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# Enhanced Tactical Inferencing Framework: Future Visualization and Collaboration Demonstration

by John Richardson, Mark Mittrick, Justine Rawal, Prabhat Kumar, and Adrienne Raglin

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***DEVCOM Army Research Laboratory***

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This report describes efforts conducted by researchers in the Content Understanding Branch in fiscal year 2023 to employ the Enhanced Tactical Inferencing (ETI) framework. ETI was developed to support experimentation and demonstration of artificial reasoning research in a multi-agent environment (data source agents, reasoning model agents, and decision maker agents). In this report, ETI is used to demonstrate an uncertainty-based decision recommendation capability within a cross-reality environment. Beginning with data from a simulated scenario plus additional external context, ETI agents reason over the uncertainty in information informing situational awareness to provide decision makers a recommended choice. Finally, the products of ETI are transformed into a cross-reality visualization to explore new modalities of human interaction.

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## Contents

## List of Figures



## List of Tables

# 1. Introduction

The Enhanced Tactical Inferencing (ETI) framework has been designed and created to support experimentation and demonstration for the Artificial Reasoning research. The current structure of ETI includes three main agents: data source agents, reasoning model agents, and decision maker agents. The data source agents are organized into broad categories: information (imagery, audio, text), devices, network, and visualization. Data source agents can capture and transfer data to other agents. Other information systems can also provide data to these agents. The reasoning model agents perform different aspects and levels of reasoning. The output of the reasoning agents will help generate the recommended decisions. The decision maker agents create the final decisions. These ETI agents can be modular, allowing processing to be serial, or parallel, as well as independent or interdependent. For this effort ETI is functioning as a decision-making aid. The main reasoning model is the Uncertainty of Information (UoI) module. This UoI module enables any information uncertainty to be considered in decision recommendations. Another capability of ETI is to enable interaction with humans including future visualization and collaboration environments. We implemented this with a demonstration in the cross-reality (XR) environment, the Accelerated User Reasoning for Operations, Research and Analysis (AURORA). Integrating into systems such as AURORA allows us to explore new modalities of intelligent system and human interaction. In this report, we will detail the process of developing our demonstration, including mapping data from our simulation environment to the visualization environment, incorporating decision points and ETI recommendations into the courses of action, and enhancing our scenario with "what-if" situations to explore the impact of our reasoning-based framework.

# 2. Background

The target of this research was to develop, integrate, and demonstrate our reasoning-based framework for decision making. The ETI framework decision recommendations were used with a scenario simulated in Division Exercise Training and Review System (DXTRS) and visualized within an XR environment, AURORA. The following section will provide background on DXTRS, our scenario, and AURORA visualization.

## 2.1 DXTRS Scenario

In the scenario, the Blue Force's (BLUFOR) objective is to push east through an area named the Agdam District of Azerbaijan, while engaging and eliminating the Opposing Force (OPFOR) who are deployed east of the river. (See Fig. 1)


**Fig. 1 Initial BLUFOR/OPFOR deployment**

As the mission unfolds, BLUFOR will encounter a river impeding their progress where they will need to perform a wet-gap crossing. (See Fig. 2)


**Fig. 2 BLUFOR attacks OPFOR and secures the river crossing**

The BLUFOR for this mission is the 1st Battalion, 22nd Infantry Regiment, which is composed of A Company, B Company, C Company, D Company, a Scout Platoon, a Mortar Platoon, and an Engineering Company. OPFOR consists of the 1st Platoon, 2nd Platoon, and 3rd Platoon from the 1st Company, 1st Battalion, 241 Infantry Brigade.

We will examine two outcomes for this scenario. In the first outcome (original scenario), the Scout Platoon will use the situational awareness (SA) determined by the simulation as certain. As a result, it will wait for reinforcements when it encounters the enemy because the provided SA will inform that the combat power

ratio (3:1) is not met. In the second outcome (alternative what-if scenario), the SA information is uncertain, and the Scout Platoon will decide to attack rather than waiting for reinforcements. Subsequent tables are given with the combat messages generated from the scenario and associated with the phases of the mission.

During the initial phase of the mission, the whereabouts of OPFOR are unknown and approximated until confirmed by the BLUFOR. Confirmation of enemy location occurs when OPFOR units come into range (visual or sensor) of a BLUFOR unit (see Table 1).

**Table 1 Combat messages for the initial phase of the mission**

| | | | | |
|---|---|---|---|---|
| H+02:42 | COMBAT | SCT PLT / 1 - 22 IN | Earned SA (via Proximity) on | 1 1 CO (TRK) / 1 BN / 241 INF BDE (TM) |
| H+03:02 | COMBAT | SCT PLT / 1 - 22 IN | Earned SA (via Proximity) on | 3 1 CO (TRK) / 1 BN / 241 INF BDE (TM) |
| H+03:54 | COMBAT | B CO / 1 - 22 IN | Earned SA (via Proximity) on | 2 1 CO (TRK) / 1 BN / 241 INF BDE (TM) |

Once a BLUFOR unit has confirmation of an enemy target, that information is immediately relayed to the rest of BLUFOR. This information is critical when determining whether the BLUFOR has the necessary combat power advantage to proceed.

The course of action (CoA) calls for the BLUFOR Scout Platoon to move forward to observe the crossing. Two companies of mechanized infantry will follow to handle any engagements (see Table 2).

**Table 2 Combat messages for the reconnaissance phase of the mission**

| | | | | |
|---|---|---|---|---|
| H+04:05 | INFO | B CO / 1 - 22 IN | Moving to fight | 1 1 CO (TRK) / 1 BN / 241 INF BDE (TM) |
| H+05:06 | COMBAT | B CO / 1 - 22 IN | Attacking (Direct Fire) against | 1 1 CO (TRK) / 1 BN / 241 INF BDE (TM) |
| H+05:06 | INFO | B CO / 1 - 22 IN | In DF range (fighting) | 1 1 CO (TRK) / 1 BN / 241 INF BDE (TM) |
| H+05:48 | COMBAT | B CO / 1 - 22 IN | Attacking (Direct Fire) ended | 1 1 CO (TRK) / 1 BN / 241 INF BDE (TM) |

The Engineer Company will facilitate the crossing when the area is free of opposition (see Table 3).

**Table 3 Combat messages for the wet-gap crossing phase of the mission**

| | | | | |
|---|---|---|---|---|
| H+05:40 | COMBAT | SCT PLT / 1 - 22 IN | Is paused at Crossing Control Point. Crossing is not traversable. | Crossing Task [Ref. 1] |
| H+06:27 | COMBAT | A CO / 1 - 22 IN | Is paused at Crossing Control Point. Crossing is not traversable. | Crossing Task [Ref. 1] |
| H+06:17 | COMBAT | B CO / 1 - 22 IN | Is paused at Crossing Control Point. Crossing is not traversable. | Crossing Task [Ref. 1] |
| H+06:07 | COMBAT | 50 ENG CO (MRBC) | Crossing Task has started. | Crossing Task [Ref. 1] |
| H+06:25 | COMBAT | 50 ENG CO (MRBC) | Crossing Task completed. Units can cross. | Crossing Task [Ref. 1] |

By doctrine, in this simulation, a unit will only attack if it has a 3:1 relative combat power (RCP) advantage. However, in our alternative "what-if" scenario, the Scout Platoon decides to attack rather than waiting for reinforcements based on the uncertain information (see Table 4).

**Table 4 Combat messages for the contact phase of the mission**

| | | | | |
|---|---|---|---|---|
| H+03:13 | INFO | SCT PLT / 1 - 22 IN | Can't attack without reinforcements. Awaiting commander's guidance | 1 1 CO (TRK) / 1 BN / 241 INF BDE (TM) |

After completing the wet gap crossing, the BLUFOR will proceed and engage the OPFOR while staying within its assigned area of responsibility. The total duration of this mission is around 10 h (see Table 5).

**Table 5 Combat messages for the engagement phase of the mission**

| | | | | |
|---|---|---|---|---|
| H+06:28 | INFO | B CO / 1 - 22 IN | Not going after OPFOR (out of assigned boundary) | 3 1 CO (TRK) / 1 BN / 241 INF BDE (TM) |
| H+06:54 | INFO | SCT PLT / 1 - 22 IN | Not going after OPFOR (out of assigned boundary) | 3 1 CO (TRK) / 1 BN / 241 INF BDE (TM) |
| H+06:58 | INFO | A CO / 1 - 22 IN | Not going after OPFOR (out of assigned boundary) | 3 1 CO (TRK) / 1 BN / 241 INF BDE (TM) |
| H+07:12 | COMBAT | A CO / 1 - 22 IN | Attacking (Direct Fire) against | 2 1 CO (TRK) / 1 BN / 241 INF BDE (TM) |
| H+07:12 | INFO | A CO / 1 - 22 IN | In DF range (fighting) | 2 1 CO (TRK) / 1 BN / 241 INF BDE (TM) |
| H+07:54 | COMBAT | A CO / 1 - 22 IN | Attacking (Direct Fire) ended | 2 1 CO (TRK) / 1 BN / 241 INF BDE (TM) |
| H+08:07 | COMBAT | | Receiving (artillery) fire | B CO / 1 - 22 IN |
| H+08:10 | COMBAT | | Receiving (artillery) fire ended | B CO / 1 - 22 IN |
| H+08:10 | COMBAT | B CO / 1 - 22 IN | Receiving (artillery) fire. Firing has stopped | |

## 2.2 AURORA Cross-Reality Common Operating Picture (XRCOP)

For exploring visualization and interaction with ETI, the DXTRS scenario and associated ETI reasoning messages were displayed in an XR environment. This environment, developed by the US Army Combat Capabilities Development Command (DEVCOM) Army Research Laboratory (ARL), is called AURORA.[1] AURORA provides a common operating framework for secure, networked, multi-device cross-reality information mediation and interaction. To facilitate the visualization a collection of scenario data was mapped into Cursor on Target (CoT) messages that AURORA could process. Section 3 of this report will explain the mapping process in detail. Figures 3 and 4 show screen captures of our scenario in the AURORA environment.

