12th International Conference on Information Fusion
Seattle, WA, USA, July 6-9, 2009

Towards the Formal Representation of Temporal Aspects of Enemy/Threat Courses of Action

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Abstract – *Enemy or Threat Courses of Action are produced during Intelligence Preparation of the Battlefield, during the Military Decision Making Process, and as part of the process of Situation Development. Due to the overwhelming amount of information involved in these processes and the limited time available to intelligence analysts, significant efforts are underway to develop computer based tools to assist in these processes. For these to be successful there needs to be a way for formally representing Enemy/Threat Courses of Action. This paper investigates the requirements for and potential solutions to this problem using OWL, elements of JC3IEDM and the OWL Time ontology.*

Keywords: ECOA, formal representation, ontologies, OWL, OWL Time, JC3IEDM.

1 Introduction

The process of situation development in the U.S. Army involves the analysis of available information with the intent of developing an understanding of what the enemy or threat is doing or planning to do [1]. The outcome from this process is one or more enemy or threat courses of action or ECOAs for short. An ECOA must describe the what, when, where, how and why of the analyst's best estimate of the enemy's current or intended actions. For any situation there are countless potential ECOAs and it is the job of the analyst to derive the most threatening and most likely candidates. It is the hope of various efforts to develop analytical and automated tools to support the generation and evaluation of ECOAs. For example, one would like to be able to provide support tools that would help analysts explore the space of candidate ECOAs; such a tool would not only be useful for organizing the analysis process but could also help ensure that all candidates have been explored or at least have been purposefully acknowledged as not being relevant. It would also be beneficial to have a way to evaluate ECOAs that are generated in order to ensure their logical consistency and to check for their level of coverage (for example, does the ECOA account for all of the enemy's resources or are some left unaccounted for and open to surprise exploitations?). A prerequisite for the development of such tools is the establishment of a formal representation for ECOAs that opens them to computer manipulation. This paper investigates the use of OWL, aspects of JC3IEDM and the OWL Time ontology for the formal representation of ECOAs. As this is a rather ambitious undertaking, the focus in this paper will be on the temporal requirements of the representation.

In the next section we present a brief overview of the Threat COA Model contained within the Army's Intelligence Preparation of the Battlefield process. We then provide some examples of ECOAs and discuss some of their temporal representational requirements. This is followed by a consideration of the OWL Time ontology in terms of its ability to meet these needs. Finally we produce a partial representation for some of the example ECOAs using OWL Time and aspects of JC3IEDM [2].

2 Threat COA Model

According to U.S. Army Doctrine [1] ECOAs are developed as a part of the Intelligence Preparation of the Battlefield (IPB) and the Military Decision-Making Process (MDMP); they can also result from the battle-time process of Situation Development [3]. An ECOA consists of 1) a situation template, 2) a description of the COA and 3) a list of high value targets (HVT). The situation template is a graphical depiction of "the expected threat dispositions" that the enemy would adopt if it were to pursue the ECOA. While the situation template concisely conveys a lot of information and is perhaps the most important artifact of the process it does not lend itself well to formal representation suitable for computer processing owing to its graphical representation; the work by the Qualitative Reasoning Group at Northwestern University represents an interesting step in this direction [4]. The list of HVTs on the other hand presents few if any representational challenges and so will not be addressed here. The description of the ECOA is our interest and we will shortly take a look at some textural descriptions of ECOAs.

At a minimum an ECOA needs to address the following five questions:

- What type of operation is it?
- When will/might the significant aspects of the operation begin/end?
- Where will the operation take place?

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUL 2009**	2. REPORT TYPE	3. DATES COVERED **06-07-2009 to 09-07-2009**

4. TITLE AND SUBTITLE **Towards the Formal Representation of Temporal Aspects of Enemy/Threat Courses of Action**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **VIStology, Inc., , ,Framingham,MA**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002299. Presented at the International Conference on Information Fusion (12th) (Fusion 2009). Held in Seattle, Washington, on 6-9 July 2009. U.S. Government or Federal Rights License.

