Discerning the Role Context Plays in the Value of Information
A Key to Designing Effective Human-Agent Teaming

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Abstract

For the military, effective human-agent teaming requires a shared understanding between the human and the intelligent agents acting on their behalf. One of the central challenges associated with developing this shared understanding originates at the information level. The simple fact is while all information may be created equal, the value of information is not. Confounding this calculation is the knowledge that the true value of information is dependent not only on its source, content and latency, but just as importantly on the context of the situation in which it is being exercised. Building upon previous research aimed at codifying the value of information, this paper presents a multi-facetted experiment meant to discern a Soldier's value of information within varying military contexts. Initial results reveal that context plays a significant role in how information is valued and more importantly provides a foundation for strengthening human-agent information understanding and collaboration.

1. Introduction

Modern military operations are framed by a myriad of information sources that provide an unprecedented volume, velocity, and variety of information not found in most other domains. While on the surface it would seem that the more information the better, the fact is having too much information increases cognitive work load and potentially results in overlooking information that is relevant to the current situation [1, 2]. Required is a process for foraging and transforming large amounts of heterogeneous data from multiple sources into useful situational understanding, that in turn would accelerate and improve the decision making process [3]. A key feature of such a process would be a method for judging the importance of pieces of information. The Value of Information (VoI) metric is such a feature [4, 5].

The task of determining which information is valuable is a difficult process. To assist in combating this challenge, the U.S. Army Research Laboratory (ARL) has established Human-Agent Teaming (HAT) as one of its essential research areas (ERA). The HAT ERA is focused on leveraging the strengths of both the human and intelligent agents to improve overall operational performance [6]. Thus, teams of humans and intelligent agents are performing military-relevant tasks more efficiently and effectively than either group does alone. One of the goals of this initiative, and the subject of this research, is *context-based information sharing to efficiently provide the information each Soldier/Agent needs;* sharing concepts, intentions, and situations while not overburdening the systems.

With that goal in mind, this paper presents the initial steps to understanding context-based information sharing with an experiment designed to discern the role context plays in the value of information. The experiment builds upon previous research that successfully captured and codified how analysts perceive the value of information (VoI) given its source, content, and latency [7, 8, 9]. The remainder of the paper is organized into the following 4 sections. Section 2 presents background on the military challenge, VoI determination, and the state of the current prototype. In Section 3, the VoI Context Study is presented followed by a look at some early results and analysis in Section 4. Concluding remarks and future directions are given in Section 5.

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2. Background

2.1. Understanding the Domain Challenge

Commander's intent is a salient characteristic in the military decision making process and dependent on developing accurate situational awareness and understanding [10]. Situational Awareness (SA) is formally defined as a person's "perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" [11]. While having good SA generally indicates knowledge of "what" is occurring, having good situational understanding (SU) leads us to recognize the "why" and potential consequences in the decision space. Relevant information is the key to developing the SU and ultimately making the correct decision.

Today's military operations utilize information from a myriad of sources that provide overwhelming amounts of data. Shown in Table 1 are the range of reports received at each military echelon and the timescale to plan and execute a mission. While the times are notional, the general policy for military planning is that one-third of the available time be used for planning at any echelon, leaving two-thirds of the time for planning at lower echelons. The execution times represent the notational time durations needed to carry out a typical mission at that echelon [12]. Needless to say, accurate and timely VoI estimations are essential to the information analysis process and integral to battlefield success. Long-term, human-agent teaming is envisioned as critical to supporting this process with intelligent information foraging and transformation agents capable of acting in concert with the *context* of the current operation and overall mission goal.

Table 1. Typical Range of Information and Executing Times [12]

Echelon	Reports per hour	Planning Time	Execution Time
Division	~Millions	Week	Week/ Days
Brigade	170K	Days	Days
Battalion	56K	Days /hours	Day
Company	18K	Hours	Hours
Platoon	6K	Hour	Hour/Min

2.2. Value of Information Determination

Assigning a VoI assessment to an information element is a multiple step process requiring intelligence collectors and analysts to judge the information's value within a host of differing operational situations. For the military, this process is abstractly defined within two documents: the annex to NATO STANAG (Standard Agreement) 2022 along with Appendix B of US Army FM-2-22.3 [13, 14]. This guidance provides two tables for judging the "reliability" and "content" of a piece of data, with each characteristic broken into six categories. Reliability relates to the information source, and is ranked from A to F (reliable, usually reliable, fairly reliable, not usually reliable, unreliable, and cannot judge). Information content is ranked from 1 to 6 (confirmed, probably true, possibly true, doubtfully true, improbable, and cannot judge). While doctrinal guidance does exist for grading an information element, it does not provide any process for combining these determinations into a VoI metric. Additionally, combining only these two assessments of a piece of information falls far short of representing all of the critical aspects that determine 'relevant' information.

