IMPROVEMENT IN THE PROVISION OF TRANSPORT SERVICES AND REDUCTION OF AIR POLLUTION IN LARGE CITIES: THE HYBRID LIGHT RAIL VEHICLE CONTRIBUTION

Eduardo Gonçalves David
Raphael Kling David
LESFER – Laboratório de Estudos e Simulações de Sistemas Metro-ferroviários
Universidade Federal do Rio de Janeiro (UFRJ)
Ilha do Fundão – bloco I sala 254 CEP 21.945-970 Rio de Janeiro Brasil
Tel/Fax 21-25628825
egdavid@pet.coppe.ufrj.br
kling@pet.coppe.ufrj.br

ABSTRACT

This text analyzes the evolution of the AC powered railroad traction and its application on mass transport. DC motors have been traditionally used for many years, but in the last 10 years, AC motors have become common in modern railroad equipments. AC motors are cheaper to build and cost less to maintain and, if equipped with electronic control systems, can be very finely adjusted, increasing the adhesion rate. The electrical system, though, is where the greatest improvements have been accomplished.

This text presents the technical characteristics of a Light Rail Vehicle (LRV) that uses Natural Vehicular Gas (NVG) as fuel for the power generating sets to produce electrical energy. The use of NVG results in large reduction in fuel cost, in comparison to the diesel powered Padron bus, taken as reference, and, in addition, reduces drastically the air pollution. An equipment with the characteristics of a LRV-NGV has the potential to revolutionize the rail transport in large cities in the world, where a bus-van market competition exists and where the only alternative has been the MTS (Mass Transit System) in exclusive lanes.

A case study, adopting the proposed LRV-NVG equipment, is discussed for Metro-Rio Line 3. Projected to connect the city of São Gonçalo to the city of Rio de Janeiro, this line has an undersea tunnel to cross the Guanabara Bay. The tunnel's construction costs are estimated as 2/3 of the whole Metro-Rio Line 3 budget. Because of its light weight, the LRV-NVG viabilizes the construction of a railroad bridge to cross the bay, utilizing the pillars of President Costa e Silva Bridge (Rio-Niterói Bridge). The cost of this alternative is estimated as 1/3 of the undersea tunnel's cost. Besides representing a cheaper option, this alternative may foster the construction of new LRV lines in Niterói and Rio de Janeiro, helping to establish a thorough connection between the rail systems in both edges of the bay.

1. INTRODUCTION

In the Marienfelde-Zossen line, near Berlin, two automotives AC powered (one of the Siemens another one of the AEG) had beaten the record of speed of 210 km/h...

Nowadays, this information would present no surprise, since the use of AC motors is currently the state of the art in railroad traction. However, the experience took place in 1903, i.e., 102 years ago!

The use of AC engines has always been a goal in railroad traction. The first test with an AC engine was carried out in 1899, by Brown Boveri, in Switzerland. Technological barriers had hindered that experience for many years. But, in the middle of the decade of 1990, with the development of the frequency inverters, gains in the adhesion rate in railroad traction were obtained, with the use AC motors, in replacement of the DC ones. An immediate consequence of the increase in the adhesion rate is the possibility to make light rail vehicles, with the same acceleration rates of the heavy vehicles. AC traction technology permitted even finer control of wheel creep - consuming little energy and with less maintenance, but with large load capacity.

However, a LRV network is considered a very expensive investment. This makes the transport authorities opt else for an equivalent system that operates on tires - the MTS, or for doing nothing. In this latter case, the option is left for the market forces. This option prevents the transport system of taking advantage of the low friction coefficient between the steel wheel and the rail and has led to the growth of the so-called "alternative transportation" such as the vans.

This text analyzes implantation alternatives of a hybrid LRV, that have the advantage of utilizing finishing components of the automotive industry (most specifically busses), diversifying the possible amount of manufacturers and obtaining the energy and environmental gains of the rail transport.