14. ABSTRACT
Enemy or Threat Courses of Action are produced during Intelligence Preparation of the Battlefield during the Military Decision Making Process, and as part of the process of Situation Development. Due to the overwhelming amount of information involved in these processes and the limited time available to intelligence analysts, significant efforts are underway to develop computer based tools to assist in these processes. For these to be successful there needs to be a way for formally representing Enemy/Threat Courses of Action. This paper investigates the requirements for and potential solutions to this problem using OWL, elements of JC3IEDM and the OWL Time ontology.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Public Release**	**8**	

- How and with what resources will it be conducted?
- Why is the operation being conducted – what is the desired end state?

An ECOA should also meet tests of suitability (will it accomplish the desired outcome?), feasibility (are the required time, space and resources available to the enemy?), acceptability (will the enemy accept the amount of risk involved?), uniqueness (is it significantly different from the other ECOAs under consideration?) and consistency (is it consistent with the enemy's known doctrine?).

3 ECOA Examples

3.1 Sample ECOA 1

In Operation Anaconda in Afghanistan in the winter of 2002 as coalition forces prepared for an offensive against Al Qaida and the Taliban forces concentrated around the town of Serkhankheyl in the foothills of the local mountains, intelligence analysts performed IPB and developed three ECOAs [5]. The third and most dangerous of which can be paraphrased as follows (the other two ECOAs are less interesting for the purposes of this paper as they do not contain interesting temporal elements): When attacked the enemy will initially disperse in multiple directions; they will then reconsolidate into pockets of resistance in order to be able to conduct subsequent guerilla attacks against coalition forces. This ECOA is graphically depicted in Figure 1 with the temporal aspects highlighted as a sequence of four steps some of which involved the simultaneous actions of multiple units. As is this ECOA is a high level sketch of what the enemy might do – a more complete and further detailed ECOA description might include specifics of the timing such as the Coalition Forces attacking at time H with the dispersement of enemy forces occurring over the time H to H+4 hours, for example.

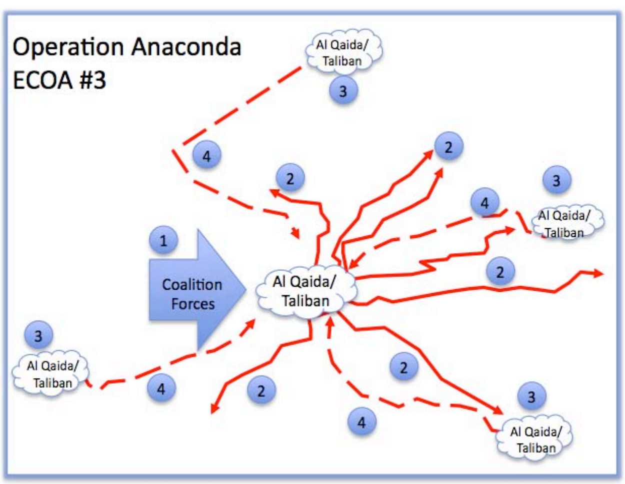

Figure 1. Operation Anaconda ECOA #3: 1) coalition forces attack, 2) enemy disperses then 3) reconsolidates in order to 4) conduct guerilla attacks.

3.2 Sample ECOA 2

In an article for Military Review, Hoffman and Shattuck [6] propose a new approach to representing operation orders (OPORDs) that they argue can be used also for the representation of ECOAs. One example that they gave is the ECOA depicted in Figure 2 of a "Defense to Delay. Their representation approach explicitly captures both the intentional (*for enemy purpose*) and temporal (*then*) aspects of COAs. As with the first ECOA example there is a sequence of actions as well as collections of action that occur at the same time. Here, within the last purpose statement there is also an element of time corresponding to a duration that is needed in order to "fortify enemy positions".

