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Framework for Situation Assessment and Threat Evaluation with Application to an Air Defense Scenario

Jose F. B. Brancalion[1]
Douglas de Oliveira Marques[2]
Embraer S.A.
São José dos Campos, Brazil
[1]jose.brancalion@embraer.com.br
[2]douglas.oliveira@embraer.com.br

Karl H. Kienitz
Instituto Tecnológico de Aeronáutica
Divisão de Engenharia Eletrônica
São José dos Campos, Brazil
kienitz@ita.br

***Abstract* – In military environment an operator needs to evaluate the tactical environments in real-time and make decisions to protect the assets against the enemy threats by selecting the appropriate means to engage the enemy target. This work is related to the reconnaissance (including the automatic identification and classification) of targets with hostile behaviors in relation to one point of interest located on the ground. We propose an integrated framework based on Bayesian networks and automated planning tools, to generate the situation awareness to the decision maker being a decision making supporting tool with great potential to be applied in the surveillance of large areas.**

Keywords: Threat assessment, Bayesian networks, automatic planning, decision support.

1 Introduction

The surveillance of large areas is a challenge for the Armed Forces because it is necessary to employ a significant number of mobile equipment (such as helicopters, aircraft, boats) and fixed equipment (such as radars, cameras) to cover huge geographical areas in order to identify, evaluate and track the agents that are present in the scenario.

However, there is a limitation in the available resources that can be used in the surveillance and protection of large areas, so it is mandatory to apply techniques to evaluate, identify and prioritize the most threatening agents that represent the higher danger to the resources and assets present in the scenario. It is needed to protect the most important entities based on their importance.

In the military scenario the information are referred to the military agents such as aircraft, helicopters, missiles, boats, cars, balloons, etc. The amount of data used in the data fusion system is generated by different types of sensors. The existent tactical systems are generally lacking in high level information fusion where the information provided by the sensors can be fused with environmental, political, operational and doctrine data, optimizing the decision process in short time. An automated tool that presents to the decision maker the most threatening agents in the scenario and provides an automated plan to combat this threat can assist the decision maker in achieving situation awareness.

The situation and impact assessment are dynamic processes, reflecting the changes in the scenario during the time, providing to the decision makers the possible states of the environment associated to the probability of occurrence.

The threat assessment shall consider the following factors: capacity, opportunity and intention. Some of these elements are presented below:

- Capacity: training, skills, knowledge, resources, weapons, organization, operation,
- Opportunity: access to the targets, operation, vulnerabilities, location,
- Intention: motivation, behaviors, activities related to the event chain.

1.1 Problem

The problem addressed in this paper is that of threat assessment, automatic target classification and intent inference based on recognition of aircraft behavior that plays out over time. We propose an integrated framework tool that can provide warnings of imminent threats, by evaluating the behavior of the aircraft, identifying and classifying the most threatening targets. The automated planning tool integrated in the framework provides automatic plans to intercept the threat, by engaging the appropriated assets, helping the decision maker in the decision process.

This paper is organized as follows. The next section presents the techniques that have been used in threat evaluation and the techniques that were chosen and integrated in the proposed tool. Section 3 presents the integrated framework for threat evaluation and automated planning developed in this work. Section 4 presents and discusses the results obtained in this work, and the Section 5 concludes this work.

2 Techniques

There are several works related to the threat and situation assessment that can be used in Air Defense Systems, using different techniques like rule base systems [1] or fuzzy logic [2]. This work proposes an automatic system for identification and classification of the targets with hostile behaviors in relation to one point of interest, based on Dynamic Bayesian Networks. Other similar works can be found in [3] and [4].

The behavior of the targets is monitored during its trajectories and the automatically identify and classifies the targets that represent a threat to one point of interest on the ground.

The techniques proposed for the evaluation of most threatening agents and for the construction of automated planning are presented in the next Sections.

