Petri Nets: an Analysis of its Properties through a Model of Titanium Injection System and Other Pulverized into Blast Furnaces by using the Software CPN Tools

LEONARDO DE CARVALHO VIDAL
Department of Electrical Engineering
Universidade Federal de Itajubá
Av. BPS, 1303, Bairro Pinheirinho, Itajubá - MG BRAZIL
leonardo.carvalho.vidal@hotmail.com

LUIZ EDIVAL DE SOUZA
Department of Electrical Engineering
Universidade Federal de Itajubá
Av. BPS, 1303, Bairro Pinheirinho, Itajubá - MG BRAZIL
edival@unifei.edu.br

DAVID DE PAULA SANTOS SILVA
Centro Universitário de Barra Mansa – UBM
Rua Luis Guilherme de Ataíde Cruz, 714, Barra Mansa – RJ
BRAZIL
daviddpssilva@hotmail.com

RICARDO SEBASTIÃO NADUR MOTTA
CSN – Companhia Siderúrgica Nacional
Rod. Lúcio Meira, Km 5001, s/n - Vila Santa Cecília, Volta Redonda – RJ BRAZIL
nadur@csn.com.br

Abstract: **-** The development of computer technologies that facilitate daily tasks is always in constant expansion. Due to this, the implementation of a system network is required to the data properly and automatically correlate. Many areas of computing and automation use the Petri Nets as base model for the creation of these technologies, e.g., communication protocols in computer systems. The objective of this article is to present an analysis of the properties found in a Petri Network, based on a model of titanium injection system and other pulverized into blast furnaces due to the high level of abstraction provided by the model by using the software CPN Tools. The result of this work is to show how the Petri Nets can be used to enhance effectiveness in a process just by analyzing its properties.

Key-Words: **-** Petri Nets, Software, CPN Tools, Process, Analysis, Properties.

1 Introduction

For a long time, man has always sought faster alternatives for solving daily problems that arose according to your needs. Tasks that were previously performed without the use of computers, such as filling out reports, entry and exit points, inventory control, financial activities, payment of salaries to employees of a company, generally entries, etc., have been replaced by powerful software systems that act as a data entry source, saving time and storage space. To develop this kind of software, the implementation of a systemic network was needed, in which it is permitted that data can be correlated correctly and automatically. Petri Nets aim to assimilate and represent these values in the form of bipartite graphs, where the state (node) network is represented by an ellipse or circle, and transitions that are represented by vertical bars corresponding actions taken by the system, and directed arcs connecting the nodes to transitions and vice versa.

The system used in this article is divided into three parts: a storage silo, an injector and injection system that has four spears with injection nozzles. The first part called Silo is used for storing the solid material that will be used for injection. It consists of the main body where the material is stored, an input solenoid valve with its limit switch and a hopper, a level sensor and a relief valve (protection against over pressure inside the silo). The filling process of the Silo is initiated by the operator through the Filling Start button on the screen of the supervisory system, which makes it opens the silo and driven fan filter. During filling, the material passes through a screen to prevent impurities from entering the silo [4].

Another important equipment of the storage-silo is the filter on top with hood which allows a residual dust content of materials with less than 20 mg/m3 waste in accordance with environmental legislation. The filter has an integrated independent control module that allows automatic operation [6].

The second part called Dispenser is a part between the Silo and the Injection, and between the lances which are part of the injection process. It is used to store the material that will be used for injection; however, it uses an applied pressure, which initiates the process of fluidization of the material. The dispenser also contains many valves with solenoids and limit switches, as well as weight and pressure sensors. If the storage silo has an appropriate level, the filling starts automatically when it is registered the minimum weight given or it can be activated in the supervisory system by pressing the Filling start button. Filling stops automatically when the preset weight value is reached or the performance of high-level metering sensor. [4]

The last part, injection system, has four lances where the fluid material passes and goes to the injection nozzles. The injection process starts by the operator in the supervisory control system, by activating a single lance at once. The process begins only if certain conditions are found: the doser be in normal conditions (status enabled), the flow on the client and the injection pressure should be above the preset value. In addition, the process can be stopped by the Material Stop Button [4].

The study focuses on the features of the software CPN Tools, dedicated to modeling, performance research, and analysis of properties of this industrial process. The objective of this work is to perform the analysis of the properties found in a Petri Network, based on a model of titanium injection system and other pulverized into blast furnaces due to the high level of abstraction provided by the model.

