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A fuzzy cognitive situation awareness for airport security*

by

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Abstract: Situation awareness is a crucial factor in decision-making. It involves monitoring and identification of relationships among the state changing objects in collaborative dynamic environments. In the domain of airport security a critical need is to support security operators in real-time management of risky airside scenarios. This work relies on a fuzzy cognitive ontology-based approach to model situation awareness and introduces an agent-based distributed evaluation architecture to address the problem. Specifically, in order to model situation awareness this work instantiates and integrates two assessed ontological meta-models, *Situation Theory Ontology (STO)* and *Saw Core Ontology (SAW)*, extended to cope with uncertainty when modeling relations among objects occurring in the addressed dynamic environment. Many task-oriented soft computing agents are in charge of monitoring the modeled situations while distributing the information evaluation process leads to achieving better real-time like performance.

Keywords: fuzzy logic, fuzzy control, situation awareness, agent systems, airport security, semantic modeling.

1. Introduction

Nowadays, *airport security* is one of the biggest issues for travelers. The millions of air passengers who pass through airports every day require high levels of security. The continuous evolution and growth of threats - from terrorism and organized crime, to drug trafficking, mass immigration and cyber attacks - force security organizations to be constantly equipped to contend with the changing risks. Security requirements arising at international level reflect the expectations and demands of the world citizens. Analyzing and addressing involved risks calls for rigorous methods, proven technological capability and the appropriate organizational and human resources. This convergence between defense and security

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has prompted the need for new solutions and technologies to support collaborative decision making by enabling organizations to share existing information and communication systems. In particular, the airport security domain reveals a growing trend towards Collaborative Decision Making (CDM) information systems. Here, security operators rely on decision making tools to face the problem of the information overload induced by the large amount of data provided by multiple heterogeneous and highly-dynamic information sources. It is broadly recognized that Situation Awareness (SA) is a crucial factor in decision-making. Maintaining a coherent situation awareness with respect to all relevant entities residing in a region of interest is essential for achieving successful resolution of an evolving situation. Situation-aware information systems support operators by the aggregation of the available information into meaningful situations (Endsley and Garland, 2000). Indeed, the primary basis for situation awareness is the acquired knowledge about objects within the region of interest, typically provided by sensors (both mechanical and human) that perform object identification and characterization. Nevertheless, this task involves the monitoring and identification of relationships among objects in collaborative dynamic environments. In order to automate reasoning on the acquired environmental knowledge we remark the leading role of the semantic technologies (W3C. Semantic Web Activity, 2006; RDF. Resource description framework (RDF) model and syntax specification, 1999; W3C. Web Ontology Language Reference OWL, 2004). Ontologies are recognized as a promising technology for implementing such systems, because of their semantically-rich kind of knowledge representation. In this sense, several systems for SA support the management of various information sources (sensor data, textual information, databases, etc.) for purposes such as information exchange and graphical presentation to facilitate decision making. In this work we take advantage of existing results in the area of situation awareness with particular reference to contributions to situation modeling given in Matheus, Baclawski and Kokar (2003), Matheus, Kokar and Baclawski (2003a), Kokar, Matheus and Baclawski (2009), Kokar and Wang (2002), where Situation Theory Ontology (STO) and Saw Core Ontology (SAW) are defined as robust and stable meta-ontologies. Furthermore, several agent-based architectures (Matheus, Kokar and Baclawski, 2003b; Gerken et al., 2003; Kodagoda et al., 2007) designed to support semantic reasoning, have been deeply analyzed. Such systems appear to lack effective capabilities to enable a deep semantic modeling of domains, providing, at the same time, efficient distribution models to support real-time reasoning. Consequently, no satisfying implementations have been detected to achieve effective and efficient airport security SA. Moreover, another important requirement, generally not satisfied, is represented by the capability to cope with uncertainty for situation awareness in complex, real application domains. Indeed, the use of soft computing techniques applied to the modeling of situation awareness to improve cognitive decision making (Endsley, 1990; Endsley and Smith, 1996) and operating performance is an important new trend. Our work is based on the adoption of a synergic approach of agent-based architecture and semantic modeling of situations by introducing fuzziness in order to satisfy the aforementioned requirements in modeling airport security situation awareness. The paper is organized as follows: Sections 2 and 3 present the state of the art of both the application domain and cognitive approaches to situation awareness. Section 4 shows the adopted information processing model enhanced with the introduction of uncertainty modeling in situation awareness ontologies. Section 5 describes the Agent-based Distributed Inference System, designed and developed to support soft computing cognitive awareness in an airport collaborative decision making framework. Sections 6 and 7 present, respectively, the general approach to airport security SA modeling and main results of the system under discussion. Finally, in Section 8 conclusions and future works are summarized.

2. Situation awareness for airport security

2.1. Situation awareness

The notion of *situation awareness* has been used with a number of different meanings. In our discussion, we refer to Situation Awareness as the perception of environmental elements within a volume of time and space, the comprehension of their meaning, and the projection of their status into the near future. Situation Awareness involves being aware of what is happening all around in order to understand how information, events, and performed actions will impact specific goals and objectives, both now and in the near future. Having complete, accurate and up-to-the-minute Situation Awareness is essential where technological and situational complexities are a concern for the human decision-maker. Situation Awareness has been recognized as a critical, yet often elusive, foundation for successful decision-making across a broad range of complex and dynamic systems, including aviation and air traffic control. In this work, the first goal is to formalize main concepts of situation awareness involved in a specific scenario of airport security using a language that is both computable by computer and commonly supported. To achieve this goal, we first need to identify appropriate concepts that can be classified as a part of the situation awareness domain. In particular, in the following sections, we will stress the concept of relationship among things (objects) involved in a specific situation as a key element in SA. Relations will be intended from the point of view of an entity as a focal object in the situation, and capture how other surrounding entities relate to it. In what follows, we will make more detailed this formalization. A relevant source of information on situation awareness is the situation theory developed by Barwise (1981, 1989) and Perry (Barwise and Perry, 1983; Barwise, Perry and French, 1981), and then successively extended by Devlin (Devlin, 1991, 2006). Computer support for logic is a popular theme in computer science, and there are many languages that have been developed for this purpose. Moreover, situation theory has already been expressed in terms of some existing logical languages.