Two other important data characteristics include latency and mission context. Latency refers to how long ago the piece of information was collected. In general, the latest time of value for a piece of information is determined by the echelon of operation. At the Company and Platoon levels for example, information perishability is within hours. As a surrogate for *mission context*, the original VoI research substituted *operations tempo* in its place. Here, operations tempo relates to the decision cycle for the mission; that is, the time that can or will be used to plan, prepare, and execute the mission. Operations tempo is generally divided into three levels: strategic, operational and tactical. On the operations tempo spectrum, strategic operations generally have decision cycles measured in months or longer. Tactical operations, on the other hand, measure their decision cycle in minutes to hours, with operational level lying somewhere between.

2.3. Current VoI Prototype

Working with analysts from the U.S. Army Intelligence Center of Excellence (USAICoE), a fuzzy-based approach was adopted for developing a prototype decision support system that assists with VoI determination. Specifically, a Fuzzy Associative Memory (FAM) model was utilized to construct the original VoI System. A FAM is a k-dimensional table where each dimension corresponds to one of the input domains of the rules. Fuzzy if-then rules are represented within the FAM [15, 16 17]. While numerous characteristics could be applicable to determining the VoI, the features of source reliability

(SR), information content (IC), timeliness, and operations tempo were used as the starting point to construct the original Single-Source VoI System. The architecture of the original Single-Source VoI System is shown in Figure 2.

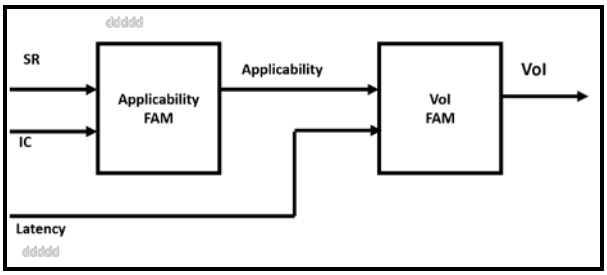

Figure 1: Single-Source VoI FAM Overview

The output from the system is determined by the standard fuzzy centroid defuzzification strategy. More detailed descriptions of the FAMs and the series of surveys and interviews with subject matter experts (SMEs) that were used to codify the cognitive requirements, collect the functional requirements, and elicit the fuzzy rules of the single-source prototype system can be found in [7, 18]. The current multi-source information amalgamation prototype is capable of determining the VoI for a combination of information elements that either complement or contradict an original element of information [19]. Limiting the current fuzzy model is the use of the *operations tempo* (strategic, operational, and tactical) as a surrogate for *mission context*. To be effective, an understanding of how *mission context* influences the VoI in a military environment must be undertaken.

3. VoI Context Study

Studying and ultimately modeling the role *context* plays in the valuation of information in a military environment is a daunting task. In addition to developing scenarios with the fidelity required to adequately define a military context, obtaining access to the number of Soldiers required to run a study is a near impossible task.

With the assistance of the U.S. Army Research Institute's Umbrella Weeks (UWs) program the challenge of Soldier access was solved. UWs are Department of Army sponsored events that mandate organizations across the Army grant an annual one-week access period to Army research agencies for the purpose of studies involving Soldiers and facilities.

For the VoI Context Study (VCS) three UWs were identified during fiscal year 2018: Fort Lewis during May 2018, Fort Bragg and Fort Riley during July 2018. During the first VCS at Fort Lewis, ARL was afforded access to 77 Soldiers from the 7th Infantry Division and the 393rd Expeditionary Support Command. The Soldiers participating in this first study varied in age from 18 to 45 years old, in experience from 8 months to over 10 years and covered over 15 different occupational specialties. The 3-day study was divided into (15) 30-minute sessions, 5 sessions per day. Each session allowed 5-7 Soldiers to participate at a time.

Each session began by defining the *macro context* of the given military scenario. This critical piece of the study was accomplished by showing and explaining the information on Figure 3. At a high-level, the Soldiers were told they were to assume they were assigned to a unit deployed to an area of operations (AO) in southern Iraq on a stability operation and one of their primary tasks was to analyze information and make judgments as to its value to the operation. The operation was further refined by defining five Priority Information Requirements (PIRs). PIRs are information that the commander has deemed vital to his/her on-going decision making process. Placing the Soldiers within a defined geographical AO and giving them definite mission objectives frames their area of interest (AI). Combined with their particular occupational training and experience, the AI, at a high-level of abstraction, defines a Soldier's *military context*.

With the macro context defined, the Soldiers were then guided through a series of vignettes that defined the *micro context* of the military situation. The vignettes served as the primary independent variable permitting manipulation of the relevancy of the information introduced to the Soldiers that was to be scored. Shown in Figure 4, the vignettes are divided into three categories: High, Medium and Low. Relevant-High vignettes contain information that *is* regarded as highly mission relevant and containing PIR information. Relevant-Medium vignettes contain information that *might be* considered mission relevant and may or may not contain PIR information. The Relevant-Low vignette contains information that *is not* considered mission relevant. Importantly, the vignettes included in the study were vetted by an Army SME before the study began.