2.1 Bayesian networks

A Bayesian Network (BN) enables for a compact representation of a full joint probability distribution. A BN consists of a directed acyclic graph (DAG) and a set of conditional probability distributions for each node in the network [5]. The graph comprises a set of nodes, with each node representing a proposition or variable within the domain of interest, and a set of directed arcs representing direct probabilistic dependencies between the variables. The only constraint on the arcs allowed in a BN is that there must not be any directed cycles: it not possible to return to a node simply by following directed arcs. The absence of an arc between two variables is interpreted as a statement of conditional independence, i.e. the two variables are independent given some subset of the other variables in the network. For each variable without parents, we need to provide a prior probability distribution. For each variable with parents, we need to specify a conditional probability distribution given each possible combination of parent states. There are many potential orderings of variables in a network, and the ordering chosen for a BN should represent the assumed dependencies and nondependencies as efficiently as possible. This usually means that the direction of an arc should follow the direction of causality when the relationship between two variables is causal.

The Bayesian Network describes a problem domain which consists in a set of random variables $U = \{X1... Xn\}$. These variables are in BN represented by a set of nodes named V, in a directed acyclic graph (DAG) $G = (V, E)$, where the set of nodes $E \subseteq V \times V$ specifies the conditional dependence and independence relations among the variables in the domain. Figure 1 illustrates an example of a simple BN.

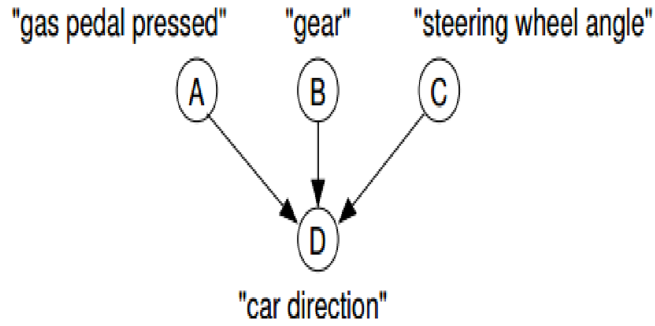

Figure 1. Illustration of a simple BN that can be used for modeling the direction of a car.

2.2 Automated planning

Automated Planning is the area of Artificial Intelligence that studies what concerns the realization of strategies or action sequences, typically for execution by intelligent agents, autonomous robots and unmanned vehicles. Its aim is to support the planning activity by reasoning on conceptual models, i.e. abstract and formal representations of the domain, of the effects and the combinations of actions, and of the requirements to be satisfied and the objectives to be achieved. The conceptual model of the domain in which actions are executed is called the planning domain, combinations of actions are called plans, and the requirements to be satisfied are called goals [6].

One motivation for automated-planning research is theoretical: planning is an important component of rational behavior—so if one objective of artificial intelligence is to grasp the computational aspects of intelligence, then certainly planning plays a critical role. Another motivation is very practical: plans are needed in many different fields of human endeavor, and in some cases it is desirable to create these plans automatically [7].

The planner's input is a planning problem, which includes a description of the system Σ, an initial situation and some objective. For example, a planning problem P might consist of a description of Σ, the initial state s0, and a single goal state s1. The planner's output is a plan or policy that solves the planning problem. A plan is a sequence of actions such as <take, move1, load, move2>.

3 Integrated tools for threat evaluation and automated planning generation

3.1 Scenario generator module

In order to generate the trajectories of the entities for the evaluation of the proposed techniques in this paper, it was developed a scenario generator module, using Matlab environment. The graphical interface of this module is presented in the Figure 2.

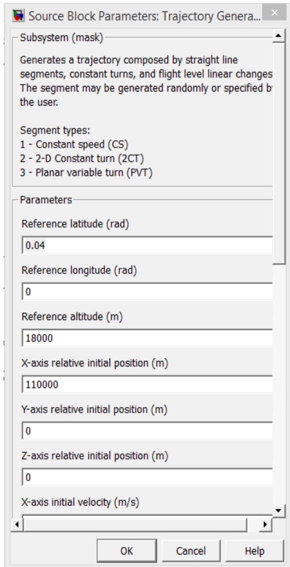

Figure 2. Trajectory generator module.

The module allows the creation of complex trajectories combining different trajectory segments, where is possible to associate a dynamic model to each segment. The available dynamic models are Constant Speed (CS), 2-D Constant Turn (2CT) and Planar Variable Turn (PVT) [8]. For each segment it is necessary to define the initial latitude, longitude and altitude of the target, the initial speeds and accelerations of the target in the X, Y and Z axis and the duration of the segment.