However, few of these languages have even been standardized, and fewer still are commonly supported by popular software tools and systems. Currently, the only languages that have such support are Semantic Web (W3C. Semantic Web Activity, 2006) languages: Resource Description Framework (RDF. Resource description framework (RDF) model and syntax specification, 1999) and Web Ontology Language (W3C. Web Ontology Language Reference OWL, 2004), based, in turn on RDF. OWL improves RDF by adding many new logical capabilities. One of the most important new capabilities is the ability to define classes in terms of other classes using a variety of class constructors such as unions, intersections and property values. Accordingly, we have chosen OWL as the reference language for situation theory formalization in our particular domain. OWL comes with three increasingly-expressive sublanguages: OWL Lite, OWL DL, and OWL Full, all of them, though, sharing the fundamental features of being self-descriptive, able to decouple facts from the containing document, as well as to reduce to simple, elementary statements. Concepts expressed in OWL and the ones expressed using description logic inference rules, together, enable the construction of a formal ontology for situation awareness. In our work, we refer to two founding upper ontologies expressed by means of OWL to model situation awareness, Saw Core Ontology (Matheus, Kokar and Baclawski, 2003a) and Saw Situation Theory Ontology (Kokar, Matheus and Baclawski, 2009), and combine them in order to allow for effective and improved SA modeling for airport security, able to manage domain uncertainty by introducing approximation and uncertainty modeling capabilities. In order to achieve this goal, we need to:

- reformulate the infon (Kokar, Matheus and Baclawski, 2009) concept of STO according to fuzziness and interpretation;
- define the formal model of a situation evaluation (interpretation);
- extend STO ontological model in order to:
  - model ontological fuzzy sets;
  - model infon of STO complying with the interpretation;
  - model situation of STO complying with the interpretation.

2.2. Airport security

Nowadays, unexpected airport situations imply emphasis on security of operators and air navigation service providers, as well as travelling passengers. Indeed, unexpected situations disrupt the smooth running of air transport operations, frequently with widespread impact. For instance, crew and passengers being late, aircraft not prepared in time, services unavailable and/or infrastructure malfunctioning generate sporadic, even though sometimes systematic, delay, inconvenience and, more generally, inefficiency. Furthermore, new types of threats (terrorism, organized crime, etc.) can make risky the normal conduct of airport operations. Sharing current information on such events, communicating it to those involved and taking collaborative decisions is essential to minimize disruption, maintaining efficient operations and consistently maximizing the effective usage of airport infrastructures. Collaborative Decision Making (CDM) aims at achieving common awareness shared by inexpensive systems and processes as well as supporting collaboration among key partners in order to enhance real-time decision making at an airport, substantially leading to more efficient operations. CDM affects the decision-making process by managing aircraft and security operations through a wider, network-oriented approach. Plans are shared, the air traffic picture is drawn, means to minimize disruption are devised and decisions to maintain fluid operations developed and executed. Airport CDM tries to replace the current central planning paradigm with a collaborative process. To establish such a process, information owned by individual partners is shared among all in a useful system-wide representation. When all airport partners have access to up-to-date information, a common situation awareness is established. As all partners involved will have a global overview, they can improve their pre-tactical and tactical planning processes. To achieve enhanced common situation awareness, the following pre-requisites are required:

- Agreed relevant data should be shared between all partners involved at the right time;
- Shared data should have enough quality to simplify improved traffic predictability and planning capabilities for all involved partners;
- Decisions should be made by the partner best placed to make them;
- Decisions made should be shared with all other partners.

3. SAW and STO outline

In this section we provide some outline about SAW and STO ontological meta-models. We refer to Matheus, Kokar and Baclawski (2003a) and Kokar, Matheus and Baclawski (2009) for further details.

3.1. SAW

In our development of a formal approach to acquire sensory information from field and reason about situations (see Matheus, Kokar and Baclawski, 2003a) we need an ontology satisfying several requirements. First, it has to be able to represent objects and relationships, as well as their evolution over time. Second, we want it to be able to express essentially any reasonable evolution of objects and relationships (although possibly only approximately). Third, the design needs to be economical so as to ultimately allow for its implementation in a real system. Saw Core Ontology covers all these requirements. In Saw Core Ontology the main classes are: Situation defined as a collection of Goals, SituationObjects and Relations. SituationObjects are entities in a situation - both physical and abstract that can have characteristics (i.e., Attributes) and can participate in relationships. Attributes define values of specific object characteristics, such as weight or color. A PhysicalObject is a special type of SituationObject, characterized by the following attributes: volume, position and speed. Relations define the relationships among ordered sets of SituationObjects. For example, inRangeOf(X, Y) might be a Relation representing the circumstance when one PhysicalObject X is within the firing range of a second PhysicalObject Y. An important aspect of Attributes and Relations is that they need to be associated with values that can change over time. To accomplish this, Attributes and Relations are associated with zero or more PropertyValues, each of them defining two time dependent functions, the first stating the current value and the other stating the certainty of that value assignment. A new PropertyValue is created for an Attribute/Relation whenever an EventNotice arrives affecting that Attribute/Relation. The value of an Attribute/Relation at a particular instant (either current, past or future) can be determined by accessing the value function of the PropertyValue instance holding at the required time. EventNotices contain information about events in the real-world situation as observed by a sensory source at a specific time that affects a specific Relation or Attribute. EventNotices are, indeed, the entities indicating changes in the situation and thus are the means by which the situation representation evolves. We refer to Matheus, Kokar and Baclawski (2003a) for a more detailed description of SAW.

3.2. STO

Although the notion of situation awarene is a part of the data fusion lexicon, this term has been used with a number of different meanings. The earliest formal notion of *situation* was introduced by Barwise and Perry to give a more realistic formal semantic basis for speech acts than what was available till then (Barwise, 1981; Barwise and Perry, 1989; Barwise, Perry and French, 1981). Furthermore, in Barwise (1989) a formal framework for Situation Theory (ST) has been developed and successively extended by Devlin (1991, 2006). In ST, information about a situation is expressed in terms of infons. Infons are expressed as

$$\sigma_i \equiv \ll R, a_1, ..., a_n, \varphi \gg$$

where R is an n-place relation and a_1,...a_n are objects appropriate for R. Since ST is multi-sorted, the word "appropriate" means that the objects are of the types appropriate for a given relation. The last item in an infon, φ, is the polarity of the infon. Its value is either 1 (if the objects stand in the relation R) or 0 (if the objects do not stand in the relation R). Infons may be recursively combined to form compound infons by using conjunction, disjunction and situation-bounded quantification. To capture the semantics of situations, ST provides a relation between situations and infons. It is called the supports relationship and relates a situation with the infons that are made factual by it. Given an infon σ and a situation s the proposition s supports σ is written as s $\models \sigma$. In Kokar, Matheus and Baclawski (2009) a formalization of Barwise situation semantics (Barwise and Perry, 1983) was presented in terms of an ontology, with some parts using mathematics and rules, and such an ontology has been named STO.