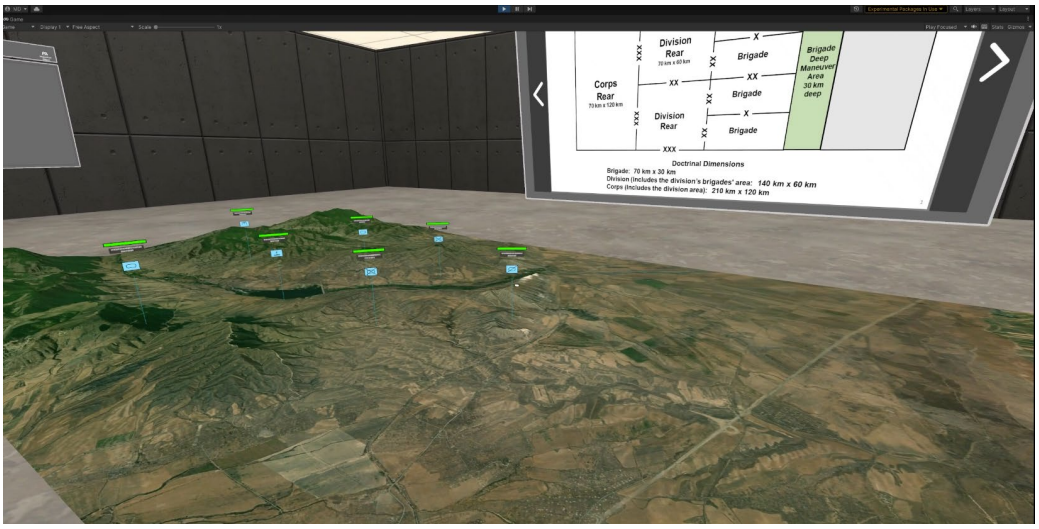


**Fig. 3 AURORA XRCOP: initial BLUFOR placement**

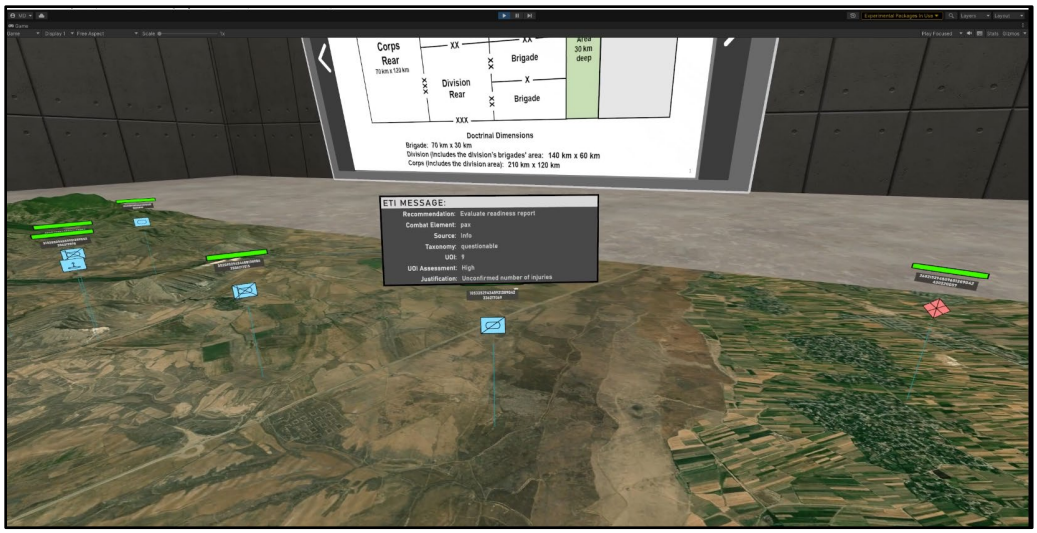


**Fig. 4 AURORA XRCOP with ETI integration**

## 2.3 ETI Decision Recommendations

As mentioned previously, ETI is designed to utilize various reasoning models as modules allowing different configurations of reasoning. The reasoning model for this effort was the UoI module. The concept of the UoI includes producing or capturing a value as well as categorizing the uncertainty value with a descriptor. This provides the decision maker with contextual information for the uncertainty and supports the reasoning for resulting recommendations. The descriptors are based on the nature of imperfect information as presented in Gershon's paper.[2,3] Currently the taxonomy consists of inconsistent, corrupt, disjoint, incomplete,

imprecise, complicated, and questionable. Together they describe the causes and types of uncertainty of a given source.

The current version of UoI expression is a weighted sum as seen in Eq. 1.

$$UoI_{dp} = \sum_{a,b=1}^{k,l} T_{a,b} * S_{a,b} + \sum_{c,d=1}^{m,n} W_{c,d} * D_{c,d} = \sum_{a,b=1}^{k,l} G_{a,b} * S_{a,b} + \sum_{c,d=1}^{m,n} W_{c,d} * D_{c,d} = \quad (1)$$

***Equation 1.*** *UoI Calculation, where* ***dp*** *is a decision point,* ***D*** *are variables that express components of the decision making that may be key factors for the task,* ***W*** *are the weights associated with the importance of those components,* ***T*** *are the categories of taxonomy weights (equivalent to* ***G****), and* ***S*** *are the categories of sources of data. The UoI value represents the contributions of the sources and factors in relationship to the uncertainties categorized.*

The following are descriptions of the seven terms within the taxonomy:

- Inconsistent: Uncertainty due to a source that varies or does not stay the same.
- Corrupt: Uncertainty due to a source containing errors.
- Questionable: Uncertainty due to a source that lacks information or its questionable.
- Disjoint: Uncertainty due to a source that lacks cohesion or organization.
- Incomplete: Uncertainty due to a source that is unfinished or not complete.
- Imprecise: Uncertainty due to a source that lacks exactness or detail.
- Complicated: Uncertainty due to a source that is convoluted or confusing.

## 3. Method

In creating this demonstration, we developed a method to convert a scenario executed in DXTRS into a CoT message enhanced with combat messages and ETI decision recommendations. Figure 5 shows an example of a CoT message. In this section we will discuss the scripts, tools, and processes encompassed by our methodology.

```
<?xml version='1.0' encoding='UTF-8' standalone='yes'?>
<event version='2.0'
        uid='18533529434592138904233621706 9'
        time='2003-08-04T18:41:09.00Z'
        start='2003-08-04T18:41:09.00Z'
        stale='2003-08-05T18:41:09.00Z'
        type='a-f-G-U-C-R-V-A'
        how='m-s'>
        <point lat='40.055181179220234'
                lon='46.980916489583294'
                le='0'
                hae='0'
                ce='0'
                />
               <detail>
                    <dxtrs>
                        <combat_strength>100</combat_strength>
                       <combat_message>
                           SCT PLT / 1 - 22 IN earned SA (via  Proximity)
                           on 3 1 CO (TRK) / 1 BN / 241 INF BDE (TM).
                       </combat_message>
                    </dxtrs>
              </detail>
</event>
```

**Fig. 5 DaVinci data converted to CoT message**

### 3.1 Generating Scenario Snapshots

The first step in our method is executing our scenario in DXTRS. To the casual user DXTRS is a black box. DXTRS does not output data in any format that can be processed automatically. To accomplish this task, we used DaVinci web service to access the data within DXTRS. DaVinci web service can initiate and monitor a DXTRS scenario, outputting the current simulation state in Javascript Object Notation (JSON) when requested. For this demonstration we decided to collect the simulation state after every 15 min of simulated time. Each collection is referred to as a snapshot, and the file format, dxtrs_<offset>. json, where <offset>, is the time

in seconds from the beginning of the simulation (i.e., dxtrs_0900.json). To communicate with the DaVinci server we used the Postman tool, an API platform that enabled us to connect to DaVinci web service via its API. We used the request GET_WARGAME_AT_TIME to get the simulation state at a specific time, creating a snapshot. Communicating with DaVinci via the API does require a Bearer Token provided by the DaVinci developers. To gather a full set of snapshots we incremented our request by 15 min and saved each result as a JSON file.

Upon completion of this process, we created a file for each 15-min snapshot. The files contained scenario state, such as unit location and relative combat power, in JSON format. These files will be the input for our scripts to create CoT messages.

## 3.2 Generating Combat Messages

The combat messages from DXTRS can be captured with DaVinci. These messages contain important events that a unit is involved in, such as changes to SA and combat. DaVinci does not have an API request for collecting combat messages, thus Postman was not a viable tool for this collection. Instead, we used node.js to execute a script that gathers all combat messages generated while the scenario executes (See the Appendix A.1, Script: Get Combat Messages from DaVinci Server). Each combat message was output as a single JSON message. To facilitate processing, we combined all the messages within a JSON wrapper.

Upon completion of this process, we had created a JSON file containing all combat messages from the simulation. The files contained the state of significant events reported during simulation in JSON format. This file will be another input, in addition to the snapshots, for our scripts to create CoT messages.

