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MORPHOLOGICAL ANALYSIS OF THE INTRODUCTION OF ELECTRIC VEHICLES IN SÃO PAULO'S URBAN TRAFFIC

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"... within the final and true world image everything is related to everything, and nothing can be discarded a priori as being unimportant."
Fritz Zwicky: Discovery, invention, research through the morphological approach

ABSTRACT

Pressures of international organizations and governmental regulations have increased substantially when it comes to the reduction of dependence on fossil fuels and transport pollutants emissions.

To meet these challenges, the automotive industry invests large sums in research and development on a broad portfolio of new technologies related to vehicular propulsion. Considering the alternatives under development, electric vehicles, specifically, have received increased attention both in Brazil and abroad.

This study aims to contribute with the construction of future scenarios in 2020 concerning the introduction of electric vehicles in São Paulo´s urban traffic, an integral part of the CNPq/FINEP research project which is being undertaken at the University of São Paulo (USP/FEA), coordinated by Prof. James T. C. Wright.

The Morphological Analysis method was adopted given the fact that it facilitates the structuring of the managerial and technological complexities of the proposed problem, with views to identifying the variables and their critical relations for the prospection of scenarios.

The variables that influence an urban transport system were structured into four logical groups: scope of usage, structural architecture and propulsion system of the vehicle, road and energy supply/recharge infrastructure and finally, business models. These groups, in turn, were analysed at distinct levels, leading to other variables. Subsequently, alternative forms, which the selected variables could take on, were generated.

The multidimensional matrix resulting from this set of combinatorial possibilities was then carefully verified in terms of feasibility and consistency in order to identify the basic settings of greatest interest to the scenarios prospecting effort.

Keywords: Prospective scenarios. Morphological analysis. Electric vehicles.

RESUMO

Têm aumentado substancialmente as pressões de organismos internacionais e regulamentações governamentais no sentido de redução da dependência de combustíveis fósseis e de emissões poluentes provenientes dos transportes.

Para responder a esses desafios, a indústria automobilística investe vultosos recursos em pesquisa e desenvolvimento em um vasto portfólio de novas tecnologias relacionadas à propulsão veicular. Das alternativas em desenvolvimento, os veículos elétricos, especificamente, têm recebido crescentemente atenção, tanto no Brasil quanto no exterior.

O presente estudo pretende contribuir para a construção de cenários futuros em 2020 relacionados à introdução de veículos elétricos no tráfego urbano de São Paulo, parte integrante de projeto de pesquisa CNPq/FINEP, em desenvolvimento na Universidade de São Paulo (USP/FEA), coordenado pelo Prof. James T. C. Wright.

Por facilitar a estruturação das complexidades tecnológicas e gerenciais do problema proposto, o método de Análise Morfológica foi utilizado, visando identificar as variáveis e relações críticas para a prospecção dos cenários.

As variáveis que influenciam um sistema de transporte urbano foram estruturadas em quatro grupos lógicos: Escopo do uso; Arquitetura estrutural e sistema de propulsão do veículo; Infra-estrutura viária e de fornecimento/recarga de energia; Modelo de negócio. Esses grupos foram analisados em distintos níveis, originando outras variáveis. Na sequência, foram geradas formas alternativas que as variáveis selecionadas poderiam assumir.

A matriz multidimensional resultante desse conjunto de possibilidades combinatórias passou por criteriosa análise de viabilidade e consistência. Isso para identificar as configurações básicas de maior interesse para o esforço de prospecção dos cenários.

Palavras-chave: Cenários prospectivos. Análise morfológica. Veículos elétricos.

1 INTRODUCTION

Mobility is acknowledged as a fundamental driver for the growth of a globalized economy and for the development of socio-cultural well being, however, the concern with the environment and with the sustainability of the current power matrix, places the transport sector in the spotlight, as one of the core issues attracting world attention.

The transportation of passsengers, consumer goods and production, accounts for 52% of the global demand for fuels which, in almost it´s totality – 94% – comprises crude oil by-products powering internal combustion engines. No other sector presents such level of dependency on a single source of primary power or similar dominance in terms of propulsion technology (Organisation for Economic Co-operation and Development [OECD], 2009).

Further per this OECD (2009) study, power generation and the transportation sector are the world´s two largest issuing agents of gases that cause the greenhouse effect, contributing with 41% and 23%, respectively, with carbon dioxide (CO_2) emissions.

Of greater concern is the observation that CO_2 emissions from transportation increased considerably – 28% – during the 1990-2006 period, despite improvements in the world fleet´s efficiency, whilst medium emissions relative to other sectors experienced a 3% reduction (European Environment Agency [EEA], 2009). It´s worth noting that most greenhouse effect gas emissions in this sector take place given day to day individual transportation, whereupon people utilize their cars on home and work routes, short distances and most often, at low speeds.

