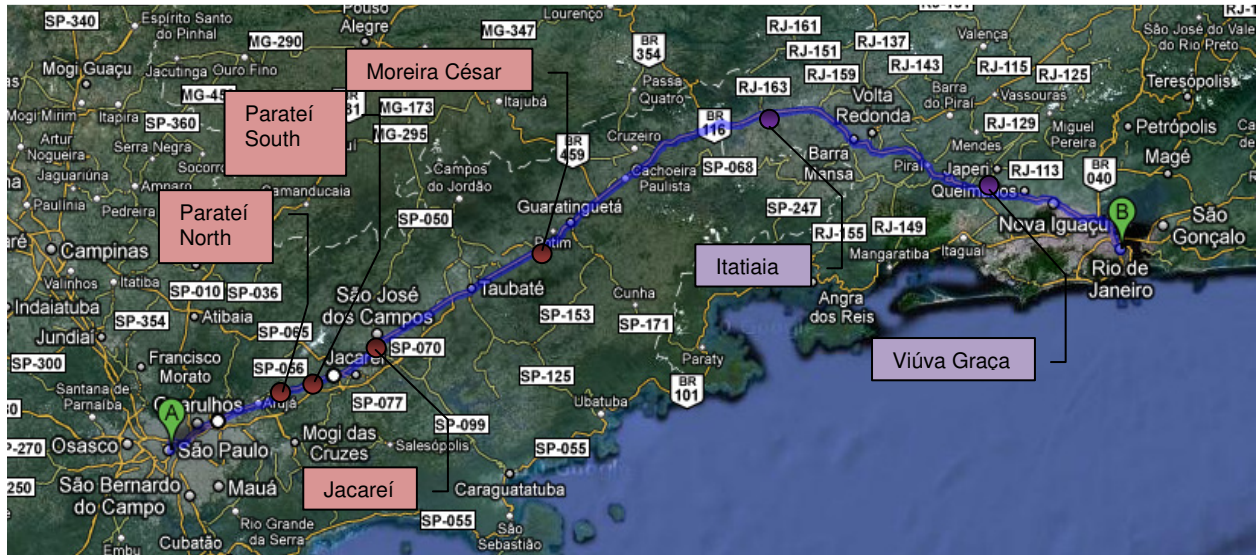


FIGURE 1 Presidente Dutra Highway map – Source: Google Maps (2011)

TABLE 1 Toll Booth Locations

Toll Booths	Location	Starting operation year
Parateí North	km 204 (SP)	1996
Parateí South	km 180 (SP)	1996
Jacareí North	km 165 (SP)	2001
Jacareí South	km 165 (SP)	2001
Moreira César North	km 80 (SP)	1996
Moreira César South	km 80 (SP)	1996
Itatiaia North	km 318 (RJ)	1996
Itatiaia South	km 318 (RJ)	1996
Viúva Graça North	km 207 (RJ)	1996
Viúva Graça South	km 207 (RJ)	1996

For this study it was used data from 1997 to 2009 in the period of January to December of each year (2). Data of 1996 year of Paratei, Moreira César, Itatiaia and Viúva Graça tool booths were not analyzed. Similar criteria was applied to Jacareí tool booths, it was used data from 2002 to 2009 because the available data of 2001 corresponds to the last months, August to December.

ECONOMIC BRAZILIAN INDEX

Many economic indicators are used to characterize trends and development of industry, commerce and agribusiness. For the present study, it was considered GDP as a parameter to represent Brazil's wealthy produced in the various areas of production.

This value is provided in reports issued by IBGE - Brazilian Institute of Geography and Statistics. There are presented in money value earned during the year and rates are presented as well. Values are given to each quarterly and each year.

This parameter is also evaluated in several countries and an annual report released by the World Bank with values of GDP – Gross Domestic Product and the ranking of countries by annual production.

On December 15th, 2010 was released the last World Bank report with updated values. The Table 2 below shows the GDP values for the top 20 countries ranked, and the annual variation percentage.

TABLE 2 GDP World Ranking for 2009's Year (Source: World Bank, 2010)

Ranking	Economy	GDP	
		Amount	%
1	United States	14.119.000	-2,63
2	Japan	5.068.996	-5,23
3	China	4.985.461	9,1
4	Germany	3.330.032	-4,72
5	Franca	2.649.390	-2,63
6	United Kingdom	2.174.530	-4,92
7	Italy	2.112.780	-5,04
8	Brazil	1.573.409	-0,19
9	Spain	1.460.250	-3,54
10	Canada	1.336.068	-2,46
11	India	1.310.171	7,66
12	Russian Federation	1.231.893	-7,89
13	Australia	924.843	1,29
14	Mexico	874.810	-6,54
15	Korea, Rep.	832.512	0,2
16	Netherlands	792.128	-3,99
17	Turkey	614.603	-4,69
18	Indonesia	540.274	4,55
19	Switzerland	491.824	-1,91
20	Belgium	471.161	-2,75
	World	58.141.498	-1,95

Figure 2 indicates, during the analysis period, the behavior of Brazilian economy in terms the growth ratio of annual Brazilian GDP. Note the first fall in 1998 with more than 3% of decreasing, shy growth to 1999 and significant production increase in 2000. In 2001 there was a

new reduction, with a slight increase in 2002 and new fall in 2003. In 2004 there was a huge increase in the GDP percentage, falling again in 2005. Growth was resumed within the next two years, with slight decrease from 2007 to 2008 and a drastic reduction in 2009.

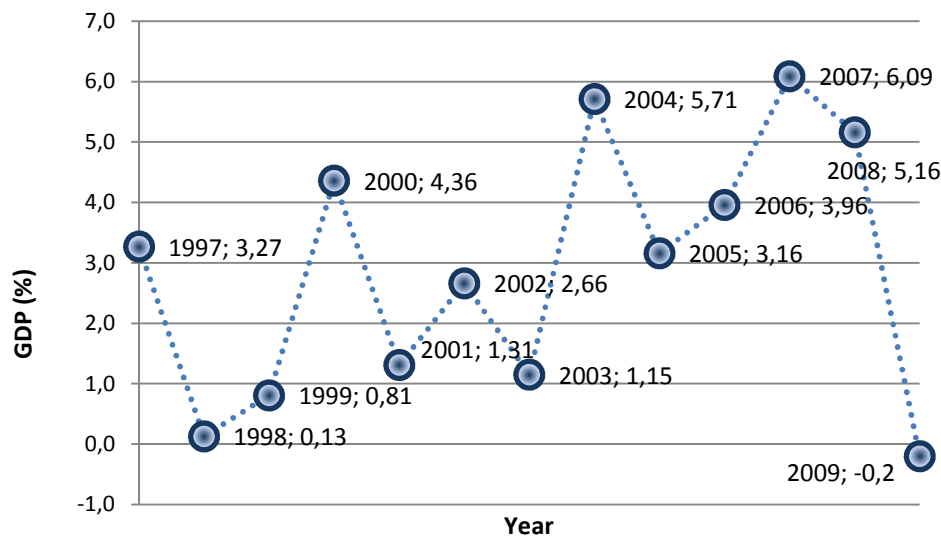


FIGURE 2 Brazilian Annual GDP ratio from 1997 to 2009. (Source: IBGE, 2010)

In 1998 there was a worldwide economic crisis that has already been suffering with the Asian crisis of 1997 and had contribution from the Russian crisis that occurred in 1998 and 1999. At that time Brazil had a great dependence of foreign capital that made the country more vulnerable to the foreign investment fluctuations (3). The country also went through a public sector accounts precarious situation, contributing to the GDP decline. In 2001 there was the Argentina's economic crisis and a currency crisis in Brazil (4) that justified the GDP reduction in this year.