While micro context served as the primary independent variable of the study, the second independent variable added to each vignette was the source reliability (SR) rating of the information given. The SR is an evaluation as to the trustworthiness of the information. This second variable was used to determine the degree to which SR had on the valuing a given context. For example, even though a given vignette could be rated highly mission relevant, the fact is was associated with an *unreliable source* could potentially diminish its perceived value. Depicted in Table 2 is the official military SR rating table. For the

study, the following four SR categories were examined: (1) fairly reliable, (2) unknown, (3) usually reliable or (4) unreliable. This variable was held constant during each participant's trial.

The SR rating along with a collection of vignettes defined an experimental Vignette Group (VG):

- **Vignette Group #1** (VG-1): contained vignettes A, B, C and D with an information source deemed *fairly reliable*.
- **Vignette Group #2** (VG-2): contained vignettes A, B, C and E with an information source deemed *unknown*.
- **Vignette Group #3** (VG-3): contained vignettes A, B, C and D with an information source deemed *usually reliable*.
- **Vignette Group #4** (VG-4): contained vignettes A, B, C and E with an information source deemed *unreliable*.

Note: Each Vignette Group contained a Relevant High A-vignette, Relevant Medium B-vignette, Relevant Low C-vignette, along with a fourth vignette of either Relevant High D-vignette or Relevant Medium E-vignette.

Table 2: Source Reliability Table

A	Reliable	**No doubt** of authenticity, trustworthiness, or competency; has a history of complete reliability
B	Usually Reliable	**Minor doubt** about authenticity, trustworthiness, or competency; has a history of valid information most of the time
C	Fairly Reliable	**Doubt** of authenticity, trustworthiness, or competency but has provided valid information in the past
D	Not Usually Reliable	**Significant doubt** about authenticity, trustworthiness, or competency but has provided valid information in the past
E	Unreliable	**Lacking** in authenticity, trustworthiness, and competency; history of invalid information
F	Unknown	**No basis** exists for evaluating the reliability of the source