Given that the demand for mobility and power increases in alignment with the expected increase in country gross national products (Velloso, 2010), this has substantially incremented international organization pressure and governmental rulings towards reducing dependency on fossil fuels and the emission of transportation pollutants. The European Union Counsel established, for member countries, a reduction of 60 to 80% of figures verified in 1990 (Hacker, 2009) in total CO_2 emissions for the year 2050.

To meet these challenges, the automotive industry has been making expressive resource investments in research and development in a vast portfolio of new technologies related to vehicular propulsion which include advances from conventional internal combustion engine (Welch, 2010), operating with fossil or renewable fuels (bio-fuels), to electric, hybrid, fuel cell or even a combination of these systems.

However, the automotive motorization technology that shall predominate in the near future still attracts a significant amount of debate and speculation and to date, scarce consensus (Book, 2009).

2 ELECTRIC MOTORIZATION

2.1 TECHNICAL ASPECTS OF ELETRIC MOTORIZATION

Current electric vehicles — whether undergoing tests, already launched or announced — resort to one or more of four types of technologies.

Hybrids or Hybrid Electric Vehicles (HEV) combine the power of an electric motor with that of a conventional internal combustion engine (ICE), fuelled with gasoline or biofuel. They cover short initial distances (10 to 15 kilometers) exclusively with electricity and when batteries die down or when the vehicle reaches a given speed, an internal combustion engine starts operating, driving the wheels and also recharging the set of batteries. The currently most sold hybrid model, the Toyota Prius, was launched in 1997 and by the end of 2010 totalled two million commercialized units.

The parallel hybrid configuration uses both engines – the internal combustion and the electric – to supply mechanical propulsion to the wheels, jointly or independently. In the series configuration, the wheels are mechanically connected only to the electric motor; the ICE generates electricity directly to the electric motor and to recharge the batteries.

The plug-in hybrids or Plug-in Hybrid Electric Vehicles (PHEV) also combine the ICE and electric motor however, the latter may be recharged at the charging stations. It has been enviosioned that, in the future, these vehicles will even be able to store electricity and return it to the network at peak times.

All the hybrids on the market have a regenerative breaking system that captures the vehicle´s kinetic energy and transforms it into electricity.

In pure electric vehicles or Battery Electric Vehicles (BEV) the battery must be recharged at the charging stations (primary energy source), given that an electric vehicle does not have capability on board to recharge the set of battery cells. Current models use lithium ion batteries that provide between 120 and 150 kilometers autonomy. An alternative business model, designed for the vehicle not to remain stationery for recharge purposes and given the high cost of the battery – approximately US$ 10 thousand – is to set up a network of sites where batteries might be exchanged and owners might have access to, on a lease basis (Renault-Nissan proposal).

Still in the research and testing phase, there is the technology of Fuel Cell Electric Vehicle (FCEV), in which the fuel cell converts an energy carrier (e.g., hydrogen) into electricity. Hydrogen can be fueled directly in the vehicle or can be produced on board of the vehicle when other fuels, like gasoline, ethanol or methanol, are used as fuel (Inovação Unicamp, 2009; International Energy Agency [IEA], 2009).

2.2 ELECTRIC VEHICLE HISTORY

At the end of the XIX$^{th.}$ Century, an era of intense fermentation of competing automotive propulsion technologies was observed. At the time, external combustion vapour engines (ECE), internal combustion engines operating with fossil and biofuels and electric engines coexisted and competed one with another.

The invention of the first internal combustion engine was credited to Etienne Lenoir, who in 1860 assembled such an engine on a tricycle powered by coal gas. However, production on an industrial scale arose via Nikolaus Otto´s hands in 1876, with engines utilising gaseous and liquid fuels – gasoline and alcohol versions (Clymer, 1950).

Nevertheless, during this period the greater share of market sales was that of the electric motor vehicle, invented in 1834 and pioneering mounted on a car in 1838 by Robert Davidson (Chan, 2002). During the last decade of the XIX$^{th.}$

Century there were several manufacturers of electric vehicles in Europe and in the United States.

Electric motorization soon lost it´s share to internal combustion engines - despite being characterized by simpler handling *vis a vis* other competing alternatives given that, in addition to being silent, it does not produce polluting gases – in part for reasons associated with the low autonomy of batteries, extended time of battery recharge as well as their limited lifespan. To date, technological bottlenecks in electric vehicles persist and they pratically dissapeared from the scenario as of 1930 (Chan, 2002; Didik, 2001).

