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An Automated Data Fusion Process for an Air Defense Scenario

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André Luís Maia Baruffaldi*
[andre_baruffaldi@yahoo.com.br]

Alexandre de Barros Barreto
[kabart@gmail.com]

José Maria P. de Oliveira
[parente@ita.br]

Henrique Costa Marques
[hmarques@ita.br]

Instituto Tecnológico de Aeronáutica
Praça Mal. Eduardo Gomes, 50 – Vila das Acácias
São José dos Campos - SP 12.228-900 – BRAZIL

* Student

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Point of Contact

André Luís Maia Baruffaldi
Instituto Tecnológico de Aeronáutica
Praça Marechal Eduardo Gomes, 50 – Vila das Acácias – São José dos Campos SP - ZIP:12.228-900 - BRAZIL
+55 12 3947-6855
andre_baruffaldi@yahoo.com.br

Abstract

The use of Brazilian airspace by aircrafts involved in illegal activities led the Brazilian National Congress to approve a law authorizing the destruction of such aircrafts in 2004. With this new attribution, the Brazilian Organizations responsible for police activities reached their management limit due to the growth of the amount of information and more complex rules that they need to manipulate in order to decide on the engagement in a constraint time situation. This paper presents a simulation and decision support model based on Petri Net that ensures the implementation of all procedures required in the process of the airspace policing. A Domain Ontology represents the various concepts involved and their relationships. The relationships among the ontology elements are normalized by rules of inference. A set of experiments has been carried out to validate such an automated data fusion process.

I. INTRODUCTION

Brazil, as a Sovereign Nation, needs attitudes to establish itself as a continental country. It develops mechanisms for monitoring, control, and punishment based on a solid foundation of safety and efficiency, such as laws and government agencies. [14]

The Brazilian Air Force is responsible for ensuring the sovereignty of the Brazilian Airspace. Therefore, it maintains the Brazilian Aerospace Defense System - SISDABRA permanently activated. For its correct and unequivocal action, several procedures were deliberated and formalized in normalizing documents, called NOSDA (Standards of Operational Aerospace Defense System). On March 5, 1998 the Brazilian Congress approved the Law of the Destruction Shot [2], which has been ruled on July 16, 2004 by Decree-Law No. 5.144/04 [1]. Thus, the Brazilian Air Force should apply the destruction shot to destroy an aircraft involved in the traffic of narcotics. This possibility forced the SISDABRA to improve the process of management and supervisory measures for the airspace policing, especially those dedicated to the destruction shot. The mandatory character of the laws and procedures specific to the measures for the aerospace policing to make that an additional effort is allocated to the decision maker, to manage the large volume of information available and make their analysis.[14]

Failure in any of the procedures, either by lack of information, forgetting to take any stance or a misinterpretation of the available information, could result in a wrong decision, impacting negatively against SISDABRA, including facing criminal charges.

The problem of the analysis of the measure of the airspace policing, presented in this paper, is actually a problem of data fusion, because information from different sources should be combined in order to generate a new knowledge.

This information, from different databases, should be concentrated to facilitate its handling and processing, so that the appropriate information is always provided in order for the decision to be made.

The certainty that the actions have been taken at the appropriate time, that the available and necessary information has been adequately analyzed and used in a timely manner are the practical expected benefits of this work.

The pursuit of excellence in the implementation of measures for the airspace policing must start by understanding and correctly mapping the involved processes.

This article is organized as follows: Section 2 provides a conceptual view of the methods employed; Section 3 deals with the data fusion model for airspace policing;

Section 4 is devoted to analyzing the results of a study case of a typical air defense scenario; finally, Section 5 presents the concluding remarks.

II. BACKGROUND

The problems in the process for implementing measures of air space policing are the large amount of information and enforcement of mandatory procedures, making it difficult to acquire and maintain situational awareness. These factors contribute to the complexity of decision making in scenario analysis.

The identification process and the environment in which airspace policing is supposed to be carried out should be clearly understood. In Figure 1, on the right, are listed the contributing factors for the proper maintenance of situational awareness and decision-making, and on the left, the technologies and concepts used to solve the problem presented.