2. THE STATE OF THE ART IN THE RAILROAD TRACTION

The utilization of electric traction vehicles using induction motors controlled by thyristors constitutes an important landmark in the development of this technology. Although the first experiences with three-phase traction had initiated in the end of century XIX, the technological obstacles were only overcome with the evolution of electronic microprocessors. In the North American railroad cargo transportation sector, the AC Locomotives were only made available in the middle of 1990. These locomotives were produced by GE (General Electric) and EMD (Electromotive Division, of the General Motors). The benefits of this new technology, including increases in cargo capacity, higher average speeds, associated with the lesser costs of maintenance of induction engines, in comparison with the DC engines, are causing a renewal of the North American locomotive fleet. Brazil has been importing second-hand locomotives from the USA, with up to 20 years of use, to attend the 42,2% increase in cargo transport demand, observed from 1996 up to 2003 (ANTT, 2005), after the Brazilian federal railroad network privatization.

2.1. Historical AC Railroad Evolution

The first AC locomotives were equipped with reeled rotor induction engines. Once the feeding frequency was fixed, the speed variation was done through series-parallel type connections of the engines and a variation in the number of poles. An example was the Budapeste-Hegyeshalom railroad in 1931, whose alteration in the number of poles produced modular speeds of 25, 50, 75 and 100 kilometer per hour (km/h).

In the 50's and also in Hungary, a different system in operation was the Ganz-Kandó system that, in addition to the change in the number of poles, also allowed the change of stator frequency (25 to 125 Hz), using a synchronous generator. In 1955, France had its first electrified single-phase line in 25 kV and 50 Hz, between Valenciennes and Thionville, where operated locomotives equipped with three-phase asynchronous engines of short-circuited rotor. These were the precursors of the modern trains, powered by induction engines and fed in changeable frequency. However, due to difficulties in the distribution of current among engines, in the departure, difficulties in the manufacturing of rotors, high costs of maintenance and high indices of damage, these locomotives were removed from service, between 1977 and 1981 (Pires, 2002).

In 1963, Brown Boveri started researching the possibility of constructing a vehicle of traction, powered by inverters and three-phase induction engines, supplied by a contact network, upon request by the Switzerland Federal Railroad. In November 1972, the locomotive class BE 4/4, number 12001, was ready for operation and, in 1973, operated regular services. In the 70´s, the German Federal Railroad (Deutsche Bundesbahn - DB) started to make experiences with diesel-electric locomotives, equipped with six asynchronous engines with squirrel cage rotor and 1,35 MW total power. Until the end of the decade, this locomotive had traveled 350,000 km, under different load conditions, proving the success of the technology (Pires, 2002).

The North American manufacturers delayed in keeping pace with the European development. In June, 1989, GE inaugurated a new era of AC traction, with the F69PH-AC, followed for the SD-60MAC (2 trucks locomotives with 3 axles each). GM EMD relies on one inverter per truck, while GE uses one inverter per axle – both systems have their merits. EMD's system links the axles within each truck in parallel, ensuring wheel slip control is maximized among the axles equally. Parallel control also means equal wheel wear, even between axles. However, if one inverter fails, then the unit is only able to produce 50% of its tractive effort. One inverter per axle is more complicated, but in the GE´s view that individual axle control can provide the best tractive effort. If an inverter fails, the tractive effort for that axle is lost, but full traction is available through the other five inverters.

2.2 Concept of Adhesion Rate and Resistance to Rolling

Dry slipping is understood as a slipping in which no elements exist between bodies in relative motion. Charles Coulomb (1736-1806) exhaustingly assayed the characteristic of the friction between bodies, classifying them in two types: static friction (μe) and cinematic friction (μc); the first one when a body is in rest relative to the other and the second, when in movement. The static friction between two steel surfaces varies from 0,15 to 0,60; the dynamic friction, from 0,05 to 0,10. Between rubber and asphalt, the static friction varies from 0,50 to 0,75 (Lanças, 1992).

