Knowledge Elicitation to Prototype the Value of Information

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Abstract

From Wall Street to the streets of Baghdad, information drives action. Confounding this edict for the military is not only the unprecedented increase in the types and amount of information available, but the ability to separate the important information from the routine. Termed the value of information (VOI), the modern military commander and his staff require improved methodologies for assessing the applicability and relevance of information to a particular operation. This paper presents the approach used to elicit the knowledge necessary to value information for military analysis and enable the construction of a fuzzy-based prototype system for automating this valuation.

Introduction

Today's military operations require information from an unprecedented number of sources which results in an overload of information. With the requirement that relevant information be consistently available to troops as they conduct operations, a primary challenge for military commanders and their staff is separating the important information from the routine (FM 6-0 2003; DoD 2010). Calculating information importance, termed the value of information (VOI) metric, is a daunting task that is highly dependent upon its application to dynamic situations and human judgment (Alberts et al. 2001).

Currently the VOI assigned a piece of information is ascertained via a multiple step process requiring intelligence collectors and analysts to judge its value within a host of differing operational situations. For example, the types and immediacy of mission information needs will influence the amount of data reviewed and the value that an analyst will ascribe. While there is doctrine that describes a process of assigning value, it is sufficiently vague to allow multiple interpretations. As such, the cognitive processes behind these conclusions resist codification with exact precision and offer an excellent opportunity to leverage a computational intelligent solution using fuzzy inference.

This paper presents the approach used for gathering parameters necessary to value information for military analysis. Section 2 reviews the background information on the military domain with respect to VOI. Section 3 is an overview of knowledge elicitation techniques and the knowledge elicitation process utilized to capture values for fuzzy VOI rules. Section 4 presents a brief overview of the resulting prototype system. The conclusions and next steps are presented in Section 5.

Background

Understanding the Domain Challenge

On today's battlefield, information drives action. Commanders must know details about important persons, places and events within their area of operations to address issues ranging from kinetic fights to adjudicating legal disputes to revitalizing a depleted economy. From sophisticated unmanned ground acoustic sensors to open-source RSS news feeds, military commanders are inundated with an unprecedented opportunity for information. Table 1 depicts military information volume. As unit echelon increases, the scope of military operations and number of information reports grows tremendously. Intelligence analysts examine this information to determine the impact of trends, important human networks, and threat tactics, techniques, and procedures on current and future plans.

As shown in Figure 1, accurate VOI estimation is essential to the intelligence analysis process, promoting improved situational understanding and effective decision-making. The entire process is designed to produce and

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Echelon	Planning time	Execution time	Reports per hour	Area of Operation
Division	Week	Week/Days	~Millions	Province
Brigade	Days	Days	170K	Province /district
Battalion	Days/hours	Day	56K	District
Company	Hours	Hours	18K	Village
Platoon	Hour/Min	Hour/Min	6K	Village/Hamlet

Table 1: Military Echelons with typical Operational Times / Areas (James 2010)

make available relevant intelligence information. For all military data, intelligence collectors are responsible for the initial estimation of information value. While there are guidelines for VOI determination, these are subject to collector/analyst interpretation. In point of fact, a recent US Army Intelligence Center of Excellence study considered "Information Validation (Data Pedigree, Corroboration and Cross Validation) and Stance Analysis (Elimination of Bias and Use of Multiple Analysis Perspectives)" as major issues (Moskal, Sudit, and Sambhoos 2010).

Proper VOI is integral to battlefield success. VOI is essential in the collect-assess portion of the intelligence process. At higher echelons, VOI is a metric useful in determining the degree of situational estimate accuracy amidst the uncertainty of combat. Additionally, VOI is a focusing element as a searchable criterion, enabling analysts to find relevant information quickly. At lower echelons, analysts can use VOI to create an optimum course of action for immediate mission execution.