4. Information processing model

4.1. Layered fuzzy ontology

One of the main goals of this work is to improve over the classical semantic approach, where real world concepts and properties are usually treated as crisp sets. In particular, we should consider the possibility of modeling uncertainty in situation awareness applied to airport security. This aim has been achieved by introducing fuzzy modeling in STO. We have called the resulting ontology Fuzzy STO (FSTO). Our interpretation of SA is based on the layering of FSTO and SAW ontological meta-models. In particular:

- SAW field layer: it aims to model the field layer referred to the acquisition and processing of environment information (i.e. radars, sensors, cameras, etc.);
- FSTO operator layer: refers to the modeling and definition of situations as observed by operator.

As show in Fig. 1, SAW is used to model environment information acquired from field sensors and events to be triggered affecting relations between objects in the specific observed scenario. In other words, with SAW we represent a first layer of knowledge, allowing to infer information on observed situations. The latter represent a second layer of knowledge to reason on, in order to detect interesting situations. For instance, as depicted in Fig. 1 the airport security SA requires the acquisition of aircraft related information through radar systems. This information is stored according to SAW. Airport security situations, modeled by FSTO, are then inferred by reasoning on the acquired information. The main reason for this layered approach is to provide two conceptual views; a high level view about observed situations, given by STO, aimed to enable qualitative reasoning on information granules, and a low level view about data acquisition, given by SAW, aimed at providing qualitative information granules as the basis for upper qualitative reasoning.

4.2. Fuzzy situation theory ontology

During the application of ontologies, more and more practitioners realized the difficulty in describing uncertain knowledge. Situation awareness is usually applied in very complex and dynamic environments and the uncertainty modeling becomes of primary importance. For example, in airport security domain the uncertainty degree at which a situation happens can become fundamental.

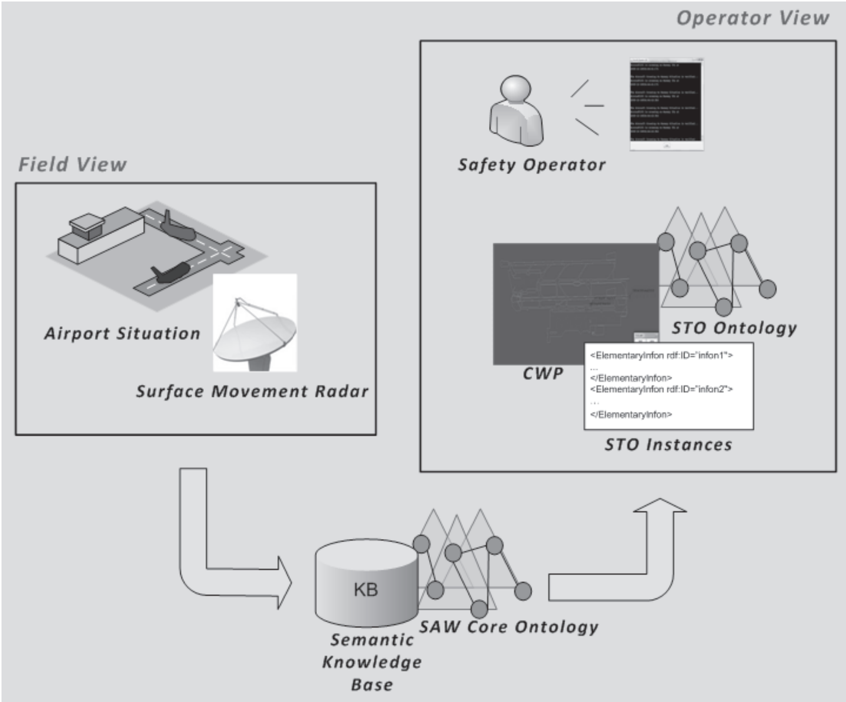

Figure 1. Layered ontology overview

FSTO meta-model for Situation Awareness can evolve in a natural way towards the approximation and uncertainty modeling. In this section, we will try to explain how fuzziness has been introduced in the above model. Devlin states that infons are not things that in themselves are true or false. Rather a particular item of information may be true or false about a situation (Matheus, Kokar and Baclawski, 2003a). Thus, in our interpretation, the polarity of an infon σ_i supporting a situation s_j can be one out of the terms defining a linguistic variable expressing infon truth. For instance, let

$$(InfonTruth, \Im(G), [0..1], G, M) \tag{1}$$

be the aforementioned linguistic variable, where G is the grammar generating terms in $\Im(G)$ and M is the semantic rule which associates each linguistic value with its meaning. The definition of the context free grammar G involves (*true*,*false*) as primary terms (whose membership function definitions are depicted in Fig. 2a), a finite number of hedges (*more of less*,*quite*,*really*,) whose evaluation in M is performed by means of concentration and dilation, the connectives *and* and *or*, and the negation *not*. Thus, the syntax of the linguistic variable given by the grammar is such that the set of terminal symbols in $\Im(G)$

consists of primary terms, modifiers, connectives and negations. According to (1), an infon σ_i supporting a situation s_j is written as:

$$\sigma_{i,s_j} \equiv \ll R_i, a_1, a_2, \ldots, a_n, \tau_{\sigma_{i,s_j}} \gg with\ \tau_{\sigma_{i,s_j}} \in \Im(G) \tag{2}$$

stating that $R_i(a_1, a_2, \ldots, a_n)$ is $\tau_{\sigma_{i,s_j}}$ in s_j.