In the case of a wheel, the traction occurs only due to the static friction between the wheel and the surface and, therefore, for each situation, exists a limit of traction for the wheel, which equals the static friction limit force, called *Limit of Tack.* The friction between the wheel and the rolling surface is considered static because, in the point of contact, the instantaneous speed is zero, since this point is the Instantaneous Rotation Center (IRC) of the composed movement of the wheel (rotation + translation), as shown in Figure 1. The operating forces in a motor wheel delivering a torque Q and tractioning a resistant force F are shown in Figure 2:

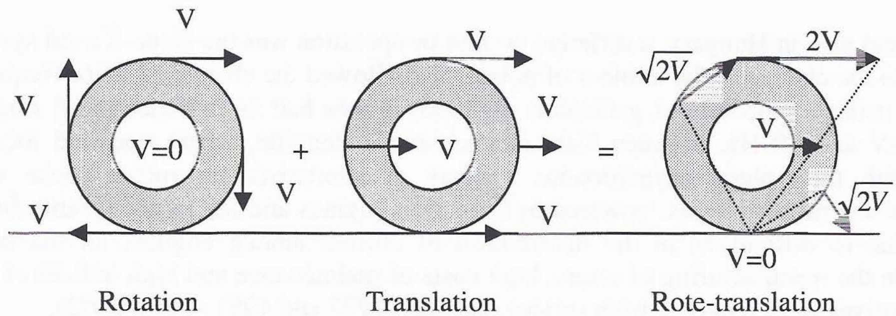

Figure 1: Rote-translation of a Wheel

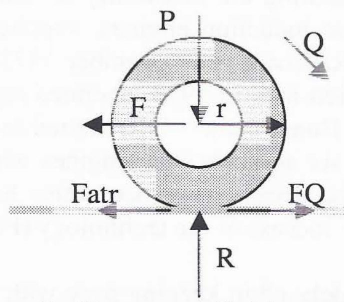

Figure 2: Forces applied in a motor wheel

Considering the wheel in static balance, we have:

$$\sum Fx = 0 \rightarrow Fatr - F = 0 \rightarrow Fatr = F$$
$$\sum Fy = 0 \rightarrow R - P = 0 \rightarrow R = P$$

$$Fatr_{máx}=\mu e.R \quad (1)$$

$$Q=FQ\,.\,r \rightarrow FQ = Q/r \quad (2)$$

Se $FQ = Fatr_{máx} \rightarrow$ wheel is in the eminence of displacement
Se $FQ < Fatr_{máx} \rightarrow$ wheel does not slip, possessing pure rolling
Se $FQ > Fatr_{máx} \rightarrow$ wheel slips
Se $F > Fatr_{máx} \rightarrow$ there is no movement

The control of the torque on the axle, i.e., the applied power, is basic to prevent the creep. With the use of frequency inverters, a 50% increase in the adhesion rate was reached in modern AC locomotives (μ=0,33 as compared with μ=0,22 of the old DC locomotives).

Another important aspect to be considered, in the comparison of the MTS and LRV, is the rolling resistance. When a cylinder, a wheel, a sphere, or any other circular revolution surface, rolls on a plain surface, there appears a resistance to this movement, called Rolling Resistance. This resistance exists because the contact between the bodies is never exactly at a point, but on some inevitable superficial deformation of the bodies. This resistance is given in kgf/t, where *kgf* is the force that opposes the movement and *t*, the vertical force (weight) operating in the wheel. In railroad, the steel wheel and rail contact varies from 1 to 2 kgf/t; in road vehicles, the contact of tire and asphalt varies from 8 to 12 kgf/t (Lanças, 1992).

3. THE HYBRID LRV PROPOSAL

In Brazil, as in other South-American countries, the urban transport on tires, with diesel powered vehicles, predominates. Diesel consumption represents 56% of all fuel used in the transportation sector (BEN, 2004). Brazilian annual diesel imports are more than US$ 2 billion, because the national refineries do not attend the demand. There exists, however, large natural gas reserves in Santos basin, capable of turning Brazil into an exporter rather than an importer of this product.

The LRV described in this text is not an *urban train* or a *rail bus*, but a vehicle that evolved from the automotive ones and has characteristics similar to the "regional trains", with some differences in design. For example, the cab will have to be strengthened, fiber-glass built; equipped with serial internal bus finishings, instead of exclusively railroad equipments, of low production and, therefore, more expensive; body in aluminum, like the busses; and higher transport capacity. The power to the hybrid vehicle will be electric energy from external source or electric energy generated internally, through generating sets powered by diesel, biodiesel, natural gas, alcohol or another available fuel in the region where the vehicle will operate.

