Ontology and Rules for International Airspace Security

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Abstract: The air transportation system will modernize over the next 15 years [1], [2]. As part of that modernization, tasks that are done manually today will be performed by automated computer functions. In the airspace security domain, automated functions need to be dynamic and able to adapt to the latest intelligence reports. These automated functions can be expressed as "if-then rules". In order to gain a better understanding of the level of effort involved in creating rules for airspace security, we chose four specific restricted airspaces we felt represented the cadre used to manage security issues and developed the set of terms and relationships needed to define them. This paper outlines the process we took to develop these terms and lists some examples. This paper also presents some sample rules and potential challenges faced in using rules in airspace security. Finally, this paper recommends that in order to obtain a near-term benefit from rules, the airspace security community should consider generalized definitions and broad scopes when developing rules. The potential application and definition of rules is being developed and will be further validated through experimentation over the next several months.

Keywords: airspace, aviation, security, ontology

I. BACKGROUND

Automated processes based on user-customized rules can help the international airspace community react more swiftly in collaborating and coordinating with internal and external security partners. There are three main instances where these rules can be helpful:

- Find the needle in the haystack – rules can help sift through the thousands of flights and find the few or single flight that matches a certain criteria. For example, rules can highlight all flights from a particular airport.
- Manage the "short-fuse" cases – rules can help highlight those cases where the time to reach a valuable target, for example a nuclear power plant, is short.
- The bad day in the airspace – rules can help deal with multiple simultaneous attacks by organizing and prioritizing each incident for the security coordinator.

II. INTRODUCTION

The use of rules for automating processes is common in many industries. The insurance industry uses rules to predetermine the level of risk and then assign a monthly premium. Credit bureaus use rules to assign a credit score to those seeking loans, and that affects what interest rates they qualify for. For the purpose of this paper, rules can be thought of as an "if-then" statement. *If* something is true, *then* a conclusion is made or an action takes place.

Although rules-architecture can differ slightly from one system to another, the basic notion is that there exists a database of information that is kept up-to-date at a specified frequency. That information is applied against the system rules and feeds into a 'reasoner'. This 'reasoner' is what executes the rules and inputs new information back into the database. The building blocks used to create rules come from ontology

The definition and use of ontologies – explicit formal specifications of the terms in the domain and relations among them [3] – has been growing and many disciplines now develop ontologies so that domain experts can use a common and structured vocabulary to share and talk about information in that field. For example, anyone interested in the classification of frogs can go to the Open Biomedical Ontologies website (obofoundry.org) and download ontology for amphibian taxonomy.

There are some existing efforts that provide a structured way of transferring structured data for airspace security. The Aeronautical Information Exchange Model (AIXM) has been developed by the Federal Aviation Administration (FAA) and EUROCONTROL to act as a 'digital (Notice To Airmen) NOTAM', with structured information which is suitable for automated computer processing.

The United States (U.S.'s) Department of Homeland Security has the Homeland Security Infrastructure Protection (HSIP) Gold, which is a collection of data and metadata relating to U.S. infrastructure. This collection of data is defined much in the same way as ontology is. This large database includes infrastructure that is relevant to airspace security such as airports, runways and key locations that may be a target of a September 11 style attack.

This paper used the restricted airspace domain to develop the specific terms and rules. Restricted airspace is a fixed volume of airspace defined with a start and end time that often prohibits all or most airborne operations. Restricted airspaces are used daily in the U.S. and published on tfr.faa.gov as a tool by the FAA to help manage the airspace from a safety and security standpoint. Some of the instances where restricted airspace can be used for security are around Very Important Persons (VIP) such as a high-ranking government official, sporting events (2010 Olympics in Canada), other high-profile events, and ground assets that might be the target of a 9/11 style attack.

The first part of this paper covers the method used to define the ontology specific to restricted airspace. The results section covers some ontology terms, classes, and some example rules that can be applied to restricted airspace. The conclusion covers what can be done to implement airspace security rules in the near-term. And finally, the future work includes future tasks and contact information.

III. METHOD

- Determine the domain and scope – we decided to limit the scope of the ontology to situations dealing with restricted airspace within the FAA. Not every distinction needs to be accounted for at this stage. For example, knowing which flag the aircraft is flying under may be unnecessary. It may be enough to know whether the aircraft is domestic, foreign or a country of interest such as a known enemy of the state.