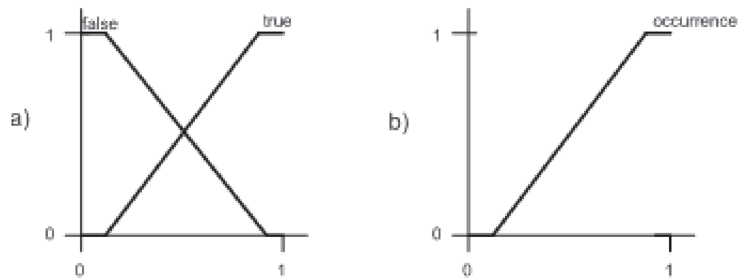

Figure 2. Membership functions definitions for a) InfonTruth and b) Occurrence

By adopting this modeling approach, the semantics of support proposition $\models$ can be stated as

$$s_j \models_{ext} \{\sigma_{i,s_j}\} \Leftrightarrow \forall i \colon R_i(a_1, a_2, \ldots, a_n)\ is\ \ \tau_{\sigma_{i,s_j}}. \tag{3}$$

This interpretation leads us to define a modeled situation occurrence as the evaluation of a corresponding fuzzy control rule:

$$\begin{aligned} &IF\ R_1\left(a_{1,1}, a_{1,2}, \ldots, a_{1,n_1}\right)\ is \quad \tau_{\sigma_{1,s_j}} \\ &\quad AND \ldots \\ &\quad AND\ R_i\ \left(a_{i,1}, a_{i,2}, \ldots, a_{i,n_i}\right)\ is \quad \tau_{\sigma_{i,s_j}}\ THEN \\ &\quad s_j\ is\ occurring \end{aligned} \tag{4}$$

otherwise formalized as:

$$\mu_{occ}\left(s_j\right) = \wedge_i\ \mu_{\tau_{\sigma_{i,s_j}}}\left[R_i\left(a_{i,1}, a_{i,2}, \ldots, a_{i,n_i}\right)\right] \tag{5}$$

where $\wedge$ is a suitable t-norm operator and *Occurrence* is a fuzzy set modeled as depicted in Fig. 2b. Finally, it is necessary to define the formal transformation process from SAW relation tuples to FSTO infons. In order to distinguish STO and SAW Relation, we use the following notation:

- R_{STO} for STO Relation;
- R_{SAW} for SAW Relation.

As depicted in Fig. 3, there is a mapping between R_{STO} and R_{SAW}. In particular, R_{STO} defines an infon, and the validity of this is determined by polarity value, that is, if polarity value is greater than zero, then the objects involved in R_{STO} are of appropriate type for that relation. R_{SAW} is defined by relation tuples. Formally R_{SAW} can be defined as:

$$R_{SAW} \equiv \bigcup_{X \in Domain(R_{SAW})} \xi(X) \tag{6}$$

where X is a class of objects involved in R_{SAW},

$$\xi\colon X \to X' \ni' \xi(X) = \{(x, \varrho_{R_{SAW}}(x)) \,|x \in X\}. \tag{7}$$

In ξ, $\varrho_{R_{SAW}}(x)$ states the participation degree of x in R_{SAW} and is modeled by means of a ValueFunction instance. Thus, we define:

$$\mu_{\tau_{\sigma_i, s_j}}[\sigma_i] \equiv \wedge_i \ \mu_{R_{SAW}}(a_i). \tag{8}$$

The above formal definitions give an interpretation model of infons and situations in terms of fuzzy values. This interpretation is aimed to improve situation awareness and particularly to satisfy predictability requirements in complex and dynamic domains.

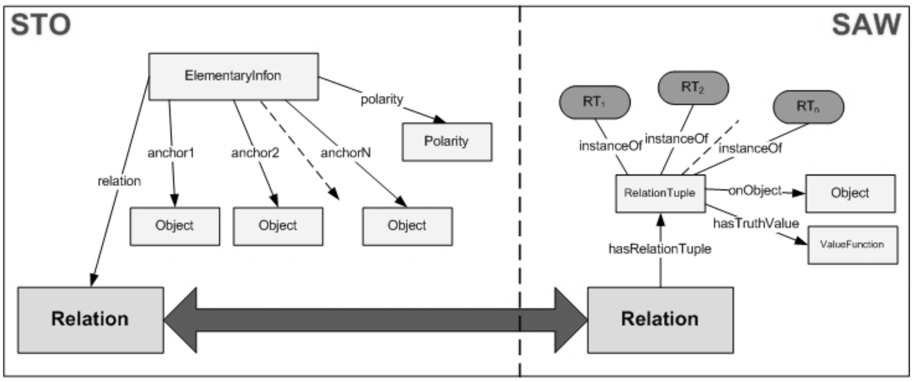

Figure 3. Mapping between STO and SAW relation

5. Agent-based distributed inference system

In this section we will show the general organization model of an architecture for cognitive awareness, together with a general description of the roles involved.

The Airport Security Agents System (ASAS) (Fenza, Furno, Loia and Veniero, 2010) (Fig. 4) organizational model, has been split into two main parts:

- Knowledge Management (KM System),
- Security.

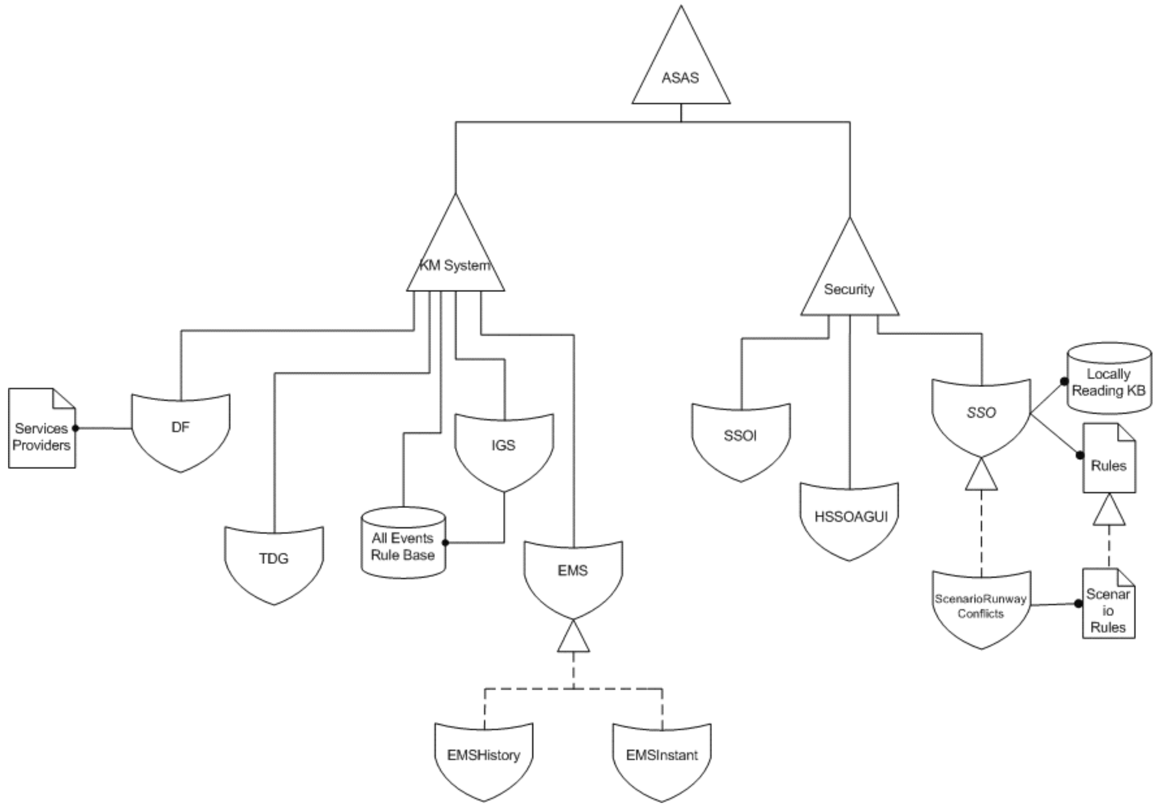

Figure 4. Organization model of an agent-based architecture for cognitive awareness based on a situation awareness ontology