3.1. Concept of Multimotorization

The electric energy that arrives at the residences and industries does not come from one only power plant, but from various hydro electrical or thermo electrical plants, linked in parallel. Why then, the energy that supplies traction engines of automotives and locomotives shall come from only one large generator?

The innovative concept of the LRV-NVG (light rail vehicle natural gas powered) uses commercial power generating sets, Otto cycle motor at 1,800 rpm that produce the electric energy. As moderns locomotives, the AC output from the alternators is rectified and filtered do DC, where the power control occurs, with the conversion back to AC (varying voltage and frequency) producing a square-wave tree-phase AC to electric motors in the axles. In case the LRV needs to pass through an underground stretch or place where lower level of noise is required or restriction on CO_2 emission is imposed, the engines in the axles may be supplied by external source - through energized third-rail or catenaries.

3.2. Technical Characteristics of the LRV-NVG

Brazilian industry must not encounter any difficulty in producing this vehicle, for the following reasons:

- as second largest world-wide bus assembler, Brazil developed a competitive and technical advanced industry; produced 24,676 units in 2004, of which 8,850 for exportation (SIMEFRE, 2005);
- WEG Equipment S/A, ranked the first Brazilian company in electromechanical sector and one of the four world-wide, developed and tested two AC motor locomotives in Ferrovia Centro-Atlântica (FCA) to Companhia Vale do Rio Doce (CVRD), (IRF, 2003);
- Brazil is a first line competitor in rolling stocks, wheels and axles that will equip the trucks; and
- because of the energy crisis in 2002, as a consequence of a vigorous drought period, which lowered dangerously the water level of the dams (responsible for 90% of the national supply), Brazil also developed a competitive industry of diesel or NVG powered generators sets.

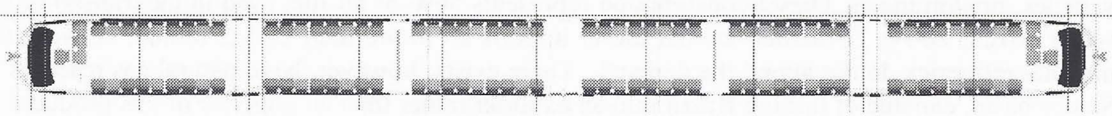

Figure 3: Plant of LRV-NGV

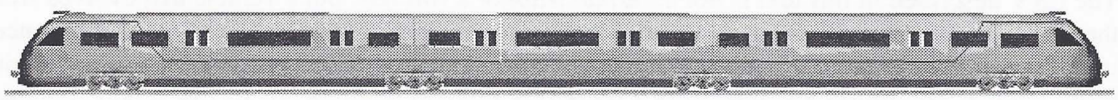

Figure 4: Side view of LRV-NGV

The total capacity of each unit-train, composed of three articulated modules, will be of 400 passengers (6 passengers/m^2), in longitudinal chairs configuration, weighting 60t in full load. The command of each train will be computerized, being possible to form trains of 5 unit-trains, totalizing 2,000 passengers per train. With a 3-minutes headway, it will be possible a maximum capacity (with the five units) of 40.000 passengers per hour. As the length of the train grows with the coupling of more automotive units, there is no need to invest in fixed power installations; therefore, its implantation can be gradual, in accordance with the reaction of the market, minimizing initial investments. Estimates indicate that a vehicle with these characteristics, produced from serial components of bus industries, would cost between USS 800,000 and USS 1 million.

3.3. Energy performance and Pollutant Comparative degree

Factors that contributed to the increase in diesel consumption in 1990's, in Rio de Janeiro, as observed by Ribeiro & Mattos (2004), were the automobile import liberalization and the unemployment in the middle class, that made grow the transport of passengers by vans, said "alternative". Although this new transport service option (municipal, interurban and interstate) had got people's adhesion, due to its characteristics of speed and flexibility, among the reactions on urban entrepreneurs, one was the replacement of the old busses, assembled on truck chassis, for microbuses, smaller vehicles, more agile and of lower power that exclude collectors (the task is accumulated by the driver).

