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Neuro-Fuzzy-Integral Model for Holistic Evaluation of an Urban Magnetic Levitation Transportation System

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Abstract

Nowadays, the management of manufacturing operations and services must respect the principles of sustainability. Various aspects involved, inherent in the production of goods or facilities and in the environment, should be considered. An Environmental Management System (EMS) allows planning, organizing, and carrying out the operational and environmental actions in a methodical and effective way. With reference to the implementation of an urban magnetic levitation transportation system, called MagLev-Cobra, this paper proposes an EMS model which results in the establishment of a Systemic Sustainability Indicator (SSI). This tool provides a simple but rigorous and objective method for analyzing, comparing, and evaluating the impacts of the project under the principles of sustainability. Concepts of Fuzzy Theory and Neural Networks were applied to obtain the SSI, which brings together the 39 environmental indicators proposed in the EMS of the MagLev-Cobra system, allowing a holistic evaluation. The modeling used followed the ANFIS standards for grouping the indicators, converting Fuzzy variables into indicators after Defuzzyfication. A Microsoft Access application was developed to generate the SSI. The model reveals that 69% of the indicators confirmed the adequacy of MagLev-Cobra sustainability; 25% showed average adequacy; and only 12% demonstrated low compliance with these precepts.

Keywords: Magnetic levitation, MagLev-Cobra, Fuzzy, Environmental management system, Sustainability.

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1 Introduction

Globalization, which is the result of the increase in commercial relations worldwide, brings together fast technological development determined by the necessity to reduce costs and to increase the level of the services provided, especially due to a change in consumers' consciousness regarding their role in the development of society.

In addition, there is an increasing need for using natural resources for the development of society, thus creating greater and more severe environmental impact and also leading to the deterioration of the quality of life. The mentioned impact should be analyzed according to the socioeconomic, political, and cultural contexts in which changes occur. From this point of view, it is important for society to tie its development to environmental protection; that is, development should be sustainable.

According to Newman et al. (1999) as cited in Ribeiro (2001), the concept of sustainability includes the greatest necessities these days, such as economic development, environmental protection (society depends on the environment to continue developing), and, finally, social justice. The universally accepted definition of Sustainable Development, which has been widely used by laymen and experts from all over the world, was presented in the Brundtland report as "the development that fulfills the needs of the present without limiting the potential for meeting the needs of future generations" (CMMAD, 1988).

Due to these aspects, it is worth noting that nowadays it is essential to manage productive systems, such as transportation, or facility service systems which are in conformity with the principles of sustainability, considering the various aspects involved, such as those inherent in the production of goods and services and the environment, which, to a certain extent, is always interacting, prodding and being prodded regarding its intrinsic features. More studies that link transportation and sustainability can be found in Litman (2008), MIT (2009) and EPA (2011).

2 Objective

The objective of this paper is to take an Environmental Management System (EMS) that was previously developed for operational control of the magnetic levitation transportation system called MagLev-Cobra and suggest a model for obtaining a Systemic Sustainability Indicator (SSI) to analyze and represent environmental conditions over time, according to the principles of sustainability.

The SSI will bring together the environmental indicators suggested by the EMS, allowing a holistic evaluation of the MagLev-Cobra system. In addition, according to management necessity, it will also be able to analyze the system under specific environmental concerns through partial indicators.

Fuzzy Theory, together with the Neural Network techniques, will be used to create the SSI and the partial indicators. For its automation, Excel and Access applications from Microsoft Office Professional will be used.

This paper is also aimed at applying the model to determine the partial indicators, in addition to the SSI, by using computerized applications, thus making it possible to validate the model.

2.1 Background

When public urban transportation is not appropriately planned, its activities create negative impacts (Paes, 2006). From an economic perspective, they cause traffic jams, car accidents, and high operational costs; from a social perspective, problems related to mobility, health, and quality of life; and from a physical perspective, air, water, soil, noise, and visual pollution.

The lack of planning or inefficient planning and control of this facility helps to create environmental liabilities; that is, components in the physical, biotic, and man-made environments which are highly damaged. If these components are not systematically recovered, the damages can increase significantly, thereby jeopardizing the quality of life of the population and the continuity of services.

It is worth mentioning that the Brazilian Environmental Crime Act, N° 9.605 (1998) imposes penalties and management sanctions against people or entities performing activities that are harmful to the environment, even if they are performed involuntarily or indirectly.

Therefore, although it is well-known that the operation of urban transportation systems that use magnetism as the main technological foundation does not involve greenhouse gas emissions and does not produce noise or vibrations, it is important to study the environmental aspects that come into play. In addition, it contributes to the rationalization of the existing urban infrastructure.