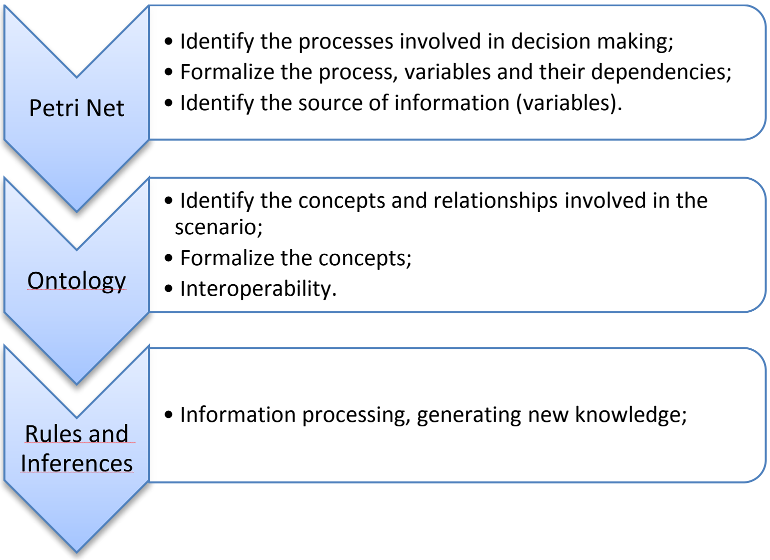


Fig. 1 - Mapping of processes, technologies and associated concepts.

A. Petri Net - PN

The PNs are mathematical modeling tools and graphics applied in modeling many systems [3], especially for non-deterministic and asynchronous. Its graphic interface allows visualizing the flow of actions throughout their implementation. Because it is a tool that enables the adoption of non-deterministic actions, transitions between different phases can be mapped by mathematical equations or equations of state that define system behavior. Besides the transitions are the places which are the variables, and arcs, which join the places with transitions.

In this study, we have adopted the PN Place-Transition, where it was assumed that all actions and conditions have the same degree of importance in a decision-making system. Thus, the transitions will be enabled when their preconditions have at least one token, i.e., when the minimum condition is attempted.

A type of PN Place-Transition [3] is represented by a quintuple, thus constituted, PN = (P, T, F, W, Mo), where:

P – is a finite set of points;

T – is a finite set of transition;

F – is the set of arcs that join P, T and T, P;

W – called weight function, where each *f* belonging to *F* has a *w* that belongs to *W*. In this study, it was assumed that *w* belongs to {0,1}.

Mo - any initial marking of *p* belonging to *P*.

A transition is said enabled if each input has at least *w*(*p*,*t*) token at each *p*, where *w* is the weight of the arc from *p* to *t* – this is considered a precondition. Despite the transition being enabled, it can or not be shot, depending on whether the event related to it actually occurred. This occurs when parallel processes are reached and just one process will be executed, depending on the decision maker criteria.

When a transition is fired, *w*(*p*,*t*) tokens are removed and then called post-condition[3].

B. Ontology

According to Gruber [4], ontologies are explicit and formal representations of a conceptualization. They are used to describe formally the domain of interest. They represent different concepts and their relationships within the predetermined area. They are essential to delineate and restrict the scope of the problem and promote interoperability with other systems, allowing for information sharing.

There are several types of ontologies, e.g.: Top, Domain and Application. However, in this work, only a Domain Ontology [13] that refers to a general area of knowledge, like the measures of air space policing, is used.

C. Rules application and decision support

This work aims to ensure that the tasks involved in air defense system, especially for measures of policing, are treated as the standards. For this, the rules to represent the standard procedures are employed. The rules can validate information and create new data inferred data [8].

III. MODEL OF SIMULATION AND ANALYSIS

To meet the principle of opportunity and provide the correct advice to the decision-making authority, it is necessary to employ some concepts and techniques to ensure that the flow of actions will be obeyed.

The Petri Net is a tool to ensure that all procedures related to a particular phase will be executed; that is inherent in the PN in their Transitions and Places. Thus, a transition is fired only when all places are associated with the minimum required number of tokens. Each token, or set of them, represents the satisfactory implementation of an established procedure. From this, the transition is fired and the next action is executed. Thus, the authority will make sure that the conclusion of one phase was followed by an analysis of all parameters that define it, not leaving the possibility of forgotten or topological changes.