Oliveira & Orrico Filho (2004), argue that this transport "alternative" made the bus industry adapt to this new scenario, making the table of coefficient of fuel consumption, produced by GEIPOT, in 1986, upon request of the EBTU (Brazilian Company of Urban Transports), outdated with relation to reality. The 6 variables considered by authors for consumption analysis were: technology, average age of the fleet, congestion, grade slope, shipment and average speed. The research, carried out in the City of Petrópolis, 60 km from Rio de Janeiro, indicated the following average results: microbuses - 0,23 km/l; light busses - 0,33 km/l and padron - 0,42 km/l. Araújo and Balassiano (2004) identified, among the associates of a cooperative of vans that operate the line São Gonçalo - Rio de Janeiro, negligence on the part of the operators as for any routine for calculating the services costs, in addition to heterogeneities in the given service. Therefore, in this study, we admit an average consumption of 0,15 liters per km or 6,53 km/l, for vans with 15 passengers capacity, in transit almost always congested.

Pires (2002), simulating the consumption of AC electric train-unit engines, found the rate of 0,025 KWh/tkm. Taking this relation for the LRV-NGV, that weighs 60 t, we verify that, in each kilometer there will be a consumption of 1,5 KWh/km. The Leon Heimer S/A, NGV powered generating sets manufacturer, indicates the specific consumption of 0,39 Nm^3/KWh. Therefore, using the same unit of the other vehicles, the average consumption of the LRV-NGV will be 0,585 Nm^3/Km.

As to atmospheric pollution, for establishing a common base of comparison for the greenhouse effect in different countries, a methodology for quantification of CO_2 emissions was elaborated, in 1996, by the Intergovernmental Panel on Climate Change (IPCC). This methodology was accepted by Brazil. The methodology allows two distinct approaches for the available data: top-down and bottom-up. In Brazil, we adopted the first one. Mattos (2001) presents a table for the calculation of the carbon content for type of fuel, indicating: 20,2 tC/TJ for cubic meter of diesel oil and 15,3 tC/TJ for a thousand cubic meter of NGV (tC/TJ standing for ton of Carbon per Tera-Joule, i.e., 10^{12} Joules).

Table 1, derived from the information previously presented, allows to establish a comparison between the competing LRV-NGV and road modalities in passengers transportation, with reference to the fuel consumption, emissions of gases of the effect greenhouse, for each carried passenger-kilometer, taking 100 as base for the urban bus of the Padron type.

Table 1: Comparison of Average and Potential Consumption of Emissions

Vehicle	Unity	Consumption Average	CO_2 Emission Index	Vehicle Lotation	Consump per 1,000 PassgKm	Fuel Base	CO_2 Emission Per 1,000 PassgKm	CO_2 Emission Base
Padron	Liter/km	0,420	20,2	69	6.09	100	122,96	100
Microbus	Liter/km	0,230	20,2	28	8,21	135	165,93	135
Van	Liter/km	0,153	20,2	15	10,22	168	206,49	168
LRV-NGV	Nm^3 /km	0,585	15,3	400	1,46	24	22,38	18

In comparison to the Padron bus, the LRV-NGV has potential to reduce the diesel consumption in more than 3/4 and the emissions of CO_2 in more than 4/5. Considering the price of the Nm3 of NGV as 65% of the price of the liter of diesel, the reduction of cost in the fuel item for passenger-kilometer will be of 84%, in comparison with the one of the Padron bus.

This LRV performance could stimulate private operators of bus lines to establish partnerships with large constructors, to install lines financed with resources caught through PPP. For the Government, it is strategically and interesting to stimulate more energetically efficient modalities, that do not depend on diesel oil – a petroleum derivative that tends to become more and more expensive, equaling that of the gasoline, as in USA and in some European countries. Currently in Brazil, one liter of diesel is 30% cheaper than one liter of gasoline for the final consumer.

4. CASE STUDY

The Secretariat of Transports of the State of Rio de Janeiro (SECTRAN) chose the winning consortium for construction of Line 3 of the Rio de Janeiro Subway System (Metro-Rio). Line 3 is composed of two lots. Lot 1 is the subway link between the "Carioca" Square (Rio de Janeiro) and the "Araribóia" Square (Niterói), through a undersea tunnel in the Guanabara bay, with an extension of 6,6 km. Lot 2 is the subway line, including permanent way, that starts in Araribóia Square and finishes in the Guaxindiba Station (São Gonçalo), with 21 km of extension. This rail link is an alternative to the São Gonçalo-Rio road corridor, second densest corridor in Rio de Janeiro Metropolitan Region (RMRJ), as shown in Figure 3. The undersea tunnel has cost estimated at US$ 750 million, not including environmental costs associated with the project.