## 3.3 Generating Cursor on Target Message

For the scenario to be visualized in AURORA, the unit data from the snapshots had to be extracted and converted into a CoT message. A CoT message is an eXtensible Markup Language (XML) message used to convey the "what, when, and where" of time-sensitive events. The CoT schema (Table 6) is in the DOD DISA XML registry.[4]

To create the CoT message a script was developed (See the Appendix A.2, Script: Generate Cursor on Target Message) to map the simulation snapshots and combat message data into an XML file based on the CoT Schema. Table 7 describes how each attribute in the CoT schema was mapped from these data sources.

Upon completion of this process, we had a folder for each 15-min interval. Within each folder was an XML CoT message for each unit in the scenario. To visualize

the scenario a tool, such as AURORA, could process the files in time order, similar to previous work to visualize StarCraft II in AURORA.[5] As a result of these steps, unit location, unit relative combat power, and significant events from the scenario have been mapped from DXTRS to CoT messages for the duration of the scenario.

**Table 6 Cursor on target schema[4]**

| Element | Attribute | Opt/ Req | Definition | XML Schema Type |
|---|---|---|---|---|
| Event | version | Req | Schema version of this event instance (e.g. 2.0) | Decimal equal to 2.0 |
| | type | Req | Hierarchically organized hint about event type | string of pattern "\w+(-\w+)*(:[^:]*)?" |
| | uid | Req | Globally unique name for this information on this event | string |
| | time | Req | time stamp: when the event was generated | dateTime |
| | start | Req | starting time when an event should be considered valid | dateTime |
| | stale | Req | ending time when an event should no longer be considered valid | dateTime |
| | how | Req | Gives a hint about how the coordinates were generated | string of pattern "\w-\w" |
| | opex | Opt | | |
| | qos | Opt | | |
| | access | Opt | | |
| Point | lat | Req | Latitude referred to the WGS 84 ellipsoid in degrees | decimal -90 to 90 inclusive |
| | lon | Req | Longitude referred to the WGS 84 in degrees | decimal -180 to 180 inclusive |
| | hae | Req | Height above the WGS ellipsoid in meters | decimal |
| | ce | Req | Circular 1-sigma or a circular area about the point in meters | decimal |
| | le | Req | Linear 1-sigma error or an altitude range about the point in meters | decimal |
| Detail | N/A | Opt | An optional element used to hold CoT sub-schema. | empty element |

**Table 7 Mapping DXTRS scenario to CoT message**

| Element | Attribute/Element | Conversion |
|---|---|---|
| Event | uid | The davinciId is extracted from the DaVinci snapshot |
| | time | This attribute was created by using the time that the CoT script was executed plus the offset (in 15-minute increments) of the snapshot from the beginning of the scenario. |
| | start | This attribute is the same as Time in this script |
| | stale | This attribute is 15 minutes from the start time due to the use of 15-minute gaps between snapshots. |
| | how | Hard coded as 'm-s' for modeling and simulation |
| | type | Using the valid Atomic Event combinations (Figure 6), this attribute was a (atom) \| f (friend) or h (hostile) \| G (Ground) \|MIL-STD-2525B Function code for the simulated which was hardcoded into the conversion script |
| Point | lat | The latitude is extracted from the DaVinci snapshot |
| | lon | The longitude is extracted from the DaVinci snapshot |
| | hae | Hard coded as 0 |
| | ce | Hard coded as 0 |
| | le | Hard coded as 0 |
| Detail | dxtrs | Element containing dxtrs simulation information |
| | combat_strength | The relative combat strength of the unit, as a percentage of maximum, extracted from the DaVinci snapshot |
| | combat_message | Significant actions involving this unit during the time span. Extracted from the combat messages JSON file |

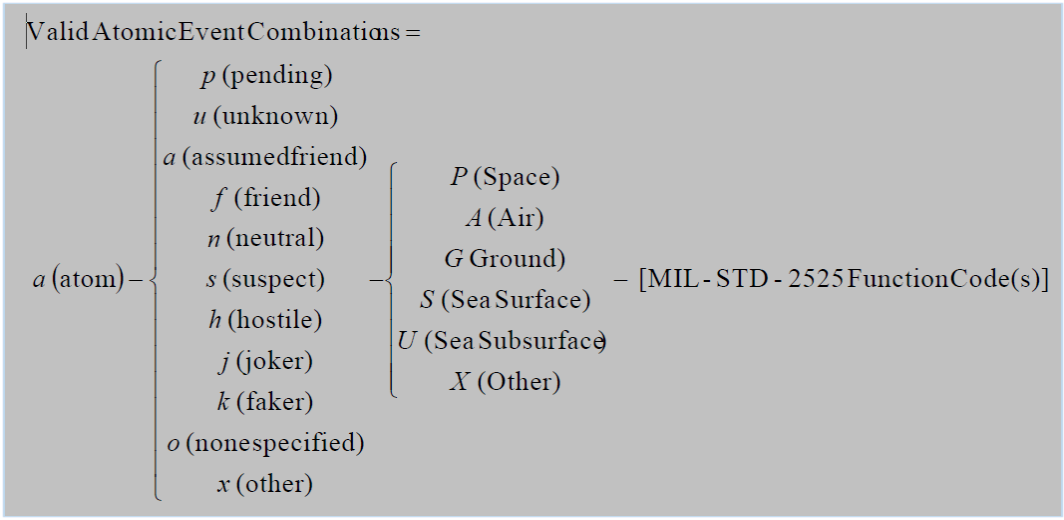


**Fig. 6 Atomic event combinations for type attribute[4]**

## 3.4 ETI Message Development

An ETI message is a decision aid providing a decision maker with a recommendation determined by reasoning over attributes, such as uncertainty, of the data informing the decision. In this demonstration, the messages were developed by combining DXTRS combat messages with context created external to the simulation. To begin, a set of decision points (DPs) were identified in the combat messages. A DP is an event in the scenario where additional operationally relevant context, appended external to the simulation, creates uncertainty in the SA. As a result, a decision maker may be aided by ETI messages that can account for uncertainty and recommend an appropriate decision. For the demonstration, we scripted a process to insert ETI messages into the CoT messages used for visualization in AURORA. In this section, we choose one DP and present the step-by-step process for creating a single ETI message, which we then apply to the other DPs.

In Fig. 7, we show a copy of the combat messages generated from the "what-if" scenario, which is described in Section 4.1. After labeling the DPs, by simply enumerating the messages, we chose eight DPs/combat messages for ETI message development and demonstration. The first three DPs (2,3,4) were chosen because they set the stage for the scenario with Scout Platoon (labeled SCT PLT /1 – 22 IN) earning SA on the three OPFOR platoons. We created context based on the combat messages providing SA Reports and any uncertainty tied to those. The next two DPs (5 and 6), detailed combat-related situations, to highlight that ETI is continuously evaluating incoming data streams even during combat events. In DP 8, BLUFOR B Company (labeled B CO / 1 – 22 IN) earns SA on OPFOR Platoon 2 (labeled 2 1 CO (TRK) / 1 BN / 241 INF BDE), which was not obtained by the Scout Platoon earlier in the scenario. Finally, in DP 18 we reach the penultimate step of BLUFOR mission, which is for the Engineering Company (labeled 50 ENG CO [MRBC]) to begin establishing a crossing over the river for all BLUFOR units to cross. Note that our vision for ETI is that it is continuously reasoning on the heterogenous incoming data streams throughout a mission; however, we only showcase ETI messages for a selected set of DPs.

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | Time | Agent | Alert Message | Target | Old CM DP | New DPs |
| 2 | H+02:23 | SCT PLT / 1 - 22 IN | earned SA (via Proximity) on | 3 1 CO (TRK) / 1 BN / 241 INF BDE | 2 | 2 |
| 3 | H+02:35 | SCT PLT / 1 - 22 IN | earned SA (via Proximity) on | 1 1 CO (TRK) / 1 BN / 241 INF BDE | 3 | 3 |
| 4 | H+02:38 | SCT PLT / 1 - 22 IN | can't attack without reinforcements. Awaiting commander's guidance | 3 1 CO (TRK) / 1 BN / 241 INF BDE (TM) | 4 | 4 |
| 5 | H+03:30 | B CO / 1 - 22 IN | moving to fight | 3 1 CO (TRK) / 1 BN / 241 INF BDE (TM). | 6 | 5 |
| 6 | H+04:26 | MORTAR PLT / 1 - 22 IN | firing (artillery) on | 1 1 CO (TRK) / 1 BN / 241 INF BDE (TM). | 7 | 6 |
| 7 | H+04:29 | MORTAR PLT / 1 - 22 IN | firing (artillery) ended | 1 1 CO (TRK) / 1 BN / 241 INF BDE (TM). | | 7 |
| 8 | H+04:31 | B CO / 1 - 22 IN | earned SA (via Proximity) on | 2 1 CO (TRK) / 1 BN / 241 INF BDE (TM). | 5 | 8 |
| 9 | H+04:32 | A CO / 1 - 22 IN | moving to fight | 3 1 CO (TRK) / 1 BN / 241 INF BDE (TM). | | 9 |
| 10 | H+04:38 | MORTAR PLT / 1 - 22 IN | firing (artillery) on | 3 1 CO (TRK) / 1 BN / 241 INF BDE (TM). | | 10 |
| 11 | H+04:40 | SCT PLT / 1 - 22 IN | Movement is resumed. | | | 11 |
| 12 | H+04:41 | SCT PLT / 1 - 22 IN | moving to fight | 3 1 CO (TRK) / 1 BN / 241 INF BDE (TM). | | 12 |
| 13 | H+04:43 | MORTAR PLT / 1 - 22 IN | firing (artillery) ended | 3 1 CO (TRK) / 1 BN / 241 INF BDE (TM). | | 13 |
| 14 | H+05:13 | B CO / 1 - 22 IN | receiving (artillery) fire. Firing has stopped. | | | 14 |
| 15 | H+05:43 | C CO / 1 - 22 IN | moving to fight | 2 1 CO (TRK) / 1 BN / 241 INF BDE (TM). | | 15 |
| 16 | H+06:06 | C CO / 1 - 22 IN | receiving (artillery) fire. Firing has stopped. | | | 16 |
| 17 | H+06:15 | D CO / 1 - 22 IN | moving to fight | 2 1 CO (TRK) / 1 BN / 241 INF BDE (TM). | | 17 |
| 18 | H+06:23 | 50 ENG CO (MRBC) | Crossing Task has started. | | 11 | 18 |
| 19 | H+06:40 | 50 ENG CO (MRBC) | Crossing Task completed. Units can cross. | | | 19 |
| 20 | H+08:35 | C CO / 1 - 22 IN | receiving (artillery) fire. Firing has stopped. | | | 20 |
| 21 | H+09:10 | SCT PLT / 1 - 22 IN | Paused(Wait reinforce). | | | 21 |
| 22 | H+09:12 | D CO / 1 - 22 IN | receiving (artillery) fire. Firing has stopped. | | | 22 |
| 23 | H+11:05 | SCT PLT / 1 - 22 IN | continues to be Paused(Wait reinforce). | | | 23 |