3.3 Sample ECOA 3

The most detailed example of an ECOA comes from an Army training workshop on building ECOAs. A high level description for this ECOA is as follows: *No later than XX2300NOV09 the Red Brigade attacks to destroy friendly forces in Kill Zones 1 and 2 in order to fix the brigade and prevent attacks against the ALPHA main effort.* We see here the common what, when, where, how and why but there are not many details about the how. To fully communicate the when and the how of the ECOA the following much more detailed description provides an example of how a complete ECOA description might appear:

Between H-24 and H-Hour the ALPHA Recon Troop conducts an area recon to identify obstacles, brigade troop disposition, and division high payoff targets (HPT) in order to determine weak points in the main battle area and trigger Reconnaissance Fires. Special forces in the area of operation conduct surveillance of friendly HPTs to support ALPHA Deep Operations. From H-12 to H-Hour the BRAVO Recon Troop conducts route and area recon of Predicted Enemy Locations (PELs) to confirm disposition of troops and obstacles along attack routes and trigger reconnaissance fires.

At H-Hour the main battle group (BTG) supporting effort, 2 x mechanized infantry carriers (MIC), attack to destroy forces on Route White and Green 1 in order to prevent the brigade from repositioning forces to defeat the main effort (ME). A mounted infantry platoon Fighting Patrol (FP) will lead these companies by 3-5 kilometers. The companies will consist of 2 mechanized platoons and may be reinforced by engineer or anti-tank (AT) assets.

Between H and H+1 the BTG assault force, a MIC reinforced with mortars, engineers, AT and air defense artillery (ADA), attacks to destroy forces along Route Red 1 to defeat the enemy battalion at OBJ Red 2 and prevent repositioning against the exploitation force.

Between H+1 and H+3 the BTG exploitation force, 2 x MIC reinforced with tanks, engineers, and ADA, attacks along Route Green 1 to destroy the enemy battalion at objective Red 1. The lead battalion will

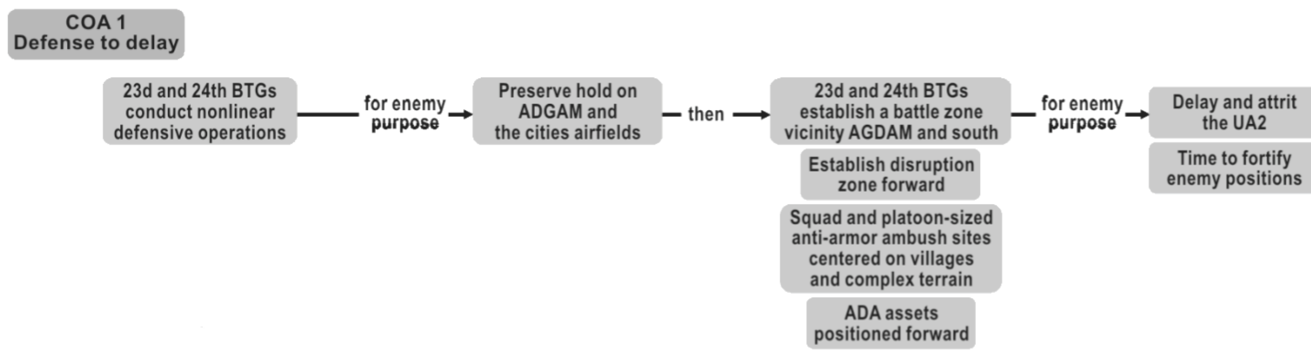

Figure 2. Sample ECOA #2: Defense to Delay (from [6])

deploy to company battle formation approx 2 kilometers from the objective and attack along both Route Green 1 and 2.

The BTG is supported by an artillery battalion. Artillery will initially focus on supporting the recon forces in contact and the destruction of HPTs. Priority of fires shifts o/o to the assault force to destroy forces along route Green 1 and then to the exploitation force to destroy defending forces. Special Purpose Forces (SPF)/Affiliated forces will conduct limited direct action missions and trigger reconnaissance fires to destroy friendly HPTs prior to commitment of the fixing forces.

EndState: BTG defeats two US battalions and the brigade is unable to reposition against the ALPHA main effort.

Clearly there is a significant amount of detail in this example, including specifics concerning numerous temporal components. It is interesting to note that there are references to 1) an event occurring at a time between two given times (H-24 and H-Hour), 2) several periods of time during which an operation/action takes place, 3) multiple operations/actions occurring in sequence 4) multiple actions occurring in parallel and 5) actions that must take place only after prior actions have occurred.

4 Temporal Concepts

In temporal reasoning there are a handful of central concepts including: point-based events, interval-based events, temporal relationships between events and arithmetic operations on temporal entities.