Regarding urban mobility, initial research indicates that the use of MagLev-Cobra as the main transportation option to be integrated with the existing infrastructure will make significant advances related to the rationalization of the public urban transportation system and will also make it possible to create a peripheral network for the principal transportation corridors, thus reducing the saturation effects of urban traffic.

A Magnetic Levitation Vehicle is an energetically efficient transportation system that does not produce noise, vibration or gas emissions. In addition, its implementation is cheaper than that of other similar rail systems.

MagLev-Cobra was developed based on the characteristics of Superconducting Levitation in order to take advantage of existing urban infrastructure. Its guiding principle is the possibility of making curves of small radius and keeping the load uniformly distributed over the road.

Superconducting Levitation (SML) seems promising for medium-speed transportation applications (lower than 70 km/h). It is based on the physical property of diamagnetism, which, in superconductors, eliminates the magnetic field inside them.

The transportation capacity of each MagLev train increases as more units are added according to demand. The units with doors can be located at different points of the train, as each unit is an independent structure. The seats can be arranged transversely or longitudinally.

The MagLev-Cobra is driven by a short-primary-type linear electric induction motor (LIM). It works with straight line motion rather than rotation, and it is the component responsible for motorizing magnetic levitation trains, which are designed such that there is no contact with the guideway.

More information about the MagLev-Cobra can be obtained in Stephan *et al.* (2007), Stephan *et al.* (2008) and David *et al.* (2009).

3 Methodology

In order to accomplish the proposed objective, the following steps were taken:

- First step: characterization and adaptation of the Input Variables to convert them into Fuzzy variables. Analysis of the 39 environmental indicators of the EMS of the MagLev-Cobra system and the definition of coding, universe of discourse and its units, linguistic terms, and membership functions.
- Second step: problem modeling in order to obtain the SSI. Use of Neural Network concepts and the ANFIS Model by grouping the

input variables in a structured manner, thus making it possible to create the partial indicators that will converge into the SSI.

- Third step: characterization and adaption of the Output Variables to transform them into Fuzzy Variables: by means of the network defined in the previous step, the output variables could be defined, as well as the coding, the universe of discourse, the linguistic terms, and the membership functions.
- Fourth step: definition of the Fuzzy Integrals: in a Neural Network there are devices called neurons that process the input variables and transform them into output pulses. These devices, which are called multiplexers in this paper, have layers with specific activities. The first layer is called Fuzzification, as it receives the input variables and transforms them into Fuzzy sets via Fuzzy integrals.
- Fifth step: creation of rules of inference and generation of output pulses: the Fuzzy sets are processed by means of the rules of inference that will make it possible to generate output pulses through defuzzification. For this step it was necessary to develop a computerized application in Microsoft Access that creates the rules of inference, processes the results, and generates the output pulses.
- Sixth step: model application: Using the computerized applications mentioned in the 4th and 5th steps, values will be submitted to the input variables of the model, and they will generate the output pulses. These will be the input in the next multiplexers until the SSI can be obtained.

3.1 Theoretical Background

3.1.1 The Fuzzy Theory

Fuzzy Theory emerged in 1965 with the publication in *Information and Control* magazine of the paper entitled Fuzzy Sets, by Lofty A. Zadeh, from the University of California, Berkley. This theory consists in modeling problems that can handle quantitative and/or qualitative variables by building algorithms based on the architecture of the consensual thought of experts or systems users. Zadeh et al. (1975) say that one of the greatly useful applications of Fuzzy Theory is in translating linguistic terms used in daily communication (natural language) into math expressions, by means of the properties of Fuzzy sets.

In formal logic, a Fuzzy set "A", defined in the universe of discourse "U", is characterized by a membership function "μ A", which maps the elements of "U" for the interval [0,1], i.e., μ A:U => [0,1]. A set of the classical set theory can be considered as a specific Fuzzy set which is usually called "crisp", where μ A:U => {0,1}. Therefore, the membership function associates a real number "μ A(x)" to each element "x" of "U" in the interval [0,1], which represents the degree of possibility (or degree of membership) of the "x" element belonging to the set "A".

The degree of membership μ A(xi) indicates the extent to which the element xi belongs to Fuzzy set A. Thus, this set can be represented by ordered pairs of a generic elements "x" and their degree of membership, as A= {x, μ A(x) | x ∈ U}. A Fuzzy singleton set "A" has a single point "x", belonging to "X", represented in the universe of discourse, with μ A(x) = 1.