**Fig. 7 A copy of the combat messages used in the simulation of the "original" scenario described in Section 4.2. In Column F, all selected messages are labeled with numeric DP values to delineate between them, choosing the first to be DP 2 for consistency with a previous demonstration. The DPs that are highlighted in light green (DPs 2, 3, 4, 5, 6, 8, and 18) were chosen for evaluation and demonstration.**

Consider DP3 for ETI message development. Nine candidate ETI messages based on three UoI value ranges and three taxonomy categories (all for one information source) were generated, then one message was selected for this demonstration. The UoI taxonomy categories for Corrupt, Questionable, and Incomplete uncertain data sources were chosen. A UoI value is an integer between [0, 10], which were partitioned into "Low" for [0, 3], "Medium" for [4, 7], and "High" for [8, 10]. While there are eight taxonomy categories, several ways to partition the UoI value ranges, and even more types of data sources, our choice for these subsets was motivated more by the ability to concisely represent this data table, as well as producing the messages. One helpful perspective to take while developing ETI messages is that, to some degree, we are working backwards: ETI is designed to intake various data sources, infer on the source using the various taxonomy categories to produce a UoI value, a recommendation for the unit/commander, and a justification for the value and recommendation; for development, we selected a UoI value and created a justification/recommendation for the particular data source and mission context.

For each taxonomy category and UoI value partition, we provided (1) an ETI recommendation for the BLUFOR unit referenced in the DP (SCT PLT) and/or BLUFOR commander and (2) a justification for ETI's recommendation. These were based on the researcher's knowledge of military-relevant events and context from the combat messages. In this DP, SCT PLT earns SA on OPFOR Platoon 1 and in turn an SA Report is produced, so ETI reasons on both the content and viability of the report. Consider the taxonomy category for "Corrupt" with a Low

UoI value, 0. A possible justification for the value may be that there were no errors on the SA Report, so the recommendation would be for the unit (and mission) to continue. Consider the taxonomy category for "Questionable" with a Medium UoI value, 6. One possible justification for this higher uncertainty may be that a Human Intelligence (HUMINT) Report was referenced in the SA Report, which has not yet been evaluated by the unit/commander due to a delay in data transfer. ETI's recommendation would be for the unit/mission to pause until the report comes in. We continue to formulate the reasons and justifications for the other pairs of taxonomy categories and UoI value ranges until we have nine sets of such reasons/justifications. Table 8 shows a summarized layout for developing DP3's ETI messages.

**Table 8 Summarized layout and contents of the Excel sheet used in developing ETI messages for DP3. The Timestamp, Unit/Commander and Target are pulled from the "Time," "Agent," and "Target" fields of DP3 in the combat messages shown in Fig. 7. Combat Power Element refers to the capability/knowledge that the BLUFOR unit has to use for the mission. Here we refer to the SA Report on OPFOR Platoon 1, but other examples include amount of ammunition, personnel, or fuel that the BLUFOR unit possesses. Data source refers to the type of data stream feeding into ETI's UoI Reasoning Module. Lastly, "LUoI," "MUoI," and "HUoI" are just the "Low," "Medium," and "High" partitions for the UoI value range. We show example UoI values, recommendations, and justifications for each Taxonomy category.**

| **Table. ETI Message Development for DP3** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Timestamp** | | | H + 02:35 | | | | | | |
| **Unit/Commander** | | | SCT PLT | | | | | | |
| **Target** | | | OPFOR Platoon1 | | | | | | |
| **Combat Power Element** | | | SA on OPFOR Platoon 1 | | | | | | |
| **Data Source** | | | Info | | | | | | |
| **Taxonomy** | **LUoI** | **Rec.** | **Just.** | **MUoI** | **R.** | **J.** | **HUoI** | **R.** | **J.** |
| Corrupt | 0 | Continue | No errors in report | … | | | … | | |
| Questionable | … | | | 6 | Pause | Database delay: HUMINT Report | … | | |
| Incomplete | … | | | … | | | … | | |

In a separate Excel spreadsheet, the ETI messages are standardized to allow the user to parse the information concisely and perform their subsequent inferences/actions. Continuing with DP3, consider the Medium UoI value message. All messages are formatted as shown in Table 9.

**Table 9 ETI message format**

| ETI message elements | Sample content |
|---|---|
| Timestamp | H + 02:35 |
| Recommendation | Request Additional Drone |
| Combat Power Element | SA on OPFOR platoon 1 |
| Data Source | Info |
| Taxonomy | Corrupt |
| UoI Value (0-10) | 5 |
| UoI Assessment | Medium |
| Justification | Sensor Malfunction on Drone |

The Timestamp is provided first to allow the user to compare to any timeline of events, followed by ETI's Recommendation for the unit/commander. Combat Power Element is provided to notify the user that ETI was evaluating on some capability/knowledge from the BLUFOR unit. Data Source provides detail for the type of information references in the Combat Power Element. Taxonomy shows which criteria ETI uses for its inference. UoI Value and Assessment provide an evaluation for the level of uncertainty pertaining to the piece of information for the reasoning ETI performs. Lastly, the Justification is the reason ETI provided the score and recommendation.

There are a few things to note about this organization and these inferences. First, we recall that this is illustrating a long-term vision for ETI. Given today's machine inferencing and reasoning capabilities, it would make sense, for example, to have the "Justification" follow immediately after the "Recommendation" to allow the user to understand the reasoning behind the recommendation; however, in the longer term we envision a system that has been tested and well-vetted enough that there is a high level of trust in the system through continuous evaluation. Depending on the situation (high-stakes vs. low-risk), presenting a user with the most pertinent information upfront is another reason to present the information in this order. Another point to note is that this is one of nine possible messages. During our demonstration we only present one of these nine messages for each of the highlighted DPs so as not to clutter the user with various inferences. Again, as a long-term vision, ETI will infer on multiple heterogeneous pieces of data simultaneously and use a more holistic aggregation of these results before presenting the user with its reasoning. For example, it may take a special weighted sum of the individual UoI values for each taxonomy to provide an overarching UoI score for the information to perform the inference.

The HUMINT and other reports used for these ETI messages were examples, to provide more of a sense of realism to the scenario. We recognized that during operations several reports may be generated by the units to provide SA or request

support. As part of our vision for ETI, the system will have knowledge of these types of reports so it may account for them in its UoI (and other reasoning modules) inferences, and recommendations. We made use of the following report types in our scenario: Air Support Request (AIRSUPREQ), Medical Report (MEDREP), Spot Report (SPOTREP), and Intelligence Report (INTREP). While the latter three were used to provide the commander with intelligence about the status of the unit or adversary, the first, AIRSUPREQ, was used supporting the ETI recommendation to request an additional drone. ETI would subsequently intake the submitted AIRSUPREQ to update its inferences, for example lower the UoI value and recommend proceeding once drone intelligence is processed.