The economic activity deceleration in the second half of 2005 was due to some dynamic loss of the external sector – originated from Real value increase - and the difficulty of consumer credit expansion ... that has opposite signal to the aggregate demand expansion and therefore the economic growth (5).

The contraction of credit availability by the national financial system, observed in the last months of 2008, resulted in reservations from financial institutions in regards to the global crisis effects in the Brazilian economy. ... Credit and external demand restrictions associated to unfavorable expectations and delay of some investment projects, have been the transmission channels of the crisis to the country (6).

In general, although it is possible to make explicit the considerations above and related to consecutive years, note that only in 2009 Brazil had a negative rate. This fact suggests that the effects may be more impactful in all economic sectors in the country.

GENERAL TRAFIC DATA OF HIGHWAY TOOL BOOTH

To evaluate the temporal behavior of the fleet is necessary to obtain a reliable and long database counting.

The activities of most of toll booths began at the end of August, 1996, with the exception of Jacarei, which began operations in August, 2001.

It was possible to do some graphics with the traffic data obtained to show during all the analysis period, their behavior year by year referring to the commercial vehicle volume.

The Figures 3 and 4 show this behavior for the toll booths. The data were sorted by traffic direction of the highway to give better visualization.

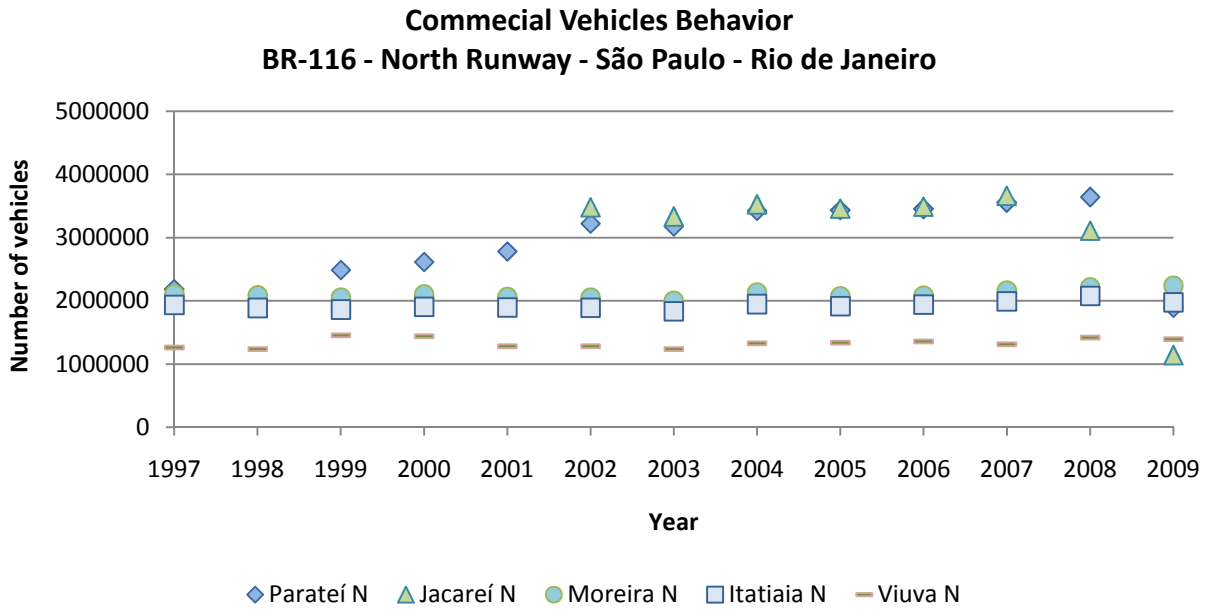


FIGURE 3 Behavior of Commercial Vehicle Fleet – Dutra’s Northbound

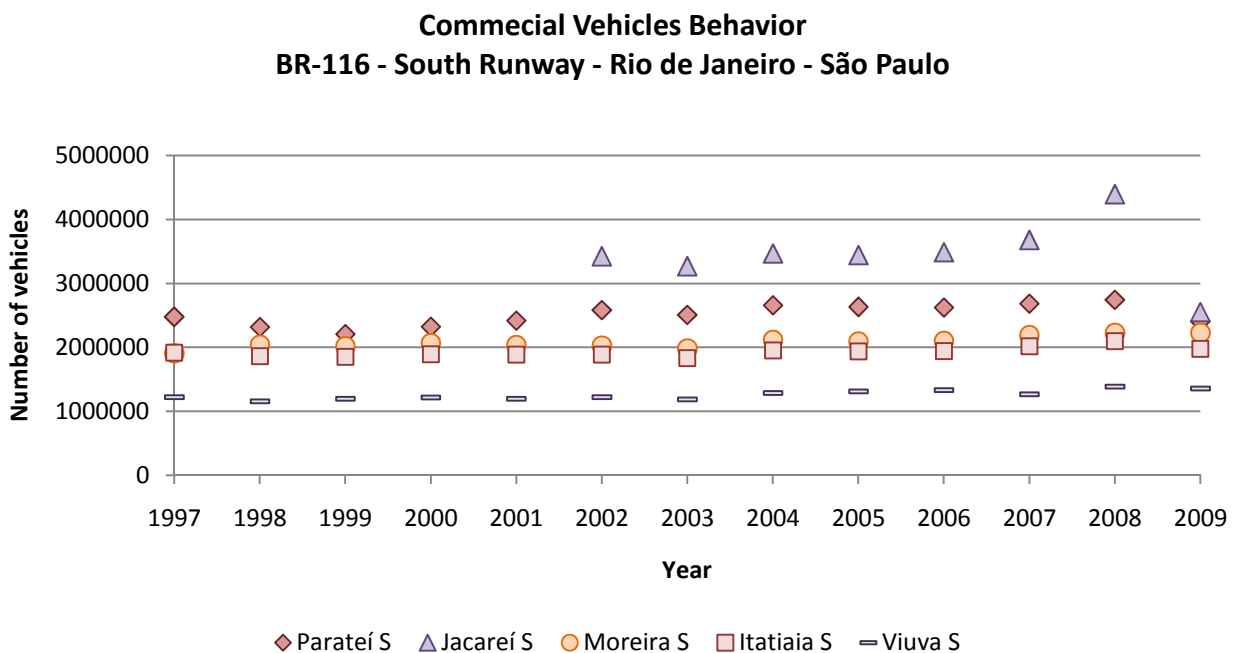


FIGURE 4 Behavior of Commercial Vehicle Fleet – Dutra’s Southbound

Note that the Paratei north traffic volume started about 2,000,000, undergoes transition between 1999 and 2001 and remained at a level of 3.5 million annual commercial vehicles until 2008, suffered a sharp volume decrease in 2009 returning to the 2,000,000. In the Paratei south toll booth, volumes ranged between 2,000,000 and 3,000,000 for all period.