- Consider reusing existing ontologies – there are many aspects of restricted airspace that can reuse existing ontologies or parts of an existing ontology. For example, distance (radius in nautical miles), time (for the start and end of a temporarily restricted airspace), a point (latitude and longitude in degrees, minutes, and seconds), and so on are all candidates for reuse. However, unique aspects of restricted airspace definitions were identified that will likely require some modifications to the existing ontologies. In the simple example of time, restricted airspace definitions sometimes have an end time specified as “until further notice”, which is not a standard reference to time. Therefore that term needed to be added. In the case of defining the shape of a restricted airspace, while most are comprised of a cylinder (Fig.1) or a polygon (Fig 2), some can by hybrids (Fig 3). These hybrids are combinations of cylinders, arcs and planes. Furthermore, the arcs can be referenced to both clockwise from a point as well as counter-clockwise.

- Enumerate important terms in the ontology – as a first step, four FAA restricted airspaces were chosen that represent the sort encountered in the security domain. Two were for VIP activity, one was over Beale Air Force Base where they often conduct Global Hawk Unmanned Aircraft System (UAS) exercises (Fig. 1), and one is over the Washington, D.C. metropolitan area (Fig. 3). In the U.S., restricted airspace definitions are communicated publicly using NOTAMs. We compared the four definitions; common and differentiating terms used for each definition were extracted. Keeping in mind “what question do we want to be able to answer?” was a key part in going through each restricted airspace definition. An example of such question is “is aircraft X allowed within the boundaries of restricted airspace Y?”

- Define the classes and the class hierarchy – the ‘combination development’ process was used for this step. [4] Protégé 3.4 was used as the environment to develop our ontology. Developed by Stanford Center for Biomedical Informatics Research, it is free, open-source and is supported by grant LM007885 from the United States National Library of Medicine. First the more salient concepts were identified and then generalized and specialized them accordingly.

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- Define the properties of classes – slots. Each class has different properties that, when put together, form that object. For example, the ‘track’ class – defined as the observed path an aircraft has traveled as noted by returns from radar – has a speed, heading, altitude and beacon code. The ‘flight object’ includes properties such as a aircraft type, nationality, flight plan, tail number, number of armed officers onboard and persons on the watch-list.

- Define the facets of the slots – slots have different facets that describe things such as value, allowed range of value, and how many values it can have. Taking the example of a coordinate, the longitude can be any number of degrees between -180 and 180 with minutes and seconds ranging from 0 to 60. A coordinate point used to define a restricted airspace can further be limited to points that lie within the airspace assigned to the country responsible. The slot-value is also defined by type. Each slot can be designated as a string (AAL123), number, Boolean (e.g. TOI or not) or enumerated (a choice from a specific list).

- Create instances – three of the restricted airspace definitions were used in the enumerating terms step (#3). They are the cylindrical restricted airspace over Beale Air Force Base, the polygon over the California forest fire and the hybrid restricted airspace over the

Washington, D.C. area. The NOTAM definition of the inner-most portion of the Washington, D.C. restricted airspace is shown in Table 1. Fixed Radial Distance (FRD) stands for Fixed Radial Distance)

Table 1. The definition of the inner-most portion of the restricted airspace over Washington, D.C.

	Latitude	Longitude	FRD
From	39º01'45"N	77º38'22"W	DCA299030
Clockwise on a 30 NM ARC Centered on:	38º51'34"N	77º02'11"W	DCA000000
To	39º12'39"N	77º29'29"W	AML004016.6
To	39º03'04"N	77º28'38"W	AML004007
Counter-Clockwise on a 7 NM ARC Centered on:	38º56'05"N	77º28'00"W	AML000000
To	39º01'41"N	77º33'24"W	AML331007
To	39º01'45"N	77º38'22"W	DCA299030

Altitude: From the surface up to but not including 18000 feet MSL
Effective Date(s): From February 17, 2009 at 0500 UTC Until further notice

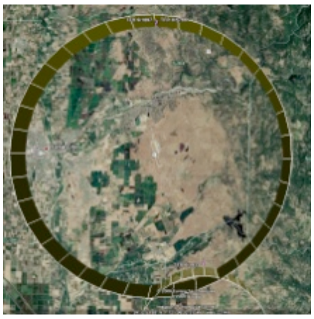

Figure 1. A restricted airspace over Beale Air Force Base is constructed using a cylinder.

Figure 2. A restricted airspace over a California forest fire is constructed using a polygon.