## 3.5 ETI Message Insertion

After generating one ETI message for each of the desired DPs, we parsed the Excel files containing the ETI messages into a format easily incorporated into the main AURORA CoT messages. Figure 8 shows a complete CoT message, including inserted ETI message, for DP3.

```
<?xml version='1.0' encoding='UTF-8'
standalone='yes'?>
<event version='2.0'
uid='18533529434592138904233621706 9' time='2022-11-
15T13:55:56.35Z' start='2022-11-15T13:55:56.35Z'
stale='2022-11-15T14:10:56.35Z' type='a-f-G-U-C-R-V-A'
how='m-s'>
<point lat='40.05232462113347' lon='46.93473485787548'
le='0' hae='0' ce='0'/>
<detail>
     <dxtrs>
     <combat_strength>100</combat_strength>
     <combat_message></combat_message>
     </dxtrs>
     <eti_msg>ETI Message
     <timestamp>H+01:15</timestamp>
<eti_rec>Continue</eti_rec>
<combat_el>SA on Red Company 3</combat_el>
<data_src>Info</data_src>
<taxonomy>Corrupt</taxonomy>
<uoi_val>0</uoi_val>
<uoi_assess>Low</uoi_assess>
<justification>No Errors on Report</justification>
     </eti_msg>
</detail>
</event>
```

**Fig. 8 Example CoT message for DP3. The text highlighted in gray is the ETI message component of the CoT message. The ETI message markup tag, and subsequent component tags, appear in the <detail> field as miscellaneous information.**

The ETI message information appears in the <eti_msg> element and its components are parsed, using a simple Python script, into the sub-elements <timestamp>, <eti_rec> for the ETI Recommendation; <combat_el> for the Combat Power Element; <data_source> for the data source; <taxonomy> for the UoI Taxonomy category being evaluated; <uoi_val> for UoI Value; <uoi_assess> for the UoI Assessment; and <justification>. After parsing the messages, they were inserted into the CoT message for the corresponding unit and nearby timestamp. By "nearby" we mean that, given the simulation's time resolutions (roughly 15 min or 900 s), it is the closest time block. For example, if an ETI message corresponds to 1 h and 20 min (4800 s) into the scenario, then we placed the message in the simulation time block for 1 h 15 min (4500 s). Later, we further adjusted the placement of the ETI message to allow for ease of reading by our audience. These timing considerations are discussed further in the Lessons Learned.

The ETI message element and its contents were used by AURORA to render the information in a visual as illustrated in Table 9. We also rendered another visual of the importance of the ETI message, using what we refer to as the ETI dot. The ETI dot is a colored circle, where green, yellow, or red indicates whether ETI evaluates the UoI to be low, medium, or high, respectively. A yellow or red dot indicates to the user that they should work to resolve the uncertainty that ETI evaluated before proceeding with the mission.

## 4. Demonstration

For the demonstration two scenarios were presented that highlighted the potential capabilities of our Artificial Reasoning research. Both scenarios will show a wet gap crossing and ETI messages were displayed. In the first scenario ("what-if"), the BLUFOR does not have access to ETI. As ETI messages appeared in the visualization we discussed how not having this capability can negatively impact the mission and prevent modifications to the CoA and associated decisions. In the second scenario ("normal"), the BLUFOR had access to ETI giving them the ability to resolve any UoI that could negatively impact the mission.

Finally, for simplicity, each ETI message displayed in the demonstration uses only one of the seven taxonomy categories for evaluating UoI. Going forward, the plan for ETI is to have it infer over all taxonomy measures, using various types of data sources simultaneously, to provide more holistic and coordinated course of action recommendations for BLUFOR.

Also note, in the following sections, there may be references to an ETI dot, which is a circular figure colored green, yellow, or red depending on whether the ETI evaluation is respectively low, medium, or high. This ETI dot appears in the AURORA visualization alongside the ETI message. Figure 9 provides a sample visualization of the ETI dot.

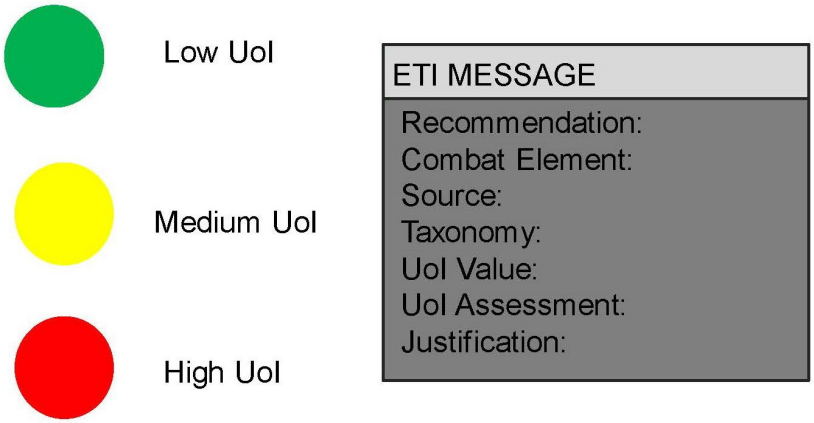


**Fig. 9 Example of ETI dots appearing alongside the ETI message during the AURORA visualization**

## 4.1 What-If Scenario

Beginning with the "what-if" scenario, the BLUFOR mission was to complete a wet gap crossing to ensure continued movement. Intelligence reports indicated there were enemies nearby. In this scenario the BLUFOR commander did not have access to the uncertainty of information values, assessments, and recommendations ETI provides. The scenario began with a Scout Platoon performing reconnaissance of the crossing area and potential enemy locations. If ETI messages were available to the Scout commander, they would have shown that there was a high level of uncertainty associated with incoming reports.

Now we will review the ETI messages that were not available to the BLUFOR commander in this scenario. **ETI Message 2 "Redeploy (additional) Drone" (Table 10):** ETI evaluated reports received about OPFOR Platoon 3 using "Information" as the data source and a taxonomy measuring the corruptness of the information. The UoI value was evaluated to be 9, which indicates high uncertainty, because ETI had found that there was a sensor malfunction on a drone.

**Table 10 ETI Message 2 "Redeploy (additional) Drone"**

| ETI message elements | Message 2 content |
|---|---|
| Timestamp | H+02:24 |
| Recommendation | Redeploy (additional) Drone |
| Combat Power Element | SA on OPFOR platoon 3 |
| Data Source | Info |
| Taxonomy | Corrupt |
| UoI Val (0-10) | 9 |
| UoI Assessment | High |
| Justification | Sensor Malfunction on Drone |

**ETI Message 3 "Request Additional Intel" (Table 11):** ETI evaluated the reports received about OPFOR Platoon 1 using "Information" as the data source and a taxonomy measuring the questionable information. The UoI value is evaluated to be 10, which indicates high uncertainty, because ETI had found that the HUMINT reported an extra adversary unit.

**Table 11 ETI Message 3 "Request Additional Intel"**

| ETI message elements | Message 3 content |
|---|---|
| Timestamp | H+02:35 |
| Recommendation | Request Additional Intel |
| Combat Power Element | OPFOR platoon 1 |
| Data Source | Info |
| Taxonomy | Questionable |
| UoI Val (0-10) | 10 |
| UoI Assessment | High |
| Justification | HUMINT reports extra adversary unit |

**ETI Message 4 "Request Retransmission" (Table 12):** ETI evaluated the SA received on OPFOR Platoon 2 using "Information" as the data source and a taxonomy measuring the incompleteness of the information. The UoI value is evaluated to be 10, which indicates high uncertainty, because ETI had found that GPS coordinates were not received.

**Table 12 ETI Message 4 "Request Retransmission"**

| ETI message elements | Message 4 content |
|---|---|
| Timestamp | H+02:47 |
| Recommendation | Request Retransmission |
| Combat Power Element | SA on OPFOR platoon 2 |
| Data Source | Info |
| Taxonomy | Incomplete |
| UoI Val (0-10) | 10 |
| UoI Assessment | High |
| Justification | SAT GPS Coords not received |

Without ETI providing these messages the Scout platoon was unaware of the uncertainty in their SA. Their information turned out to be wrong, and as they proceeded to the crossing point they were ambushed.

**ETI Message 6 "Request Cargo Truck Status" (Table 13):** ETI evaluated the SA received on vehicles using "Information" as the data source and a taxonomy measuring questionable information. The UoI value is evaluated to be 6, which indicates medium uncertainty, because ETI had received data that there was damage to 2.5-ton cargo truck which was previously unavailable.

**Table 13 ETI Message 6 "Request Cargo Truck Status"**

| ETI message elements | Message 6 content |
|---|---|
| Timestamp | H+03:19 |
| Recommendation | Request Cargo Truck Status |
| Combat Power Element | Vehicles |
| Data Source | Info |
| Taxonomy | Questionable |
| UoI Val (0-10) | 6 |
| UoI Assessment | Medium |
| Justification | Damage to 2.5-Ton Cargo Truck Unavailable |

**ETI Message 7 "Await Report" (Table 14):** ETI evaluated the SA received on personnel using "Information" as the data source and a taxonomy measuring the incompleteness of the information. The UoI value is evaluated to be 5, which indicates medium uncertainty, because ETI had found that there was no injury report received.

**Table 14 ETI Message 7 "Await Report"**

| ETI message elements | Message 7 content |
|---|---|
| Timestamp | H+03:23 |
| Recommendation | Await Report |
| Combat Power Element | PAX |
| Data Source | Info |
| Taxonomy | Incomplete |
| UoI Val (0-10) | 5 |
| UoI Assessment | Medium |
| Justification | No Injury Report Received |

The consequence of not having ETI to indicate theses high uncertainties caused the Scout platoon significant attrition. After the Scout Platoon was routed, additional BLUFOR units arrived in the area and took fire from the enemy.

**ETI Message 8 "Continue" (Table 15):** ETI evaluated the SA received on fuel levels using "Information" as the data source and a taxonomy measuring the corruptness of the information. The UoI value is evaluated to be 0, which indicates low uncertainty, because ETI had data confirming that there was sufficient fuel for the light truck.

**Table 15 ETI Message 8 "Continue"**

| ETI message elements | Message 8 content |
|---|---|
| Timestamp | H+03:31 |
| Recommendation | Continue |
| Combat Power Element | Fuel |
| Data Source | Info |
| Taxonomy | corrupt |
| UoI Val (0-10) | 0 |
| UoI Assessment | Low |
| Justification | Fuel Info for Light Truck Confirmed |

At this point in the mission B Company was also reduced in their combat power and was waiting for reinforcements to engage with OPFOR Platoon 2 while paused at the Crossing Point.