The traffic volumes for Jacareí toll booths had similar behavior for both directions of traffic. In the period between 2002 and 2007 showed an average volume between 2,000,000 and 3,000,000. In the year 2008 had different volumes depending on the direction, to the northbound there was a decrease of volume of approximately three million commercial vehicles while for the southbound direction there was a significant increase to over than 4,000,000. Finally in 2009, both directions showed decreasings 1,000,000 for northbound and 2,500,000 for southbound.

Number of vehicles of Moreira Cesar toll booths, both directions, north and south, is showing volume approximately constant of 2,000,000 commercial vehicles throughout the period. The same trend is observed for the Itatiaia toll booths, in both directions. Variations are observed during the period for both tolls, but the fluctuations are smaller than those presented for previous toll booths.

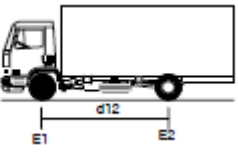

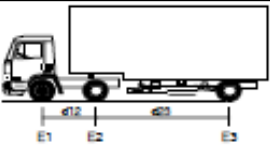
The volume of commercial vehicles presented for the Viúva Graça toll booths seems to be constant along all the period of analysis for the two traffic directions as observed for Moreira Cesar and Itatiaia toll booth. However, the volume of vehicles is lower, surrounding 1,200,000 vehicles per year.

Although at first glance tolls located in Sao Paulo state seem to portray with greater intensity of variations in flow, the remaining toll booths also present fluctuations, however less significant on the scale that is presented in the general data. The evaluations made for modeling the data related to GDP depicted these variations in a more detailed way.

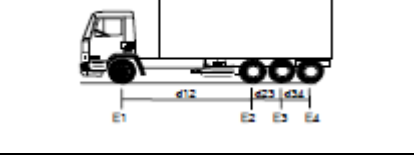
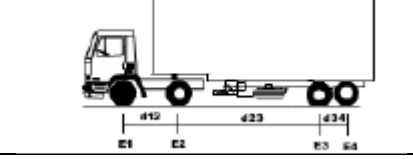

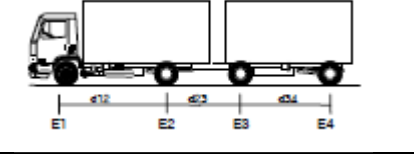
COMMERCIAL VEHICLE VOLUME DATA SORTED BY NUMBER OF AXLES

Counting obtained for this study provides information about the number of axles of each commercial vehicle.

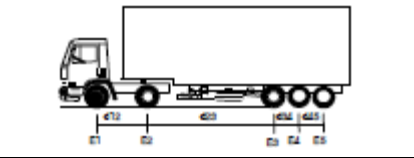

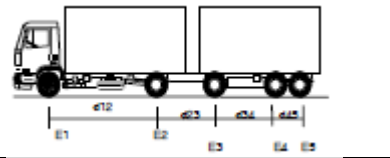
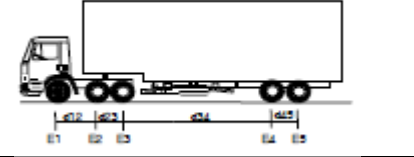
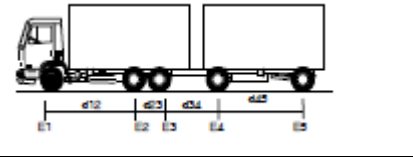
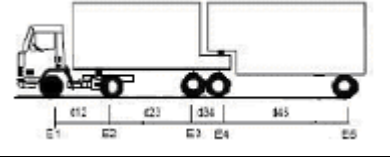
Vehicles up to 10 axles were also counted, however, these vehicles are not discriminated by the axle configuration. Vehicles that passed through the toll booths were defined according to the Brazilian's Standards (7) and are presented on the Figure 5. Vehicles with ten axles are special vehicles did not shown.

Two axles vehicles		
		
2C		
Three axles vehicles		
		
3C	2S1	

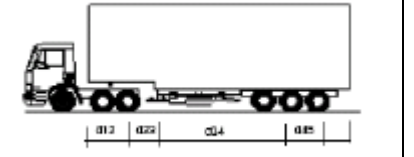

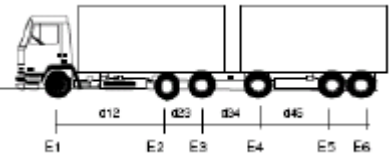
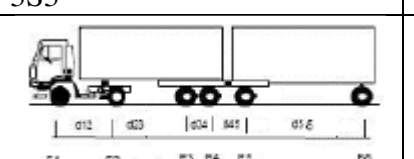
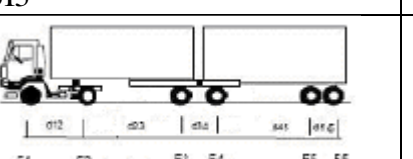
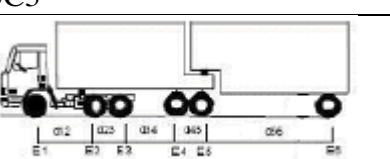
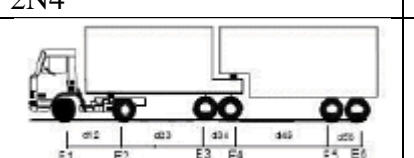
Four axles vehicles