In order to represent a discrete Fuzzy set A, the formation A= {μ A(x1) / x1, μ A(x2) / x2, ..., μ A(xn) / xn}is used, where the symbol "/" is only a separator. When the universe of discourse U

is discrete, the Fuzzy set A can be represented by A= ∑ μ *A* (*x*) / x.

$x \in U$

When the universe of discourse U is continuous, the Fuzzy set A is expressed by the Fuzzy integral as follows: A = ∫ μ *A* (*x*) / x.

U

It is worth mentioning that the symbols "∑" and "∫" are used to represent the logical union operation; thus, they do not represent the summation and integration operators generally used.

3.1.2 Neuro-Fuzzy Networks

The Artificial Neural Networks (ANN) are distributed parallel systems that are inspired by the functional aspects of the human brain and which can learn to predict the real world and adapt to it. They consist of simple processing units, called "neurons", which process certain relations. These units are arranged in one or more layers and are interconnected by connections.

The neuron model proposed by McCulloch and Pitts in 1943, which is called McCulloch–Pitts (MCP), is a simplification of the biological neuron described at that time. It consists of *n* inputs and one output, as shown in Figure 1. (Medeiros *et al.*, 2003).

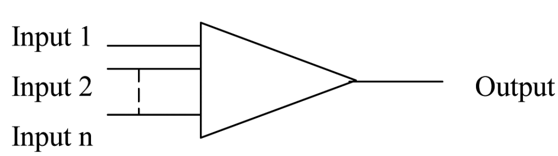

Figure 1: MCP neuron model.

According to Souza (1999), Neuro Fuzzy Systems (NFS) are one of the most studied hybrid systems nowadays, as they combine the technical advantages of ANNs with Fuzzy Theory. Internally, these systems map the Fuzzy regions from the input space onto the Fuzzy regions of the output spaces by means of Fuzzy inference rules.

The NFS consists of three stages of fuzzy reasoning called 'layers' (the name comes from ANNs), with the following features:

- Fuzzification layer of the input variables: it receives the input variables (crisp) and transforms them into Fuzzy sets.
- Intermediate layer (hidden layer): it receives the fuzzy sets from the previous layer and submits them to the fuzzy reasoning rules, thus producing output pulses.
- Defuzzification or output layer: it treats the output pulses and represents them as output variables, going back to the crisp set.

Sandri *et al.* (1999) and Ortega (2001) propose the representation of the input and output variables of the multiplexers (neurons) as X, U, T(X), M, where X is the name of the variable, U is the universe of discourse, T(X) is the set of names (linguistic terms) for the X values, and M is a function that associates a membership function to each element of T(X). Figure 2 shows an example of a graphical representation of a certain input variable.

One of the most known and applied neuro fuzzy networks is the ANFIS (Adaptive Neuro Fuzzy Inference System) structure proposed by Jang (1993). More details of this architecture may be found in Souza (1999), Pagliosa (2003), Ludwig Júnior (2004), Sandmann (2006), Becker Júnior (2008) and Rodrigues (2010). This structure consists of five layers:

- Layer 1: it receives the input variables and fuzzyfies them.
- Layer 2: each node of this layer represents a Fuzzy inference rule that defines the discharging degree of the rule when it receives the fuzzy input variables.
- Layer 3: it is defined by the normalization of the discharging degree of each rule and it is considered to be a pre-processing of defuzzification.