3.2 Bayesian Network tool

The DBN was defined using GeNIie [9]. GeNIe is a development environment for graphical decision-theoretic models developed at the Decision Systems Laboratory, University of Pittsburgh. Figure 3 presents the graphical interface for the itSIMPLE tool.

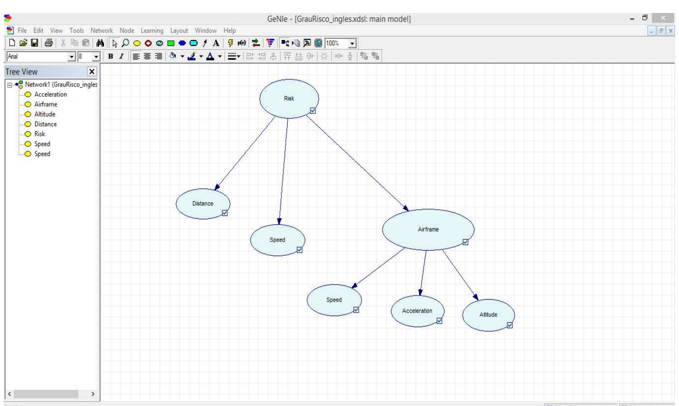

Figure 3. Geenie interface for modeling with Bayesian networks.

3.3 Automated planning tool

The automated planning tool integrated in the developed framework was itSIMPLE [10].

The itSIMPLE tool was designed to give support to users during the construction of a planning domain application mainly in the initial stages of the design life cycle [11]. These initial stages encompass processes such as domain specification, modeling, analysis, model testing and maintenance, all of them crucial for the success of the application.

Starting with requirements elicitation, specification and modeling, itSIMPLE proposes a special use of UML – Unified Modeling Language - in a planning approach (named UML.P) which we believe can contribute to the knowledge acquisition process (from different viewpoints) as well as to the domain model visualization and verification.

3.4 Integrated framework

The integrated framework was developed in Matlab environment. It integrates the trajectory generator module, the Bayesian Network tool and the automated planning tool. Figure 4 presents an illustration of this framework.

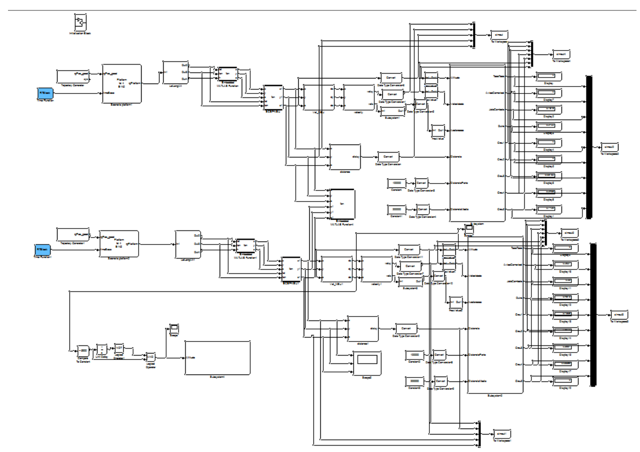

Figure 4. Integrated framework developed in Matlab environment.

4 Results

In this analysis we generated two trajectories of aircraft, there is one point of interest located on the ground. The trajectory generator produces periodically the state vector of the the targets which contains the position, speed and acceleration of the targets. These information are the input for the Bayesian network. There is a classifier that identify and classify automatically the aircraft based on their dynamic behaviors. The possible classes for the aircraft are: Small, Commercial, Fighter and Other. The inference tool identifies dynamically the risks associated to each aircraft, where Risk 1 represents the lowest risk and Risk 5 represents the higher risk. The risk is associated to the probability to cause damages to the point of interest.

Figure 5 and Figure 6 present the simulated trajectories and the positions in relation to the point of interest. From the point of interest are defined concentric regions, each one represents the threat level for the aircraft in relation to the point. The more distant regions represent less danger to the point of interest; the regions closer to the point represent more danger.

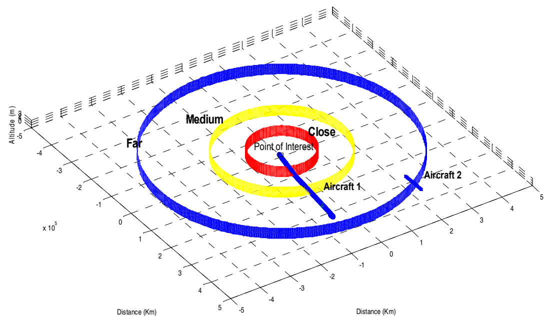

Figure 5. Trajectories of the aircraft related to the point of interest.