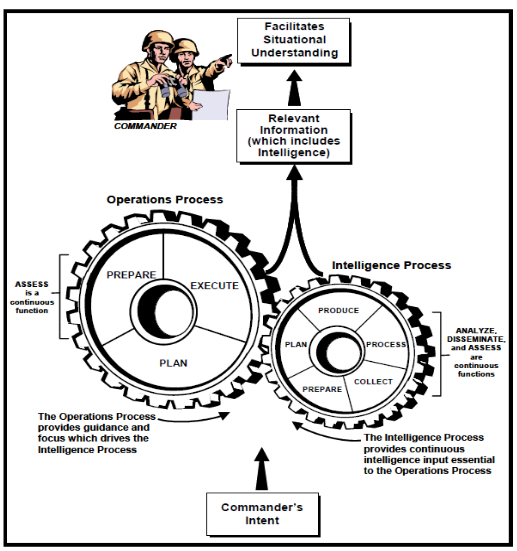

Figure 1: Military Information Process (FM 2-22.3 2006)

VOI Guidelines

The procedure for alphanumerically rating the "confidence" or "applicability" assigned a piece of information is essentially described in the annex to NATO STANAG (Standard Agreement) 2022 as well as in Appendix B of US Army FM-2-22.3 (FM 2-22.3 2006; NATO 1997). The NATO standard further dictates that, where possible, "an evaluation of each separate item of information included in an intelligence report, and not merely the report as a whole" should be made. The weight given each piece of information is based on the combined assessment of the *reliability of the source* of the information with the assessment of its *information credibility or content*.

As depicted in Table 2 and Table 3, respectively, the alphabetic *Reliability* scale ranges from A (Completely Reliable) to E (Unreliable) while the numeric *Content* scale ranges from 1 (Confirmed by other sources) to 5 (Improbable) (FM 2-22.3 2006; NATO 1997). Both scales account for the information that cannot be judged for source reliability or content with ratings F and 6.

So as an example, a piece of information that was received by a source that has in the past provided *valid* information would be scored a *Reliability Rating* of either B or C; depending on the degree of doubt in authenticity. That same piece of information, if not confirmed, but seeming logical, would receive a *Content Rating* of either 2 or 3; again depending on the degree the information was consistent with other information. It quickly becomes obvious the subjective nature of the ratings (B2 vs. C3) can quickly lead to ambiguity.

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	Cannot Judge	**No basis** exists for evaluating the reliability of the source

Table 2: Source Reliability (NATO 1997)

1	Confirmed	**Confirmed** by other independent sources; **logical** in itself; **Consistent** with other information on the subject
2	Probably True	Not confirmed; **logical** in itself; **consistent** with other information on the subject
3	Possibly True	Not confirmed; **reasonably logical** in itself; **agrees with some** other information on the subject
4	Doubtfully True	Not confirmed; possible but **not logical; no other information** on the subject
5	Improbable	Not confirmed; **not logical** in itself; **contradicted** by other information on the subject
6	Cannot Judge	**No basis** exists for evaluating the validity of the information

Table 3: Information Content (NATO 1997)

In an attempt to guide the application of composite ratings (i.e., B2 vs. C3) to varied operational situations, organizations have generalized the usefulness of data by developing charts similar to the one shown in Figure 2 (Hanratty et al. 2011). Positioned along the x-axis are the possible ratings for source reliability while the y-axis reflects those possible for information content. Combined, these ratings form a composite that in general reflects the generic value of a piece of information to analysis efforts; that is, a value within a general context. As shown in Figure 2, a piece of information can have three distinct value states, namely black is good, grey is questionable, and white is not useable. This rudimentary attempt to form a composite value shows progress, but the three states encompass several combined categories resulting in a blurred understanding of VOI. Capturing the complexity of analyst's intuitive knowledge through elicitation methods required an increased specificity of VOI states.

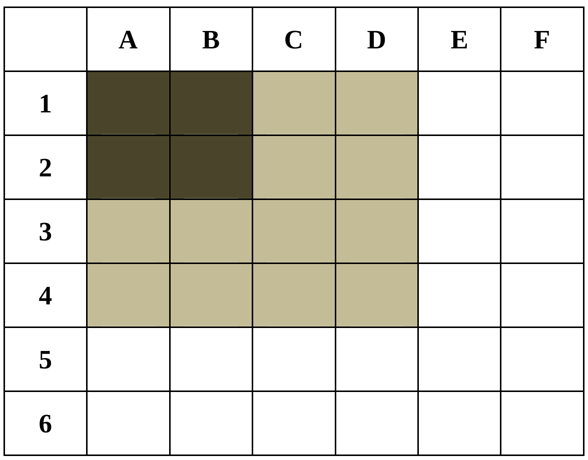

Figure 2: Example Information Source / Reliability Matrix (Hanratty et al. 2011)

Knowledge Elicitation

Overview of Knowledge Elicitation

Knowledge elicitation is generally the first step in the construction of a system that seeks to use expert knowledge to solve a problem. In the process of building such a system, the knowledge engineer must interact with one or more Subject Matter Experts (SMEs) to gather, organize, and codify the appropriate domain specific problem-solving expertise (Martin and Oxman 1988).