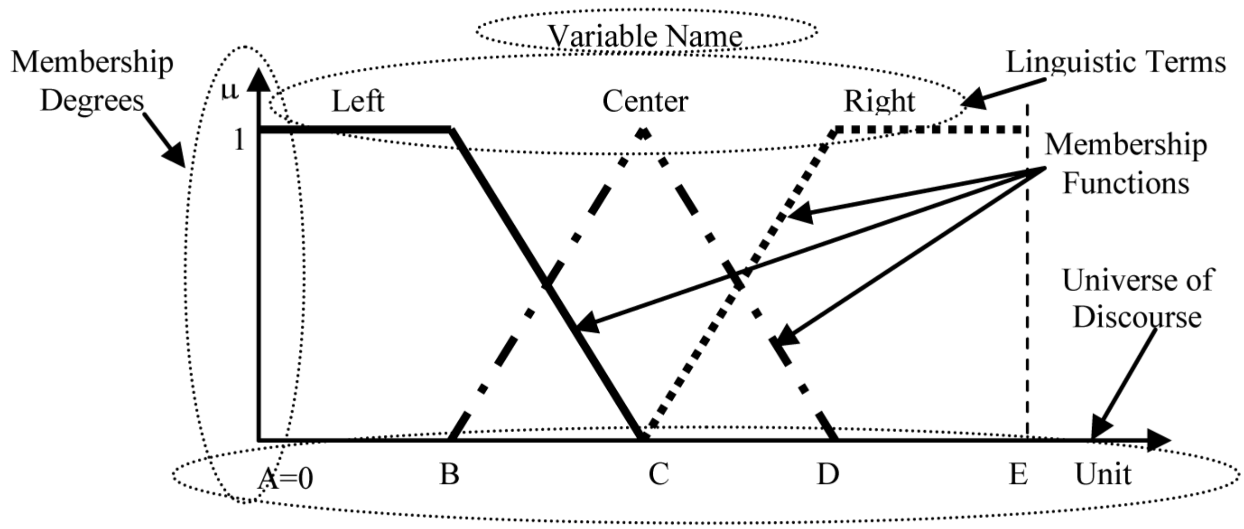

Figure 2: Example of a graphical representation of a variable.

- Layer 4: we multiply the normalized discharging degree of the rule and the processed values in each rule, which correspond to the singletons or the linear combination of the input variables.
- Layer 5: the output layer of each multiplexer is calculated; that is, the sum of the products of Layer 4 is defuzzified.

3.2 The Neuro Fuzzy Integral Model

Following the suggested methodology, Table 1 summarizes information about the input and output variables defined in steps 1 and 3. The following information is available for the variables: coding (the Ident. column); universe of discourse together with its unit (columns "U" and Unity, respectively); linguistic terms in column T(X); and membership functions, according to the pattern shown in Figure 2, which are characterized in the "Notable Values" column. These values apply to the Fuzzy integrals shown in expressions 1, 2, and 3 defined in the 4th step. The variables are distinguished in the "Type" column, where "I" refers to Input and "O" refers to Output. A computerized application was developed on Microsoft Excel for the Fuzzy integrals processing and the input variable fuzzification:

$$\text{Left} = \int_{0\to 1}^{30\to 1} 1/X + \int_{30\to 1}^{50\to 0} \frac{(x-C)}{(B-C)}/X \quad (1)$$

$$\text{Center} = \int_{30\to 0}^{50\to 1} \frac{(x-B)}{(C-B)}/X + \int_{50\to 1}^{70\to 0} \frac{(x-D)}{(C-D)}/X \quad (2)$$

$$\text{Right} = \int_{50\to 0}^{70\to 1} \frac{(x-C)}{(D-C)}/X + \int_{70\to 1}^{100\to 1} 1/X \quad (3)$$

where B, C and D are notable values following the pattern of Figure 2, and x is an input value included in the universe of discourse X.

The modeling mentioned in step 2 of the methodology is shown in Figure 3, where the triangles represent the multiplexers. All the outputs of the triangles, except the SSI, represent the partial indicators of the model.

According to step 5, inference rules were created with the aid of the application developed by

Microsoft Access, making it possible to obtain the partial indicators and the SSI.

With the exception of the SSI, the output variables of the multiplexers emit pulses that represent the partial inputs to those ahead.

Therefore, accomplishing the 6th step, the next topic will show the results due to the application of the Model.

3.3 The Application of the Neuro Fuzzy Integral Model - Results

Table 2 shows the values of the input variables, and Table 3 shows the results of the output variables after data processing by the computerized applications that are the result of the partial environmental indicators and the SSI.

Table 3 shows that the results can be either evaluated quantitatively, through the "Value" column, or qualitatively, through the "Dominant Qualification" column. In the latter, we can see green, yellow and red indicators, indicating the best condition, a warning situation and a non-satisfactory condition, respectively. The linguistic term follows what was shown in Table 1 and the percentage value next to it indicates how preponderant the linguistic term is, where 100% reveals total representativeness.

From the results shown above, it is important to initially highlight the SSI result, which characterizes the MagLev-Cobra system as Sustainable. Table 4 presents the results of Table 3 in decreasing order, without the SSI value, so that the person who decides can evaluate which parts of the system managed by the EMS are the most critical ones; that is, which parts deserve more attention and which may require possible management attitudes, such as resource allocation, training needs, etc. Concerning the "red" indicators shown above, we can see that they represent the MN-Maintenance and TR-Transportation parts, indicating that they are issues that are intertwined