Point-Based Events. Point-based events (aka, "instant" events) occur at a specific point in time without any duration. For example the taking of a photograph is an event with specific time at which it was taken. It is sometimes convenient to view point events as having a begin time that is equal to its own end time.

Interval-Based Events. Interval-based events (aka "activities") take place over a period of time and have a specific begin time and a specific end time. A company patrol, for example, is an interval-based activity that begins at some point in time and continues to occur through to some end point in time. Note that begin times and end times can be considered as point-based events since they have a specific instant at which they occur.

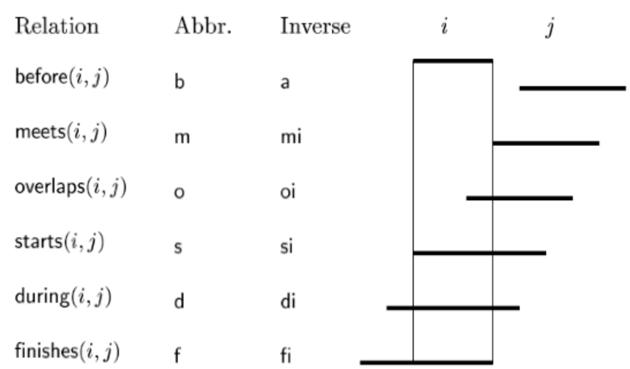

Figure 3. The temporal relationships of Allen's temporal interval calculus.

Temporal Relationships: Events can stand in relationship to one another; the widely accepted delineation of these relationships can be found in Allen's Temporal Interval Calculus [7] with its six temporal relations shown in Figure 3. In brief these relationships can be informally defined as follows:

before: an event occurs *before* another event if its end time is strictly less then the other event's begin time. The inverse of *before* is *after.*

meets: an event *meets* another event if its end time is equal to the other event's begin time.

overlaps: one event *overlaps* with another event if either event's begin time is greater than the other's begin time but less than the other's end time.

starts: an event *starts* another event if their two begin times are equal.

during: an event occurs *during* another event if its begin time is greater than the other's begin time and its end time is less than the other's end time.

finishes: an event *finishes* another event if their two end times are equal.

Formal mathematical definitions for these relationships – a requirement for automated reasoning -- can also be specified. For example, *before* can be defined logically as follows (based on 8):

$$(\forall\ e1,e2)\ [\mathit{before}(e1,e2) \Leftrightarrow (\exists\ t1,t2)[\mathit{ends}(t1,e1) \wedge \mathit{begins}(t2,e2) \wedge \mathit{before}(t1,t2)]]$$

where `e1` and `e2` are Temporal Things (as defined in the OWL Time ontology as shown in Figure 4 and `t1 and t2` are times. Similar axioms exist for the other temporal relationships and will be included in the semantics of a complete temporal reasoner.

Events need to be associated with specific times and this requires not only specific representational formats but also the ability to perform some basic arithmetic operations on them. For example, a document may refer to an event that occurred "2 weeks ago" and lasted for "3 days and 4 hours". Interpreting these times requires the concepts of "weeks", "days" and "hours" and an understanding of the relationships between them, e.g., that one week is equal to seven days. The basic units of time here include seconds, minutes, hours, days, weeks, weekday, months, monthdate, years, yeardate and timezone, along with their standard equivalence relations. The basic arithmetic operations needed are addition, subtraction, multiplication and division.

Another issue that needs to be addressed when comparing times of events is the variation in precision and/or accuracy of the times. For example, one document may vaguely reference an event's time as being "three days ago" whereas another may specify the event's time down to the exact number of seconds. To be able to compare these times and determine if it is possible for them to have occurred at the same time (for example) requires representing the uncertainty of the vague time as some probability of it having occurred at some specific time during the day. Even when the times are highly precise, say down to the level of seconds, their sources may employ measures using varying degrees of accuracy, potentially rendering the same events to be taken to have occurred at different times (i.e., the times are precise but inaccurate); again we will need the ability to represent notions of uncertainty in our temporal reasoning. Determining principled ways of doing this falls within the scope of research we are carrying out.