While knowledge *elicitation* and knowledge *acquisition* are occasionally used interchangeably in the literature, most researchers draw a clear distinction between the two; additionally, knowledge *engineering* is a third concept that appears in the literature (Addis 1987; Cooke 1999; Daintith 2012; Hoffman et al. 1995; Sagheb-Tehrani 2009). Though some slight differences exist in how the three terms are defined and described, the following categorizations are used in this research and generally capture the essence of the distinctions. *Knowledge engineering* is the over-arching process of building knowledge based systems which includes elicitation, representation, and implementation. *Knowledge acquisition* is a subset of knowledge engineering, and consists of the gathering of all forms of domain knowledge using any methods. Finally, *knowledge elicitation* is a subset of knowledge acquisition and encompasses the extraction of domain knowledge from human experts. While all the steps involved with knowledge engineering must be performed to construct a usable knowledge-based system, herein we only seek to describe our knowledge *elicitation* efforts.

The knowledge elicitation process is much more complex than just arranging a meeting or meetings with SMEs. One important but perhaps subtle aspect of the process is the need to choose experienced and available experts that have excellent communication skills as well as at least some commitment to the project at hand (Liou 1992). Additionally, it is important that the knowledge engineer have at least a working knowledge of the domain, including the terminology and basic concepts regarding the problem and the problem-solving process in the specific environment (Waterman 1983). Finally, it is also important that the appropriate knowledge elicitation method or methods are chosen (Liou 1992).

Knowledge Elicitation Methods

There are a myriad of assessments of knowledge elicitation methods and numerous representations for how to classify them. For our purposes here, we will present and briefly describe the four categories of knowledge elicitation methods identified by Cooke (1999).

<u>Observation</u>. This process consists of watching an SME perform the task or tasks in question. Typically, great care should be taken to avoid disrupting the SME during the reasoning process. The observations are recorded somehow (video, photographs, audio, notes, and the like). This method can be particularly useful as a beginning technique to allow the knowledge engineer to understand enough to develop more structured knowledge elicitation sessions.

<u>Interviews</u>. Interviews are used to simply ask SMEs what they know. The interviews may be structured, unstructured, or a combination. Unstructured interviews are free-form and use open-ended questions; they may be useful in the beginning knowledge elicitation efforts to get a preliminary understanding of the domain. Structured interviews set up an artificial scenario to impose constraints on the SME's responses. Interview methods are often specifically tailored to the particular domain or problem so that some precise type of knowledge may be obtained. The Critical Decision Method falls into this category of techniques.

Process Tracing. This method is used for gathering information that is procedural in nature; it looks at behavioral events that are sequential in form. It is useful to ascertain conditional rules or note the order in which cues are used by the decision maker. The "think-aloud" technique is included in this category.

Conceptual Methods. This process attempts to gather conceptual structures present within the domain that are derived as concepts and interrelations. Steps include: 1) discovering relevant concepts, perhaps through interviews; 2) gathering opinions from one or more SMEs as to how the concepts relate; 3) representing the relationships; and 4) interpreting the result. One method of obtaining the SME's beliefs as to how the concepts relate is by using a grid approach. In this method, concepts are rated across a set of dimensions, and then the similarity among concepts can be determined in some way.

Knowledge Elicitation Within the VOI Domain

In general, military operations are defined by their associated *operation tempo*; that is, the time it takes to plan, prepare and execute an exercise. High-tempo operations typically require the decision cycle to be measured in minutes to hours. Slower tempo operations will generally allow the decision cycle to be measured in months or longer. Absent from the model presented in Section III is the application of the *information applicability* rating to a specific operation type. Without the specific framework of a given operation type the associated impact of information latency (or information timeliness) requirements are lost. Restated, the true VOI is dependent upon the type of military operation to which the information is being applied. For instance, in a high-tempo operation, where decisions are made in short timeframes, added emphasis is assigned to information that has high applicability and was more recently received than others.