This proposal discusses a model based on PN, to command and control air defense operations, focused on the application of the destruction shot. The model, Figure 2, was constructed and simulated by using a PN simulator, where places represent the procedures to be performed in the course of operations or represent a decision point, when the authority should decide what action to follow. The transitions represent the conclusion of the phase.

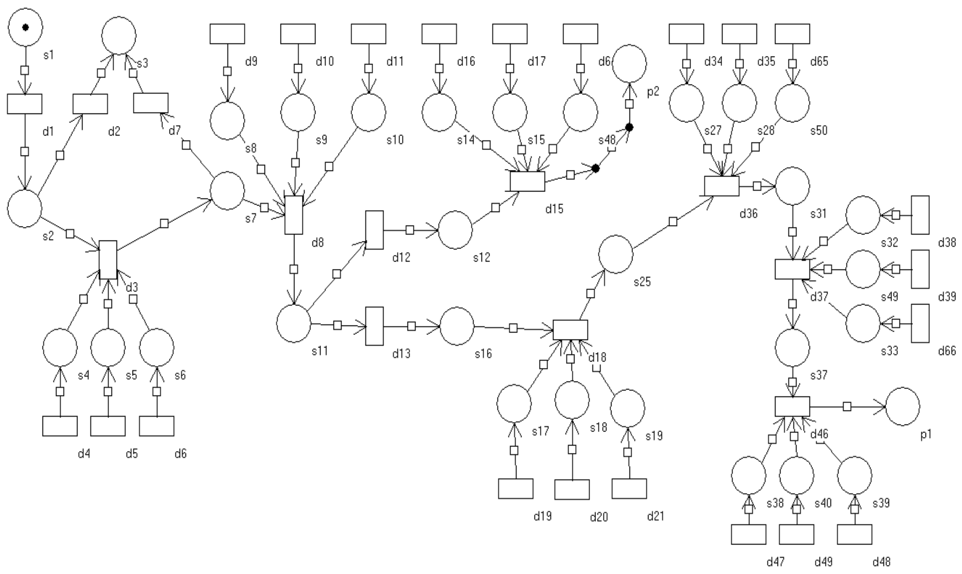


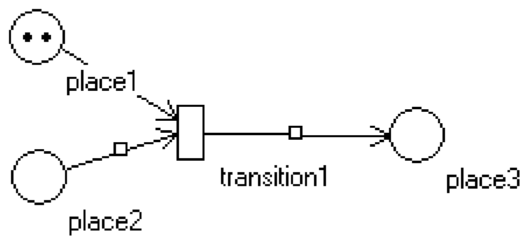
Figure 2 – Part of Air Defense Petri Net [14]

In order to build the model, it was necessary to understand the process and the elements involved in the problem.

To understand the process, it is necessary to apply the law [1][2][3], and the specific air defense procedures. Thus, the defined transitions correspond to phases of air space policing measures. Yet, the transitions could be the interface with the information sources.

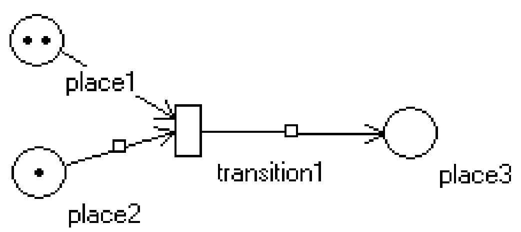
As a way of representing the behavior of enabling and firing of transitions used in this model, the following models define the adopted structures:

a) Transition not enabled:

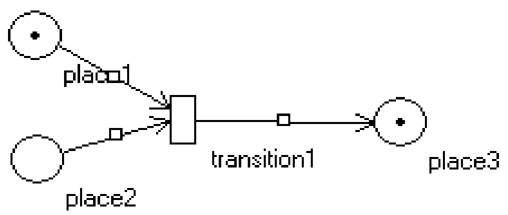


Comparing the above representation to Figure 2, place1 is equivalent to s8, s9 and the place2 transition1 to d8. For example, s8 and s9 represent some law requirements. There are two tokens in place1, but none in place2. Thus, transition1 isn't enabled because *w*(*p2*,*t1*) is equal to 1 and place2 is empty. If place 3 is the order to apply the destruction shot, it will not occur.

b) Transition enabled, but not fired:



c) Transition after being fired:



In c, note that after firing, the transition consumes one token from place1 and another one from place2, while adding one token in place3. In this work, all arcs have weight 1, i.e. w(p,t) and w(t,p) is equal to 1.