4.1.1 Formal Ontologies

An ontology is an explicit, formal, machine-readable semantic model that defines the classes, inter-class relations and data properties relevant to a problem domain. There are various approaches to representing formal ontologies including OWL [9], conceptual graphs [10], topic maps [11], KIF [12] and others. Ontologies are the basis for the Semantic Web [13] where they are being used to create machine-readable, semantic-descriptions of Web content that can be shared, combined and reasoned about automatically by intelligent software. As part of its Semantic Web effort, the W3C has been developing the Web Ontology Language (OWL) [14], an XML-based ontology definition language. OWL is an emerging standard for ontologies and knowledge representations based on the Resource Description Framework (RDF) [15] and the DARPA Agent Markup Language (DAML), two early ontology languages. OWL is a declarative, formally defined language that fully supports specialization/generalization hierarchies as well as arbitrary many-to-many relationships. Both model theoretic and axiomatic semantics have been fully defined for the elements in OWL/DAML providing strong theoretical as well as practical benefits in terms of being able to precisely define what can and cannot be achieved with these languages. Many tools have been developed (and many more are on the horizon) for creating OWL/DAML ontologies and processing OWL/DAML documents (for a review of such tools see [16]). We have been active in the development of such tools including a consistency checker for DARPA, ConsVISor [17], and a forward-chaining inference engine, BaseVISor [18], that has been optimized to work with RDF/OWL triples [19].

Ontologies capture *potential* objects and potential relations; that is to say, they do not describe what is in "the world" but rather what can be in the world. Ontologies, however, can be used to annotate or mark-up descriptions of instances of the world in what are called *instance annotations.* It should be noted that the job performed by ontology languages cannot be accomplished with purely syntactic languages such as XML Schema or relational data models. An XML Schema specification, for example, can define the structure of objects (*i.e.,* their composition) but it cannot capture the semantic meaning implicit in the relations that might exist between objects. To do this requires knowledge about how the classes relate to one another semantically (as opposed to structurally or syntactically). This type of *meta-knowledge* is what ontologies are designed to capture. With appropriate meta-knowledge to explain how the data is to be interpreted, intelligent systems can reason about the data and make inferences that can be logically proven to be sound.

In our approach we will use a dialect of OWL to define as much of the time ontology as possible. There are, however, inherent representational limitations in OWL that prevent certain types of relationships to be captured due to the language's lack of relational joins and composite properties. For example, the relationship *uncleOf* cannot be fully captured in OWL• because it requires a composition (or join) across the values of two other properties, i.e., *parentOf* and *brotherOf*. OWL also has some

• In the forth-coming W3C OWL 2 Recommendation this type of relationship can be represented using the new construct of *property chains*.

computational complexities that make it ill suited for the otherwise very efficient forward chaining inference engines (see discussion below). For this reason we often employ an ontology language called R-Entailment [20] or Horst OWL. R-Entailment is closely related to OWL as it includes all of RDF/RDFS and many of the elements of OWL, but, it has more favorable computational characteristics and includes the ability to represent Horn clause rules, i.e., simple if-then rules with variables that permit the definition of composite properties such as *uncleOf*. Moreover, while OWL can encode the temporal ontology relations, in order to be able to support automatic inference over such relations, the full interpretation of these relations would have to be augmented with additional semantics.

4.1.2 Examples of Time Ontologies

A number of time ontologies have appeared in recent years. Cyc [21] and SUMO (Suggested Upper Merged Ontology) [22] are extensive upper ontologies (i.e., high level ontologies intended to serve as the foundational core of more domain specific ontologies) designed for encoding general common sense knowledge. Both include elements that can be used to represent general temporal concepts but they tend to be intertwined with other aspects of the overall ontology and thus force users to accept all or many of the other ontological commitments these languages make. While we will review these ontologies for possible elements to include in our time ontology they are not good candidates for a possible foundation for our work.