		
4C	2S2	3S1
		
2C2		

Five axles vehicles

		
2S3	2I3	2C3
		
3S2	3C2	2LD

Six axles vehicles

		
3S3	3I3	3C3
		
2N4	2J4	3LD
		
2D4		

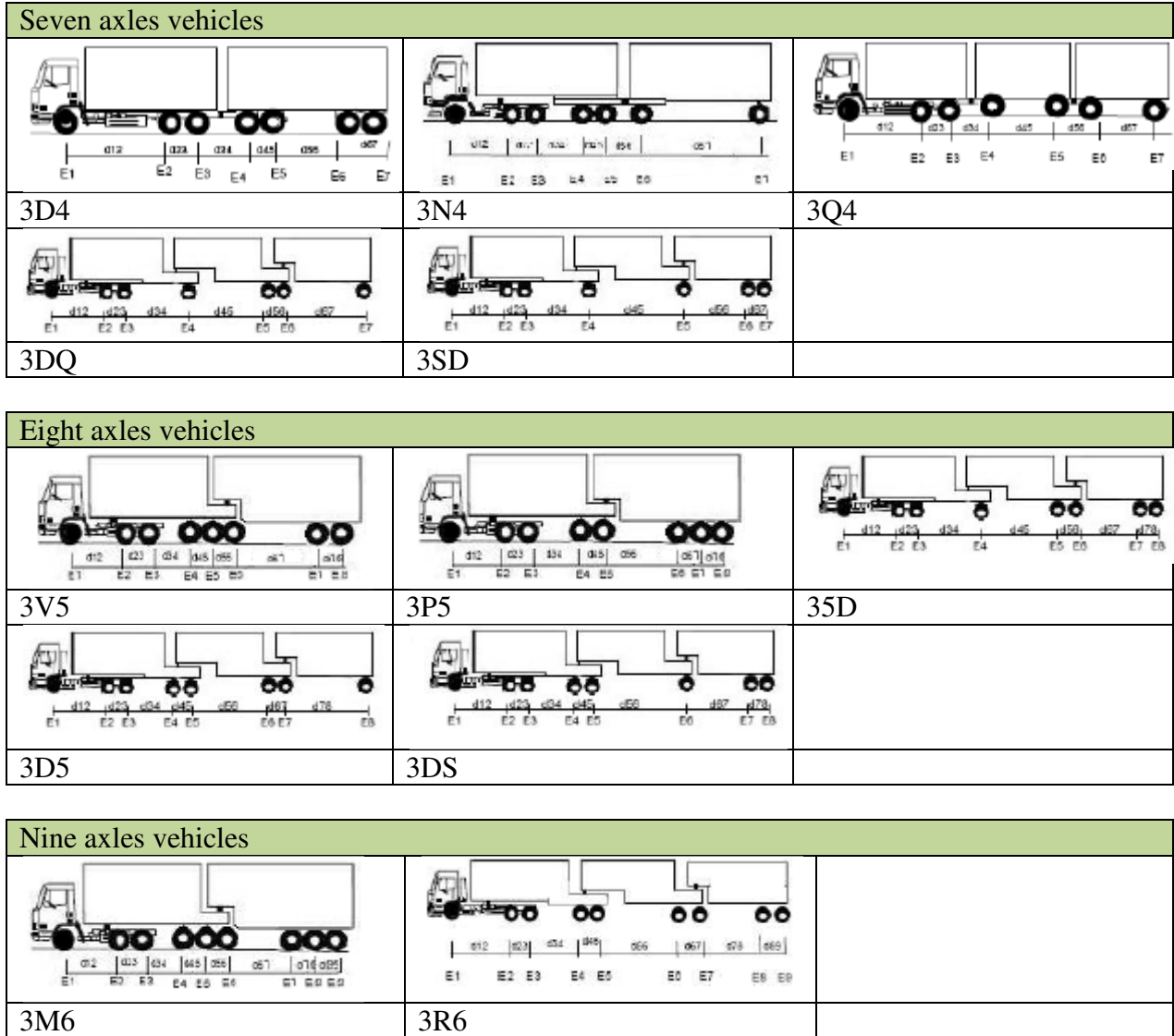


FIGURE 5 Axle Configurations of Trucks

Figures 6 to 14 present the number of vehicles passed through each toll booth from 1997 to 2009. It is reminded that the commercial vehicle volumes collected in 2001 at Jacaréí toll booths and in 1996 at other toll booths correspond to the period from August to December. So, these data were not considered in the analysis.