The black dots in place1 and place2 represent the performing procedures for policing the airspace. The assignment of this dot in place means that the action relating to it was executed and returned a value that allows the procedure to continue. The absence of dot represents the procedure will not continue and might mean that the action has not been executed, or that it returned an unfit value. Example: A procedure for transition1 represents the “Action1”, so that to occur it needs to know the status of situation1 (place1) and the status of situation2 (place2) until situation (place “n”), where “n” represents the last situation. In the model "b" above, place1 and place2 were filled with, at least, one black dot, then the two conditions were satisfied and the transition could be fired, but it has not been fired yet. This information indicates that all proceedings concerning that phase were completed and met the established standards.

The main objective of Petri Net is to ensure that flow control is maintained and that all mandatory actions have been were observed.

The ontology in this work represents the activity of Air Defense, focused on measures of air space policing to comply with legal requirements for the destruction shot [1]. The classes, attributes and properties analyzed were represented in a Domain Ontology. Figure 3 represents a segment, unclassified, of the ontology and their relationships.

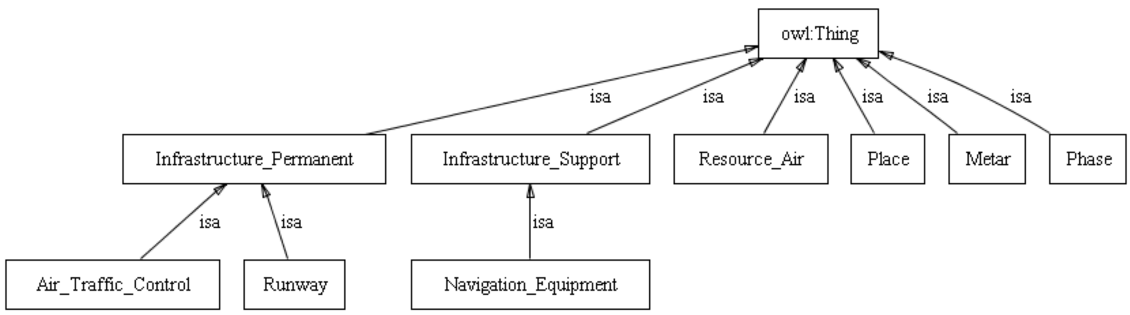


Figure 3 – Part of Air Defense Ontology

The data of each instance of the classes represents a place on the PN. The Class Phase represents the transitions.

The update in some data of the domain is performed in the ontology, e.g. the Meteorological Condition (Location attribute) is the result of application of rules (inferences) by comparing the information visibility and ceiling (attributes). The Operational Conditions result from the reasoning of information from Weather Condition, Figure 4, and Infrastructure Condition, Figure 5.