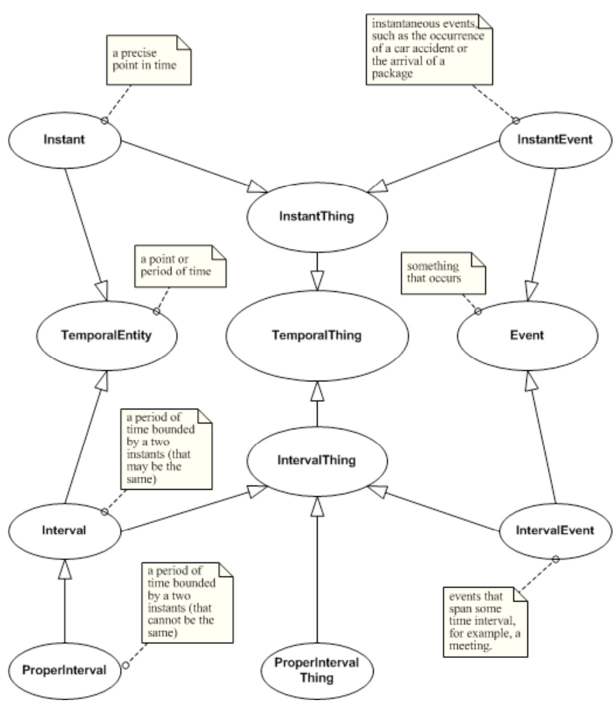

Figure 4. OWL-Time Class Diagram from [23].

TimeML [24] was specifically designed for specifying event and temporal expressions in natural language text. It's not really a formal ontology but is rather an XML Schema that identifies key temporal elements and the syntactic relationships they can have to one another. We are including it in our investigation because it has been influential on the development of other time ontologies and efforts have been made to define a denotational semantics for the language (though with less then complete success) [25].

OWL-Time [26] is an updated version of DAML-Time [27] that permits the representation of point events, interval events and common temporal relationships using OWL and some higher-level axioms. The classes of OWL-Time are depicted in Figure 4 while the temporal relationships related to point and interval events are shown in Figure 5. Note that while Allen's temporal relationships described above are included in OWL-Time they are given different names and in some cases are extended to include their inverses. OWL-Time is the culmination of Feng Pan's 2007 USC Ph.D. Dissertation and represents arguably the most fully developed time ontology, and most certainly the most complete time ontology in OWL. While the OWL-Time ontology goes a long way towards providing a basis for reasoning about time it does not afford a complete solution as it does not address the problems of representing uncertainties regarding the accuracy and precision of times, nor does it attempt to align itself with a command and control language such as JC3IEDM.

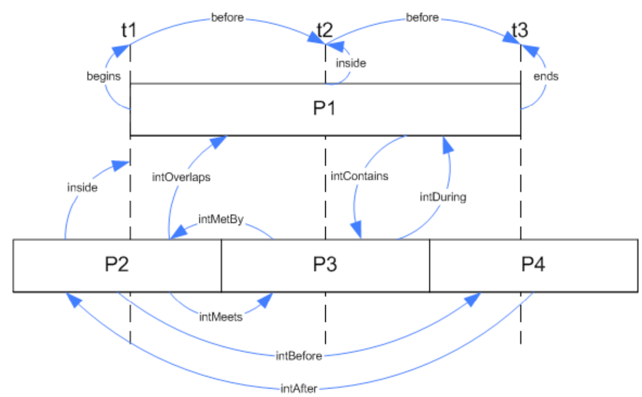

Figure 5. OWL-Time Temporal Relationships from [23].

A very good and comprehensive survey of time extensions to description logics (to which OWL DL belongs) can be found in [28]; this document will serve as a solid grounding for the theoretical aspects of our investigation of the temporal elements to include in (or alternatively exclude from) our final time ontology.

5 ECOA's with OWL Time

We will now sketch out how OWL Time might be used along with elements from JC3IEDM to begin to represent the temporal aspects of ECOAs. Due to space constraints we limit our attention to the first sample ECOA outlined above. Note that we use the namespace prefixes of tm: and jc3: to refer to the vocabularies for the Time ontology and JC3IEDM respectively. isA is a shorthand notation for the RDF notion of a type (i.e., rdf:type).

5.1 ECOA Sample #1

Figure 6 shows the timeline of events that occur in ECOA 1 along with OWL Time predicates describing the temporal relationships between the events. The *begins* predicates relates the first interval event to time T1. The other predicates relate the interval events to one another.