At the beginning of the XX$^{th.}$ Century (period 1900-1920) the dissemination of internal combustion engines powered by gasoline was rapid, most probably not for technical reasons but mainly due to favourable factors in the socio-economic and organizational contexts – the externalities to technology. The oil industry contributed with the installation of an extensive network of fuel distribution, the intense exploration activity slashed petroleum prices, in addition to the notable expansion verified in the road network, particularly in the United States (Taminiau, 2006; van der Wal, 2007). Thus, the internal combustion engine technology was sovereign during the entire XX$^{th.}$ Century.

One might consider that the modern history of electric vehicles started in the 70´s as oil prices soared, providing further arguments to environmental pressures in favour of the electric vehicle option, with views to reducing the consumpt of this type of fuel.

One of the iniciatives that became notorious at the time refers to the rule passed by the California Air Resources Board (CARB), dated 1990, which sets forth that as of 1998 an increasing percentage of future car sales, within the mentioned American state, should be of the zero emission. Coping with the enourmous resulting market given this and other similar rulings, qualifies the electric vehicle as a natural candidate.

Sales picked up again in the mid 90´s in the United States via General Motors (GM), that launched the EV1 model in 1996, the first electric mass produced car. This manufacturer was followed by Ford (Think and Ranger), Honda (EV Plus), Toyota (RAV4) and Nissan (Altra EV). All these models were only sold under leasing conditions, at a cost of 250 to 600 dollars per month. Despite success amongst users, in 1999, the EV1 no longer was manufactured. GM had invested US$ 1 billion in the development of the model during the 90´s but decided to discontinue the project, claiming that it was impossible to profit under leasing terms. The equivalent price of the EV1 would be US$ 44 thousand to users but it´s production cost for GM exceeded US$ 80 thousand (Maynard, 2008).

At the start of the current decade, all other manufacturers decided to withdraw the electric cars from circulation and, by force of the same leasing system, demanded that consumers return the vehicles.

Over the past few years, the concept of electromobility expanded and became a strategic research and development priority at all car manufacturers. Competition in terms of electric vehicles picked up and attracted more participants.

Toyota, world sales leader which till recently concentrated efforts in hybrid models, announced massive investments in the development of full electric propulsion by presenting, at the end of 2010, the RAV4 EV prototype, with production start scheduled for 2012 (Vinholes, 2010). Nissan, on the other hand, started in October 2010, in Japan, the large scale manufacturing of the electric model Leaf – initially 50,000 units per year – and forecasting a second plant in the United States by 2012.

In Brazil, the year 2010 accounted for the introduction of the sales of electric cars with the launch, on the domestic market, of Ford´s Fusion Hybrid model, produced in Mexico (Mora, 2010).

3 RESEARCH METHODOLOGY – CONCEPTUAL ASPECTS

3.1 THE CONSTRUCTION OF SCENARIOS

A scenario is a rich and detailed picture of a feasible future world that enables the planner to clearly identify and understand problems, challenges and opportunities which such an environement might present, according to the definition set forth by The Future Group (Glenn, 1999).

For A. Porter et al. (1991) however, scenarios are partial sketches of some aspects of the future that can be structured in an entirely narrative format or even detailed models with quantitative data. Further, in Godet´s (1993) perspective, a scenario must include key player actions and the estimated probability of uncertain events, articulated in such a manner as to describe the transition from the original situation to another in a future moment in a consistent manner.

Given the vast number of existing variables in the real world and the complexity of its interactions, it is far more attractive to work with various future possibilities or multiple scenarios.

However, amongst the main authors, the idea of presenting, at the end of the study, only a handful of scenarios, is consensual. For M. Porter (2002), an adundance of scenarios might drive analysis costs to such an extent that strategic issues become less relevant; three or four scenarios would be enough to reduce uncertainties and stimulate decision makers to engage in new challenges with views to improving the building of the set of scenarios so as to cover the possibilities of future occurrence of relevant variables, analysed in a systemic manner and by means of coeherent hypothesis (Sturari, 2008).

Given that strategic thinking leads to long term envisioning, the prospection of future scenarios might be understood as a valuable support instrument to corporate investment decisions, competitive intelligence, new products, markets, etc.

Mason (1994) states that planning based on scenarios consists in looking ahead, in a creative and open manner, in search of emerging patterns, which leads to a learning process as to the future. Schoemaker (1995) reinforces the importance of structuring (discipline) the various methodologies so as to envision the future so that common mistakes might be avoided such as overestimating or underestimating the pace and impact of changes. Ringland (1998) also mentions in special, improvements in the quality of decisions and comprehension of implications for corporate competitive strategies, given sound scenario planning.