**ETI Message 14 "Continue Engagement" (Table 16):** ETI evaluated the SA received on ammunition using "Information" as the data source and a taxonomy measuring the questionable information. The UoI value is evaluated to be 1, which indicates low uncertainty, because ETI had data confirming sufficient ammunition for BLUFOR.

**Table 16 ETI Message 14 "Continue Engagement"**

| ETI message elements | Message 14 content |
|---|---|
| Timestamp | H+04:26 |
| Recommendation | Continue engagement |
| Combat Power Element | Ammo |
| Data Source | Info |
| Taxonomy | Questionable |
| UoI Val (0-10) | 1 |
| UoI Assessment | Low |
| Justification | Confirmed Ammo Quantity |

Due to BLUFOR attrition the Mortar Platoon began indirect fire on OPFOR Platoon 1 and quickly overpowered OPFOR. BLUFOR Companies A, B, C, and D proceeded towards the crossing point and awaited the engineers.

**ETI Message 24 "Continue" (Table 17):** ETI evaluated the SA received on the mission tasks using "Information" as the data source and a taxonomy measuring the inaccuracy of the information. The UoI value is evaluated to be 2, which indicates low uncertainty, because ETI had information confirming that the crossing point is secured.

**Table 17 ETI Message 24 "Continue"**

| ETI message elements | Message 24 content |
|---|---|
| Timestamp | H+06:22 |
| Recommendation | Continue |
| Combat Power Element | Mission Tasks |
| Data Source | Info |
| Taxonomy | Inaccurate |
| UoI Val (0-10) | 2 |
| UoI Assessment | Low |
| Justification | Crossing Point Secured |

The crossing was established, and units could cross.

In conclusion, we demonstrated that without ETI the uncertainty associated with incoming reports was not considered, leading to inaccurate SA, unnecessary attrition, and jeopardizing the mission. If ETI were available, it could have provided confirmation on data as the mission unfolded.

## 4.2 Normal Scenario

In the "normal" scenario, the BLUFOR objective was the same as the previous scenario. The difference was BLUFOR systems integrated with ETI for this scenario. ETI continuously reasons as the mission unfolds, producing ETI messages for driving decisions and courses of actions.

As ETI accesses data, it determines the UoI value, highlighting the level of uncertainty from various data sources. When the UoI value is medium or high, ETI requests additional information. ETI will use this additional data to infer whether the uncertainty is resolved; if so, ETI lowers the UoI value, after which the units proceed with their respective tasks, and ETI transitions to its next evaluations. The same ETI messages as in the "what-if" scenario appear in this scenario, but the BLUFOR will work to resolve the medium and high uncertainty messages as they appear in this scenario.

**ETI Message 1 "Continue" (Table 18):** A green dot was shown to indicate "Low" UoI. Early in the scenario the scouts earned SA on an OPFOR unit. ETI evaluated the SA received on OPFOR Platoon 3 using the "Information" data source and a taxonomy measuring the corruptness of the information. The UoI value is evaluated to be 0, which indicates low uncertainty of the information source, because ETI has found that there are no errors on the incoming SA.

**Table 18 ETI Message 1 "Continue"**

| ETI message elements | Message 1 content |
|---|---|
| Timestamp | H+02:23 |
| Recommendation | Continue |
| Combat Power Element | SA on OPFOR platoon 3 |
| Data Source | Info |
| Taxonomy | Corrupt |
| UoI Val (0-10) | 0 |
| UoI Assessment | Low |
| Justification | No Errors on Report |

**ETI Message 2 "Request Additional Drone" (Table 19):** A yellow dot was shown to indicate "Medium" UoI. During this time period, the scouts were attempting to earn SA again, this time on another OPFOR unit.

**Table 19 ETI Message 2 "Request Additional Drone"**

| ETI message elements | Message 2 content |
|---|---|
| Timestamp | H+02:35 |
| Recommendation | Request Additional Drone |
| Combat Power Element | SA on OPFOR platoon 1 |
| Data Source | Info |
| Taxonomy | Corrupt |
| UoI Val (0-10) | 5 |
| UoI Assessment | Medium |
| Justification | Sensor Malfunction on Drone |

ETI evaluated the SA received on OPFOR using the "Information" data source and a taxonomy measuring the corruptness of the information. The UoI value is evaluated to be 5, which indicates medium uncertainty of the information source, because ETI received a report indicating a sensor malfunction on the reconnaissance drone they deployed, which, to note, is not depicted in the simulation. As a result, ETI recommended BLUFOR "Request an additional drone" for improved SA. The unit, now integrated with ETI, followed the recommendation, and submitted an Air Support Request for an additional drone.

As part of the demonstration, the data viewer in AURORA displayed an AIRSUPREQ using simulated and other illustrative details, just for supporting this demonstration. Upon obtaining the SA and resolving the uncertainty, ETI lowered the UoI value (and UoI assessment) and the BLUFOR continued the mission.

Next, the scouts were paused awaiting guidance before engaging OPFOR, but there were unexpected injuries among the units.

**ETI Message 4 "Evaluate Readiness Report" (Table 20):** A red dot was shown to indicate 'High" UoI. ETI evaluated information about personnel status (labeled "PAX" in the message) using a taxonomy category describing a data source's questionability. ETI could not confirm the "number of injuries" within the unit and assigns a high UoI value of 9 for which it recommends "evaluating a readiness report" before proceeding. As part of assessing readiness BLUFOR prepares a MEDREP for the commander, which was depicted in the AURORA data viewer, again with illustrative details only for the purposes of this demonstration. Upon evaluating updates, ETI lowered the UoI value.

**Table 20 ETI Message 4 "Evaluate Readiness Report"**

| ETI message elements | Message 4 content |
|---|---|
| Timestamp | H+02:38 |
| Recommendation | Evaluate Readiness Report |
| Combat Power Element | PAX |
| Data Source | Info |
| Taxonomy | Questionable |
| UoI Val (0-10) | 9 |
| UoI Assessment | High |
| Justification | Unconfirmed Number of Injuries |

At the next step in the simulation, BLUFOR B Company was moving to engage with OPFOR Platoon 3.

**ETI Message 6 "Continue" (Table 21):** A green dot was shown to indicate "Low" UoI. ETI evaluated fuel information using a taxonomy category measuring corruptness of the data source. In this case, it evaluated the fuel info with a low UoI value of 0, because ETI could confirm the fuel level for B Company's Light Truck, which holds important supplies, and recommended B Company continue with their engagement.

**Table 21 ETI Message 6 "Continue"**

| ETI message elements | Message 6 content |
|---|---|
| Timestamp | H+03:30 |
| Recommendation | Continue |
| Combat Power Element | Fuel |
| Data Source | Info |
| Taxonomy | Corrupt |
| UoI Val (0-10) | 0 |
| UoI Assessment | Low |
| Justification | Fuel Info for Light Truck Confirmed |

In this timestep, the BLUFOR Mortar Platoon began artillery fire on OPFOR.

**ETI Message 7 "Request Updated Report" (Table 22):** A yellow dot was shown to indicate "Medium" UoI. ETI evaluated the information on incoming SPOTREPs to infer on the BLUFOR Equipment. Using a taxonomy measure for completeness of a data source, ETI produces a medium UoI value of 5 due to conflicting SPOTREPs for a Blue team and recommends the team request an updated report.

**Table 22 ETI Message 7 "Request Updated Report"**

| ETI message elements | Message 7 content |
|---|---|
| Timestamp | H+04:26 |
| Recommendation | Request Updated Report |
| Combat Power Element | Equipment |
| Data Source | Info |
| Taxonomy | Incomplete |
| UoI Val (0-10) | 5 |
| UoI Assessment | Medium |
| Justification | Conflicting SPOTREP for BLUFOR Team A |

As part of the demonstration, the AURORA data viewer displayed a SPOTREP that helped deconflict previous reports, allowing ETI to downgrade the uncertainty and recommend mission continuation.

**ETI Message 9 "Re-Eval Report & Readiness" (Table 23):** A red dot was shown to indicate "High" UoI. Progressing to the next step, B Company was advancing to improve SA on OPFOR Platoon 2.

**Table 23 ETI Message 9 "Re-Eval Report & Readiness"**

| ETI message elements | Message 9 content |
|---|---|
| Timestamp | H+04:31 |
| Recommendation | Re-Eval Report & Readiness |
| Combat Power Element | SA on OPFOR platoon 2 |
| Data Source | Info |
| Taxonomy | Questionable |
| UoI Val (0-10) | 10 |
| UoI Assessment | High |
| Justification | HUMINT Reports Extra Adversary Unit |

Based on the questionability of an incoming HUMINT report, ETI yields a high UoI score of 10, because the HUMINT reported more units than previously thought and recommended Re-Evaluation of the Report and Readiness.

As part of the scenario, the AURORA data viewer displayed INTEL HUMINT Report (INTREP). On the data viewer, an example INTREP reports no extra units, so ETI reduced its evaluated UoI score to 0 and recommended proceeding with the mission.

At this part in the scenario, the engineer company arrived at the crossing point and prepared to begin the Crossing Task.

**ETI Message 11 "Confirm/Update SA; Continue" (Table 24):** A yellow dot was shown to indicate "Medium" UoI. ETI, in this step, evaluated the most up-to-date SA on the full OPFOR, considering all previous SAs. Using a taxonomy measuring completeness of the full SA, it finds that an OPFOR vehicle was missing information and inferred a medium UoI value of 5 while it recommended BLUFOR confirm and update the SA before continuing the mission.