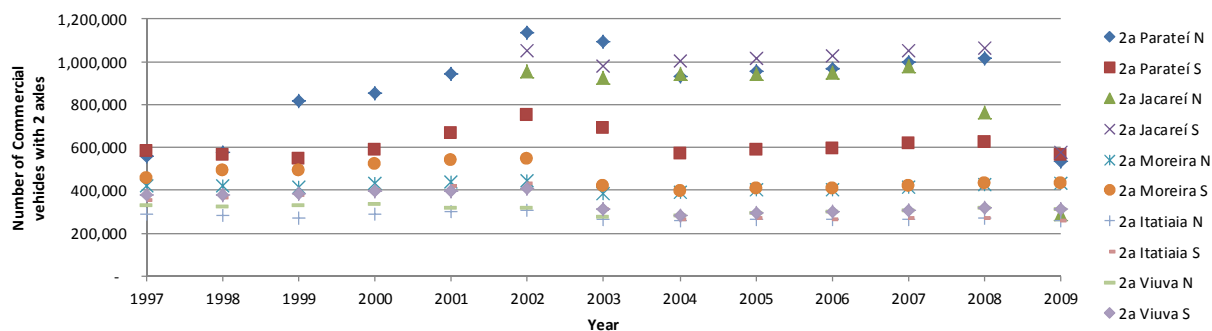


FIGURE 6 Temporal variations of two axle vehicles

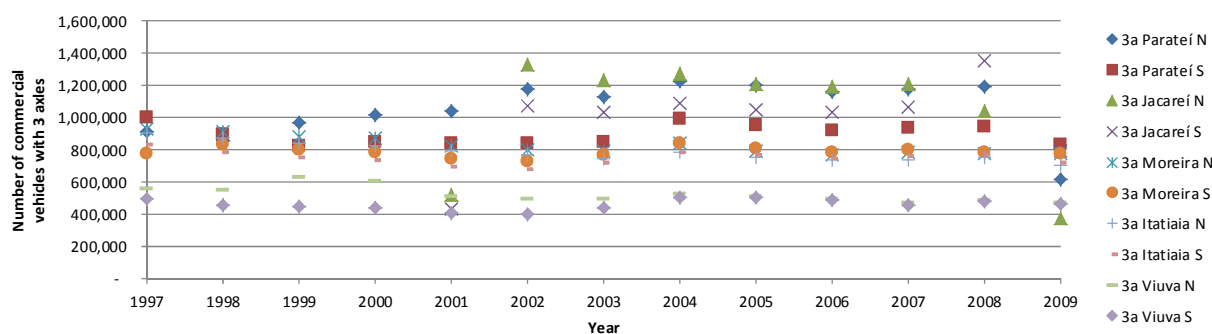


FIGURE 7 Temporal variations of three axle vehicles

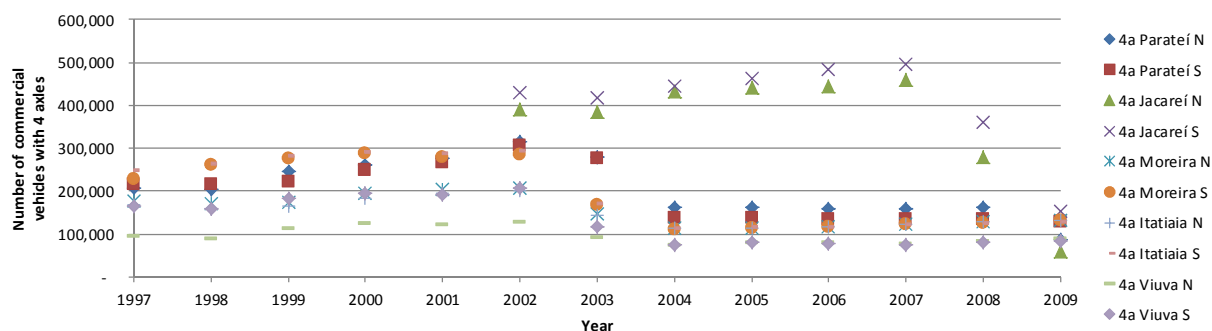


FIGURE 8 Temporal variations of four axle vehicles

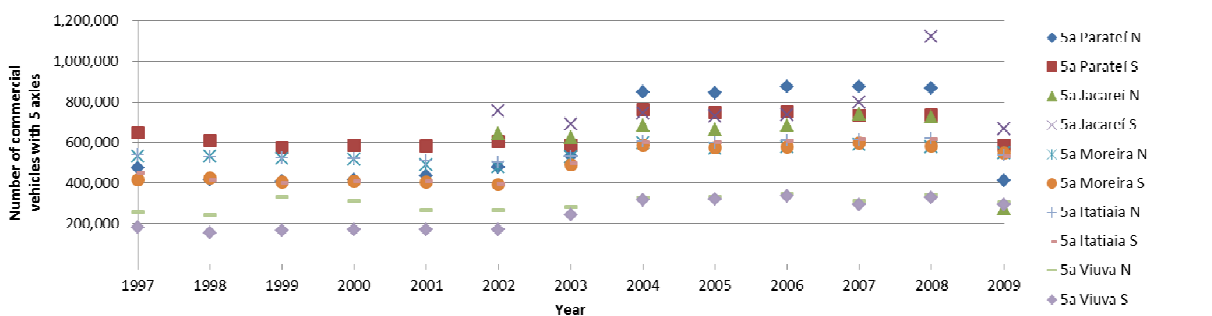


FIGURE 9 Temporal variations to five axles vehicles

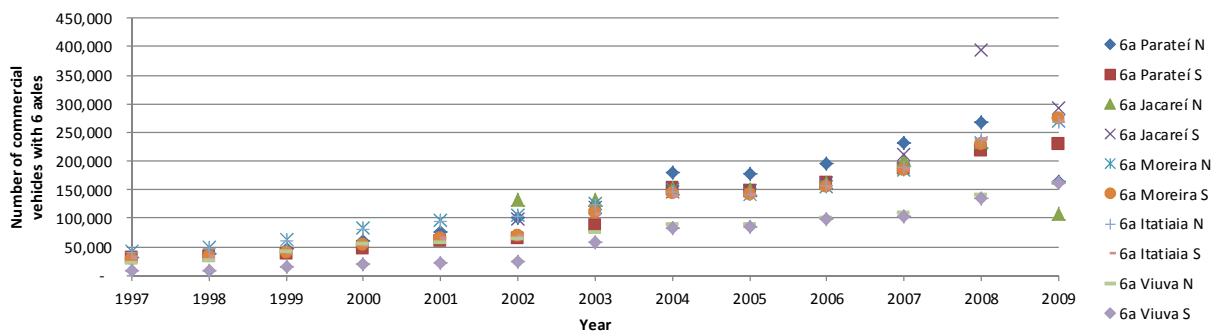


FIGURE 10 Temporal variations of six axle vehicles

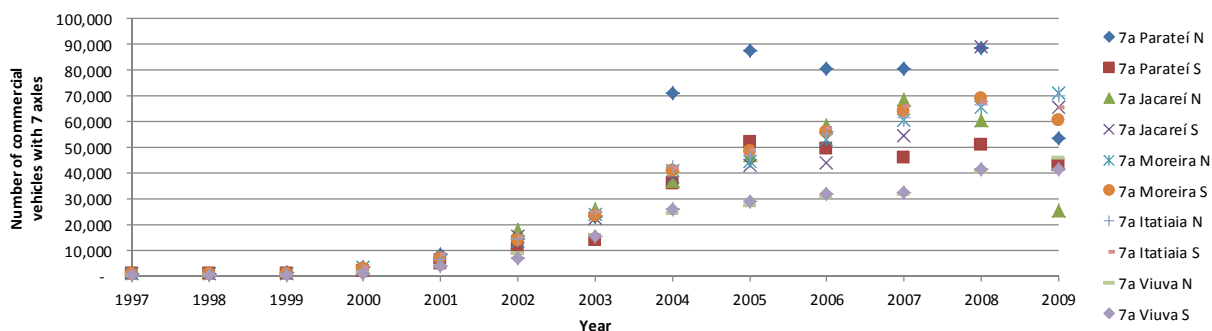


FIGURE 11 Temporal variations of seven axle vehicles

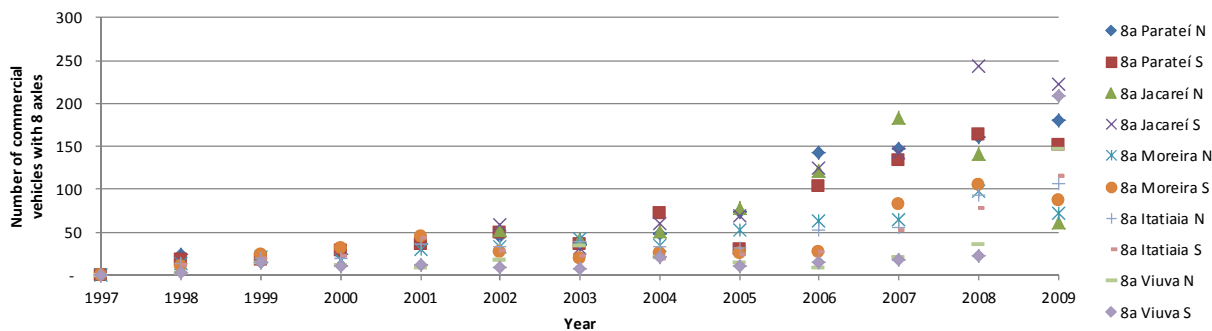


FIGURE 12 Temporal variations of eight axle vehicles

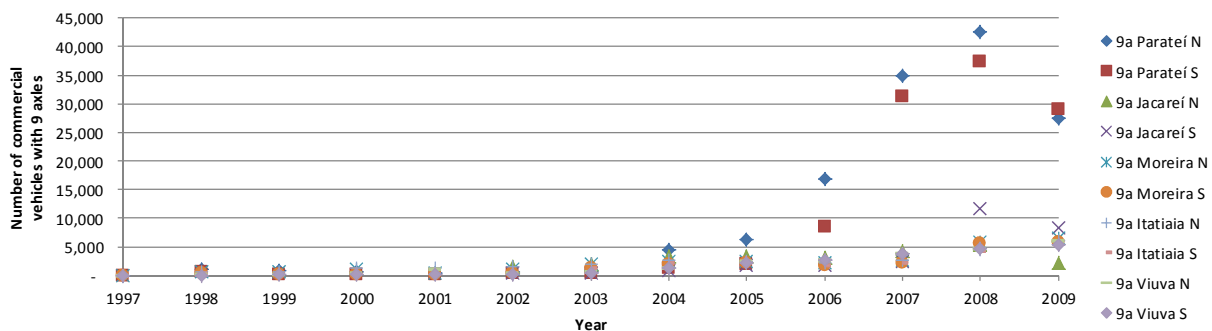


FIGURE 13 Temporal variations of nine axle vehicles

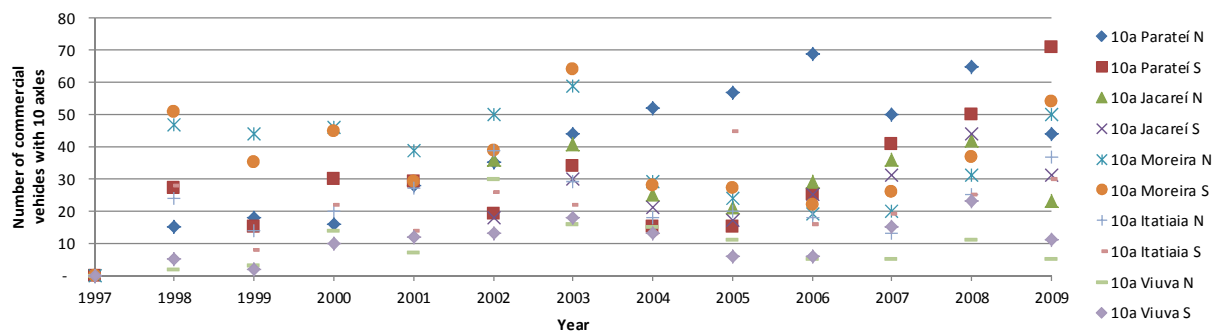


FIGURE 14 Temporal variations of ten axle vehicles

For vehicles with two axles (Figura 6) was noted growth since 2001, mainly for Paratei north. There was a significant decreasing in 2009 in most of the toll booth.

Vehicles with three axles (Figure 7) showed a slight reduction in 2001, resuming growth in the sequence and a large reduction in 2009.

The Figure 8 showed the behavior for vehicles with four axles and indicates differences depending on the toll booth during the period from 2003 to 2007. In the case of Jacareí toll booth, there was a substantial increase in volume of this vehicle while the other counts showed drop in same year and flat behavior until the end of the analysis period.

The volume of vehicles with five axles (Figure 9) presented constant value up to 2002 and 2003, when there was a volume increase which was maintained stabilized until 2008. Most of counts showed a volume reduction in 2009.

The six axles vehicles (Figure 10) showed little volume increasing up to 2001 when the volume started to grow significantly. Different from the trend observed in the other graphs discussed, showed no volume reduction in 2009.

Similarly to the chart for six axles, the volumes for seven axle vehicles (Figura 11) showed a growing from 2003, though it was observed a slight drop in volume in 2009.

Substantial growth in volume from 2006 is what is shown in the Figure 12 that represented the volumes for eight axles vehicles. Note the slight decrease in 2009.

Vehicles with nine axles also showed a fleet growth since 2006, mainly in Paratei toll in both directions. It also presents a small drop in volume in 2009.

Special vehicles with ten axles do not exhibit a undefined tendency, which is expected for this type of vehicle, because it is used only in special cases for the transport of large components and sporadically.

It is possible to consider that most of the fleet was represented by vehicles with two, three and five axles with bigger annual volume than others. Vehicles with eight, nine and ten axles represent low volume per year.