Therefore, the preparation of future scenarios, considering multiple and uncertain alternatives does not consist in an exercise in search of precision in predictions, but rather, in an effort to describe consistent and feasible possible future situations, constituting a fundamental tool for the strategic planning of public and private institutions as presented by Wright and Spers (2006).

Various methods for the development of scenarios have been reported in literature. Each situation where scenarios were utilised provides a new opportunity of enriching the method with techniques and more elaborate procedures or simply search a more adequate approach to the situation under study (Nóbrega and Stollenwerk, 1999).

The long term scenario preparation method developed by the Administration Institute Foundation´s (FIA/USP) Future Studies Program, foresees a sequence of events that include: identification and structuring of variables, trends and critical scenario events; forecasting of variable future conditions with their probabilities of occurrences and the identification of different driving themes for each scenario whereby these themes (variables or critical uncertainties) are the elements that drive the scenario maps, determining the story´s development. Irrespective of the scenario construction method, the next phase consists in combining forecast future states for core variables in a consistent manner, utilizing morphological analysis techniques, a step that procedes the written description and validation of future scenarios (Wright & Spers, 2006).

In this study, the Morphological Analysis method is emphasised to structure and evaluate the combination of critical parameters (variables) and the different forms (alternatives) presented by them to compose future scenarios.

3.2 MORPHOLOGICAL ANALYSIS

Morphological analysis is a non-quantitative technique for the structuring and evaluation of the set of relations inherent to a complex multidimensional problem, proposed by Fritz Zwicky in the 60´s (Zwicky, 1969). A. Porter (1991) classifies it as a structural prospection method given it explicitly considers the interrelations between technological variables and other elements of the context.

Godet´s scenario preparation method is structured in three phases. It starts with the construction of the analytical and historical base of the current system, including the identification of variables and its relations, as well as with the positioning of interested parties in view of the variables. Furthermore, prior to the phase of scenario preparation – possible intermediate and final status – there are exploration activities involving possible evolutions that, by means of a morphological analysis, decompose the studied problem into essential dimensions, defining and analysing those most probable (Ribeiro, 1997).

The method´s basic hypothesis is that a complex problem might be decomposed into fundamental variables (major elements and basic functions) that are subject to systematic analysis of the alternative shapes these might take on, thus generating a set of states or values.

Problem fraccioning is logic to the extent that it deals with less complex issues than the original system ensuring a deeper analysis of parts (subsystems with different forms and functions). Fractions are based under varied criteria and may be per activities or functions developed by subsystems, by object attribute, concepts or technologies.

Combining all these states one may lay forth the entire universe of possibilities that the issue might present. Those which are intrinsically inconsistent, technically unfeasible and economically unsustainable are discarded, generating selected alternative groups – a multidimensional matrix – that form the base for the development of scenarios. Innovations emerge from the recombination of feasible subsystems (existing or conceptual) in new, to be explored, options.

The morphological dimensions of the generated matrix are defined by the elements, functions or parameters and by the alternative forms and might take on "n" dimensions according to the problem´s complexity and the ambition of the research group.

Given that morphologic analysis is a technique that promotes the forecasting of the set by means of the analysis of it´s component parts, interdisciplinary solutions and creative speculation (Johnson et al., 1987) ends up favouring the generation of ideas concerning innovative alternatives and new connections between technical and environmental subsystems. Therefore, the method stimulates creativity and promotes novelty upon presenting for evaluation, combinations of situations that would be neglected or even rejected by linear rationale (Nóbrega & Stollenwerk, 1999).

4 MORPHOLOGICAL ANALYSIS OF THE INTRODUCTION OF ELECTRIC VEHICLES IN SÃO PAULO´S URBAN TRAFFIC

To facilitate the structuring of complex questions involving technological options that impact the social-economic-environmental context, such as the challenge to prospect technological alternatives for transportation modes in the municipality of São Paulo – focus on electric vehicles – the morphological analysis technique was utilized with views to identifying the variables and critical relations for the subsequent construction and analysis of future scenarios.

4.1 SCOPE DEFINITION

The present study intends to contribute with the CNPq/FINEP research project "Introduction of Electric Vehicles in São Paulo´s Urban Traffic: Impact Analysis in Multiple Scenarios and Contributions for the Sustainable Urban Mobility" , which is being developed by a group of São Paulo University´s (USP/FEA) researchers, under the coordination of Prof. James T. C. Wright.

The core issue of the research is to prospect alternative technologies for transportation modalities and analyse social, economic and environmental impacts concerning its adoption in the municipality of São Paulo, and, specifically, for the alternative of electric vehicles in the future year 2020 scenario.

To analyse the impact of the introduction of electric vehicles in São Paulo´s urban traffic a set of specific methodologies must be applied and an overview to this effect is hereinafter presented (Wright & Spers, 2000).