**Table 24 ETI Message 11 "Confirm/Update SA; Continue"**

| ETI message elements | Message 11 content |
|---|---|
| Timestamp | H+05:12 |
| Recommendation | Confirm/Update SA; Continue |
| Combat Power Element | SA on OPFOR |
| Data Source | Info |
| Taxonomy | Incomplete |
| UoI Val (0-10) | 5 |
| UoI Assessment | Medium |
| Justification | OPFOR Light Vehicle Missing from SA Report |

As part of the scenario, the AURORA data viewer displayed a SPOTREP that provided the missing info and resolved the vehicle uncertainty, upon which ETI reduced the uncertainty and recommended proceeding with the crossing task.

After the crossing is established, BLUFOR remained on alert and paused for reinforcements at certain points, but ultimately the simulation ended with successful completion of the Crossing Task and minimal attrition.

# 5. Conclusion

This ETI demonstration was presented at the Future Visualization and Collaboration Deep-Dive hosted by Mission Command Capability Development Integration Directorate (MC CDID) in January 2023. The demonstration and feedback provided us with important lessons learned and was extremely valuable. Furthermore, it provided focus for future work required to deliver impactful decision aids to the Soldier.

## 5.1 Lessons Learned

In the beginning of building this demonstration we decided to record the DXTRS scenario in 15-min snapshots. This decision was made because our process for gathering the snapshots was a manual process. At the time we did not have any automation for using Postman to query DaVinci or to save the query results. Once this data was visualized in AURORA it was apparent that the playback was not smooth enough going forward. As a result, we consulted with the DaVinci developers and were able to obtain a new script to automate the snapshot process. The script also enabled us to configure the delay between snapshots and increase playback quality. The improved snapshot capturing script is provided in Appendix A.3 (Script: Automated Scenario Snapshot Gathering).

We showed several examples of the ETI messages that appeared during the demonstration; however, we are considering possible improvements to its presentation. To reiterate, the current fields we display are Timestamp, Recommendation, Combat Power Element, Data Source, Taxonomy, UoI Value (0–10), UoI Assessment, and Justification, in this order. However, these fields were selected based on information from the simulation and the context we provided for the scenario. As we look to add complexity to our simulations or even think about real-world/in-field applications, these ETI message fields should probably be adjusted. It will be relevant, for example, to include information about the units in question; our simulation only works with a handful of Blue/Red units, but in the real-world there can and will be several more units likely dispersed in space. As we mention, we aim for ETI to infer both on the individual unit/small group actions and intentions, as well as those for the aggregate/holistic battlefield. The current ETI messages may do well for the individual case, but the aggregate case may need something like timeframe (as opposed to a timestamp), a field which aggregates the

data sources, a holistic UoI assessment, and a justification field that summarizes the component ETI inferences. Additionally, depending on ETI's dissemination, it may be helpful to have different ETI message displays for different units/individuals. For example, a scout unit may only need ETI inferences for its immediate targets, whereas the commander may need that same inference along with an overall evaluation of the mission.

## 5.2 Future Work

In the future, we plan to continue our research in several directions. We will continue to collaborate with other government agencies and our academic partners to capture the modalities of the uncertainty of information. Different factors that influence decision making including uncertainty are important concepts in our reasoning framework and generating models for these across multiple heterogenous data sources continues to be a research challenge. It follows that we will also actively seek new data sources to connect to ETI. Finally, in this demonstration our reasoning was based on a decision tree algorithm, but we plan to explore additional decision-making algorithms, expanding the capability of ETI.

## 6. References


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# Appendix A: Script Examples

## A.1 Script: Get Combat Messages from DaVinci Server

```
"use strict";
exports.__esModule = true;
var io = require("socket.io-client");
var mpxsStaticModule_1 = require("./staticModule/mpxsStaticModule");
var PublishedMessage = mpxsStaticModule_1.mpxs.pubsub.PublishedMessage;
var pubsub = mpxsStaticModule_1.mpxs.pubsub;
var axios = require('axios')["default"];
var fs = require("fs");
var counterFriendly = 1;
var counterEnemy = 1;
// Your mechanism for storing the token replaces this
function getTokenForSession() {
    return "12345"; //unique token required
}
// Create the web socket
var options = {
    transports: ['web socket', 'polling']
};
var socket = io('http://localhost:8090', options);
var token = getTokenForSession();
var missionId = "530017411494413890422673430000";
var timeMS = 600000;
var davinciURL = "http://localhost:8090/mpxs/request";
function davinciPost(data) {
    return axios({
        baseURL: davinciURL,
        method: 'put',
        data: data,
        headers: {
            'authorization': 'Bearer ' + token
        }
    });
}
/**
 * Some application specific function implementation to process the published messages
 */
function onPublishedMessage(message) {
    // do something with this message.
    //console.log('Bare message: ' + JSON.stringify(message, null, ' '));
    var instanceMessage = PublishedMessage.fromObject(message);
    //console.log('Instance message: ' + instanceMessage.toJSON());
    switch (instanceMessage.publishedType) {
        case pubsub.PublishedType.PUB_COMBAT_MESSAGE:
            console.log('Combat message: ' + JSON.stringify(instanceMessage.toJSON())+
            '\n' );

            var cm = JSON.stringify(instanceMessage.toJSON());

            fs.appendFileSync('./output/combatMessagesCombined.json', cm);

            /*
            var cmp = JSON.parse(cm);
                //console.log(cmp.combatMessage);

                if(cmp.combatMessage.affilation ===  "AFF_FRIEND"){
                    //console.log("FRIEND");
                    fs.writeFileSync('./output/friendly/combatMessage' + counterFriendly
                    + '.json', 'Combat message: ' +
                    JSON.stringify(instanceMessage.toJSON())+'\n' );
                    counterFriendly++;
                }
                else{
                    //console.log("ENEMY");
                    fs.writeFileSync('./output/enemy/combatMessage' + counterEnemy +
                    '.json', 'Combat message: ' +
                    JSON.stringify(instanceMessage.toJSON())+'\n' );
```

```
                    counterEnemy++;
                }

            //fs.writeFileSync('./output/combatMessage' + counter + '.json', 'Combat
            message: ' + //JSON.stringify(instanceMessage.toJSON())+'\n' );
            //counter++;
            */
    }
}
if (!process.argv[2]) {
    console.log("usage: node davinci.js <missionID> [<timeMS>]\n    <missionId> must be
    a valid mission and wargame Id\n    [<timeMS>] is an optional parameter for runtime
    in miliseconds, defaults to one minute\n");
    process.exit(0);
}
missionId = process.argv[2];
if (process.argv[3]) {
    timeMS = parseInt(process.argv[3]);
}
console.log("Runtime: ".concat(new Date(timeMS).toISOString().substr(11, 8)));
socket.on('connect', function () {
    console.log('initweb socket on connect');
    var response = {
        token: token
    };
    // Send token
    socket.emit('authenticate', response);
}).on('authenticated', function () {
    // Listen for authenticated in response to "authenticate"
    console.log(' websock authenticated');
}).on('unauthorized', function () {
    console.log(' websock unauthorized');
}).on('disconnect', function () {
    console.log(' websock disconnect');
}).on('publishedMessage', function (msg) {
    onPublishedMessage(msg);
}).on('publishedMessages', function (pms) {
    // I don't think publishedMessages benefit from .fromObject() at this level
    for (var _i = 0, _a = pms.publishedMessage; _i < _a.length; _i++) {
        var msg =  a[ i];
        onPublishedMessage(msg);
    }
});
function startWG(missionId) {
    return davinciPost({
        "requestType": "CHANGE_PLANNING_WARGAMING_START",
        "missionContext": { "missionId": missionId, "wargameId": missionId }
    })
        .then(function (response) {
        console.log("Starting Wargame:\n".concat(JSON.stringify(response.data)));
    })["catch"](function (error) {
        console.log(error);
    });
}
function pauseWG(missionId) {
    return davinciPost({
        "requestType": "CHANGE_PLANNING_WARGAMING_PAUSE",
        "missionContext": { "missionId": missionId, "wargameId": missionId }
    })
        .then(function (response) {
        console.log("Pausing Wargame:\n".concat(JSON.stringify(response.data)));
    })["catch"](function (error) {
        console.log(error);
    });
}
function restartWG(missionId) {
```

```
127         return davinciPost({
128             "requestType": "CHANGE_PLANNING_WARGAMING_RESTART",
129             "missionContext": { "missionId": missionId, "wargameId": missionId }
130         })
131             .then(function (response) {
132             console.log("Restarting Wargame:\n".concat(JSON.stringify(response.data)));
133         })["catch"](function (error) {
134             console.log("ERROR: ".concat(error));
135         });
136     }
137     console.log("Running WargameId: ".concat(missionId));
138     startWG(missionId);
139     setTimeout(function () {
140         socket.close();
141         pauseWG(missionId).then(function (result) {
142             console.log("Wargame Paused");
143             return restartWG(missionId);
144         }).then(function (result) {
145             console.log("Wargame Restarted");
146             process.exit(0);
147         });
148     }, timeMS);
149
```