2 Problem Formulation

The titanium injection system and other sprayed on blast furnace that was used in this work does not present all the properties of Petri Net, for instance: reversibility, boundedness and safeness. Due to this, the adaptation of the network was necessary to get these three properties. The advantages of developing a project based on this model is the flexibility and the high power of abstraction. Besides that, it allows a real-time simulation of Petri Network, achieving a result with a margin of error minimized, and that can be implemented in the corporate production process in order to reduce costs, time and other factors like. The study of Petri nets constructed from graphs, provides a panoramic vision of the behavior of a system through the workflow that is nothing more than an activity set business, data flow, and some specification of control, aiming to simplify the management of important decisions [7]. Another advantage of the analysis of Petri nets is that the analysis by Petri nets facilitates functional development, creating a model that can be used to test different control logic simply changing the functions used [8].

There are four ways to analyze a Petri Net: generation reachability tree, state equation analysis, digital simulation and reduction techniques. The project addressed this technique is the digital simulation using the software CPN Tools [1,4]. The network that has been made available for this project aims to describe a model of titanium injection system and other pulverized into blast furnaces.

The main network system has the goal of showing an overview of the system and its operation stages, starting from the silo's filling, moving to the doser and later injection. The network's operation happens by inserting tokens of external influences, such as Filling Start button, high-level metering, flow rate customer ok, etc., within the corresponding places in the system as shown in the Fig.1.

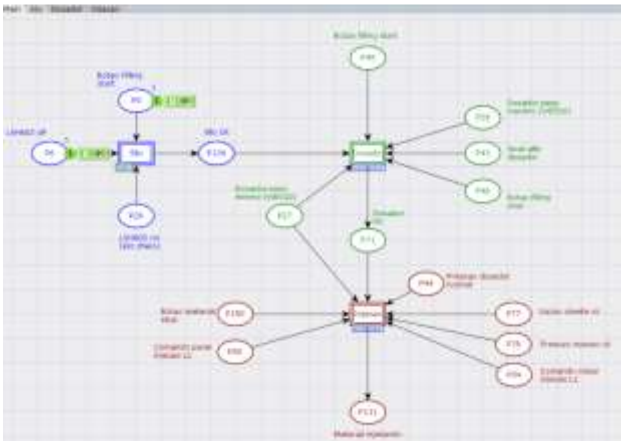

Fig. 1: Main part of the model analyzed.

3 Problem Solution

To start the network analysis made by using the CPN Tools software, it is necessary to open the simulation tool called State Space, as shown in Fig. 2, and verify if all the external network influences have a token to activate all the transitions. The set of all cases of an elementary network that occur during system implementation is called state space [5]. The state space checks the syntax indicating possible violations of constraints, such as, assigning unique names to locations and transitions used [4].

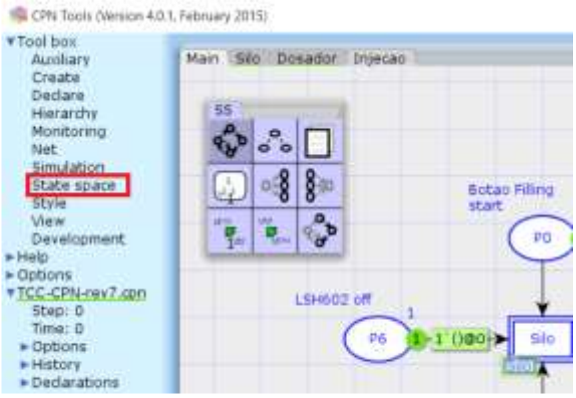

Fig. 2: State Space Analysis Tool.

Before generating the report, it is necessary to run another tool, Calculate SCC Graph, as shown in Fig. 3 below.

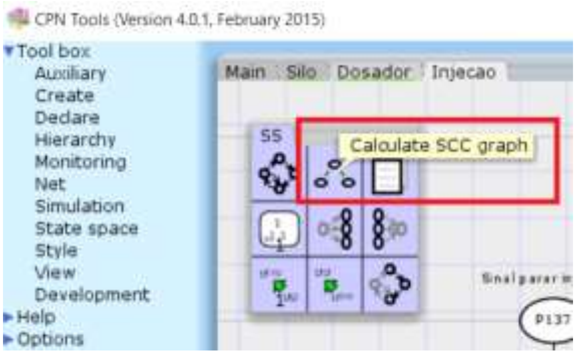

Fig. 3: Strongly connected components tool

Finally, it is necessary to generate the report. Simply select the Save Report button next to the Calculate SCC graph, Fig. 3, and choose a folder that you would like to save.