To prepare medium and long term scenarios, the proposal is to follow a sequence of activities which includes the identification of scenario critical variables, built by means of the model analysis and structuring technique; the prospection of variable trends (trend extrapolation and application of the Delphi technique) - duly structured by means of morphological analysis - with the intent of preparing a matrix of the scenarios that provides the information for the analysis of impacted trends (Martino, 1993; Schoemaker, 1995).

4.2 IDENTIFICATION OF FUNDAMENTAL VARIABLES

This stage was prepared via mapping and analysis of specialized bibliography in the fields of engineering and automotive businesses, without calling on the collaboration of specialists on the theme, at this initial fase of the methodological research. Nevertheless, it is worth acknowledging the valuable contribution posed by such groups in as much as generating ideas and exchanging an assortment of knowledge and experiences, is concerned.

The variables that influence an urban transportation system were structured into four logical groups: SCOPE, as related to the purpose of use, if for the transport of passengers and/or goods; VEHICLE, as related to the structural architecture and propulsion system: powertrain, energy storage and performance; INFRA-STRUCTURE, road restriction and energy supply/recharge; BUSINESS MODEL. These groups, in turn, were decomposed into distinct levels, giving rise to other variables, namely, in the current exploratory exercise, a total of 18 parameters or variables, to be analysed. Attempts were made not to restrict suggestions at this stage. The structuring of variables is presented in Figure 1.

4.3 CONSTRUCTION OF THE MULTIDIMENSIONAL MATRIX FOR VEHICULAR TRANSPORT SYSTEMS

Subsequently, a session to generate proposals and suggestions concerning alternative forms that the selected variables could take on was promoted. As mentioned, the exploratory exercise was conducted by the author, however, the intent is to expand participation to include specialists in the field under study.

The set of alternatives or possible states, associated with the parameters (variables) is also represented in Figure 1.