Generally, it was observed a trend of increasing the volume of commercial vehicles. It was also possible to say that in the last years (after 2004) vehicles with six, seven, eight and nine showed a tax growth higher than other types.

MODELING DATA TRAFFIC AND ECONOMIC INDEX

The relationship between the traffic volumes counted at the toll booths during the period between 1997 and 2009 and GDP economic index was searched through data processes and simulations, always aiming to get the behavior of both parameters.

As the parameter chosen for this analysis is the GDP rate, traffic volumes were also converted to growth rates of traffic volume.

Once known that rates of gross domestic product are supplied by IBGE, on quarterly values, it was determined the traffic volumes by quarter values as well. However, the traffic data exhibits seasonality. For example, the first quarter of the year corresponds to the holiday months, the fleet of commercial vehicles is lower, impacting on the quarter values. Thus, the treated samples of GDP quarterly calculated did not show good correlation with the quarterly traffic volumes as proposed for this work.

The GDP growth rates are also provided as annual rates and thus the data were treated to annual growth rates.

Table 3 presents the annual growth rates calculated for the commercial vehicles as well as the values of GDP growth rates per year in Brazil.




TABLE 3 Growth Rates of Commercial Vehicles Fleet and Brazilian GDP Ratios

Year	Parateí North	Parateí South	Jacareí North	Jacareí South	Moreira Cesar North	Moreira Cesar South	Itatiaia North	Itatiaia South	Viúva Graça North	Viúva Graça South	GDP
1997	-2,05	-2,21			-5,89	-10,47	-4,00	-2,90	-16,15	-14,93	3,27
1998	-4,26	-6,23			-0,64	7,09	-2,56	-2,70	-2,22	-5,43	0,13
1999	18,90	-4,84			-1,62	-1,18	-1,32	-0,61	17,67	3,32	0,81
2000	5,11	5,40			2,42	2,50	2,34	2,34	-0,99	1,93	4,36
2001	6,44	3,97			-1,99	-1,41	-0,46	-0,28	-10,74	-1,79	1,31
2002	15,78	6,77	-2,75	-3,41	-0,42	-0,49	-0,33	-0,05	-0,02	2,19	2,66
2003	-1,46	-2,90	-4,29	-4,57	-2,37	-2,24	-3,06	-2,97	-3,54	-3,01	1,15
2004	7,86	6,01	5,81	6,23	6,52	6,76	6,35	6,43	6,99	8,36	5,71
2005	0,30	-0,98	-1,72	-0,63	-2,96	-1,08	-1,73	-0,56	0,89	2,06	3,16
2006	0,58	-0,29	0,84	1,28	0,62	0,33	1,33	0,28	1,68	1,56	3,96
2007	2,93	2,27	4,89	5,37	3,79	4,27	2,76	3,87	-3,55	-4,75	6,09
2008	2,37	2,26	-15,03	19,42	2,46	1,54	4,17	3,85	8,33	9,41	5,16
2009	-8,36	-12,35	-63,95	-42,48	1,09	0,15	-4,87	-5,79	-1,98	-2,21	-0,2

The rates calculated for the Jacareí toll booths during the years of 2008 and 2009 showed inconsistent values because in both years the transition to a new toll system affected the data. Therefore, those data were purged from the research.