KM System is in charge of managing the whole domain knowledge, whereas Security realizes the airport operator point of view. This layer performs the following tasks:

- Track Data Generator (TDG). It acquires raw data from field (i.e. sensors, radars, etc.) and transforms them into the ontological format;
- Event Manager System (EMS). It generates useful information for checking airport situations. This role has been specialized in order to enhance systems performance. For instance:
  - EMSHistory: it generates and stores historical information concerning airport situations;
  - EMSInstant: it works on instantaneous information concerning airport situations.
- Information Gathering System (IGS). It gathers events from EMS and dispatches them toward security division roles interested in specific info (situations).
- Directory Facilitator (DF). It provides the yellow pages service and allows each agent to register and search the services.

The Security division is, in turn, composed of the following roles:

- Scenario Security Operator (SSO). It carries out reasoning on situation awareness applied to a crisis scenario for airport security (i.e. runway conflicts, airport vehicle conflicts, etc.);
- Scenario Security Operator Interface (SSOI). It interfaces the security operator, showing him the log on airport situations and activates an alert signal, when needed.
- Historical SSO Agent GUI (HSSOAGUI). It interfaces the security operator, showing him the log on historical airport situations by querying.

In our work, Scenario Security Operator refers to Scenario Runway Conflict, since we are concerned the situation where a conflict on runway has occurred. A typical process flow in the proposed architecture foresees the following steps:

1. Track Data Generator acquires raw data from air and ground radars annotating them as ontological events. After that, it sends generated information to EMSInstant and EMSHistory.
2. EMSHistory receives data from TDG and stores it in its Knowledge Base. Historical SSO Agent GUI will query EMSHistory Situation Model to show historical log.
3. EMSInstant, on the other hand, receives data from TDG and transforms it in Situation info;
4. IGS receives data from EMSInstant and dispatches it to SSO specialization (i.e. ScenarioRunwayConflict);
5. SSO reasons on a situation of interest for Airport Security (i.e. Scenario Runway Conflict) and notifies the awareness results to Scenario Security Operator Interface;

6. SSOI shows log relating to an observed situation and eventually reasons on a situation of interest for Airport Security (i.e. ScenarioRunwayConflict) and, by virtue of this, it shows an alert message.

These steps are modeled with the collaboration model in Fig. 5.

6. Representing airport security situations

In this section we present a use case relating to a specific security scenario of airport domain. The case study we will draw in the following part of this article is characterized by simplifications introduced into the field complexity. We will refer to Situation Theory Ontology (Kokar, Matheus and Baclawski, 2009) in order to draw out elements and situations involved in a simplified scenario.

6.1. Use case scenario

The use case considered involves two aircraft in two distinct phases on a shared runway:

- landing phase. The phase where the aircraft starts to lose quote before knocking down and freeing the runway;
- holding point approaching phase. The phase where the aircraft starts to move from the apron toward the several taxiways before arriving at the last holding point incident on the runway.

In Fig. 6 we show a snapshot of the scenario concerning the observed security situation. Airport regulation for this scenario requires the two phases to be performed exactly in the previously listed order. Therefore, in normal conditions the aircraft in holding point approaching phase can hold the runway only after that the landing aircraft has left it. Hence, the aim here is to monitor all situations that can occur in order to avoid undesired risky behaviors.

6.2. Background knowledge

To model relevant situations to be monitored in the selected scenario we first have to shortly depict the domain elements involved in the above scenario. These elements are listed below.

- Aircraft: it is a vehicle which is able to fly by being supported by the air;
- Runway: it is a strip of land at an airport on which aircraft can take off and land. Runways are a part of the maneuvering area;
- Holding Point: it is a geographically or electronically defined location used for aircraft stationing. It represents a crossing point between taxiways so it can be incident on runway as well;
- Exit point: it is a geographically or electronically defined location used to drive an aircraft end-landing towards a rapid exit taxiway;