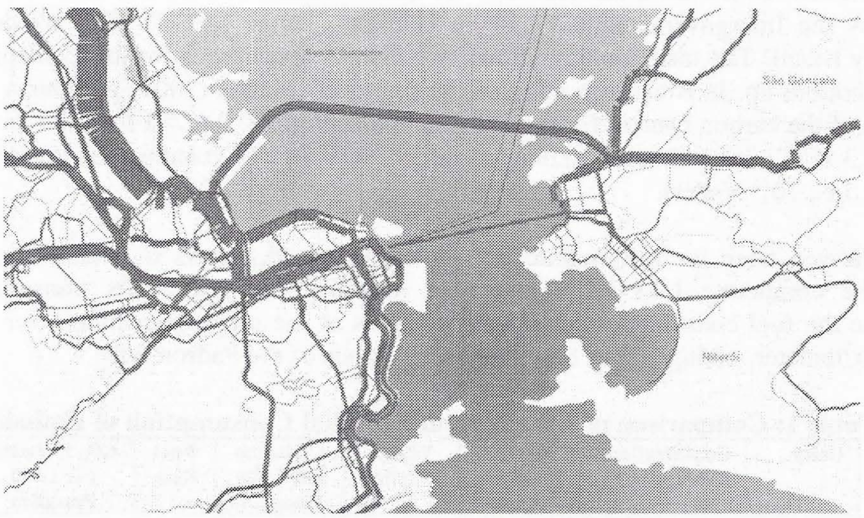

Figure 5: Shipment of Mesh RMRJ

4.2. Alternative to the Undersea Tunnel: The LRV in the Rio-Niterói Bridge

The idea to install railroad lines on Rio-Niterói bridge is not new, for the road bridge, 31 years of age, shows several exhaustion signals. Originally it was designed to accommodate 55,000 vehicles/day. Today, the bridge has a daily movement of 130,000 vehicles (Pinto & Santos, 2004). The first proposal consisted of the implantation of two tracks on the central lane of the bridge pavement. This implied the elimination of two road lanes of the existing six, i.e., 1/3 of the total bridge width, and the risk of interrupting the trains circulation due to road vehicles accidents. Another proposal would be the installation of tracks in the laterals of the bridge, therefore, not eliminating lanes. Both previous proposals would face construction problems, as well as legal disputes, since the road exploration is already private. The solution proposed in this text consists of the installation, under the bridge pavement, of three metallic bridges, supported by the bridge pillars, as shown in Figure 6.

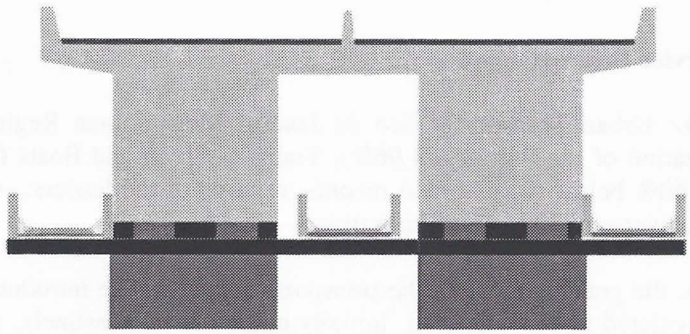

Figure 6: Three lines under the bridge pavement.

For the 89 gap distances between pillars over the sea (varying from 80m to 114m), pony plate girders would be utilizes; for the "central" gaps, of 200m and 300m, it would be necessary a through truss type, constructed in structural steel of high resistance to corrosion, as shown in Figure 7 (a) and (b).