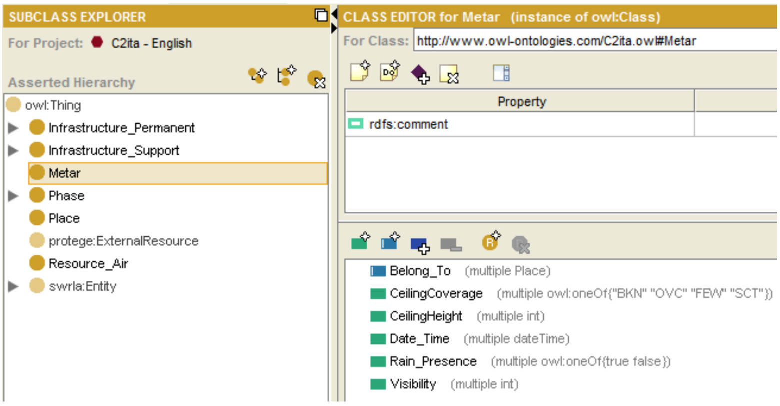


Figure 4 – METAR class and attribute

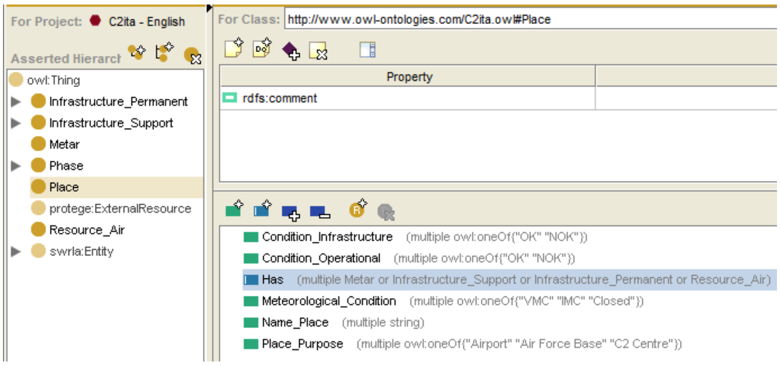


Figure 5 – Local class and attribute

The main classes involved in the ontology are: Place, Resource_Air, Metar, Phase and Infrastructure_Support, Infrastructure_Permanent.

This model maximizes the view of systemic processes inherent in the analyzed activity. Nowadays, the process is made by operators, but the formalization through the rules implemented in the ontology by SWRLJess[8], Figure 6, turn it automatic and free of possible human error.

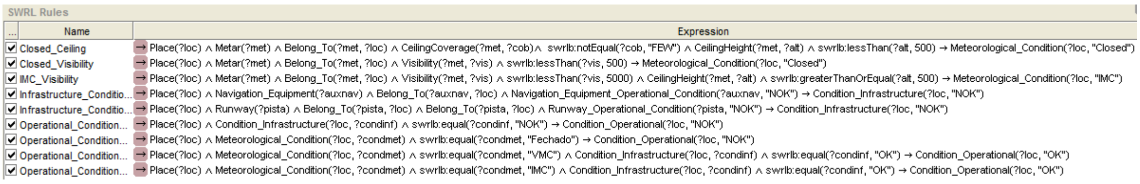


Figure 6 – Rule of the Ontology

The developed ontology represents the concepts involved with the activity of air defense. The ontology was structured to have the ability to store information, to make inferences about this information thus generating new information on the domain. The inferences are based on rules established by subject matter experts in air defense domain.

In a real situation, a decision support tool for the air defense authority can be provided by the available information, shared by the ontology, and reasoning in the employment rules of the ontology itself.

In practical terms, the implementation of the model represents the correct process to support the air space policing measures.

IV. TYPICAL AIR DEFENSE SCENARIO, IN PEACE TIME – CASE STUDY

Each year numerous unidentified aircrafts are observed flying over Brazilian airspace [9]. Many of them are not threats to national security, such as farmers, flight instruction aircrafts, Light-Sport aircrafts, and others. However, there are those that are involved with illicit substances. As a consequence, policing actions have been adopted. One of these actions is the use of air defense aircrafts.

A classical activity is the report of unknown aircrafts (target) by the air traffic control (ATC), which notifies the air defense system. At First, applying Flight Plan control and contacting another ATC Center makes the aircraft identification. If this identification fails, then the possibility of intercepting the unknown aircraft is the next action to be taken.

To intercept an unknown aircraft, many factors should be evaluated, e.g. meteorological conditions, distance from the air base or performance of the target. Many of these requirements are associated to flight safety, others to tactical and operational requirements.

After interception is ended, the interceptor could return to the base or determine the target to land in an airfield defined by the air defense authority. To do this, another checklist should be verified. Just in case the target does not follow the order to change the local to land, the authority could determine to apply the warning shot. To apply it, some mandatory items, provided by law [1], should be obeyed, for example, the area should be sparsely populated, and the target should have been classified as suspicious. As a way of representing the air space policing measures, a segment of PN is presented in Figure 7 to demonstrate the method proposed in this paper.