In the first part of the report, it is possible to observe the number of nodes that the network obtained during the execution for each reachable marking, the amount of arcs for each connected element, the time taken to perform the simulation, and network status, which was it partly because the software failed to generate all the data, due to the size of the network. Even though the result is partial, it is possible to extract information that will be used to analyze and define the properties of the network. The components strongly connected, as previously mentioned, have the same amount of network nodes, in other words, they all have a path that connect through the network arcs.

```
Statistics
------------------------------------------------------------------------

 State Space
    Nodes:  22267
    Arcs:   96650
    Secs:   300
    Status: Partial

 Scc Graph
    Nodes:  22267
    Arcs:   96650
    Secs:   1

Boundedness Properties
------------------------------------------------------------------------

 Best Integer Bounds
                          Upper      Lower
    Dosador'P29 1         1          0
    Dosador'P30 1         1          0
    Dosador'P31 1         1          0
    Dosador'P32 1         1          0
    Dosador'P33 1         1          0
    Dosador'P34 1         1          0
    Dosador'P35 1         1          0
    Dosador'P36 1         1          0
    Dosador'P37 1         1          0
    Dosador'P38 1         1          0
    Dosador'P39 1         0          0
    Dosador'P40 1         1          1
    Dosador'P41 1         0          0
    Dosador'P42 1         1          1
    Dosador'P47 1         3          0
    Dosador'P48 1         2          0
    Dosador'P50 1         1          0
    Dosador'P51 1         1          0
```

Fig. 4: Report generated by the software CPN Tools demonstrating the properties of the network.

The penultimate part of the report produced by the CPN Tools software comes the following properties of a Petri net: reversibility and vivacity.

Finally, the last part of the report shows that the network is completed after processing a certain amount of requests if you use a stopping point, ie, it does not present endless occurrences sequences if a stopping point is defined [3].

As can be observed in the Fig. 5, in the section Home Properties, this is not a reversible network because the tokens do not return to its original position. Due to this, a new modeling of the network will be made, so it is expected a more consistent result, assuming it is no longer necessary to replace the tokens of external influence ever

```
Home Properties
------------------------------------------------------------------------

 Home Markings
    Initial Marking is not a home marking


Liveness Properties
------------------------------------------------------------------------

 Dead Markings
    12532 [9999,9998,9997,9996,9995,...]

 Dead Transition Instances
    Dosador't23 1
    Dosador't24 1
    Dosador't25 1
    Dosador't30 1
    Dosador't31 1
    Dosador't32 1
    Dosador't33 1
    Dosador't34 1
    Dosador't35 1
    Dosador't36 1
    Dosador't37 1
    Injecao't54 1
    Injecao't56 1
    Injecao't58 1
    Injecao't61 1
    Injecao't62 1
    Injecao't65 1
    Injecao't66 1
    Injecao't67 1
    Injecao't68 1
    Injecao't69 1
    Injecao't74 1
    Injecao't80 1
    Silo't4 1
    Silo't7 1
    Silo't8 1

 Live Transition Instances
    None
```

Fig. 5: Part of the report generated by CPN Tools demonstrating the properties of the network.

In the section dealing with the liveness of the network, Fig. 5, the report shows that there are 12,532 dead markings. This value corresponds to network locations that received no token during simulation, i.e., no transition was enabled through them. In the section that deals with dead transitions instances, is indicated the transitions which have never been activated by the reachable markings, totaling 26 transitions. Additionally, the live transitions instances, represent the transitions which may always be activated at least once by 1 reachable markings, as shown in the report, there were 0 transitions that failed to be achieved [3].

In the analyzed model, the system partially presented the property reachability, since most of the markings, as the shots were fired, managed to reach the next transition or place through a sequence of shots originate from M_0 to M_n.

A conservative network is one that maintains a constant amount of tokens during its simulation, at this point, the network had 58 tokens and some of them were consumed by the transitions, so the network did not keep constant the amount of tokens. Because of that, the network cannot be considered conservative.

During the simulation of the network was not found any cases of deadlock. The transitions that were active did not depend on no other transition in order to carry out the shooting of marks, ie, they did not suffer the deadly blockade.