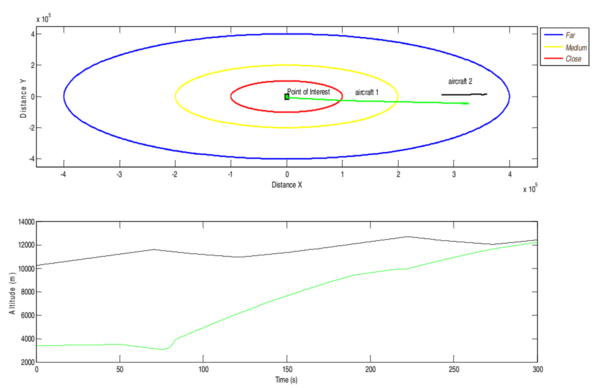

Figure 6. Location and altitude of the aircraft.

Figure 7 and Figure 8 present the Bayesian network and its structure, used in the threat assessment system, where the Risk is dynamically inferred from the information about the distance of the aircraft in relation to the point of interest, speed, altitude and type of aircraft (based on the estimation of dynamic behavior of the aircraft from the state vector of the aircraft).

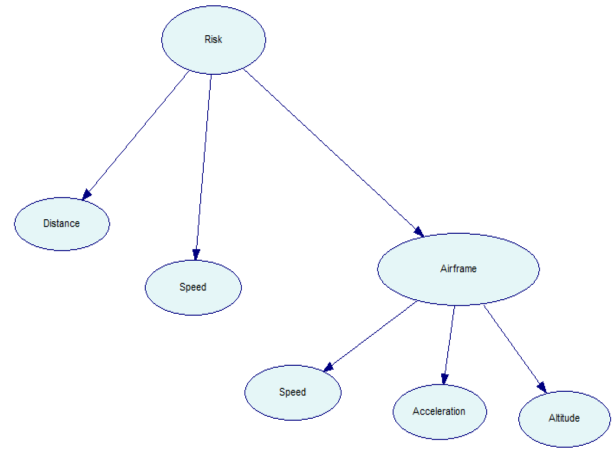

Figure 7. Bayesian network describing the scenario.

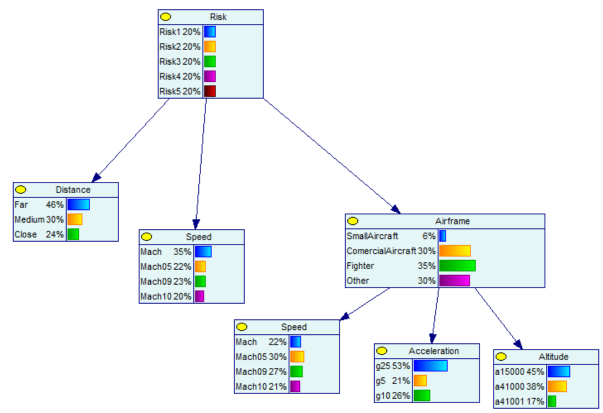

Figure 8. Structure of the Bayesian Network.

Figure 9 presents the speed, altitude and the risks associated to the aircraft 1. Figure 10 presents the classification and the risks associated to the aircraft 1. The probabilities associated to the classification of the aircraft change in the time; initially the higher probability was associated to Commercial aircraft. When the speed of the aircraft increased the probability associated to the Commercial type decreased and the probability associated to Fighter type increased. The risk associated to the aircraft is also calculated during the trajectory of the aircraft. The aircraft is approaching the point of interest and its type changed from Commercial to Fighter, so its associated risk changed from Risk 2 to higher risks degrees, Risk 4 and Risk 5. The higher the risk associated to the aircraft the higher the threat represented by the aircraft to the point of interest.