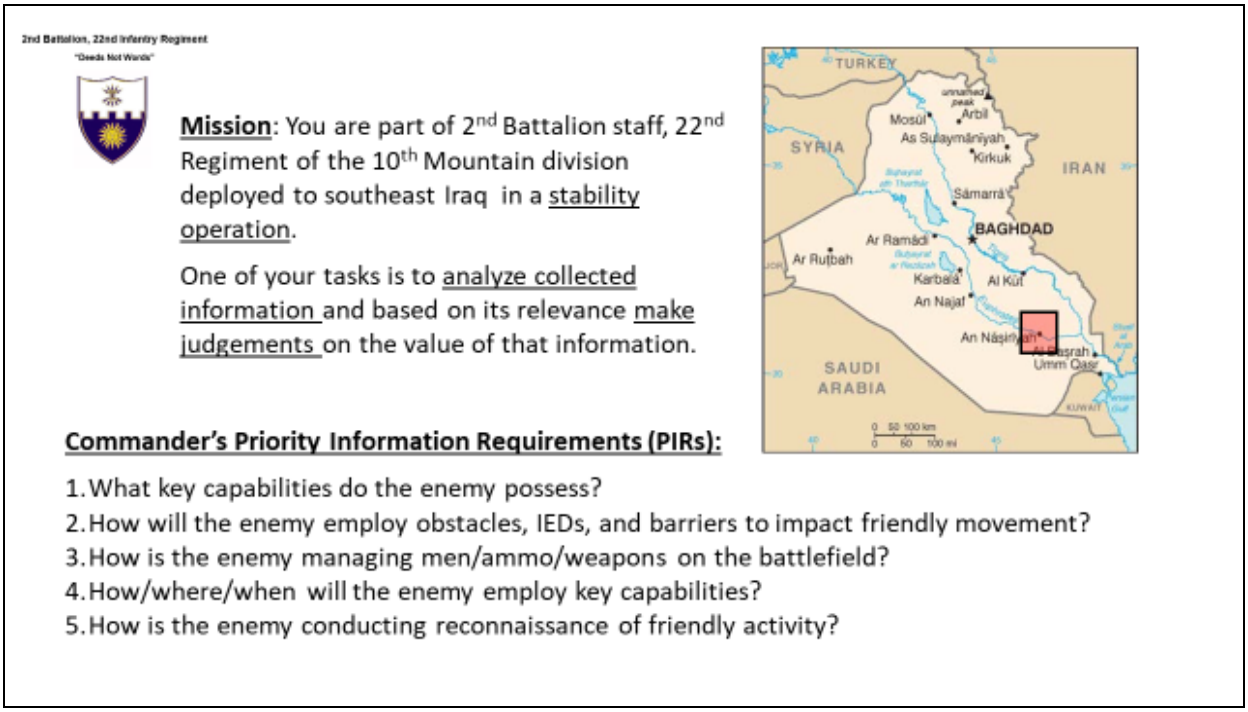

Figure 2: Military Operation - Macro Context Overview

Relevant High	Relevant Medium	Relevant Low
IED Vignette (A) Background: 'MSR CHEVY' has not had an IED event in over 6 months and was pronounced clear by a route reconnaissance mission this AM Report: A Tactical Interrogation Report from a **fairly reliable source** dated last night mentions an expected IED emplacement on MSR CHEVY.	**CSS Protest Vignette (B)** Background: Deep divides between local Shia and Sunni Muslims have existed for centuries. Areas where these factions are in close proximity can cause protests and violence. Report: Reports from a **fairly reliable source** indicate that Sunni protests against Shia merchants in the downtown market area are planned and threaten to disrupt normal patterns of life	**Outside AO Vignette (C)** Background: The boarder situation along Syria and Turkey has always been an area of contention between Turkey and the Syrian Kurds. Tension between militia groups could lead to all out conflict. Report: COMINT from a **fairly reliable radio** station reports increased cross border engagements between Syrian Kurds and the Turkish military.
ADA Vignette (D) Background: HQ is planning an air insertion into a remote village to search for weapons caches. Air traffic at the FOB is heavy with no significant threat incident in the last 3 months. Report: A **fairly reliable** HUMINT source indicates that threat forces are planning attacks on US air assets	**Sentiment Vignette (E)** Background: The populace within the AO has been generally neutral toward US presence. Friendly attacks on threats have recently resulted in collateral damage. Report: A **fairly reliable informant** reports that a local Imam is voicing anti-US sentiment and antagonistic views.	

Figure 3. Military Vignettes - Micro Context

With the macro and micro context defined, Soldiers were first guided through a practice vignette to acquaint them with the scoring process and allowed to ask any questions. After that they were guided through a randomized series of vignettes associated with one of the predefined Vignette Groups.

Shown in Figure 5 is the Context Survey Form used in the VoI Context Study. The survey consists of 3 measures: Mission Relevancy, PIR existence, and the Information Value Scale. The first two measures (Mission Relevancy and PIR Existence) served as robustness checks and to validate the *micro context* manipulations; ostensibly verifying the context agreement. The Mission Relevance Scores will later be used as a surrogate dependent variable and correlated against the value scores. The third measure, the value scale, measured the Soldier's perceived value of the information given the *context* of the macro and micro environment. To keep it in a military vernacular, the anchors on the value scale were chosen to represent typical military response to new information.

During each vignette, after the background statement was read, Soldiers were asked to mark, in no particular order, how mission relevant the new piece of information was, whether it addressed any of the PIRs, and how valuable they perceived the information to be. Each Soldier scored the four vignettes associated with his/her VG.

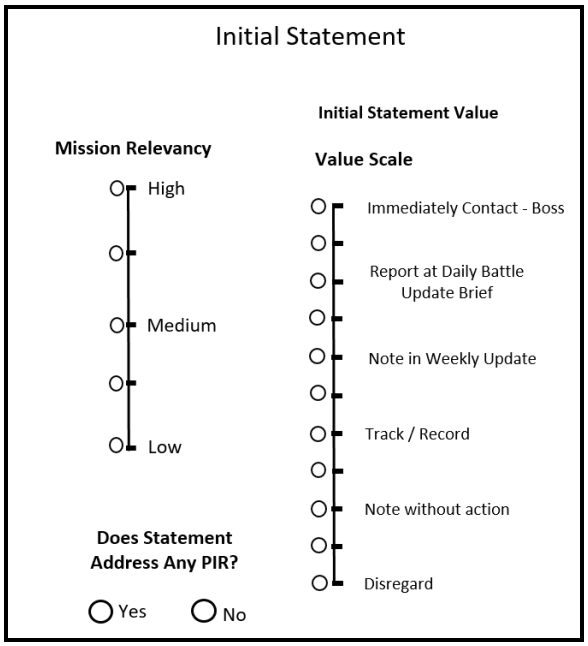

Figure 4: Context Survey Form

4. Results and Analysis

Analysis of the results reveals that context and source reliability play a significant role in how information is valued depending on its perceived relevance to the current operation. More importantly, the results provide an early understanding as to why information is valued differently. To facilitate the analysis presentation, each Vignette Group (the collection of vignettes associated with its information source rating) will be examined separately. For completeness, a covariance analysis for each VG and each vignette type is included.

4.1. Vignette Group #1 Results and Analysis - *Fairly Reliable Source*

Included in VG-1 are vignettes A, B, C and D. The SR associated with VG-1 is *fairly reliable*. This rating was held constant for all the vignettes in this vignette group.