It is observed that in the place called Dosador’P47, supports a maximum of 3 tokens, Fig. 6, this limitation of the network place breaks the rule that defines whether a network is limited or not, because for it to be limited, the places must support a maximum of one token. Furthermore, the network cannot be considered safe for the K-limit, because the Dosador'P47 place token exceeds is 3-limited, and to be safe, it is required just 1 token. As one of the places does not fit the standards, the entire network is considered unsafe.

Boundedness Properties

Best Integer Bounds

	Upper	Lower
Dosador'P29 1	1	0
Dosador'P30 1	1	0
Dosador'P31 1	1	0
Dosador'P32 1	1	0
Dosador'P33 1	1	0
Dosador'P34 1	1	0
Dosador'P35 1	1	0
Dosador'P36 1	1	0
Dosador'P37 1	1	0
Dosador'P38 1	1	0
Dosador'P39 1	1	0
Dosador'P40 1	1	0
Dosador'P41 1	1	0
Dosador'P42 1	1	0
Dosador'P47 1	3	0
Dosador'P48 1	2	0
Dosador'P50 1	1	0
Dosador'P51 1	1	0

Fig. 6: The maximum number of tokens in place is used as a parameter to define whether the network is limited or not.

As the network did not show the reversibility, boundedness and safeness properties, a new system will be developed to achieve results that are more consistent and to apply again the theory of the Petri Nets upon the results.

The first step in making the reversible network is to evaluate the points where it receives external influences. As can be observed in Fig. 7, there is an external influence in the Main section that aims to enable Silo transition. This place called P26, can be easily removed to create a reversal in the network as it receives a token (input) of himself in the silo section, so it's possible to eliminate this connection and duplicity.

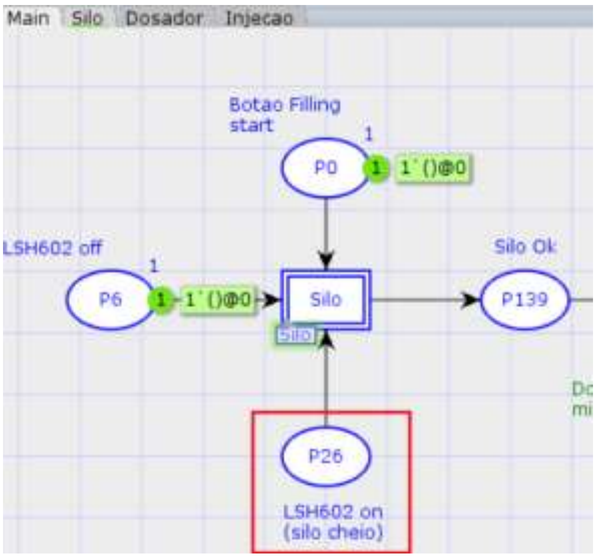

Fig. 7: Place P26 can be removed to create the network reversibility.

To create the reversibility in this part of the network, it must remove these two places, P26 (Main) and P26 (Silo), and connect the place until the transition t14 (LSH602 Stop filling), as shown in Fig. 8. The reversibility takes place when the P5 token goes to the transition t14 and comes back to the position P5, ending the filling process with a token at the output of P139 place (Silo ok).

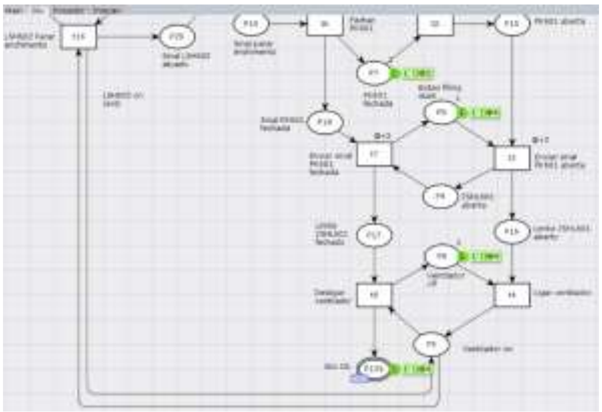

Fig. 8: Place P5 connected to transition t14 creating reversibility on the network.

To continue the process, it is necessary to remove three places in the feeder section, P46, P43, and P28, and their transitions, Fig. 9.