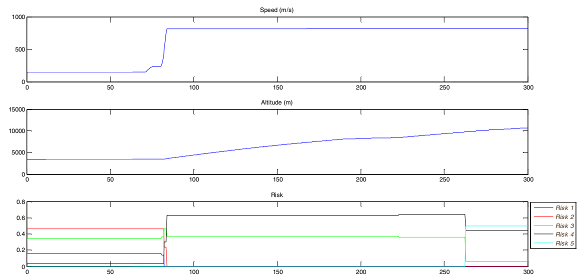

Figure 9. Speed, altitude and risk associated to Aircraft 1.

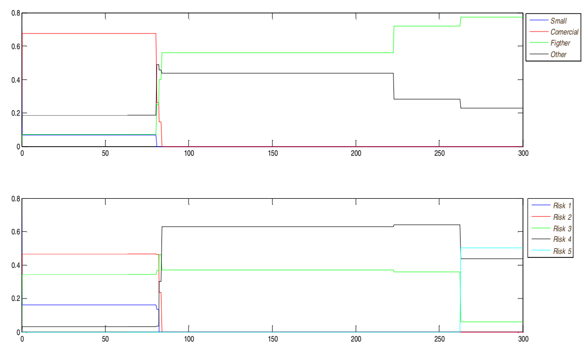

Figure 10. Classification and risk associated to Aircraft 1.

Figure 11 presents the speed, altitude and the risks associated to the aircraft two. The risk associated to the aircraft 2 is also calculated during the trajectory of the aircraft. The risk initially associated to it was Risk 2, kept constant during the entire trajectory. As the aircraft is located far to the point of interest during the entire trajectory, the risk did not change.

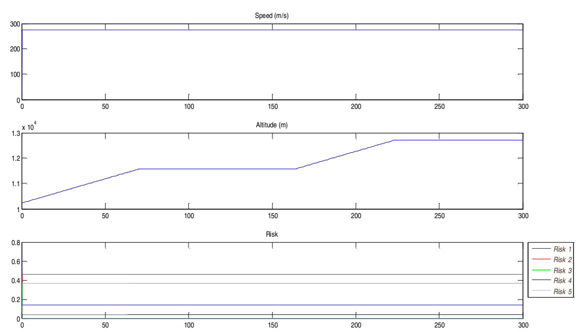

Figure 11. Speed, altitude and risk associated to Aircraft 2.

Based on the evaluated risks the system automatically identify that there is a high potential threat to the point of interest represented by aircraft 1 and automatically trigger the automatic planning tool to generate a plan to intercept the aircraft 1.

Figure 12 presents the graphical interface for itSIMPLE tool used to generate the plans.

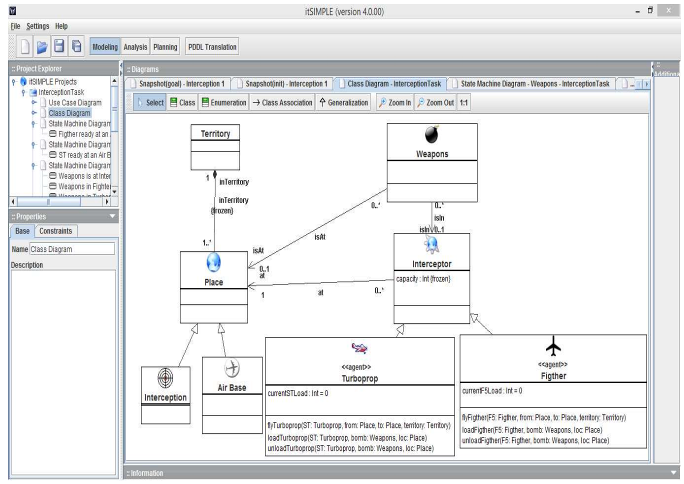

Figure 12. itSIMPLE4.0 interface for modeling with UML.P

The class diagram is the commonly used in object oriented modeling process. Classes capable of performing actions are what we call classes of agents, while others are considered only resources in the model. Figure 13 illustrates the class diagram for the Interception domain.