As depicted in Table 3 and Figure 6, analysis of VG-1 shows dramatic and distinct differences across the primary vignettes (A, B & C). The Value of Vignette A (Relevant-High) that dealt with the possible appearance of an improvised explosive device scored an average of 8.33 – meaning it fell just short of *Report at the Daily Brief* on our Likert Scale rating, where the value of Vignette C (Relevant-Low) that had to do with a skirmish along the Syrian border (not in area of operation) scored 4.8 – meaning it was in the *Note without action* range. In this instance, given information with the same source reliability, the 4 point difference on the Likert Scale is significant and shows context played a major role in valuing the new information.

The PIR score of 1 for Vignette A indicates every participant identified this information as meeting a commander's priority information requirement. Notably, the measures between Vignettes A and D (both Relevant High) scored almost identical across the board. The PIR for Vignette B and C were significantly lower along with the Mission Relevancy scores.

To test that the VoI scores were from different population distributions, a Kolmogorov-Smirnoff 2-Sample test was run across all the VoI scores. Figure 7 shows that with a D score of .62 and a P value of .000004, the scores associated with Vignette A and C are definitely not from the same distribution. And as expected in Figure 8, we see that with a D score of .23 and P value of .53, Vignette A and D (both Relevant High) share the same distribution characteristics.

Table 3. VG-1 Average Scores

Vignette	Mission Relevancy	VoI Score	PIR Score
A (R-High)	4.28	8.33	1
B (R-Med)	3.11	6.14	.38
C (R-Low)	2.47	4.8	.23
D (R-High)	4.42	8	.95

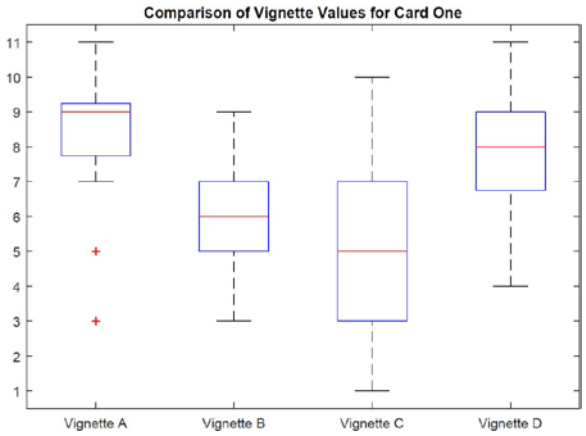

Figure 5. Box Plot VoI Results of VG-1

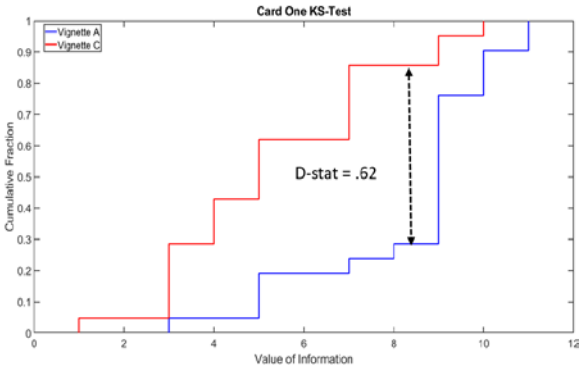

Figure 6. KS comparison of VG-1 (A vs C)

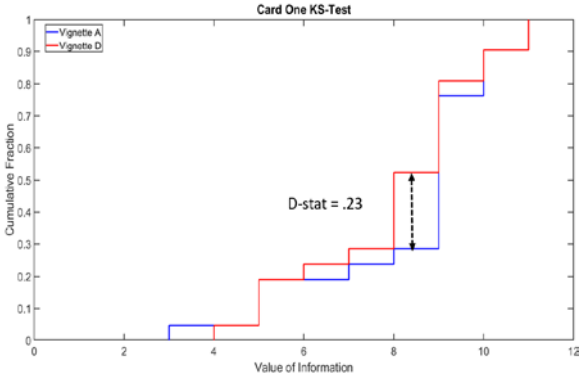

Figure 7. KS comparison of VG-1 (A vs D)

4.2. Vignette Group #2 Results and Analysis - *Unknown Source*

Associated with the VG-2 are vignettes A, B, C and E. The SR assigned to VG-2 is that of *unknown*. Meaning, 'no basis' exists for evaluating the reliability of the source. This rating was held constant for all the vignettes in this vignette group.

Interestingly, analysis of VG-2 *does not* show a dramatic or distinct difference across the vignettes. In point of fact, analysis of Table 3 and Figure 9 reveals Vignettes B, C and E share similar VoI scores. Where we do see a difference is between Vignettes A (Relevant High) and the rest of the vignettes. The Kolmogorov-Smirnoff 2-Sample test between Vignette A and the other VG-2 vignettes confirms this belief with an average P score of .007 and a D score of .56. For completeness, Figure 10 shows the KS plot for Vignette A versus C; with B and E being similar.