For each of the traffic datasets, which are separated by toll booth and direction of traffic, it was made a graphic and a statistic model was determined relating annual traffic growth to annual GDP rate.

Figures 15 to 24 show graphs for each toll booth and traffic direction. Lines have different meanings as described below:

-  Best fit line of model;
-  Prediction data limits;
-  95% of confidence limits;

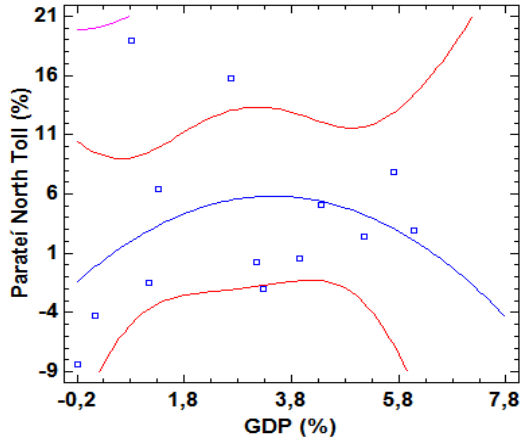


FIGURE 15 Parateí North

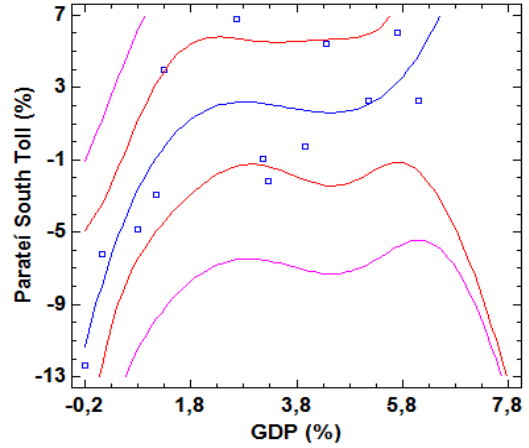


FIGURE 16 Parateí South

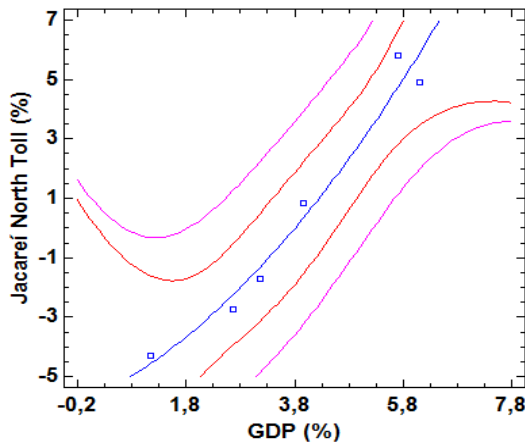


FIGURE 17 Jacareí North

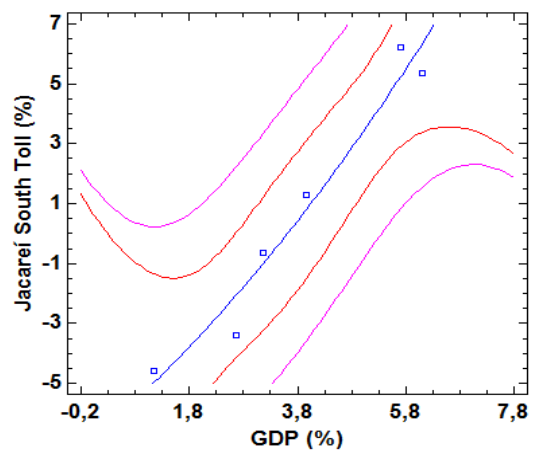


FIGURE 18 Jacareí South

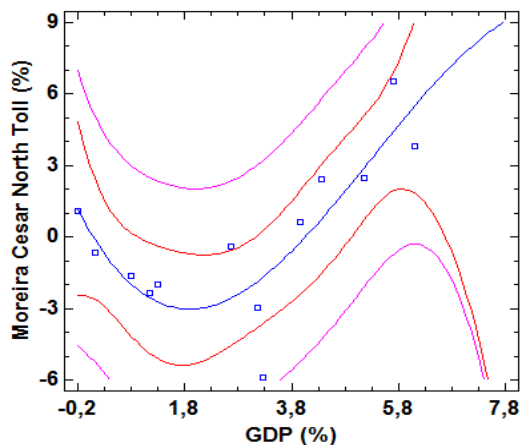


FIGURE 19 Moreira Cesar North

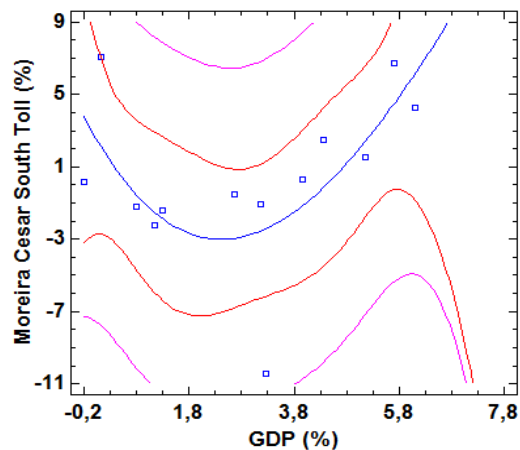


FIGURE 20 Moreira South

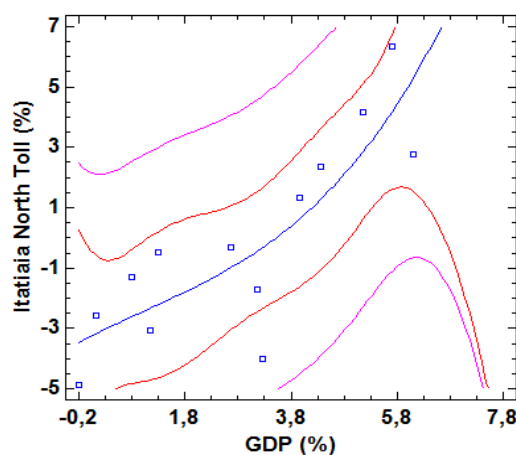


FIGURE 21 Itatiaia North

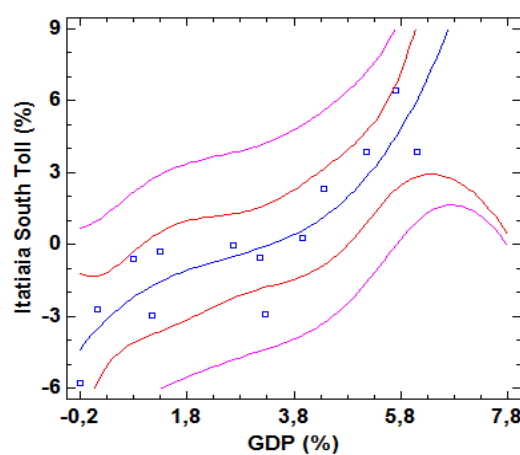


FIGURE 22 Itatiaia South

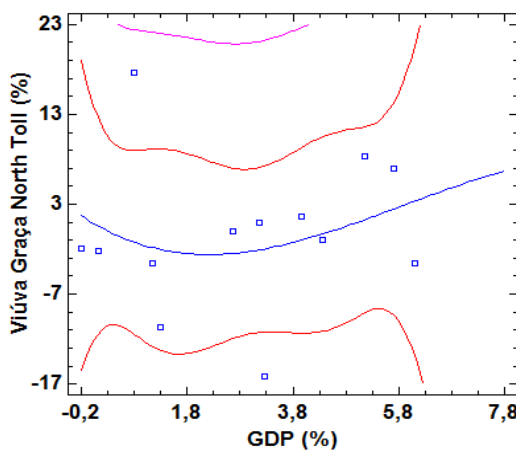


FIGURE 23 Viúva Graça North

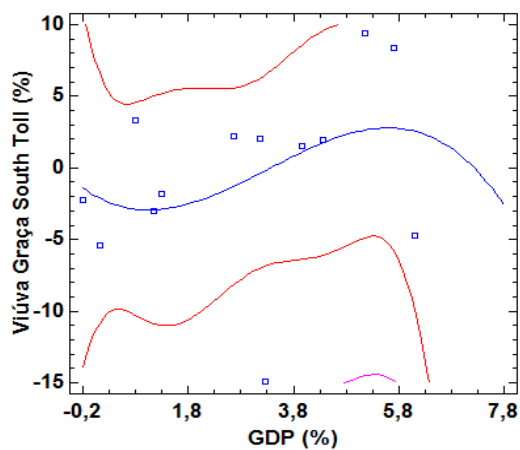


FIGURE 24 Viúva Graça South

The adjusted models are always polynomial, since the logarithmic and linear models showed poor relationship between data. The models are always the second or third order for the data used in this work. The processing was performed by Statgraphics Centurion XVI.I program. (8).

Some models showed weak relationship and do not fit the the assumptions of this work. For the Paratei north toll the error was 0.094 and P-value was 0.61. For Paratei south, the error was 0.70, almost the acceptance limit, and P-value of 0.01. Error of 0.455 and P-value of 0.125 were obtained for Moreira César south, values of errors and P-value were 0.054 and 0.91 for Viuva Graça north toll and 0.122 and 0.75 for Viuva Graça south.

Table 4 below presents the model, the setting error and the P-value for each toll.

TABLE 4 Correlation Models Between Commercial Vehicle Fleet Growth and Brazilian GDP Ratio

Modeling	R ²	P- Value
Parateí North Toll %PN = -0,540554 PIB² + 3,7322 PIB -0,633133	0,093812	0,6118
Parateí South Toll %PS = 0,275377 PIB³ - 2,98606 PIB² + 10,2544 PIB -9,15445	0,696068	0,0150
Jacareí North Toll %JN = 0,169902 PIB² + 0,876865 PIB - 5,79663	0,968011	0,0057
Jacareí South Toll %JS = 0,106989 PIB² + 1,50871 PIB - 6,85397	0,958263	0,0085
Moreira César North Toll %MCN = -0,0788701 PIB³ + 1,25725 PIB² - 3,89651 PIB + 0,37833	0,719585	0,0074
Moreira César South Toll %MCS = -0,0503462 PIB³ + 1,22883 PIB² - 5,0643 + 2,75435	0,455023	0,1251
Itatiaia North Toll %IN = 0,028012 PIB³ - 0,0865992 PIB² + 0,890726 PIB - 3,28719	0,718699	0,0015
Itatiaia South Toll %IS = 0,0986569 PIB³ - 0,759155 PIB² + 2,58047 PIB - 3,84734	0,797258	0,0018
Viúva Graça North Toll %VGN = -0,0561437 PIB³ + 0,983193 PIB² - 3,52354 PIB + 0,998867	0,05430	0,9124
Viúva Graça South Toll %VGS = -0,1227 PIB³ + 1,22343PIB² - 2,17486 PIB - 1,86226	0,12200	0,7452