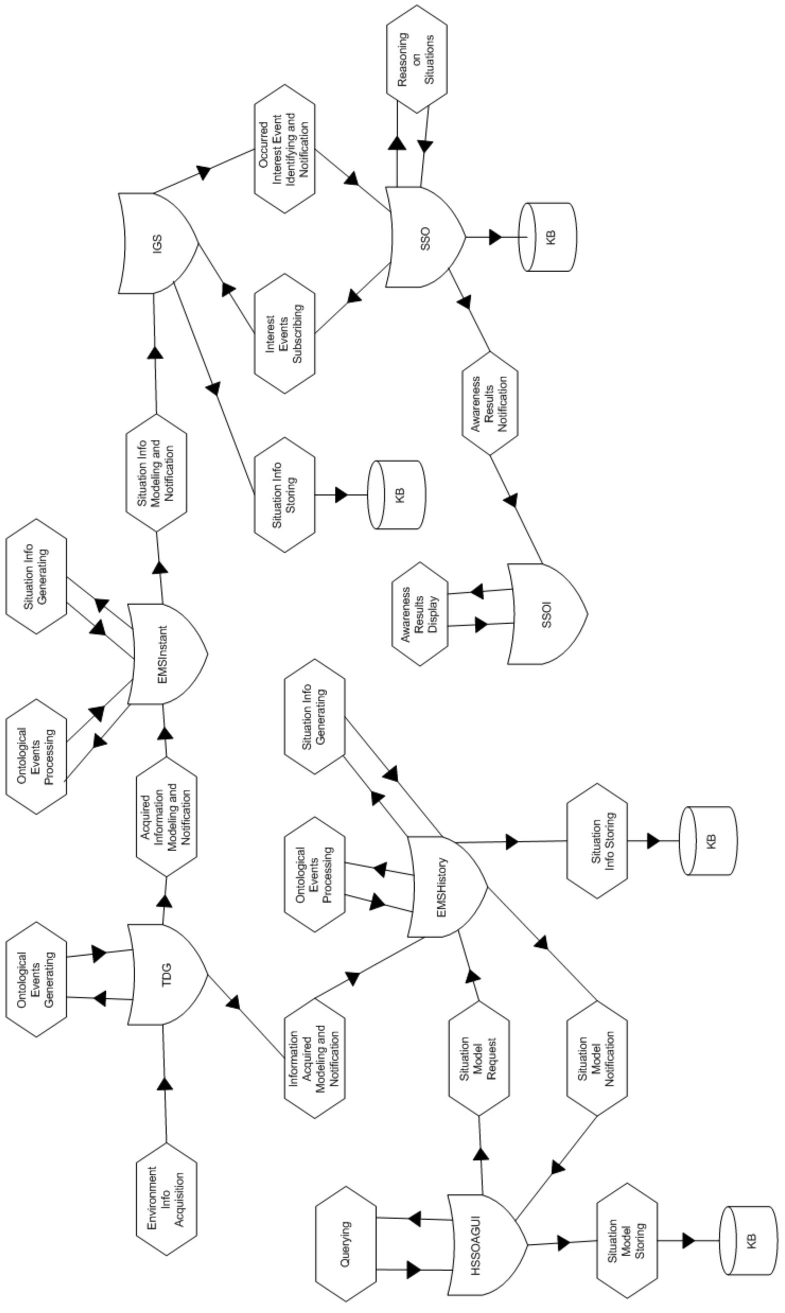

Figure 5. Collaboration model of an agent-based architecture for cognitive awareness based on a situation awareness ontology

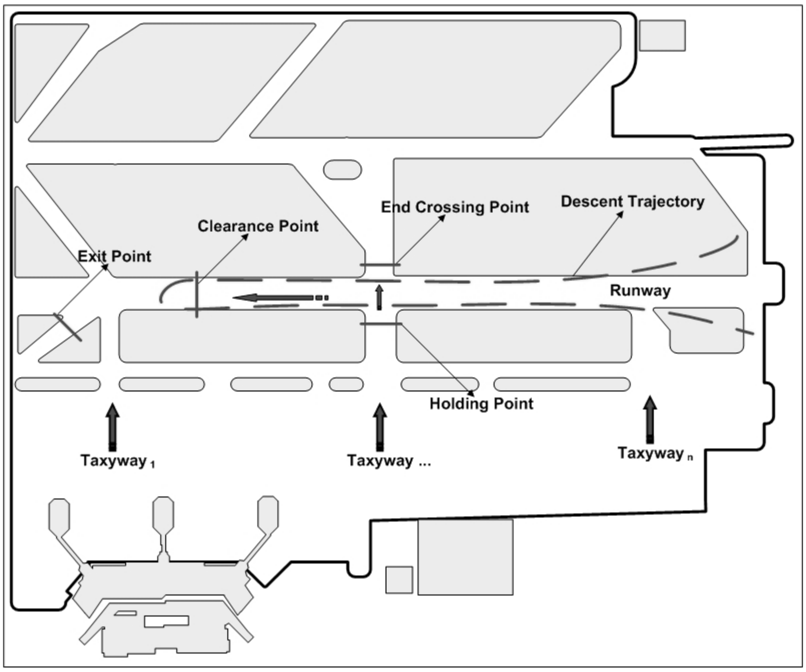

Figure 6. Use case scenario snapshot

- Clearance Point: it is a geographically or electronically defined location used in aircraft end-landing in order to state the safe release of the runway;
- EndCrossing Point: it is a geographically or electronically defined location indicating the end of runway crossing for an aircraft.

Relevant attributes for listed elements will include: location, speed and time. Basing on aforementioned definitions we can now describe the identified interesting situations allowing for monitoring the risky scenario. We remember that in our interpretation of situation theory, information about a situation is expressed in terms of infons as defined in (1) and (2).

6.2.1. AircraftLandingOnRunway situation

In this situation an aircraft is in landing phase on a runway. The relations involved are:

R11. inDirectionOf(X, Y): it points out a binary relation where the first parameter X is the subject, that is the aircraft, and the second parameter Y is the target object, that is the Runway where the aircraft should land. The infon for this relation is:

$$\ll inDirectionOf, Aircraft, Runway, quite\ true \gg;$$

R12. isApproachingToLandingZone(X, Y): it is a binary relation where the first parameter X is represented by an Aircraft and the second parameter Y is represented by a Runway. The landing zone is represented by a descent trajectory resembling a cone. This trajectory end is determined by a clearance point meaning that an aircraft stopped at the holding point can cross the runway. The infon for this relation is:

$$\ll isApproachingToLandingZone, Aircraft, Runway, quite\ true \gg .$$

6.2.2. AircraftCrossingOnRunway situation

In this situation an aircraft is over the last Holding Point before the runway, that is, the aircraft has crossed the runway. The relations involved are:

R21. isArrivedToHoldingPoint(X, Y): it points out a binary relation where the first parameter X is the subject, that is the Aircraft, and the second parameter Y is the target object, that is the Holding Point where the aircraft should stop. The infon for this relation is:

$$\ll isArrivedToHoldingPoint, Aircraft, HoldingPoint, quite\ true \gg;$$

R22. isMoving(X): it points out a unary relation where the single parameter X is represented by an Aircraft in movement. The infon for this relation is:

$$\ll isMoving, Aircraft, not\ false \gg;$$

R23. isStopBar(X): it is a unary relation where the single parameter X is represented by the Holding Point and the aim of this relation is to verify if the Holding Point is the last before runway. The infon for this relation is:

$$\ll isStopBar, HoldingPoint, true \gg;$$

R24. connected(X, Y): it is a binary relation where the first parameter X is represented by the Holding Point, and the second one Y is the Runway, where it is connected. The infon for this relation is:

$$\ll connected, HoldingPoint, Runway, true \gg;$$

R25. isArrivedToEndCrossingPoint(X, Y): it points out a binary relation where the first parameter X is the subject, that is the Aircraft, and the second parameter Y is the target object, that is the EndCrossing Point where the aircraft should arrive. The infon for this relation is:

$$\ll isArrivedToEndCrossingPoint, Aircraft, EndCrossingPoint, false \gg .$$

6.2.3. RunwayConflicts situation

This situation is the one that must be observed in order to detect possible conflicts on a runway. In its general form it can be stated as the result of the intersection between the two aforementioned situations:

$$intersectionOf(AircraftLandingOnRunway,$$
$$AircraftCrossingOnRunway) \Rightarrow RunwayConflicts.$$

specifically, the corresponding model form depends on the two aforementioned supported situations, together with the assertion that the involved aircrafts and runways are different. Let us say:

S1. AircraftLandingOnRunway (X_1, Y_1) where X_1 is the landing aircraft and Y_1 is the targeted runway;

S2. AircraftCrossingOnRunway (X_2, Y_2) where X_2 is the crossing aircraft and Y_2 is the traversed runway.