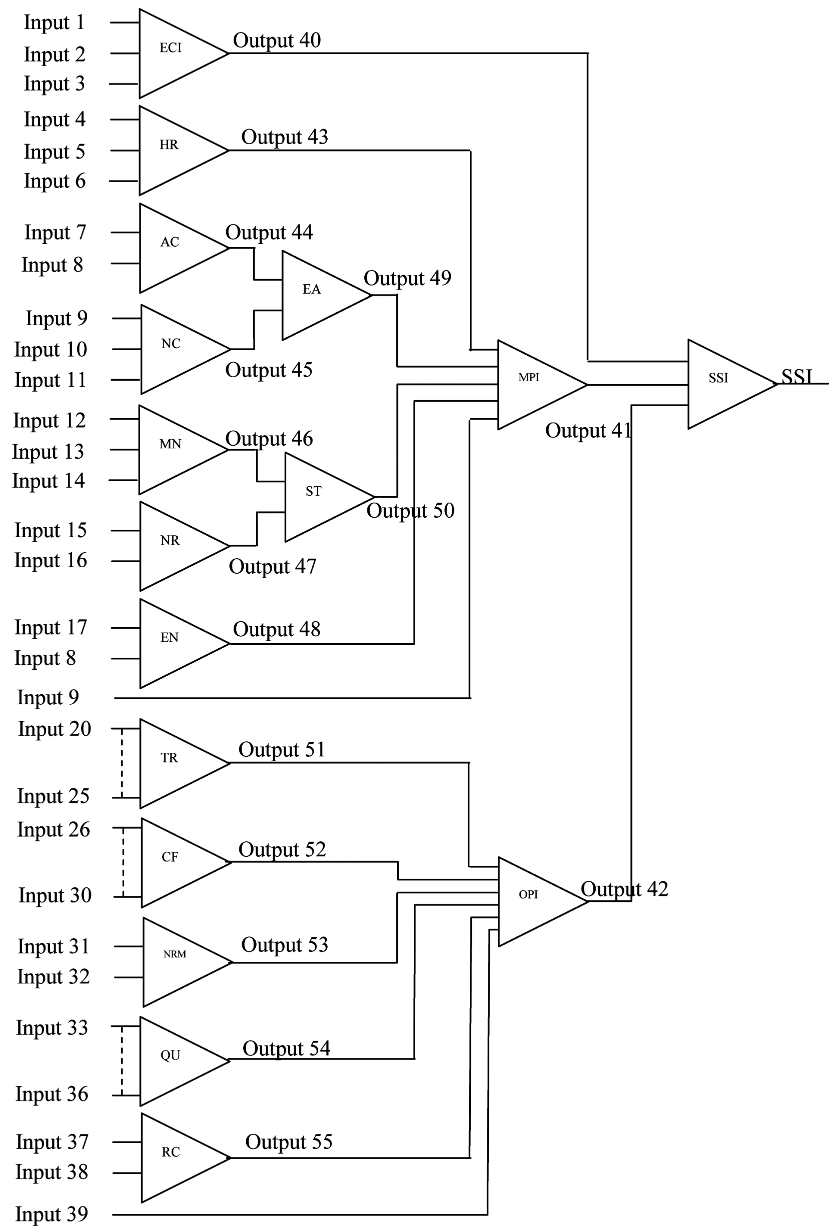

Figure 3: Multiplexer aggregation for the ANFIS Neuro Fuzzy network formation.