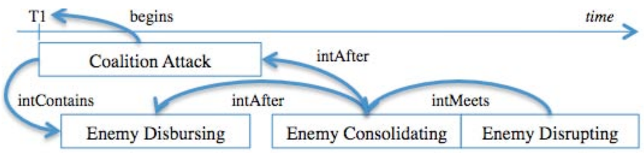

Figure 6. ECOA #1 Timeline with OWL Time predicates.

Figure 7 shows the same timeline using JC3IEDM constructs to partially depict the temporal relationships. In place of the *begins* predicate JC3IEDM uses *PlannedStart* to associate the first action with time T1. Only the relationship between the first two actions is shown due to the more complex structure required to represent temporal associations: for each association a *TemporalAssociation* entity is created and is linked to the subject and object actions as well as to a specific *TemporalAssociationCateogry*, in this case *StartAndEndsDuring* which captures the equivalent meaning to the "intContains" predicate in OWL Time.

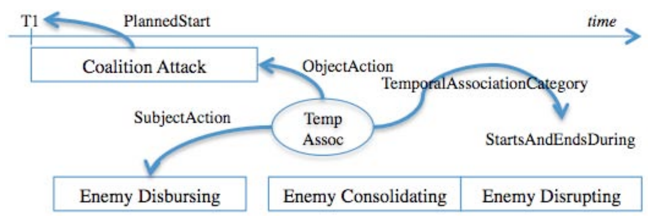

Figure 7. ECOA #1 Timeline with JC3IEDM temporal relationships (partial).

The following snipet of pseudo code captures the fundamental representation of ECOA #1 using a mixture of OWL Time and JC3IEDM with emphasis (in italics) on the temporal relationships/associations.

```
:CoalitionForces isA jc3:Unit
   jc3:hostility-status jc3:Friendly

:AlQiada/Taliban isA jc3:Unit
   jc3:hostility-status jc3:Hostile
                ______________
:Action1
  isA jc3:ActionTask
  jc3:name-text "Coalition Forces Attack"
  jc3:ActionTaskActivity jc3:DeliberateAttack
  jc3:OrganisationStructure :CoalitionForces
  jc3:ObjectiveItem :AlQiada/Taliban
   isA tm:IntervalEvent
   tm:begins :T1
   jc3:plannedStart :T1
                ______________

:Action2 isA jc3:ActionEvent
   jc3:name-text "Al Qaida/Taliban
                   Disperse"
   jc3:ActionEventCategory jc3:Distributing
   jc3:OrganisationStructure AlQaida/Taliban
  jc3:ObjectiveItem :CoalitionForces
   isA tm:IntervalEvent
   jc3:isSubjectOf :TempAssoc1

:Action1 tm:intContains :Action2

:TempAssoc1 isA jc3:TemporalAssociation
   jc3:SubjectAction :Action2
   jc3:ObjectAction  :Action1
   jc3:TemporalAssociationCategory
         jc3: StartsAndEndsDuring
                ______________

:Action3 isA jc3:ActionEvent
   jc3:name-text "Al Qaida/Taliban
                   Re-consolidate"
   jc3:ActionEventCategory jc3:Consolidating
   jc3:OrganisationStructure AlQaida/Taliban
   isA tm:IntervalEvent
   jc3:isSubjectOf :TempAssoc2
   jc3:isSubjectOf :TempAssoc3

:Action3 tm:intAfter :Action1
:Action3 tm:intAfter :Action2

:TempAssoc2 isA jc3:TemporalAssociation
   jc3:SubjectAction :Action3
   jc3:ObjectAction  :Action1
   jc3:TemporalAssociationCategory
jc3:StartsAfterEndOf

:TempAssoc3 isA jc3:TemporalAssociation
   jc3:SubjectAction :Action3
   jc3:ObjectAction  :Action2
   jc3:TemporalAssociationCategory
jc3:StartsAfterEndOf
                ______________

:Action4 isA jc3:ActionEvent
   jc3:name-text "Al Qaida/Taliban
                   Guerrilla Attacks"
   jc3:ActionEventCategory jc3:Disrupting
   jc3:OrganisationStructure
:AlQaida/Taliban
   jc3:ObjectiveItem :CoalitionForces
   isA tm:IntervalEvent
   jc3:isSubjectOf :TempAssoc4

:Action3 tm:intMeets :Action4

:TempAssoc4 isA jc3:TemporalAssociation
   jc3:SubjectAction :Action3
   jc3:ObjectAction  :Action4
   jc3:TemporalAssociationCategory
     jc3:StartsNoLaterThanAfterEndOf
   jc3:ReferenceDuration 00
```