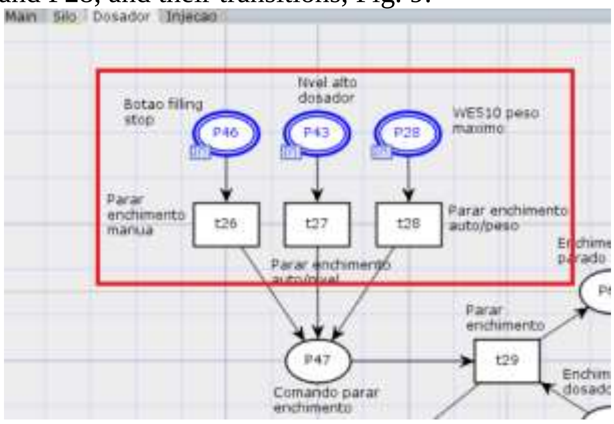

Fig. 9: Places P46, P43 and P28 and their transitions must be removed.

It necessary to remove these three parts of the system, because they receive inputs from the main section within the *Dosador*. For the process to proceed without having a deadlock and this part become reversible, it is necessary to connect the transition t21 to the place P47, as shown in Fig. 10 below.

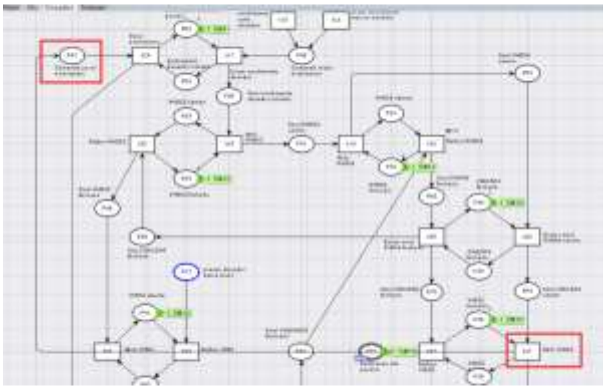

Fig. 10: Transition t21 place and P47 are connected to create reversibility.

When the simulation runs, it is also observed that the place P129 can support 2 tokens of different colors at the same time, Fig. 11, this indicates that the network is not secure, or limited, because for this to occur, it can only support 1 token

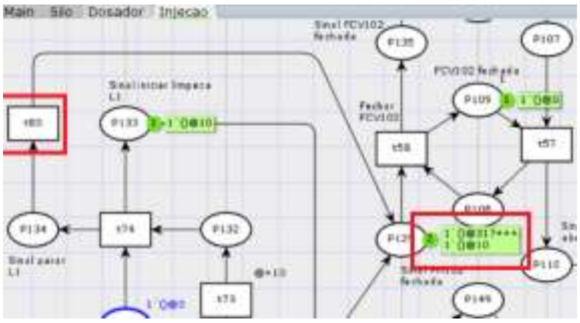

Fig. 11: Place P129 receiving two different tokens.

For this to be solved, it is necessary to replace the arc of transition t80 that connects to P129 place by a type of arc called Inhibitor arc, Fig. 12. This type of arc inhibits the passage of the token, if the place already has a token [2].

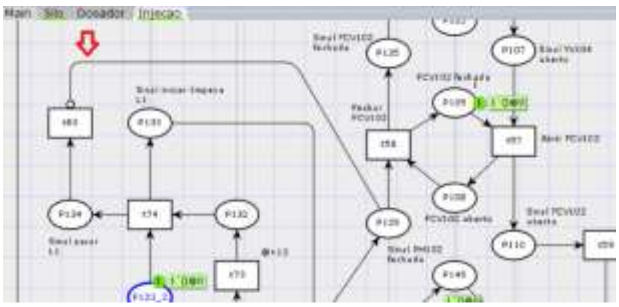

Fig. 12. Inhibitor arc and P129 place with only one token.

Most of all tokens from external influence were eliminated. However, most of those who are pre-existing conditions to start the process continued in the network, reorganized through the reversibility property.

Having the new model of the network, it can be seen that it was not possible to model the network in order to make fully reversible because there are places that are initial conditions for the process to start, so it is not possible to remove.

As shown in Fig. 13, it can be seen that the network is embedded in the standards for it to be considered safe and limited because the maximum amount of tokens was only 1 unit.