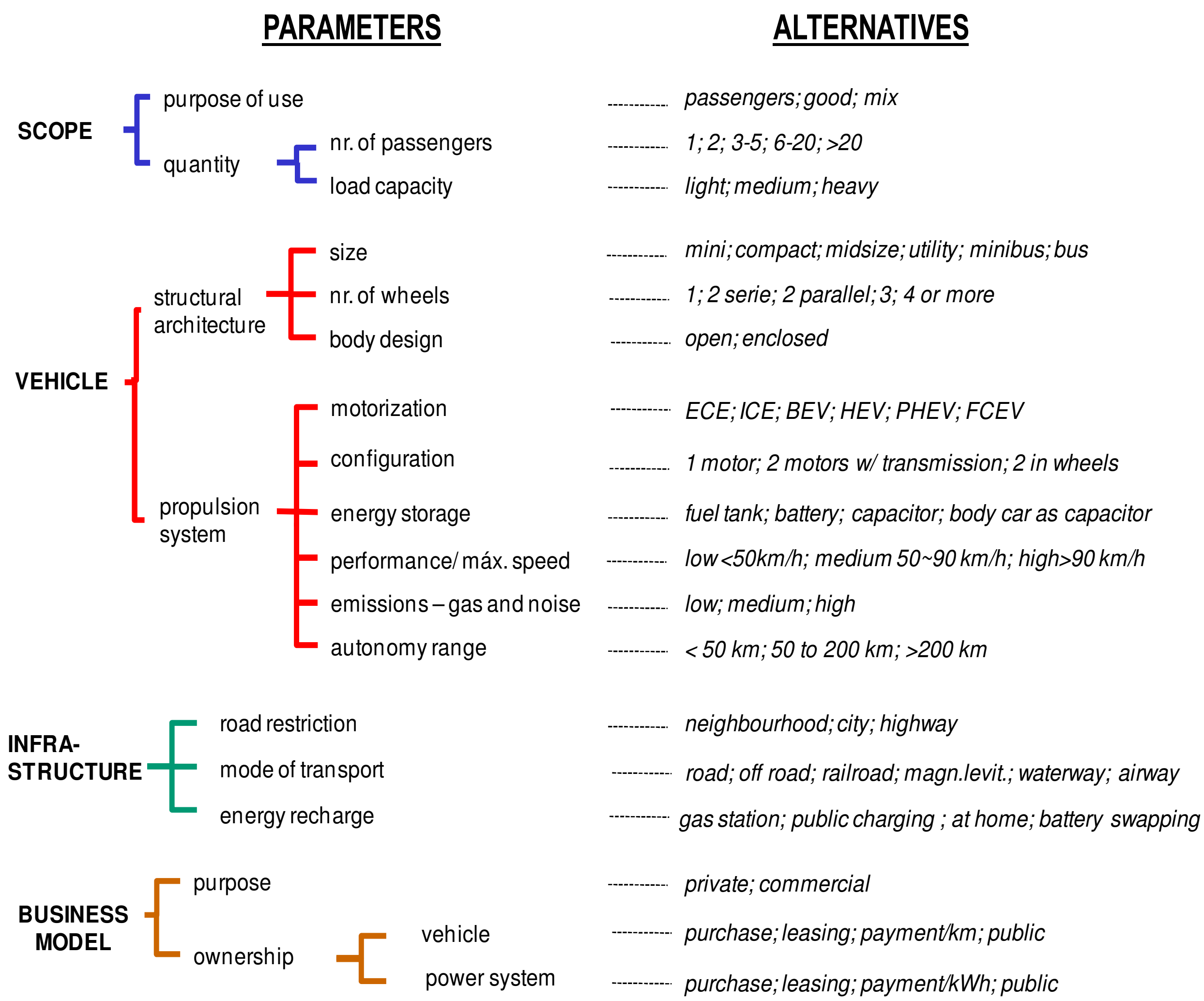

Figure 1: Selected parameter (variables) and alternatives structure for vehicular transport system. Source: prepared by the author

As can be noted, the total sum of possibilities that arose renders, as expected given complex systems, a significantly high number:

Scope = 3 x 5 x 3 = 45 combinations

Vehicle = 6 x 5 x 2 x 6 x 3 x 4 x 3 x 3 x 3 = 116,640 combinations

Infra-structure = 3 x 6 x 4 = 72 combinations

Business Model = 2 x 4 x 4 = 32 combinations

VEHICULAR TRANSPORT SYSTEM = 45 x 116,640 x 72 x 32 = 12,093,235,200

If one resorts to morphological analysis, slightly more than 12 billion possible configurations arise. The multidimensional matrix generated as of this set of parameters and alternatives is to be found in Figure 2.

The next step proceeded with a careful analysis of the feasibility and consistency of the configurations generated concerning the proposed issue.

MORPHOLOGICAL ANALYSIS - Vehicular Transport System

PARAMETERS	SCOPE			VEHICLE - structural architecture and propulsion system									INFRA-STRUCTURE			BUSINESS MODEL		
ALTERNATIVES	purpose of use	nr. of passenger	load capacity	size	nr. of wheels	body design	motorization	configuration	energy storage	max. speed	emissions	autonomy range	road restriction	mode	energy recharge	purpose	vehicle ownership	power system ownership
alternative 1	passengers	1	light	mini	1	open	ECE	1 motor/ engine	fuel tank	low <50 km/h	low/zero	< 50 km	neighbourhood	road	gas station	private	purchase	purchase
alternative 2	good	2	medium	compact	2 serie	enclosed	ICE	2 motors w/ transmission	battery	medium 50 to 90 km/h	medium	50 to 200 km/h	city	off road	public charging	commercial	leasing	leasing
alternative 3	mix	3 - 5	heavy	midsize	2 parallel		BEV	2 in wheels	capacitor	high > 90 km/h	high	> 200 km/h	highway	railroad	at home		payment/km	payment/kWh
alternative 4		6 - 20		utility	3		HEV		body car as capacitor					magn. levitation	battery swapping		public	public
alternative 5		> 20		minibus	4 or more		PHEV							waterway				
alternative 6				bus			FCEV							airway				

Figure 2: Multidimensional matrix of a vehicular transport system

Source: prepared by the author

4.4 FEASIBILITY EVALUATION FOR THE INTRODUCTION OF ELECTRIC VEHICLES IN SÃO PAULO´S URBAN TRAFFIC

Taking the group of variables pertaining to the SCOPE into account, choice fell upon restricting the evaluation, at first, to the introduction of electric passenger cars and motorcycles, considering that cargo and mixed vehicles are already subject to restricted circulation in most of São Paulo´s metropolitan area.

In the VEHICLE group, a large assortment of alternatives was maintained related to the vehicle´s structural architecture, a trend when it comes to electric vehicles in circulation in Europe and in the United States (Clemenger, 2008). In terms of automotive propulsion systems however, considering the relatively short period of one decade, the study will concentrate on the use of the electric motorization technology, with power generation and supply via the electric network and with the possibility of the conventional engine resorting to complementary propulsion in hybrid plug-in systems, whilst the power storage system relies on batteries.

In terms of road INFRA-STRUCTURE, the only alternative taken into account was that of roadways, maintaining the choice of electric battery recharge alternatives open, given forecasts concerning a period of fermentation, with several technical and corporate options for an eventual bottleneck in the supply of this new source of vehicular power.