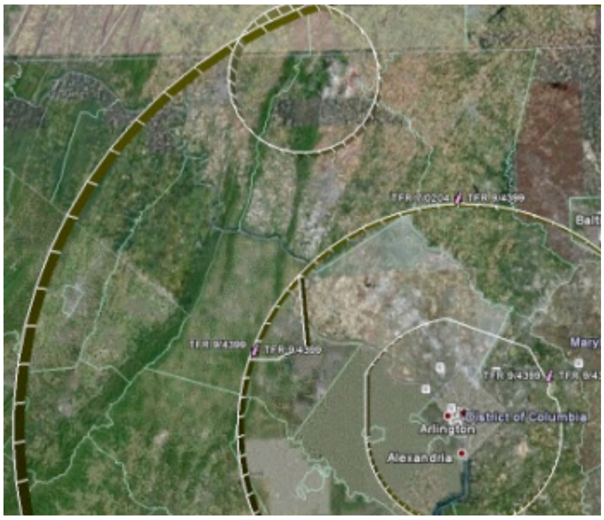

Figure 3. A more complex restricted airspace over the Washington, D.C. area is constructed using a combination of inner and outer cylinders, arcs, planes and cutouts.

IV. Results

The terms making up restricted airspace ontology totaled over 150 for our analysis. Some examples of those terms are:

practice instrument approaches

flight training	location
aerobatic flight	glider
parachute	ultralight
SRFA	altitude
including	not including
center	radius
latitude	longitude
clockwise	counter-clockwise
NOTAM	SOSC

An example of a 'class' within the ontology is the Aero Navaids. It has a sub-class of VHF Omnidirectional Range (VOR), VOR/Distance Measuring Equipment (DME), VHF Omnidirectional Range Tactical Aircraft Control (VORTAC) and NonDirectional Beacon (NDB). Each of those subclasses has an attribute of a latitude and longitude, which is determined by their geographical location. An instance of a Navaid is the one for John F. Kennedy airport in New York City. Its name is JFK, it is a VOR/DME and has a lat/long of 40-37-58.400N / 073-46-17.000W.

Rules can be built and exchanged using this ontology. For example, a user may apply the following rule to the display of his radar:

- *If* aircraft is inside restricted airspace X *and* is a banner-towing operation, *then* sound an alarm.

Applying this rule to the whole airspace would relieve the airspace security coordinator from manually completing that task.

4-D trajectories forecast where an aircraft will be within a given timeframe. It is a computer generated estimation based on the most recent aircraft track. Making use of 4-D trajectories would allow for the use of a rule such as:

- *If* aircraft X is headed for restricted airspace Y *and* is has turned off its transponder, *then* sound an alarm.

That alarm could mean one thing to a restricted airspace over a forest fire (likely an accident), and mean something else with a restricted airspace over an inauguration speech (perhaps an attack). In the first case the airspace security coordinator could help alert the pilot, whereas in the second, defense resources may need to be put into place.

In both of these examples, the definition of the restricted airspace can be complicated and involve more terms than the rule itself. The conclusion section of this paper includes a recommendation on how to overcome this.

V. Conclusion

The terms necessary to formulate restricted airspace ontology are numerous. The times and irregular shapes are difficult to account for and situations are dynamic. Part of the difficulty comes from making the ontology account for rare security events. Today's intelligence report might contain a new watch-list item that was not included in the original ontology definition.

For the airspace security community to obtain the benefits of rules in the near-term, we recommend limiting the scope and complexity of the ontology and rules. For example, instead of listing each specific type of operation not authorized within a restricted airspace (flight training, aerobatic flight, glider operations, parachuting, hang gliding etc...) develop a single category to group operations by risk level. This way, if a new unauthorized operation needs to be addressed, it can be referred to as an existing category. This system is already used in describing in-flight disturbance levels. From 1 to 4, each level carries a higher impact to the security of the aircraft than the other. Creating rules that monitor aircrafts entering into complex restricted airspaces is another example. These rules need only monitor the general area encompassing the complex shape. This could be accomplished by a single cylinder that assumes most of the complex shape but not all, and covers some areas that are not included by the complex shape. The resulting alarm would bring the approaching threat to the attention of the authority and he/she could monitor that flight more closely.

VI. Future Work

More work needs to be done to refine and grow this ontology. In addition, rules created from the ontology will need to be validated and verified

For more information, please contact the Aviation Security Modernization and Evolution group of MITRE-CAASD at rhenriques@mitre.org.

References

[1] NextGen Fact Sheet, faa.gov/news/fact_sheets/news_story.cfm?newsId=8768, Retrieved January 15, 2010

[2] SESAR Brochure, www.eurocontrol.int/ sesar/public/subsite_homepage/homepage.html, Retrieved January 15, 2010

[3] Gruber, T.R. (1993). A Translation Approach to Portable Ontology Specification. Knowledge Acquisition 5: 199-220.

[4] Noy, N. F. and McGuineness, D. "Ontology Development 101: A Guide to Creating Your First Ontology". *Stanford Knowledge Systems Laboratory Technical Report* KSL-01-05 and *Stanford Medical Informatics Technical Report* SMI-2001-0880, March 2001.

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