Table 1: Input and output variables for the SSI calculation

Ident.	Name (X)	Type	Unity	Universe of Discourse (U)(U)	Linguistic Terms T(X)			Notable Values				
					Left	Central	Right	A	B	C	D	E
				ECI – Environmental Condition Indicator								
1	Nitrogen Dioxide Concentration in the Systems Region	I	µg/ m3/1h	0-3,000	Low	Medium	High	0	900	1,500	2,100	3,000
2	Smoke Concentration in the Systems Region	I	3µg/m /24h	0-500	Low	Medium	High	0	150	250	350	500
3	Carbon Monoxide Concentration in the Systems Region	I	ppm/8h	0-40	Low	Medium	High	0	12	20	28	40
				MPI – Management Performance Indicator								
4	Employees' SatisfactionFuncionários	I	-	0-10	Not Satisfied	Satisfied	Very Satisfied	0	3	5	7	10
5	HR Qualification	I	-	0-100%	Incapable	Being Qualified	Capable	0	30	50	70	100
6	Employees' Schooling	I	-	0-100%	Low	Medium	High	0	30	50	70	100
7	Evaluation of Accident Risks	I	-	0-30	Low	Medium	High	0	9	15	21	30
8	Workplace Accident Index	I	-	0-100%	Low	Medium	High	0	30	50	70	100
9	Compliance with the Environmental Legislation	I	-	0-100%	Low	Medium	High	0	30	50	70	100
10	Internal Audit Nonconformity	I	-	0-10	Low	Medium	High	0	3	5	7	10
				MPI – Management Performance Indicator								
11	Legal NonconformitiesRelated to the Environment	I	-	0-10	Low	Medium	High	0	3	5	7	10
12	Activity Efficiency of the Corrective Maintenance	I	-	0-100%	Low	Medium	High	0	30	50	70	100
13	Activity Efficiency of the Preventive Maintenance	I	-	0-100%	Low	Medium	High	0	30	50	70	100
14	Maintenance Program Quality	I	-	0-100%	Low	Medium	High	0	30	50	70	100
15	Water Use	I	m3/day	0 – 10.000	Low	Medium	High	0	3,000	5,000	7,000	10,000
16	Energy Use	I	kW/day	0 – 10.000	Low	Medium	High	0	3,000	5,000	7,000	10,000
17	Environment Investment Index	I	-	0-100%	Low	Medium	High	0	30	50	70	100
18	Environmental Suggestion Index	I	-	0-100%	Low	Medium	High	0	30	50	70	100
19	Emergency Mocks	I	-	0-5	Low	Medium	High	0	1.5	2.5	3.5	5
				OPI – Operational Performance Indicator								
20	Accessibility	I	-	0-100%	Low	Medium	High	0	30	50	70	100
21	Safety	I	-	0-100%	Low	Medium	High	0	30	50	70	100
22	Tariff	I	-	0-100%	Low	Appropriate	High	0	30	50	70	100
23	Journey Time	I	-	0 – 10	Low	Medium	High	0	3	5	7	10
24	Noise Level during Operation	I	dB	0-250	Low	Medium	High	0	75	125	175	250
25	Quantity of Accidents	I	-	0 – 10	Low	Medium	High	0	3	5	7	10

Key: I – Input Variable; O – Output Variable.

Table 1 (Cont.): Input and output variables for the SSI calculation

Ident.	Name (X)	Type	Unity	Universe of Discourse (U)(U)	Linguistic Terms T(X)			Notable Values				
					Left	Central	Right	A	B	C	D	E
				OPI – Operational Performance Indicator								
26	Acclimatization(vehicle and facilities)	I	-	0 - 10	Low	Medium	High	0	3	5	7	10
27	Information for Users	I	-	0-100%	Low	Medium	High	0	30	50	70	100
28	Systems Cleaning(vehicle and facilities)	I	-	0 - 10	Low	Medium	High	0	3	5	7	10
29	Service Level[1]	I	-	0 -100%	Low	Medium	High	0	30	50	70	100
30	Average Occupied Area	I	Pax/m^2	0 - 10	Low	Comfortable	Tight	0	3	5	7	10
31	Hydric Efficiency	I	m^3/Pax	0 - 100	Low	Medium	High	0	30	50	70	100
32	Energy Efficiency	I	kW/Pax	0 - 100	Low	Medium	High	0	30	50	70	100
33	Index of Complaints about the Environment	I	-	0-100%	Low	Medium	High	0	30	50	70	100
34	Systems Quality	I	-	0-100%	Low	Medium	High	0	30	50	70	100
35	The Clients' Environmental Satisfaction Index	I	-	0 - 10	Low	Medium	High	0	3	5	7	10
36	Company x User Relationship	I	-	0-100%	Low	Medium	High	0	30	50	70	100
37	Liquid Waste Recycling	I	-	0-100%	Low	Medium	Appropriate	0	30	50	70	100
38	Solid Waste Recycling	I	-	0-100%	Low	Medium	Appropriate	0	30	50	70	100
39	Innovation	I	-	0-100%	Low	Medium	High	0	30	50	70	100
				Output Variables								
40	ECI – Environmental Condition Indicator	O	-	0-100%	Bad	Medium	Great	0	30	50	70	100
41	MPI – Management Performance Indicator	O	-	0-100%	Bad	Medium	Great	0	30	50	70	100
42	OPI – Operational Performance Indicator	O	-	0-100%	Bad	Medium	Great	0	30	50	70	100
43	HR – Human Resources	O	-	0-100%	Low	Medium	High	0	30	50	70	100
44	AC – Work. Accid.	O	-	0-100%	Low	Medium	High	0	30	50	70	100
45	NC – Nonconformity	O	-	0-100%	Low	Medium	High	0	30	50	70	100
46	MN – Maintenance	O	-	0-100%	Low	Medium	High	0	30	50	70	100
47	NR – Natural Resources	O	-	0-100%	Low	Medium	High	0	30	50	70	100
48	EN – Environment	O	-	0-100%	Low	Medium	High	0	30	50	70	100
49	EA – Environmental Appropriateness	O	-	0-100%	Low	Medium	High	0	30	50	70	100
50	ST – Sustainability	O	-	0-100%	Low	Medium	High	0	30	50	70	100
51	TR – Transportation	O	-	0-100%	Low	Medium	High	0	30	50	70	100
52	CF – Comfort	O	-	0-100%	Low	Medium	High	0	30	50	70	100
53	NRM – Natural Raw Materials	O	-	0-100%	Low	Medium	High	0	30	50	70	100
54	QU – Quality according to the User's Opinion	O	-	0-100%	Low	Medium	High	0	30	50	70	100
55	RC – Recycling	O	-	0-100%	Low	Medium	High	0	30	50	70	100
56	SSI	O	-	0-100%	Inappropriate	Appropriate	Sustainable	0	30	50	70	100