Boundedness Properties

Best Integer Bounds

	Upper	Lower
Dosador'P29 1	1	0
Dosador'P30 1	1	0
Dosador'P31 1	1	0
Dosador'P32 1	1	0
Dosador'P33 1	1	0
Dosador'P34 1	1	0
Dosador'P35 1	1	0
Dosador'P36 1	1	0
Dosador'P37 1	1	0
Dosador'P38 1	1	0
Dosador'P39 1	1	0
Dosador'P40 1	1	0
Dosador'P41 1	1	0
Dosador'P42 1	1	0
Dosador'P47 1	1	0
Dosador'P48 1	1	0
Dosador'P50 1	1	0
Dosador'P51 1	1	0
Dosador'P52 1	1	0
Dosador'P53 1	1	0
Dosador'P54 1	1	0
Dosador'P55 1	1	0
Dosador'P56 1	1	0
Dosador'P57 1	1	0
Dosador'P58 1	1	0
Dosador'P59 1	1	0
Dosador'P60 1	1	0
Dosador'P61 1	1	0
Dosador'P62 1	1	0
Dosador'P63 1	1	0
Dosador'P64 1	1	0
Dosador'P65 1	1	0
Dosador'P66 1	1	0

Fig. 13: Maximum number of tokens in the network was only 1 unit.

Thus, unlike the previous network and the new network is that there is a reduction in the number of locations, and transitions. There was also the use of the safeness property, boundedness and partly reversibility property. Furthermore, the network showed a considerable reduction in the number of dead transition instances and dead markings, as shown in Fig. 14.

```
Liveness Properties
------------------------------------------------

 Dead Markings
    104 [10528,10527,10526,10525,10524,...]

 Dead Transition Instances
    Dosador't16 1
    Dosador't32 1
    Injecao't39 1
    Injecao't40 1
    Injecao't41 1
    Injecao't42 1
    Injecao't65 1
    Injecao't67 1
    Injecao't69 1
    Injecao't75 1
```

Fig. 14: There was a reduction in the number of dead markings and dead transition instances.

4 Conclusion

This article presented the theory behind the Petri Nets, and how, from the theory and in conjunction with a software able to model and manage the networks, it can be used to perform an analysis of a system. It was presented that several properties of the Petri Nets were not found in the titanium injection system and other sprayed on blast furnace that was used as the basis of this work, and because of that, the adaptation of the network was necessary to get these three properties of Petri Nets, for instance, reversibility, boundedness and safeness. Even after modeling the new network, it can be concluded that not all Petri Nets can become reversible, as occurred in this study, as there are initial parameters, which cannot be removed, since they are of paramount importance to the beginning of the simulation and process. In the case of the boundedness and safeness properties, as one depends on the other, and as there was an adaptation of one of the network arcs (inhibitor arc) that only allows the passage of a single token during the simulation, the network can be considered 1-limited and safe, because the maximum number of tokens during the simulation was only 1 unit.

It can be concluded that all pre-established objectives at the beginning of the work were achieved, since it was possible to understand the operation, use, modeling and interpretation of the results of the Petri Nets through the software. To conclude, this article presented an effective way analysis of a system modeled using the Petri Nets that can be useful prior to actual deployment within an industry or in the computer sector, since it can be observed how would be the process steps if the logic were amended or replaced.

References:

[1] GUSTIN, G. D. B. *Aplicação de redes de Petri interpretadas na modelagem de sistemas de elevadores em edifícios inteligentes*. 1999. 179f. Dissertação (*Mestrado em Engenharia Mecânica/Mecatrônica*) - *Universidade de São Paulo* - USP, São Paulo - SP, 1999.

[2] H.M.W. Verbeek, M.T. Wynn, W.M.P. van der Aalst, A.H.M. ter Hofstede. Reduction Rules for Reset/Inhibitor Nets. 28 May 2009.

[3] KIM, Kangseok., A Framework for Synchronous and Ubiquitous Collaboration. Indiana University, 2007.

[4] LINDEBECK, G. Gabriel, ASSIS, L. Emerson. *Utilização de Redes de Petri na automação de Sistema de injeção de materiais sólidos. Trabalho final de Curso*, UBM. Barra Mansa – Rio de Janeiro. 2013

[5] MARRANGHELLO, Norian. *Redes de Petri: Conceitos e Aplicações*. UNESP. March 2005.

[6] VIDAL, Leonardo C., SOUZA, Luiz E., LIMA, Raphael F., MOTTA, Ricardo S. N., NOBLAT, Sebastiao J. X., STEIN, Sebastian. Article The CSN AF#3 Titanium's Injection System. Düsseldorf, Germany, 15 – 19 June 2015

[7] LEYMANN, F. ROLLER, D. Workflow-based applications. IBM Systems Journal, v.36, n.1.1997

[8] VIDAL, Leonardo C. *Seminário sobre as Redes de Petri na injeção de TIO2*. Itajubá – Minas Gerais, 2013