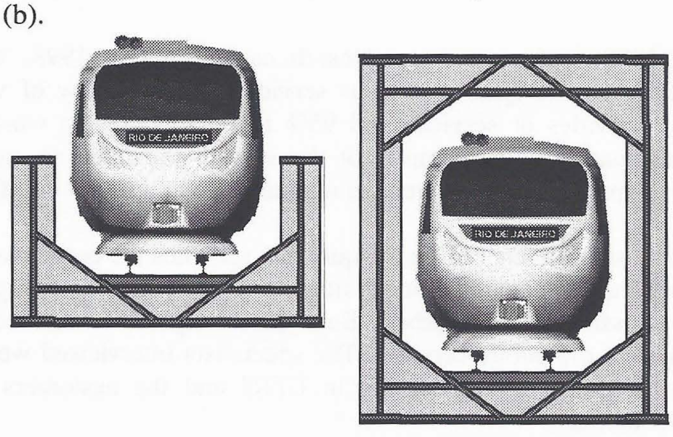

Figure 7 (a): LRV in pony plate girder and (b) LRV in through truss

Table 2 indicates an estimate of the metallic railroad bridges construction cost, assuming an exchange rate of R$ 2,40 per American dollar. It can be noted that, taking advantage of the existing infrastructure, the investments represent 1/3 of the investments estimated for the undersea tunnel. If we take into account the construction time, the savings could be still bigger.

Table 2: Bridge Cost Estimate to LRV Cross Guanabara Bay

ESPECIFICATION	UNITY	VALUE
Extension on the sea	m	8.800
Unitary steel weight (three bridges)	Kg/m	7.036
Total weight steel	t	61.922
Average worked steel cost	US$	3.958,33
Steel Structure Investment	US$ 10^3	245.109,37

4.2. Quality of Service Improvement

The Master Plan for Urban Transport - Rio de Janeiro Metropolitan Region (PDTU-RMRJ) identified low utilization of the Subway (4,96%), Trains (4,36%) and Boats (0,74%), these two last ones operating 50% below its historical records, relative to the leaders: vans (15,10%) and bus (74,84%), in a universe of 13 million daily trips.

In the last ten years, the greatest news in the transport sector was the introduction of vans as an alternative to the regulated public transport. Initially operating clandestinely, the vans generated an opposition from the regulated transport operators. However, this opposition seemed inadequate (Balassiano & Braga, 2000). According to these authors, better it would be to admit different forms and options of transport operating in a co-coordinated fashion. Considering that the average occupation rate of a particular car in the city is below of 1,25 passengers per vehicle per trip, there exists a potential case for each van more than substitute for the trips of ten particular cars.

Balassiano & Braga (2000), referring to a research carried out in 1998, with RMRJ vans operators, sought to evaluate the quality of vans service. The majority of vans users (71%) worked in commercial activities or services and 95% to be traveling to work; 64% used bus services before. The evaluation of the quality of the service indicated as most important the following factors: first - trip time; second - vehicle maintenance and third - comfort.

Forte & Bodmer (2004), using the Delphi Technique, that searches the consensus between people around determined problem, selected the most important attributes for the passengers public transport by boat for crossing the Guanabara Bay. The sample was divided in two groups: specialists and customers of the public services. The specialists interviewed were professors and post-graduate students in transport engineering in UFRJ and the customers of the transport system. This research concluded:

- While the specialists found that the attribute *time* would be of greater importance (22%) the customers had assigned only 13% to it.
- Accessibility was the attribute most important for the customers (34%) against 13% in the opinion of the specialists.

Pinto e Santos (2004) indicates that the Rio-Niterói Bridge operates with the double of its capacity. In the peak hour, the movement is of 8,000 vehicles. The average trip time is 30 minutes. Therefore, with the growth of the individual transport, a world-wide phenomenon, it is possible to anticipate in the future bigger and bigger congestion in the Bridge. Speed, accessibility, comfort and security will be main attractive attributes of a new transport system capable of attracting demand in the Rio-Niterói link.