Key: I – Input Variable; O – Output Variable.

Table 2: Values of the input variables for the SSI calculation.

Variable	Value	Variable	Value	Variable	Value	Variable	Value	Variable	Value
1	1400	9	80	17	80	25	4	33	45
2	250	10	4	18	34	26	3	34	68
3	30	11	6	19	2	27	52	35	8
4	8	12	60	20	32	28	6	36	80
5	54	13	15	21	56	29	66	37	48
6	80	14	45	22	45	30	7	38	98
7	20	15	8500	23	4	31	72	39	35
8	80	16	4250	24	78	32	51		

Table 3: Results of the output variables for the SSI calculation.

Variable	Value	Dominant Qualification
40	64.33	Great/72%
41	75.42	Great/100%
42	53.27	Average/84%
43	80.86	High/100%
44	89.04	High/100%
45	70.00	High/100%
46	33.49	Low/83%
47	81.17	High/100%
48	60.22	High/51%
49	90.00	High/100%
50	59.10	Medium/55%
51	29.36	Low/100%
52	46.35	Medium/82%
53	71.49	High/100%
54	54.50	Medium/77%
55	72.22	High/100%
SSI	77.44	Sustainable/100%

Table 4: Results of the output variables in decreasing order of value

Variable	Value	Dominant Qualification
49	90.00	High/100%
44	89.04	High/100%
47	81.17	High/100%
43	80.86	High/100%
41	75.42	Great/100%
55	72.22	High/100%
53	71.49	High/100%
45	70.00	High/100%
40	64.33	Great/72%
48	60.22	High/51%
50	59.10	Medium/55%
54	54.50	Medium/77%
42	53.27	Average/84%
52	46.35	Medium/82%
46	33.49	Low/83%
51	29.36	Low/100%

due to their objectives and that represent danger regarding environmental issues.

4 Conclusions

An EMS is oriented according to the management model based on a continuous cycle called PDCA, which sticks to the principle that everything should be planned before operating a system. In addition, after its effective operation, working conditions should be verified; operation should be reevaluated and confronted with what was previously planned; and feedback regarding process suitability, the scripts, and working routine should be provided.

Focusing on MagLev-Cobra's EMS indicators, which are essential to provide information necessary to decision-making, the use of the Neuro Fuzzy Integral Model – the focus of this paper – makes it possible to observe the evolution of the issues that maintain the system by means of the input variables, the partial indicators, and the SSI.

The observation of the demand for certain parts of the system over time may indicate critical situations, optimizing the financial and human resources in search of sustainable transportation.

The use of Fuzzy Theory and of the Neuro Fuzzy hybrid architecture made it possible to gather linear and nonlinear variables, with different dimensions, in a single model. In addition, it makes it possible to expand knowledge acquired by experts during the development of the MagLev-Cobra technology.

Concerning the necessity to develop computerized applications, it was observed that the architecture of the Neuro Fuzzy networks has made it possible to develop in a simple manner a database to store the input variables and the results provided by the model, as well as the screens for its management. These can be achieved by using basic and low-cost applications as compared to Business Intelligence (BI) platforms and expert software.

References

Becker Júnior, O.M. (2008) Criação do Pneumoperitônio por Punção no Hipocôndrio Esquerdo: Sistema Nebuloso (Fuzzy) de Suporte de Decisão pela Relação Pressão/Volume do Posicionamento da Ponta da Agulha de Veress. Tese de Doutorado em Cirurgia e Experimentação. Universidade de São Paulo, São Paulo.

Brazilian Environmental Crime Act, N° 9.605, February 12 (1998). D.O.U. 13/02/1998.

CMMAD – Comissão Mundial sobre Meio Ambiente e Desenvolvimento (1998) Nosso Futuro Comum, Relatório Brundtland. Fundação Getúlio Vargas, Rio de Janeiro.