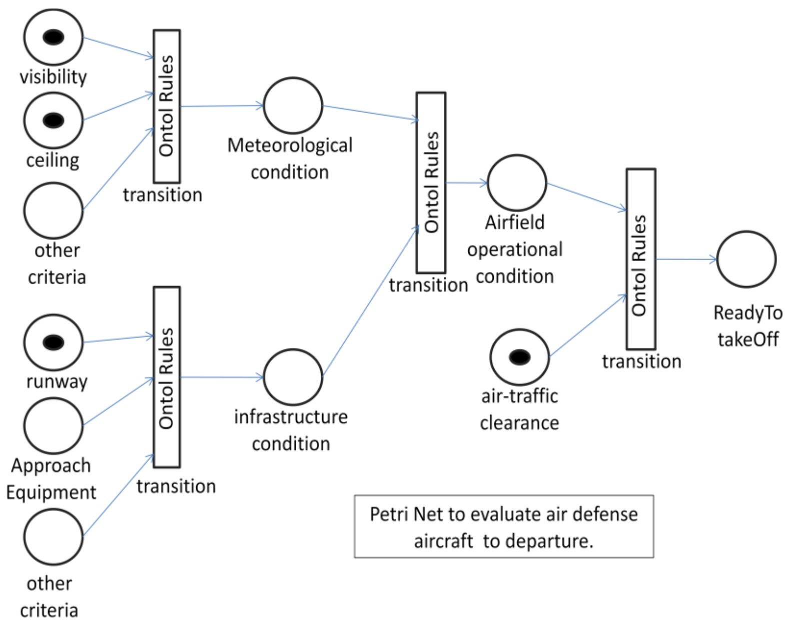


Figure 7 – Petri Net

From Figure 7, we can see the elements of the PN: Places, Arcs and Transitions, and elements of the ontology: Individuals (the places) and Attributes (the value of the place).

The rules, represented in the transitions, are implemented in the ontology, where the values for the individuals of the ontology refer to places in the PN.

Figure 7 illustrates the process for deciding if an interceptor aircraft should intercept an unknown aircraft. For example: an unknown aircraft was detected by Air Traffic Control and it was decided that an air defense aircraft should take off to intercept the unknown aircraft. For this to occur, certain procedures should rigorously be followed, such as checking the weather and infrastructure conditions.

If the information about the ceiling isn't available or its value is smaller than the minimum required, the place does not receive a token and, consequently, the meteorological condition transition isn't enabled. The same reasoning will occur to other transitions and phases of the process.

Figure 8 represents the process to evaluate the meteorological condition, applying a PN. The same process, in Figure 9, represents the infrastructure condition evaluation.

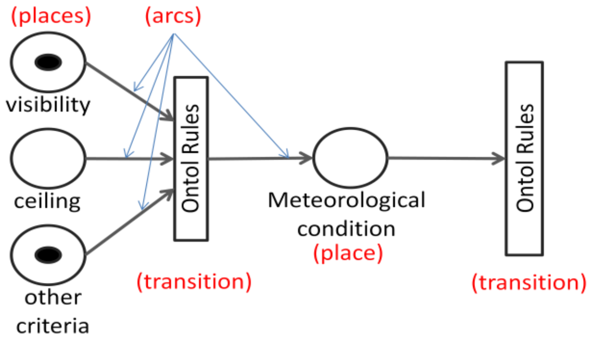


Figure 8 – Meteorological Conditions Rules

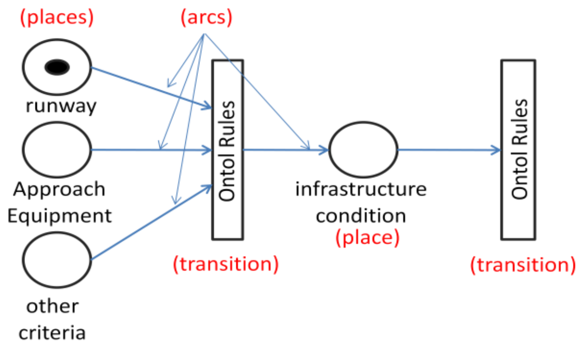


Figure 9 – Infrastructure Conditions Rules

The Figure 10 represents the Place "SBPA" before the rules related to Meteorological and Infrastructure Conditions are applied. It is the reference to apply the model as showed in Figure 8 and Figure 9.