The same rationale was employed when the BUSINESS MODEL possibilities matrix was kept wide open, considering the introduction of the innovative transportation system in the city of São Paulo.

The alternatives selected are represented in the matrix of Figure 3.

After the previously mentioned considerations, a new total of slightly more than two million possibilities - still a high figure - were calculated:

Scope = 1 x 3 = 3 combinations
Vehicle = 3 x 4 x 2 x 2 x 3 x 2 x 3 x 2 x 2 = 3,456 combinations
Infra-structure = 3 x 1 x 4 = 12 combinations
Business Model = 2 x 3 x 3 = 18 combinations

SÃO PAULO ELECTRIC VEHICLES Program =3x3,456x12x18= 2,239,488 combinations

MORPHOLOGICAL ANALYSIS - Electric Vehicles (cars and motorcycles) in SÃO PAULO's Urban Traffic

PARAMETERS	SCOPE		VEHICLE - structural architecture and propulsion system									INFRA-STRUCTURE			BUSINESS MODEL		
ALTERNATIVES	purpose	nr. of passenger	size	nr. of wheels	body design	motorization	configuration	energy storage	max. speed	emissions	autonomy range	road restriction	mode	energy recharge	purpose	vehicle ownership	power system ownership
alternative 1	passengers	1	mini	2 serie	open	BEV	1 motor	fuel tank + battery	low <50 km/h	low	< 50 km	neighbourhood	road	gas station	private	purchase	purchase
alternative 2		2	compact	2 parallel	enclosed	PHEV	2 motors w/ transmission	battery	medium 50~90	medium	50 to 200 km/h	city		public charging	commercial	leasing	leasing
alternative 3		3 - 5	midsize	3			2 in wheels		high > 90 km/h			highway		at home		payment/km	payment/kWh
alternative 4				4 or more										battery swapping			

Figure 3: Multidimensional matrix of electric vehicles in São Paulo.

Source: prepared by the author

4.5 ANALYSIS OF SELECTED CONFIGURATIONS

For illustrative purposes, some of the configuration possibilities may be identified and individualized from Figure 2´s matrix.

At the end of year 2010, most of the seven million fleet of vehicles that move around in the metropolitan region of São Paulo is concentrated in the configuration of compact and mid-sized passenger cars (5.1 million) and motorcycles (0.9 million), both with conventional motorization powered by liquid fuels (gasoline or bioetanol). These configurations are described via the set of alternatives selected in Figure 4´s matrix.

MORPHOLOGICAL ANALYSIS - Conventional Passenger Vehicles (cars and motorcycles)

PARAMETERS	SCOPE		VEHICLE - structural architecture and propulsion system									INFRA-STRUCTURE			BUSINESS MODEL		
ALTERNATIVES	purpose	nr. of passengers	size	nr. of wheels	body design	motorization	configuration	energy storage	max. speed	emissions	autonomy range	road restriction	mode	energy recharge	purpose	vehicle ownership	power system ownership
alternative 1	passengers	1	mini	2 serie	open	BEV	1 engine	fuel tank	low <50 km/h	low	< 50 km	neighbourhood	road	gas station	private	purchase	purchase
alternative 2		2	compact	2 parallel	enclosed	PHEV	2 motors w/ transmission	battery	medium 50~90	medium	50 to 200 km/h	city		public charging	commercial	leasing	leasing
alternative 3		3 - 5	midsize	3		ICE flex-fuel	2 in wheels		high > 90 km/h			highway		at home		payment/km	payment/kWh
alternative 4				4 or more										battery swapping			

Figure 4: Multidimensional matrix indicating the São Paulo 2010 traffic:cars and motorcycles with conventional motorization.

Source: prepared by the author

With respect to electric vehicle recently launched, the Chevrolet Volt and the Nissan Leaf models (Figure 5), which are amongst the three finalists for the Year 2011 Car of the Year Award granted by the North American Automotive Press Association, were chosen in this study.

Figure 5: Chevrolet Cars Volt PHEV (left) and Nissan Leaf BEV (right).

From a morphological analysis perspective, if one evaluates the hybrid electric automobile (PHEV) Chevrolet Volt launched in 2010, with a 10,000 units production forecast for the year 2011, one might envision the configuration presented in the matrix of Figure 6. The architecture of the vehicle and of the propulsion set is closed and some car selling and/or electric power recharge alternatives might be considered.

Considering the battery electric model (BEV) Nissan Leaf that is already being produced in Japan – initially 50,000 units per year and a forecast of 200,000 per year as of 2012 –, this car´s configuration is presented in Figure 7´s matrix.