There were many factors contributing to the GDP data deviation. Creation of new flow generators poles or their extinction in certain regions can have significantly influence in the relationship.

The weak relationship showed to values from Paratei North could be explained for its position, located at metropolitan region of Sao Paulo, it has strong influence of urban traffic of goods and not only long distance transport.

The emphasis is given to the Viuva Graça toll booth that is near to the metropolitan region of Rio de Janeiro with the highest number of cases disposed of statistical calculations, especially in the northbound. Note the significant reduction of this fleet compared to the others and the sums of evidences observed indicates significant outflow of commercial vehicles passing through toll Itatiaia and serve as local steelmakers CSN - Companhia Siderurgica Nacional in Volta Redonda city and CSA – Companhia Siderurgica do Atlantico in Santa Cruz town. Thus, although the long distance transport of goods between Rio de Janeiro city and the south by the BR-116, the characteristic of the fleet becomes less significant in relation to national GDP.

CONCLUSIONS

The analysis performed by observing the figures for traffic evolution for each axle group show that vehicles with higher load capacity and with six to eight axles show growth of the fleet

from 2002. Vehicles with nine axles started to increase volume from 2004 to 2009. At the same time, vehicles with two, three and five axles showed volume growth. The exception is vehicles with four axles although were counted in most of the toll in this period presented similar traffic growth.

Given the considerations made for the volumes sorted by number of axles, it is concluded that the fleet of vehicles has grown not only regarding vehicles already in use for a long time, but the new vehicles as well. There was volume of vehicle growth in most of counts.

The data analysis from counts made in the toll booths, between 1997 and 2009 in comparison to the values of GDP allow relationship verifications between parameters. So it was performed calculations to verify the correlation of these parameters. For each year, it was considered the annual rates of change, taking as reference the value of the previous year, for the two parameters. The models proved satisfactory for all sets of data. Processed data indicate local factors influence, which justifies different models for each of toll booths.

Considering the obtained settings for all values of all tolls used in this study, it is concluded that the fleet of this highway has close relationship with the national economic index for gross domestic product - GDP, with all values represented by annual rates.

ACKNOWLEDGEMENTS

Acknowledgements to CCR NovaDutra Concessionaire for support and assistance provided.

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