Table 3. VG-2 Average Scores

Vignette	Mission Relevancy	VoI Score	PIR Score
A (R-High)	4.43	8.00	1
B (R-Med)	3.38	5.3	.62
C (R-Low)	2.56	4.9	.37
E (R-Med)	3.00	5	.56

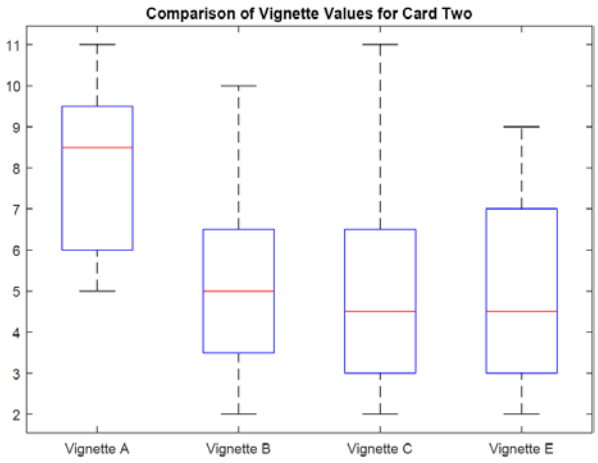

Figure 8. Box Plot VoI Results of VG-2

The question then is: with everything being equal except for the information source – why does VG-2 differ radically from VG-1? Army SMEs explained the possible difference this way: If you received a phone call from an unknown source telling you there was a bomb in the building, you have to react as if it is true; the consequence is potentially very high. On the other hand, if an unknown source tells you a local cleric is happy with US presence in the area – you might more easily dismiss it. In this case, the consequence of not reacting immediately is far less.

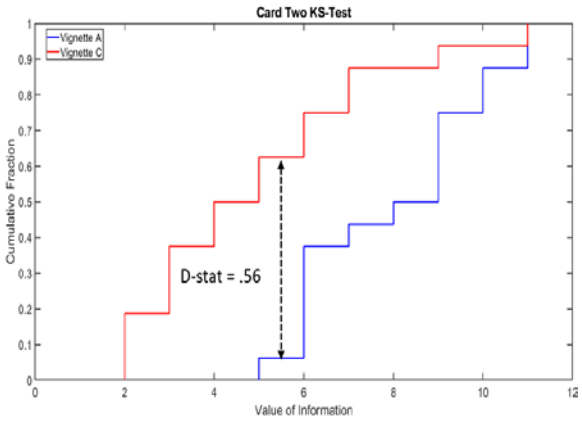

Figure 9. KS comparison of VG-2 (A vs C)

4.3. Vignette Group #3 Results and Analysis - *Usually Reliable Source*

Included in VG-3 are vignettes A, B, C and D. Similar to VG-1, the only difference between the two vignette groupings is the SR rating. Rather than a *fairly reliable* SR rating, VG-3 utilizes a higher rated *usually reliable* source rating. This SR rating was held constant for all the vignettes in this vignette group.

Not unexpectedly, the results of VG-3 follow a similar pattern as VG-1. As depicted in Table 4 and Figure 11, analysis of VG-3 shows dramatic and distinct differences across the primary vignettes (A, B & C). Interestingly, the average VoI score associated with Vignette A is actually a little higher (9.27 vs 8.33) in VG-3 than that found in VG-1. SME analysis attributed this higher scoring to the source reliability being higher; the higher the reliability the higher the trust. In that same vein, all the VoI Scores in VG-3 were higher than the other vignette groups; ostensibly because of the higher information source rating.

To test that the distributions were from different populations, a Kolmogorov-Smirnoff 2-Sample test was run across all the VoI scores. Figures 12 and 13 respectively, reveal vignette A and C are not from the same distribution with a D score of .67 and an associated P-value of .0009; and vignettes A and D share the same distribution characteristics with a D score of .27 and an associate P value of .52.

Table 4. VG-3 Average Scores

Vignette	Mission Relevancy	VoI Score	PIR Score
A (R-High)	4.7	9.27	.95
B (R-Med)	3.7	7.33	.38
C (R-Low)	2.44	5.33	.23
D (R-High)	4.37	8.61	.83