5. CONCLUSIONS AND SUGGESTIONS:

The conventional LRV, being an expensive and of medium capacity solution, has not deserved due consideration in mass transport alternatives. However, creating a standard model using bus serial equipment; multimotorization system with NGV powered sets and AC motors for traction, in the case of Guanabara Bay cross, it is possible to obtain:

- 50% reduction in the cost of an European model imported vehicle;
- 2/3 reduction in cross time Rio-Niterói bridge (30 minutes to 10 minutes);
- 75% reduction in infrastructure investment (3 railroad bridges under Rio-Niterói bridge vs. Undersea Tunnel);
- 76% reduction in fuel consumption for passenger-kilometer, comparing to the bus standard;
- 82% reduction CO_2 emission, comparing to the bus standard;
- 84% fuel cost reduction, utilizing NGV; and yet
- utilize existing vans and microbus as transport complementation, enhancing public accessibility and, thus, compensating a deficiency of the railroad system.

Such evidences justify examination, by BIRD (World Bank), BID (Inter-American Development Bank) and others, of this transport alternative in other South American large cities, where market competition between vans and buses and the LRV alternative exists. A LRV-NGV can, also, comparatively to the MTS, when the stretch will be in raised lane, present lower infrastructure costs; that is, the railroad bridge, where the longitudinal beams can function as support for the rails, is cheaper than the road bridges that demand flagstone for pavement with at least 7m width, guard-rail, illumination etc. The hybrid standard AC LRV can be the inauguration of a new age in mass rail transportation.

REFERENCIAS

ANTT, Agência Nacional de Transportes Terrestres. (2005). Ferrovias comentário fina, antt.gov.br, Brasília, DF.

Araujo, A. M. & R. Balassiano. (2004). Uma contribuição metodológica para o cálculo dos custos do transporte alternativo por vans. **Anais II Rio de Transportes, Rio de Janeiro**.

Balassiano, R. & M.G.C. Braga. (2000). Competição do transporte rodoviário de passageiros: caso do rio de janeiro. **Transporte em tempos de reforma. LGE Editora, Brasília**.

BEN. (2004). Balanço energético nacional. Ministério das Minas e Energia. mme.gov.br.

Forte, M. G. & M. Bodmer. (2004). As diferenças de percepção dos diferentes agentes sobre atributos de qualidade de serviço de transporte urbano de passageiros na travessia da baía da

Guanabara. **Anais do XVIII Congresso de Pesquisa e Ensino em Transportes, Rio de Janeiro**.

IRF (2003 Informe Revista Ferroviária, EFVM testa locomotivas de corrente alternada, RF 09/10/2003. revistaferroviaria.com.br.

Lanças, K. P. (1992). **Manual de Mecânica Aplicada. Departamento de Engenharia Rural,** FEPAF Fundação de Estudos e Pesquisas Agrícolas e Florestais.

Mattos, L.B.R. (2001). A importância do setor de transportes na emissão de gases do efeito estufa –o caso do município do rio de janeiro. Tese de Mestrado, Programa de Engenharia de Transportes, COPPE, UFRJ, Rio de Janeiro.

Oliveira, G.S. & R.D. Orrico Filho. (2004). Análise do consumo de combustível de ônibus urbanos. **Anais XVIII Congresso de Pesquisa e Ensino em Transportes, Rio de Janeiro**.

PDTU-RMRJ (2005). Plano diretor de transporte urbano – região metropolitana do rio de janeiro. Secretaria Estadual de Transporte, governo do Estado do Rio de Janeiro. Edição.

Pinto, F.C.V. & R.N. Santos. (2004). Redução de dióxido de carbono através da maior utilização da modalidade hidroviária no transporte de passageiros: um caso da ligação rio-niterói. **Anais do XVIII Congresso de Pesquisa e Ensino em Transportes, Rio de Janeiro.**

Pires, C.L. (2002). Simulação de marcha de composição ferroviária acionada por motores de indução e PWM. Tese de Mestrado em Engenharia, Escola Politécnica da Universidade de São Paulo, São Paulo.

Ribeiro, S.K. L.B.R. Mattos.(2004). A importância do setor de transporte rodoviário no aquecimento global, caso da cidade do Rio de Janeiro. **Anais XVIII Congresso de Pesquisa e Ensino em Transportes, Rio de Janeiro**.

SIMEFRE. (2005) Sindicato Interestadual da Indústria de Materiais e Equipamentos Ferroviários e Rodoviários, Serie Estudos Rodoviários. SHR Serviço de Assessoria – Rio de Janeiro, RJ, Janeiro de.