For further explanation, a paraphrasing of the first action Action1 reads as follows: *There is an action task labeled "Coalition Forces Attack" that is of activity type DeliberateAttack that is to be carried out by the*

CoalitionForces organization against the AlQiada/Taliban entity with a planned start time of T1.

We have juxtaposed the OWL Time and JC3IEDM temporal representations to help show how the two are compatible with each other while also highlighting OWL Time's parsimony.

To further contrast and compare the two representations, Table 1 lists all of the JC3IEDM Temporal Association Category Codes along side their comparable representation in OWL Time. JC3IEDM provides a long list of temporal associations, which can be captured using OWL Time constructs although with the need for additional conjunctive and disjunctive operators. If in addition to *after* and *before* OWL Time included predicates for *onOrBefore* and *onOrAfter* each of the disjunctive sentences on the OWL Time side of the table could be replaced with a single compound predicate.

Table 1. JC3IEDM Temporal Association Category Codes and their equivalent representation using OWL Time. Note: *ends* and *begins* operate on actions to return a time and *after* and *before* compare two actions/intervals. SA and OA stand for Subject Action and Object Action.

JC3IEDM	OWL Time
Ends after end of	after(ends(SA),ends(OA))
Ends after start	after(ends(SA),begins(OA))
Ends no earlier than after end of	after(ends(SA),ends(OA)) or ends(SA) = ends(OA)
Ends no earlier than after start of	after(ends(SA),begins(OA)) or ends(SA) = starts(OA)
Ends no later than after end of	before(ends(SA),ends(OA)) or ends(SA) = ends(OA)
Ends no later than after start of	before(ends(SA),begins(OA) or ends(SA) = begins(OA)
Starts after end of	after(begins(SA),ends(OA))
Starts after start of	after(begins(SA),begins(OA))
Starts and ends during	intDuring(SA,OA)
Starts at and ends at the same time as	begins(SA) = begins(OA) and ends(SA)=ends(OA)
Starts at the same time and ends after	begins(SA) = begins(OA) and after(ends(SA),ends(OA))
Starts before and ends before end of	intOverlaps(SA,OA)
Starts during & ends after	intOverlaps(OA,SA)
Starts during & ends at same time as	intDuring(SA,OA) and ends(SA) = ends(OA)
Starts no earlier than after end of	after(begins(SA),ends(OA)) or begins(SA) = ends(OA)
Starts no earlier than after start of	after(begins(SA),begins(OA)) Or begins(SA) = begins(OA)
Starts no later than after end of	before(begins(SA),ends(OA)) or begins(SA) = ends(OA)
Starts no later than after start of	before(begins(SA),begins(OA)) Or begins(SA) = begins(OA)

6 Conclusions

In this paper we have begun an investigation of the problem of formally representing temporal aspects of threat or enemy courses of action. Some of the key requirements for this problem include the ability to specify 1) point-based events (i.e., something happened a specific point in time), 2) interval-based events (i.e., something happened/is-to-happen over a given period of time), 3) events with partially constrained time of occurrence (e.g., a point event or an interval event that might occur sometime between T1 and T2), 4) events that occur in sequence, 5) events that occur in parallel, and 6) events that are dependent upon other events occur prior to their own occurrence. We looked at Allen's temporal interval calculus to see how well it fit these needs. We then argued that a formal representation should be grounded in formal ontology and that OWL is a strong candidate as an ontology language for this purpose. In addition, OWL Time is a formal OWL ontology that captures the essence of Allen's interval calculus and provides the representation power required for representing all of the temporal elements we have encountered in our sample of ECOAs and is capable of expressing the temporal relationships that are part of the JC3IEDM data model.

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