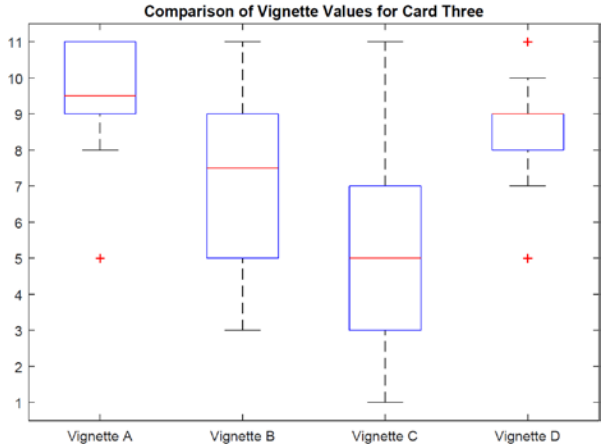

Figure 10. Box Plot VoI Results of VG-3

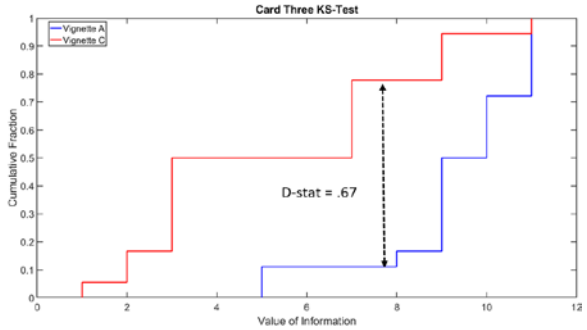

Figure 11. KS comparison of VG-3 (A vs C)

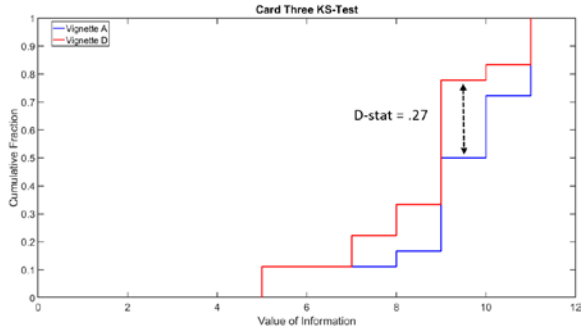

Figure 12. KS comparison of VG-3 (A vs D)

4.4. Vignette Group #4 Results and Analysis - *Unreliable Source*

Associated with VG-4 are vignettes A, B, C and E. VG-4 has a SR rating that is *unreliable*; the lowest possible information source rating. This source rating was held constant for all the vignettes in this vignette group.

Similar to VG-2, VG-4 reveals an interesting trend. Analysis of Table 5 and Figure 14 reveal there is virtually little difference in the mission relevance and VoI scores. The only difference between the vignettes is the PIR rating with vignette A.

Kolmogorov-Smirnoff 2-Sample tests run across the entire set of VoI scores revealed none of the distributions were from different populations. In the best case, shown in Figure 15, the difference between the Relevant-High Vignette-A and Relevant-Low Vignette-C, was scored a D statistic of .26 a P value of .47.

Army SME analysts attribute the consistently low scores associated with this vignette group to the unreliable information source. One SME used the crying wolf analogy to describe the results …. *once someone has proven to fabricate the truth it is nearly impossible to move beyond that point.*

Table 5. VG-4 Average Scores

Vignette	Mission Relevancy	VoI Score	PIR Score
A (R-High)	4.15	5.8	1
B (R-Med)	3	4.78	.42
C (R-Low)	2.8	4.78	.42
E (R-Med)	3.15	4.42	.42

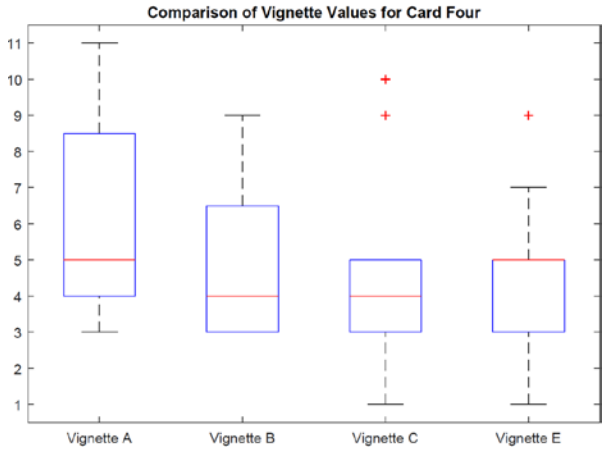

Figure 13. Box Plot VoI Results of VG-4

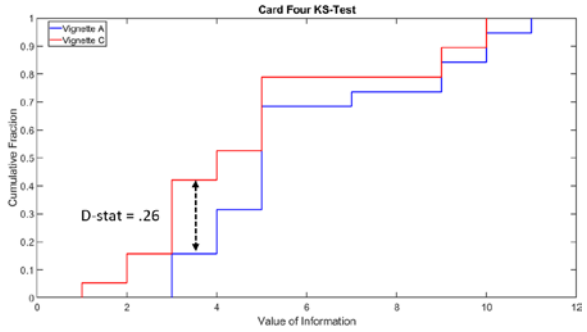

Figure 14. KS comparison of VG-4 (A vs C)

4.5. Correlation Analysis of VGs and Vignette

With a goal of being able to model and test the results of the study, one of the other outcomes of interest was whether monotonicity existed between the dependent (micro context) variable and the independent (perceived information value) variable. The general hypothesis was that the greater the relevance to the "mission", the higher the perceived value of the information should be; and further, the higher the SR rating of the information, the greater the magnitude associated with that valuation. To test for correlation, a Spearman's rank-order correlation statistic was calculated between the surrogate dependent variable *Mission Relevance Score* and the *Information valuation score*. Shown in Tables 6 and 7 are the correlation coefficients associated with aggregated scores for each vignette group and the individual vignettes, respectively. In each case a positive correlation exists between mission relevance and the information valuation.