David, E.G.; Tourinho, J.F.G. and Stephan, R.M. (2009) Sistema de transporte de levitação magnética supercondutora Maglev-Cobra, etapas para implantação. Edição 591, pp. 143-146, Rio de Janeiro. Available: http://www.brasilengenharia.com.br/ed/591/Eng_Transporte_II.pdf. Access: 8 February.

EPA – United States Environmental Protection Agency. (2011) Sustainable Transportation Performance Measures. Available: http://www.epa.gov/smartgrowth/pdf/Sustainable_Transpo_Performance.pdf. Access: 8 February, 2012.

Jang, J-S.R. (1993) ANFIS: Adaptive-Network-Based Fuzzy Inference System, in: IEEE Transactions on Systems. Man and Cybernetics, Vol. 23, No 3, pp. 665-685.

Litman, T. (2008) Sustainable Transportation Indicators – A Recommended Research Program for Developing Sustainable Transportation Indicators and Data, Sustainable Transportation Indicators Subcommittee of the Transportation Research Board (ADD40 [1]). Available: http://www.vtpi.org/sustain/sti.pdf. Access: 8 February, 2013.

Ludwig Júnior, O.; Schnitman, L. and Lepikson, H. (2004) Uma Arquitetura Neural Híbrida para Extração de Regras Nebulosas, in: IEEE Latin America Transactions, Vol. 2, No 2.

Medeiros, A.V. de; Souza, F.E.C. and Maitelli, A.L. (2003) Implementação de um Sistema de Extração de Conhecimento de Redes Neurofuzzy. Universidade Federal do Rio Grande do Norte, II Workshop Técnico Científico do DIMAp.

MIT – Department of Urban Studies + Planning (2009) Sustainable Transportation an International Perspective, MIT Journal of Planning – Projections, Vol. 9.

Ortega, N.R.S. (2001) Aplicação da Teoria de Conjuntos Fuzzy a Problemas da Biomedicina. Tese de Doutorado. Universidade de São Paulo, Instituto de Física, São Paulo.

Paes, G.K.A.A. (2006) Sustentabilidade Ambiental dos Sistemas de Transportes Públicos em Centros Urbanos. Dissertação de Mestrado – IME, Rio de Janeiro.

Pagliosa, A.L. (2003) Obtenção das Funções de Pertinência de um Sistema NeuroFuzzy Modificado pela Rede de Kohonen. Dissertação de Mestrado em Automação Industrial. Universidade do Estado de Santa Catarina, Joinville.

Ribeiro, S.K. (2001) Transporte Sustentável – Alternativas para os Ônibus Urbanos. Centro Clima, COPPE/UFRJ, Rio de Janeiro.

Rodrigues, M.C. (2010) Identificação Fuzzy-Multimodelos para Sistemas não Lineares. Tese de Doutorado em Engenharia Elétrica e da Computação. Universidade Federal do Rio Grande do Norte, Natal.

Sandmann, H.R. (2006) Predição não-linear de Séries Temporais usando Sistemas de Arquitetura Neuro-Fuzzy. Dissertação de Mestrado em Engenharia, Escola Politécnica da Universidade de São Paulo, São Paulo.

Sandri, S. and Correa, C. (1999) Lógica Nebulosa. Instituto Tecnológico da Aeronáutica – ITA. V Escola de Redes Neurais, São José dos Campos: pp. C073-c090.

Souza, F.J. (1999) Modelos Neuro-Fuzzy Hierárquicos. Tese de Doutorado em Engenharia Elétrica. Pontifícia Universidade Católica do Rio de Janeiro – PUC-RIO, Rio de Janeiro.

Stephan, R.M. and David, E.G. (2007) Maglev-Cobra: O Transporte Urbano Sobre Trilhos Magnéticos, 3º Concurso de Monografia CBTU – A Cidade nos Trilos. Available: http://www.cbtu.gov.br/monografia/2007/trabalhos/richardmagdalena.pdf. Access: 8 February, 2012.

Stephan, R.M. and David, E.G. (2008) Maglev-Cobra: Um Veículo Para Transporte Urbano Energeticamente Eficiente e Ambientalmente Correto, SOBRAEP – Sociedade Brasileira de Eletrônica de Potência, UFRJ – Universidade Federal do Rio de Janeiro. Available: http://www.sbpcnet.org.br/livro/60ra/textos/CO-RichardStephan.pdf. Access: 8 February.

Zadeh, L. A. *et al.* (1995) Fuzzy Sets and their Applications to Cognitive and Decision Process. New York: Academic Press.