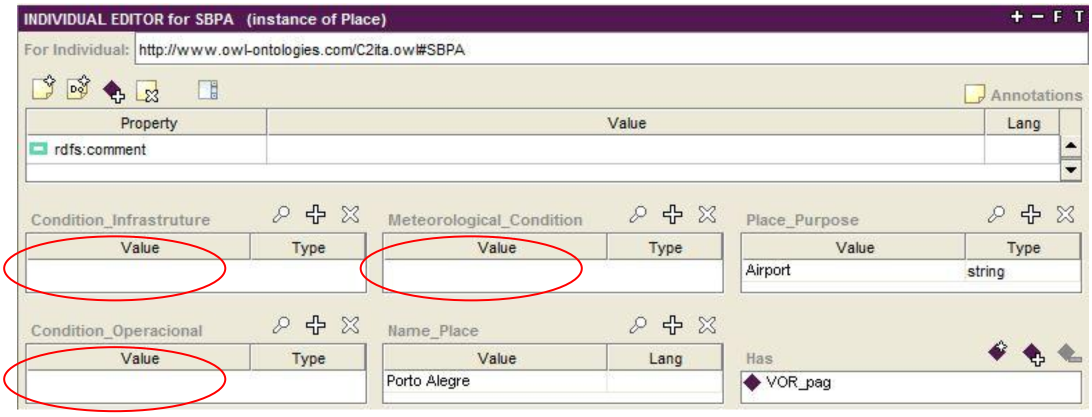


Figure 10 – Individual of the Ontology, before rules applied.

The Figure 11 represents an Individual of the ontology after the rules be applied, as showed in Figure 6.

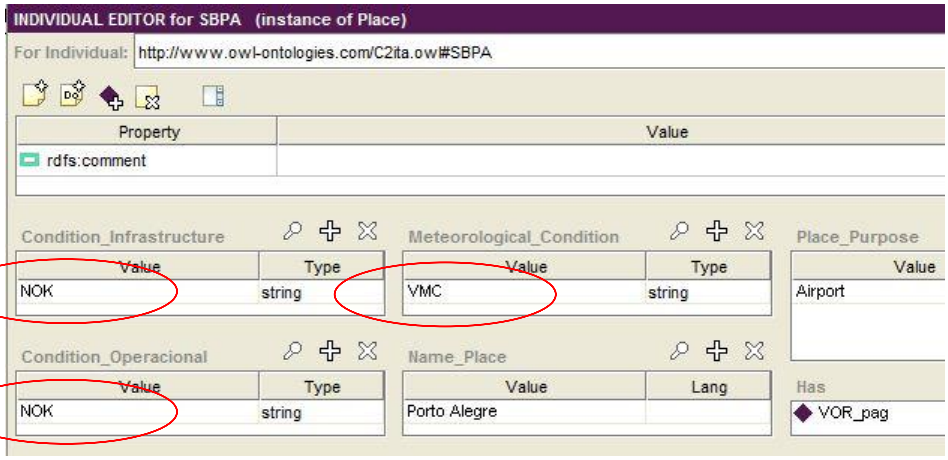


Figure 11 – Individual of the Ontology, after rules applied.

V. CONCLUSION

This paper proposes a decision support based on PN, which contains tools for simulation and analysis. The model proposes that the decision maker can be sure that all pre-requisites for its decision were reviewed and judged appropriate.

A proper understanding of the process involved in the destruction shot, viewed through the Petri Net, led to the definition of various concepts involved and their intrinsic relations, generating the ontology.

From the PN it could be observed what the needed information was. The PN also determines the sequencing of actions. Another feature of PN is to ensure that, with the firing of a transition, it is known that all of its pre-conditions have been observed.

The model is fully applicable in other operating environments that are governed by the decision flow, such as management of support equipment, calamities, and vehicle control.

For future work, the use of Colored Petri Nets will improve the decision support process.

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