## A.2 Script: Generate Cursor on Target Message

```
import json
import os
import string
from datetime import datetime, timedelta

unitIDsDict = {
"185335294345921389042336217069": 'SCT PLT / 1 - 22 IN',
"313255294333921389042336217078": 'MORTAR PLT / 1 - 22 IN',
"110425294393761389042365217055": '50 ENG CO (MRBC)',
"278345294334401389042336217000": 'A CO / 1 - 22 IN',
"302095294346881389042336217015": 'B CO / 1 - 22 IN',
"145665294340321389042336217039": 'C CO / 1 - 22 IN',
"183115294336641389042336217054": 'D CO / 1 - 22 IN',
"268215294509601389042430220007": '1 1 CO (TRK) / 1 BN / 241 INF BDE (TM)',
"116735294501441389042430220002": '2 1 CO (TRK) / 1 BN / 241 INF BDE (TM)',
"506752945092813890424302200005" : '3 1 CO (TRK) / 1 BN / 241 INF BDE (TM)'
}

def milstd252_to_cot(milstd2525_str):

    event = "a"
    affiliation = milstd2525 str[1].lower()
    battle_dimension = milstd2525_str[2]
    function_id = milstd2525_str[4:10].replace("-","").strip()
    cot_str = event + affiliation + battle_dimension + function_id
    cot_str = "-".join(cot_str)

    return cot str

def get_combat_message(cmdata, unitId, offset):
    cm_msg=""
    for x in cm_data['message']:
        if x['combatMessage']['affilation'] == "AFF_FRIEND" and x['combatMessage'][
        'timeOffset'] >= offset and x['combatMessage']['timeOffset'] < (offset + 900):

            if ('agent' in x['combatMessage'] and unitId == x['combatMessage']['agent'][0
            ]['unitId']['davinciId']):
                cm_msg_agent = unitIDsDict[x['combatMessage']['agent'][0]['unitId'][
                'davinciId']]
                cm msg body = x['combatMessage']['body']
                cm_msg = cm_msg_agent + " " + cm_msg_body

                if ('target' in x['combatMessage']):
                    if('unitId' in x['combatMessage']['target'][0]):
                        cm_msg_target = unitIDsDict[x['combatMessage']['target'][0][
                        'unitId']['davinciId']]
                        cm_msg = cm_msg + " " + cm_msg_target
                cm_msg = cm_msg + ". "
    return(cm_msg)


def get datetime(h zero, h offset):
    delta_minutes = h_offset/60
    dateTimeFormat = '%Y-%m-%dT%H:%M:%S.%f'

    h_time = ((h_zero + timedelta(minutes=delta_minutes)).strftime(dateTimeFormat))[:-4]
    + 'Z'
    return h time

if __name__ == '__main__':

    now = datetime.today()

    with open(os.getcwd() + "\\cm\\cm.json", 'r') as cm file:
        cm_data = json.load(cm_file)

```

```
61      for filename in os.listdir(os.getcwd()):
62          f = os.path.join(os.getcwd(),filename)
63          if os.path.isfile(f) and filename.rsplit( ".", 1 )[ 1 ] == 'json':
64              dirname = filename.rsplit( ".", 1 )[ 0 ]
65              if not os.path.exists(os.getcwd() + "//" + dirname):
66                  os.mkdir(dirname)
67
68              with open(f, 'r') as dxtrs_file:
69                  dxtrs_data = json.load(dxtrs_file)
70              coa = dxtrs data['wargame']['coa']
71
72              for c in coa:
73                  units = c['taskOrg'][0]['unit'][0]['subordinate']
74                  for x in units:
75                      if 'latitude' in x['unitState']['location'] and 'longitude' in x[
                        'unitState']['location'] :
76                                  cot_msg = "<?xml version='1.0' encoding='UTF-8'
                                    standalone='yes'?>"
77                                  cot_msg = cot_msg + "<event version='2.0' "
78                                  cot_msg = cot_msg + "uid='" + x['unitState']['unitId'][
                                    'davinciId'] + "' "
79                                  cot msg = cot msg + "time='" + get datetime(now, int(x[
                                    'unitState']['planTimeOffset'])) + "' "
80                                  cot_msg = cot_msg + "start='" + get_datetime(now, int(x[
                                    'unitState']['planTimeOffset'])) + "' "
81                                  cot_msg = cot_msg + "stale='" + get_datetime(now, int(x[
                                    'unitState']['planTimeOffset']) + 900 ) + "' "
82                                  cot type = milstd252 to cot(x['gsdIdentifier'])
83                                  cot_msg = cot_msg + "type='" + cot_type + "' "
84                                  cot_msg = cot_msg + "how='m-s'"
85                                  cot_msg = cot_msg + ">"
86                                  cot_msg = cot_msg + "<point lat='" + str(x['unitState'][
                                    'location']['latitude']) + "' "
87                                  cot msg = cot msg + "lon='" + str(x['unitState'][
                                    'location']['longitude']) + "' "
88                                  cot_msg = cot_msg + "le='0' "
89                                  cot_msg = cot_msg + "hae='0' "
90                                  cot_msg = cot_msg + "ce='0'"
91                                  cot_msg = cot_msg + "/>"
92                                  cot msg = cot msg + "<detail>"
93                                  cot_msg = cot_msg + "<dxtrs>"
94                                  cot_msg = cot_msg + "<combat_strength>"
95                                  if 'strength' in x['unitState']:
96                                      cot_msg = cot_msg + str(x['unitState']['strength'])
97                                  else:
98                                      cot msg = cot msg + "0"
99                                  cot_msg = cot_msg + "</combat_strength>"
100                                 cot_msg = cot_msg + "<combat_message>"
101                                 cot_msg = cot_msg + get_combat_message(cm_data, x[
                                    'unitState']['unitId']['davinciId'], x['unitState'][
                                    'planTimeOffset'])
102                                 cot msg = cot msg + "</combat message>"
103                                 cot_msg = cot_msg + "</dxtrs>"
104                                 cot_msg = cot_msg + "</detail>"
105                                 cot_msg = cot_msg + "</event>"
106
107                                 if 'planTimeOffset' in x['unitState']:
108                                     output = x['shortName'].translate(str.maketrans('',
                                        '', string.punctuation)) +  "_" + str(x['unitState'][
                                        'planTimeOffset']) +".xml"
109                                 else:
110                                     output = x['shortName'].translate(str.maketrans('',
                                        '', string.punctuation)) +  "_0.xml"
111                                 xml = open(os.getcwd() + "//" + dirname + "//" + output,
                                    "w")
112                                 xml.write(cot_msg)
113                                  xml.close()
114
```

## A.3 Script: Automated Scenario Snapshot Gathering

```
var axios = require('axios');
var fs = require('fs')
var path = require('path')

let totalHours = 12 //Total number of Hours in the Wargame
let timeIncMin = 15 //Pull WG every X minutes
let missionId = "530017411494413890422673430000"
let wargameId = "530017411494413890422673430000"

let totalLoops = ((60/timeIncMin) * totalHours ) +1 //Total number of loops
let timeIncSec = 60 * timeIncMin //Time increment in seconds

var data = {"missionContext":{"missionId":missionId, "wargameId":wargameId},"requestType"
:"GET_WARGAME_AT_TIME",    "dataType":"COMMON_FILTER","commonFilter":{"planTimeOffset":0
}};

var config = {
  method: 'put',
  url: 'http://localhost:8090/mpxs/request',
  headers: {
    'Content-Type': 'application/json',
    'Authorization': 'Bearer 12345' //unique token required
  },
  data : data
};

i=0

function loop(){
    setTimeout(()=>{
        if( i < totalLoops){
            callDavinci(i)
            i+=1
            loop()
        }
    }, 2000)
}

async function callDavinci(j){
    // Setting to 0 seems to yeild the runtime, if 0 set to 1  to avoid this
    if(j != 0)
        data.commonFilter.planTimeOffset = (j * timeIncSec)
    else
        data.commonFilter.planTimeOffset = 1
    config.data = JSON.stringify(data)
    let res = await axios(config)
    //let time = convertToDHMS(j * timeIncSec).replaceAll(':','-')
    //let time = convertToDHMS(j * timeIncSec).replace(/:/g, "-")
    let time = (j * timeIncSec)
    fs.writeFile(path.join(__dirname,'Responses',`Wargame_${time}.json`), JSON.stringify(
    res.data), ()=> {
        console.log(`Wargame ${time}.json`)
    })
}
function convertToDHMS(seconds){
    let days = Math.floor(seconds/(3600*24))
    return days+':'+new Date((seconds)*1000).toISOString().substr(11, 8)
  }

loop()

```

## List of Symbols, Abbreviations, and Acronyms

| | |
|---|---|
| AIRSUPREQ | Air Support Request |
| API | application programming interface |
| ARL | Army Research Laboratory |
| AURORA | Accelerated User Reasoning for Operations, Research and Analysis |
| BLUFOR | Blue Force |
| CoA | course of action |
| CoT | Cursor on Target |
| DEVCOM | US Army Combat Capabilities Development Command |
| DP | decision point |
| DXTRS | Division Exercise Training and Review System |
| ETI | Enhanced Tactical Inferencing |
| HUMINT | Human Intelligence |
| INTREP | Intelligence Report |
| JSON | JavaScript Object Notation |
| MC CDID | Mission Command Capability Development Integration Directorate |
| MEDREP | Medical Report |
| OPFOR | Opposing Force |
| RCP | relative combat power |
| SA | situational awareness |
| SPOTREP | Spot Report |
| UoI | Uncertainty of Information |
| XML | eXtensible Markup Language |
| XR | cross-reality |
| XRCOP | Cross Reality Common Operating Picture |

| | |
|---|---|
| 1 (PDF) | DEFENSE TECHNICAL INFORMATION CTR DTIC OCA |
| 1 (PDF) | DEVCOM ARL FCDD RLB CI TECH LIB |
| 6 (PDF) | DEVCOM ARL FCDD RLA IC J RICHARDSON M MITTRICK J RAWAL P KUMAR A RAGLIN R HOBBS |