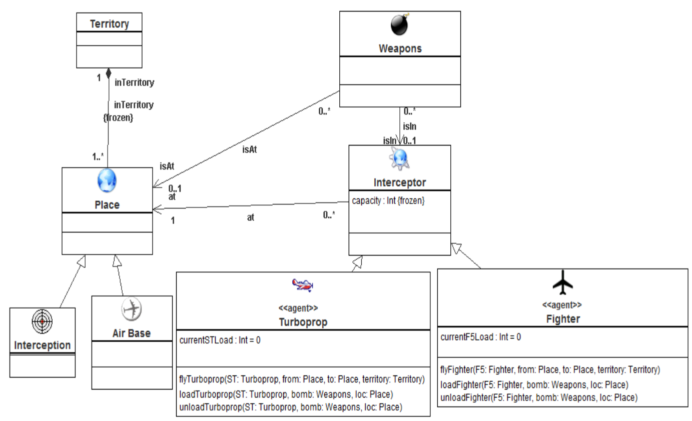

Figure 13. Modeling static features with class diagram.

Another diagram used for modeling the domain features is the state chart diagram. In UML.P the state chart diagram is responsible for representing dynamic features of the domain model. Such dynamic representation is actually the bottleneck in the planning domain modeling process. Figure 14 presents the state chart diagram for the Weapons class.

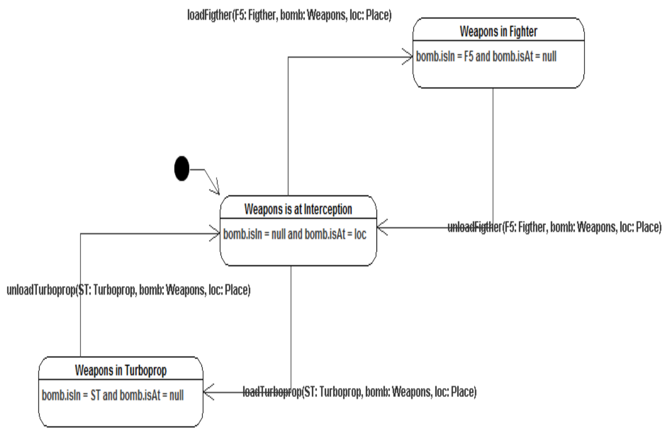

Figure 14. State chart diagram for the Weapons class.

Figure 15 presents the state chart diagram for the Fighter class.

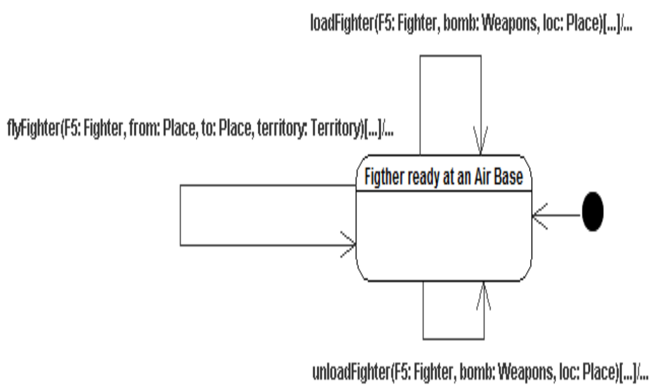

Figure 15. State chart diagram for the Fighter class.

A problem statement in a planning domain is usually characterized by a situation where only two states are known: the initial and goal states. The diagram used to describe these states is the object diagram or Snapshot. Figure 16 presents the initial state for the Interception problem and Figure 17 presents the final state for the Interception problem.

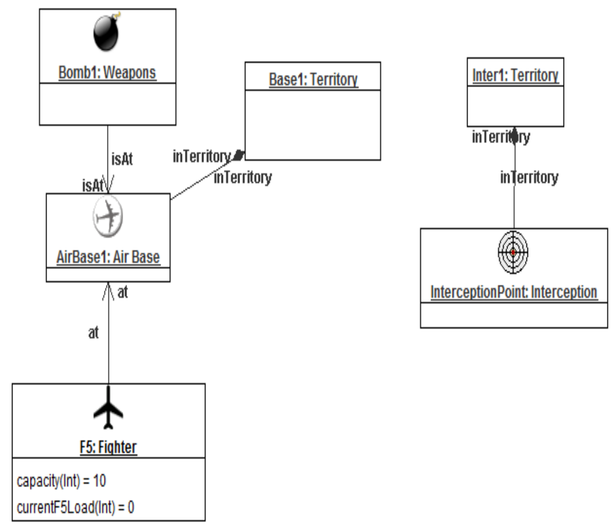

Figure 16. The initial state of an Interception problem.