In order to define the RunwayConflictsSituation, two more relevant relations will be stated, together with the corresponding infons:

R31. differentIndividual(X_1, X_2);

R32. sameIndividual(Y_1, Y_2).

In the following Figs. 7 to 9, we depict three different phases in runway conflict anomalies evaluation.

PHASE 1										
Instant	AircraftLandingOnRunway(A104, R35L)			AircraftCrossingOnRunway(A101, R35L)						RunwayConflict(A101, A104, R35L)
T	R11	R12	S1	R21	R22	R23	R24	R25	S2	RC_Occurrency
5	0,8	0,8	0,8	0,5	0,7	1	1	0	0,5	0,5
6	0,8	0,8	0,8	0,5	0,7	1	1	0	0,5	0,5
7	0,9	0,9	0,9	0,7	0,7	1	1	0	0,7	0,7
8	0,9	0,9	0,9	0,7	0,7	1	1	0	0,7	0,7

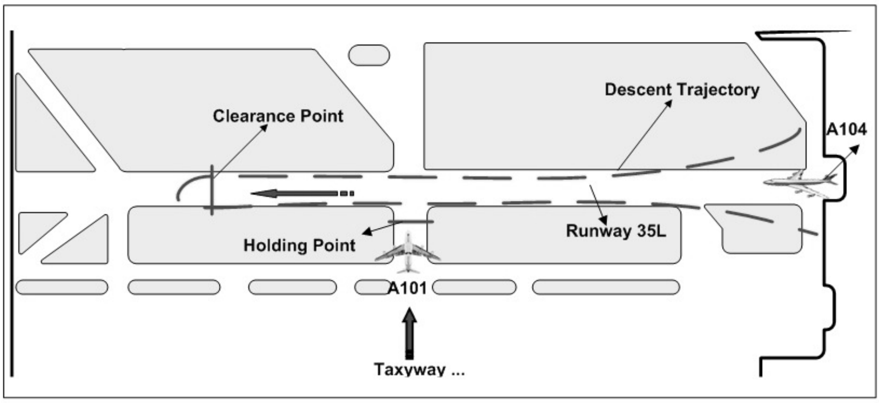

Figure 7. This first phase shows a landing aircraft and another one approaching the holding point

PHASE 2										
Instant	AircraftLandingOnRunway(A104, R35L)			AircraftCrossingOnRunway(A101, R35L)						RunwayConflict(A101, A104, R35L)
T	R11	R12	S1	R21	R22	R23	R24	R25	S2	RC_Occurrency
9	1	1	0,999	0,9	0,6	1	1	0	0,6	0,6
10	1	1	0,999	0,9	0,6	1	1	0	0,6	0,6
11	1	1	0,999	1	0,5	1	1	0	0,5	0,5
12	1	1	0,999	1	0,5	1	1	0	0,5	0,5
13	1	1	0,999	1	0,6	1	1	0	0,6	0,6
14	1	1	0,999	1	0,6	1	1	0	0,6	0,6
15	1	1	0,999	0,9	0,8	1	1	0,1	0,8	0,8
16	1	1	0,999	0,8	0,8	1	1	0,2	0,8	0,8
17	1	1	0,999	0,7	0,8	1	1	0,3	0,7	0,7

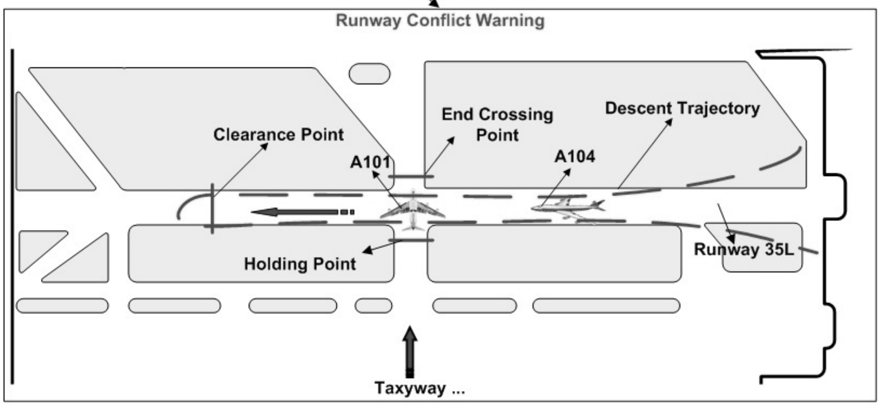

Figure 8. This second phase shows a critical situation, where an aircraft is landing and another one is crossing the same runway

In particular, we show a table with fuzzy infons for the aforementioned situations, followed by a snapshot of observed airport scenario in a specific time slice. Let us observe that:

- in the first phase, with a high degree of AircraftLandingOnRunway occurrence and a medium degree of AircraftCrossingOnRunway occurrence, due to A101 moving towards the holding point, we obtain a medium-high degree of RunwayConflict occurrence;
- in the second phase, with a high degree of AircraftLandingOnRunway occurrence and a high degree of AircraftCrossingOnRunway occurrence we obtain a high degree of RunwayConflict occurrence;
- in the third phase, with a low degree of AircraftLandingOnRunway occurrence and a low degree of AircraftCrossingOnRunway occurrence we obtain a low degree of RunwayConflict occurrence.