The automobile reaches a maximum speed of 140 km/hour, powered by lithium ion batteries. With autonomy of 160 km, the model requires eight hours to be recharged at a conventional 220 volts socket or 30 minutes at a quick recharge station. Leaf model technologies include the regenerative breaking system and a solar collector situated on the hood of the trunk of the car that supplies power for minor functions inside the vehicle. Several car sales, storage system and electric power recharge alternatives were kept open to draw attention to the business opportunities to be explored.

MORPHOLOGICAL ANALYSIS - Electric Vehicles in SÃO PAULO's Urban Traffic

PARAMETERS	SCOPE		VEHICLE - structural architecture and propulsion system									INFRA-STRUCTURE			BUSINESS MODEL		
ALTERNATIVES	purpose	nr. of passenger	size	nr. of wheels	body design	motorization	configuration	energy storage	max. speed	emissions	autonomy range	road restriction	mode	energy recharge	purpose	vehicle ownership	power system ownership
alternative 1	passengers	1	mini	2 serie	open	BEV	1 motor + 1 ICE	battery + fuel tank	low <50 km/h	low	< 50 km	neighbourhood	road	gas station	private	purchase	purchase
alternative 2		2	compact	2 parallel	enclosed	PHEV	2 motors w/ transmissio	battery	medium 50~90	medium	50 to 200 km/h	city		public charging	commercial	leasing	leasing
alternative 3		3 - 5	midsize	3			2 in wheels		high > 90 km/h			highway		at home		payment/ km	payment/kWh
alternative 4				4 or more										battery swapping			

Figure 6: Multidimensional matrix of electric vehicles in São Paulo, indicating the introduction of the PHEV Chevrolet Volt.

Source: prepared by the author

MORPHOLOGICAL ANALYSIS - Electric Vehicles in SÃO PAULO's Urban Traffic

PARAMETERS	SCOPE		VEHICLE - structural architecture and propulsion system									INFRA-STRUCTURE			BUSINESS MODEL		
ALTERNATIVES	purpose	nr. of passengers	size	nr. of wheels	body design	motorization	configuration	energy storage	max. speed	emissions	autonomy range	road restriction	mode	energy recharge	purpose	vehicle ownership	power system ownership
alternative 1	passengers	1	mini	2 serie	open	BEV	1 motor	fuel tank	low <50 km/h	low/zero	< 50 km	neighbourhood	road	gas station	private	purchase	purchase
alternative 2		2	compact	2 parallel	enclosed	PHEV	2 motors w/ transmission	battery	medium 50 to 90 km/h	medium	50 to 200 km/h	city		public charging	commercial	leasing	leasing
alternative 3		3 - 5	midsize	3			2 in wheels		high > 90			highway		at home		payment/km	payment/ kWh
alternative 4				4 or more										battery swapping			

Figure 7: Multidimensional matrix of electric vehicles in São Paulo, indicating the introduction of the BEV Nissan Leaf.

Source: prepared by the author

4.6 EVALUATION OF CONSISTENCIES AND SELECTION OF THE CONFIGURATIONS OF INTEREST

The next phase, following the morphological analysis process, deals with consistency evaluations of combinations, resulting from the alternative parameters of the multidimensional matrix. An example of inconsistency is a vehicle configured with a single wheel, powered by two electric engines – parameters interconnecting the vehicle´s architecture with the propulsion system.

From a technological aspect, it would be incompatible for a battery electric vehicle producing gas emissions via the exhaustion system (non existent), or a vehicle with hybrid propulsion (gasoline and electric engines) developing a maximum speed of 50 km/h and/or with less than a 50 km autonomy.

A careful technical evaluation points out the non feasibility of several other sets of alternatives. Various other technically difficult configurations, though possible, might be subject to verification of potential benefits versus technical complexity.

A complementary evaluation of economic feasibility might discard several other configurations such as the construction of a midsized vehicle/four wheels, with a complex hybrid motorization (two engines) for one single passenger.

The result of these evaluations, under distinct approaches, is the reduction of the multidimensional space which initially considered all combining possibilities, identifying basic configurations of greater interest for the forecasting effort during the subsequent scenario building stage.

At this point, the participation of other specialists on the theme was considered vital so as to enrich the discussion with specific knowledge, other distinct experiences and perspectives.

5 FINAL CONSIDERATIONS

The construction of prospective scenarios, providing an overall vision of the challenges and opportunities inherent to complex problems, promotes an optimized modality of comprehending the articulations between the many variables present which, in turn, impact future situations.

It is expected that, upon dealing with the technological and managerial complexities related to the introduction of electric vehicles in São Paulo´s urban traffic, the Morphological Analysis process might instigate creativity towards the suggestion and development of new solutions. In addition, it might contribute with the effort to systemize the generation of knowledge for an improved evaluation of the critical issues related to the distinct configurations that might appear.

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