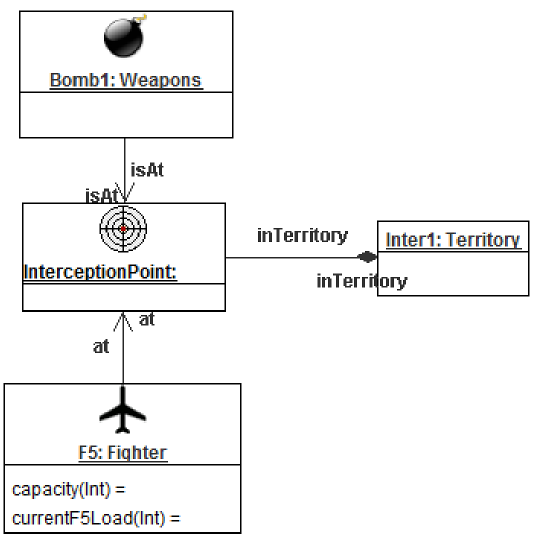

Figure 17. The final state of an Interception problem.

The itSIMPLE offers several planners to create the plans. In this work it was as used the Metric-FF planner [12] to generate the following automatic plan:

0:(LOADFIGHTER F5 BOMB1 AIRBASE1) [1]
1:(FLY F5 AIRBASE1 INTERCEPTIONPOINT) [1]
2:(UNLOADFIGHTER F5 BOMB1 INTERCEPTIONPOINT) [1]
3:(FLY F5 INTERCEPTIONPOINT AIRBASE1) [1]

5 Conclusion

This paper focuses on the problem of evaluating aerial aircraft that can represent potential threats to a point of interest located on the ground, and proposes an integrated framework for automatic identification, evaluation, classification of the threats present in one area of interest. The developed tool also provides an automated planning tool that creates plans to aid the decision maker in the process to engage the most appropriate asset to combat the threat.

As future work we propose the integration of others types of information in the Bayesian network, like geographical and political for instance. In the planning tool we propose to incorporate other information in the plan, like the best weapon to be used to engage the threat based on its classification.

References

[1] M. J. Liebhaber, B. Feher, "Air Threat Assessment Research, Model and Display Guidelines", Proceedings of the 2002 Command and Control Research and Technology Symposium, Monterey, CA, USA 2002.

[2] F. Johansson, G. A. Falkman, "Comparison Between Two Approaches to Threat Evaluation in an Air Defense Scenario", Proceedings of the 5th International Conference on Modeling Decisions for Artificial Intelligence. Sadabell, Espanha 2006.

[3] A. Dahlbom, P. Nordlund, "Detection of Hostile Aircraft Behaviors Using Dynamic Bayesian Networks", 16th International Conference on Information Fusion. Istambul, Turkey 2013.

[4] P. Louvieris, A. Gregoriades, W. Garn, "Assessing critical success factors for military decision support", Expert Systems with Applications. no. 37, pp. 8229–8241, 2010.

[5] K. R. McNaught, V.V.S.S. Sastry, B. Ng, "Investigating the Use of Bayesian Networks to Provide Decision Support to Military Intelligence Analysts", Proceedings 19th European Conference on Modeling and Simulation, Riga Latvia, 2005.

[6] A. Cimatti, M. Pistore, P. Traverso, "Handbook of Knowledge Representation", chapter 28, Automated Planning, Elsevier, 2008.

[7] D. S. Nau, "Current Trends in Automated Planning", AI Magazine, vol. 28, no. 4, pp. 43-58, 2007.

[8] X. R. Li; V. P. Jilkov. "Survey of Maneuvering Target Tracking Part I: Dynamic Models", IEEE Transactions on Aerospace and Electronic Systems. vol. 39, no. 4, pp. 1333-1364, October 2003.

[9] DSL, "GeNIe and SMILE," Decision Systems Laboratory, University of Pittsburgh, Pittsburgh, PA, USA, 2013.

[10] Available in: https://code.google.com/p/itsimple/

[11] T. S. Vaquero, V. Romero, F. Tonidandel, J. R. Silva, "itSIMPLE2.0: An Integrated Tool for Designing Planning Domains", ICAPS 2007, Providence, Rhode Island, USA, pp. 336-343.

[12] Available in http://fai.cs.uni-saarland.de/hoffmann/