Table 6: Vignette Group Correlation Scores

Vignette Group	Spearman Rank Correlation Coef.
VG-1	.66
VG-2	.76
VG-3	.78
VG-4	.59

Table 7: Vignette Type Correlation Scores

Vignette Type	Spearman Rank Correlation Coef.
A (R-High)	.59
B (R-Med)	.57
C (R-Low)	.79
D (R-High)	.53
E (R-Med)	.61

Evidence of the monotonic relationship between Mission Relevance vs Information Valuation can be seen in Figure 16 (a), (b) and (c); illustrated are the scatter plots associated with Vignettes A, B, and C. For each scenario a positive correlation can be seen.

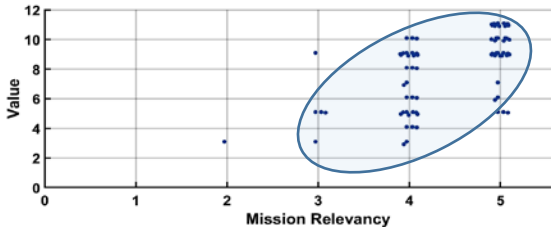

Figure 16(a) Vignette A - Scatterplot

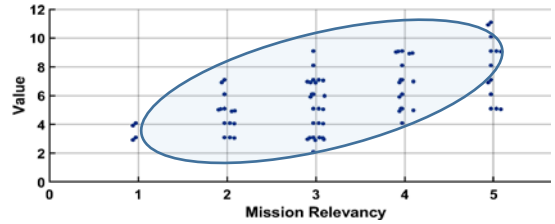

Figure 16(b) Vignette B - Scatterplot

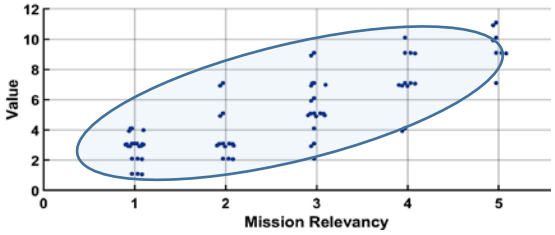

Figure 16(c) Vignette C - Scatterplot

5. Conclusion / Future Direction

Development of effective human-agent teaming requires a shared understanding between the human and the intelligent agents acting on their behalf, especially at the information level. With a goal of providing effective, context-based information sharing, this paper presents the initial steps necessary to discern the role context plays in the value of information and lays the foundation for modeling information valuation in a military environment.

Analysis of the results revealed that *context* plays a statistically significant role in *how* information is valued depending on its perceived relevance to the current operation. For this study, the mechanics of *how* proved to be fairly intuitive – the greater the mission relevance, the greater the perceived information value. However, digging a little deeper, the results also unveiled some less obvious trends and give an early

understanding as to "*why*". For example, in the cases where the source of the information was *unknown* (VG2), only in the relevant-high vignette (where the *projection of the consequence* was life threatening) did the value of the information correlate. Likewise, when the source of the information was rated *usually unreliable*, even though the mission relevance was rated high, the information valuation did not follow the general trend and actually treated it the same for all four vignettes. Army SME analysts attribute the consistently low scores associated with this vignette group to a crying wolf analogy …. *once someone has proven to fabricate the truth it is nearly impossible to move beyond that point*.

Obviously with a topic as subjective as information valuation much research remains to be done – from the psychological underpinnings of confirmation bias to effective group intelligence. That said, armed with the insights from this study, two logical next steps are planned. First, a human-in-the-loop validation experiment is scheduled for the middle of fiscal year 2019 where software agents codified with improved *context-enable* VoI FAMs will act to prioritize an information foraging assignment. Second, working with Army SMEs, the mission context concept will be further expanded to include the information elements of the operations order (OPORD). An OPORD is the official military directive given in order to coordinate execution of a specific operation.

With the advent of improved machine learning and artificial intelligence, the realization of effective teams of humans and intelligent agents performing military-relevant tasks is fast becoming a reality. In the future, not only will the right information be delivered at the right time, in the right form – but sharing the concepts, intentions, understanding and beliefs will become commonplace.

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