PHASE 3										
Instant	AircraftLandingOnRunway(A104, R35L)			AircraftCrossingOnRunway(A101, R35L)						RunwayConflict(A101, A104, R35L)
T	R11	R12	S1	R21	R22	R23	R24	R25	S2	RC_Occurrency
18	1	1	0,999	0,5	0,8	1	1	0,5	0,5	0,5
19	1	1	0,999	0,4	0,8	1	1	0,6	0,4	0,4
20	1	1	0,999	0,4	0,8	1	1	0,6	0,4	0,4
21	0,9	1	0,9	0,3	0,8	1	1	0,7	0,3	0,3
22	0,9	1	0,9	0,3	0,6	1	1	0,7	0,3	0,3
23	0,9	1	0,9	0,3	0,6	1	1	0,7	0,3	0,3
24	0,8	0,9	0,8	0,3	0,6	1	1	0,7	0,3	0,3
25	0,8	0,9	0,8	0,2	0,6	1	1	0,8	0,2	0,2
26	0,8	0,8	0,8	0,2	0,6	1	1	0,8	0,2	0,2
27	0,7	0,8	0,7	0,2	0,6	1	1	0,8	0,2	0,2
28	0,7	0,8	0,7	0,1	0,6	1	1	0,9	0,1	0,1
29	0,7	0,7	0,7	0,1	0,6	1	1	0,9	0,1	0,1
30	0,7	0,7	0,7	0	0,8	1	1	0,5	0	0

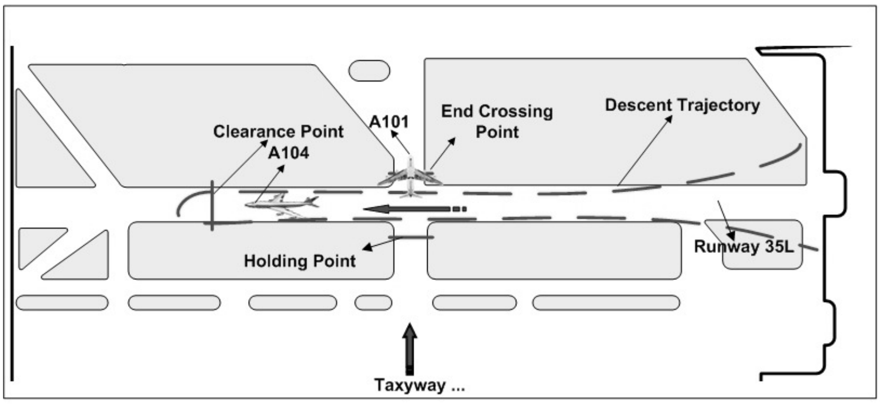

Figure 9. This third phase shows an aircraft approaching the clearance point and another one approaching the end crossing point

7. Main results

With the advent of the machine age, our emphasis shifted to creating a new class of tools to help people perform tasks, largely those physical in nature. The computer age and now the information age have followed rapidly on the heels of basic mechanization. The tools provided are no longer simple; they are amazingly complex, focused on not just physical tasks, but elaborate perceptual and cognitive tasks as well. The pilot of todays aircraft, the air traffic controller, the power plant operator, the anesthesiologist: all must perceive and comprehend a dazzling array of data, often changing very rapidly (Endsley, 1993, 1994, 2000). Todays systems are capable of producing a huge amount of data, both on the status of their own components, and on the status of the external environment. Due to achievements in various types of data-link and internet technologies, systems can also provide data on almost anything anywhere in the world. The problem with todays systems is not the lack of information, but finding what is needed when it is needed (Endsley, 1994, 1997; Endsley, Farley, Jones, Midkiff and Hansman, 1998). The architecture proposed in this work aims to design a system able to provide needed information and capabilities to airport security operators, in a way that is both cognitively and physically usable. Situation awareness, therefore, is represented as a sort of precursor to Airport Collaborative Decision Making, where all airport partners share information flows by combining data from different sources. Furthermore, we have modeled our decision making system by means of an agent-based architecture able to distribute the computational charge among task-oriented soft computing agents and improving real-time situation awareness by means of fuzzy situations modeling. Meant for airport security, our distributed approach to situation awareness, based on ontology and fuzzy decision making,

- improves pre-tactical and tactical airport security processes;
- supports the airport risk situations monitoring;
- supports data sharing among airport partners;
- provides a simple and intuitive modeling tool, open to extensions;
- allows for the computational charge distribution;
- allows the Airport Security Operator to make conscious choice in the decision to implement the linked recognition-primed decision action plan or to devise a new one.

Having a high level of SA is perhaps the most critical factor for achieving success in aviation (Endsley and Garland, 2000a). A recent study of human error in aircraft accidents found that 26.6% involved situations where there was poor decision making even though the aircrew appeared to have adequate situation awareness for the decision (Endsley and Garland, 2000b; Endsley and Rodgers, 1994, 1998). In a study of accidents among major airlines 88% of those involving human error could be attributed to problem with situation awareness as opposed to problems with decision making or flight skills (Endsley, 1995). Conversely, it is also possible to make good decisions even with poor SA, if only by luck.

8. Conclusions

Nowadays an inappropriate SA is the main factor of accidents in sensible domains, and therefore, supporting SA is particularly important in environments where the information flow can become very high and wrong decisions can cause serious effects (i.e. piloting an aircraft, etc.) (Gerken, Jameson, Sidharta and Barton, 2003; Nullmeyer, Stella, Montijo and Harden, 2004; Do, Filippidis, Jain and Hardikar, 2003). Lately, the trend is to use cognitive approach for modeling of environments, objects and situations by moving the focus increasingly towards knowledge modeling. Furthermore, SA stresses native requirements of the agent paradigm: real-time responsiveness, continuous working for a long time, pro-activeness and predictability of highly dynamic contexts. After drawing this scenario, we can say that the main contribution of this work is to support and improve SA introducing a distributed agent approach, based on ontology and soft computing components and applying it to the airport security field. In order to achieve this goal, we have showed a layered ontological modeling of SA in the specific application domain and the possibility to introduce fuzziness (Cheng-Li Liu and Kuo-Wei Su, 2006; Do, Filippidis, Jain and Hardikar, 2003) in a situation awareness ontological meta-model (Kokar, Matheus and Baclawski, 2009). In particular, we have presented a feasible modeling tool for situation awareness in the airport domain based on a fuzzy interpretation of situation theory ontology. Then, we have also depicted an agent-based architecture to support Airport Security Operator decisions with several roles involved. In conclusion, we have highlighted the benefits deriving from our architectural proposal, based on merging an agent-based distributed architecture and a fuzzy cognitive awareness founded on meta-ontologies. The expected future works relate to:

- extending the airport security scenario including more complexity. In particular, we want to be able to monitor risky situations deriving from several threats (i.e. terrorism, organized crime, etc.);
- applying this approach in other interesting fields (i.e. military, diagnostic and so on);
- evaluating the goodness of situation awareness by means of analysis, measurements and error estimation (Endsley, 1995; Endsley and Garland, 2000b).

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