In order to capture the cognitive requirements necessary to refine our model and build the fuzzy association rules, the team applied the Conceptual Method posed by Cooke. A review of the military intelligence process revealed several relevant concepts such as operational tempo mentioned above. The team and the SMEs then discussed the relationships between data age, operational tempo, and information applicability. These relationships were developed into a two-part Likert survey instrument and the final product presented to the SMEs to gather specific values; the process of using the two surveys is detailed further in the rest of this section. The initial interpretation of the results led to the fuzzy rules that were codified in the prototype. Of course, any sort of "validation" of the system actually implies that the SMEs must corroborate the fuzzy rules, which basically requires other iterations of knowledge elicitation to ensure that the resulting system is accurate and precisely reflects the meaning and relationships the SMEs intended to convey. These efforts are briefly discussed in later sections.

The first survey was used to capture the generic *information applicability* rating from the doctrinal model described in Section III; that is, how to define the potential importance of a piece of information given a specific type of operation. The second survey was used to calculate the actual VOI based on the temporal latency of the information and a particular operational tempo. In this case the temporal latency was defined as either: recent, somewhat recent or old. It is particularly noteworthy that the cognitive concept of temporal latency was purposefully left as a subjective construct for the SME. In general, the surveys provided contextual structure for the structured interview. Additionally, the matrices proved useful in physically recording SME VOI determination responses to the questions of information applicability and the value within military mission execution context.

For the first part of the survey, a Likert instrument was developed that incorporated the military doctrinal information rating system. This system features a combination of information content and source reliability. Information content is rated on a scale of one thru five with one (best case) being termed as, "Confirmed by other independent sources" and five (worst case) being termed as, "Not confirmed." Likewise, source reliability is also rated on a scale of one thru five; with one being termed as, "No doubt of authenticity, trustworthiness, or competency", and five being termed as, "Lacking in authenticity, trustworthiness, an competency" (FM 2-22.3 2006). The authors have coined the combination of these two ratings as a general "*information applicability*" rating for a given piece of information. The composite rating is expressed on a Likert scale of one through nine with nine being extremely applicable and one being least applicable to military missions. The instrument, shown in Figure 3, is the matrix used to capture SME ratings reflecting applicability.

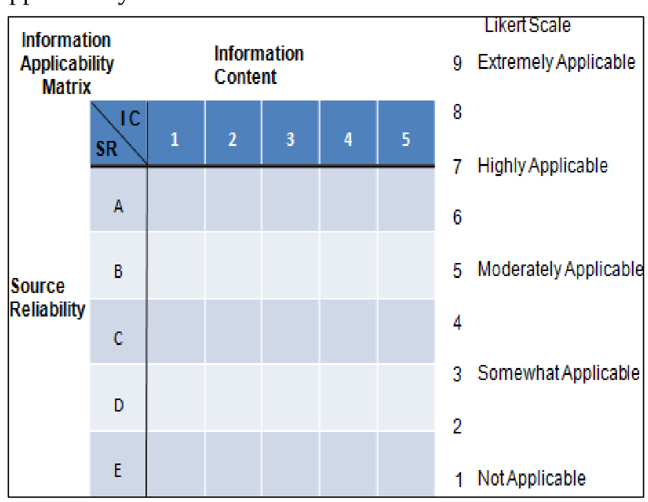

Figure 3: Likert Survey for Refined Information Applicability

During the pilot session, three intelligence analysts rendered their opinions on the generic applicability of data with ratings reflected within each cell of the matrix. For example, an applicability rating of "A1" that reflects the most applicable data would lend itself to the *Extremely Applicable* rating of 9. The averaged information applicability ratings for the three analysts are shown in Figure 4.

With the generic *information applicability* ratings completed, the second step involved applying those ratings against the *aspects* associated with a specific mission type. While many different *aspect* possibilities exist, the focus of this pilot survey was on the two primary military aspects of operational tempo and the temporal latency of the information. In this case the operational tempo was defined as either 'tactical', 'operational' or 'strategic', where the differences between the operational tempos is defined by the immediacy of the mission and is measured in the amount of time it takes to plan, prepare and execute a mission. The temporal latency of the information, on the other hand, was measured as a degree to which the information was either recently collected, somewhat recently collected or old.

The resulting VOI matrix that would be used for one of the specific operational tempos is shown in Figure 5. Here the composite VOI rating is expressed on a Likert scale of zero thru ten with ten being extremely valuable and zero equally no value to the mission.

The SMEs used three individual surveys to gauge the VOI for military mission immediacy of data use, namely one for use within a short time, one for use within a moderate time and one for use within a long time. The VOI results gained for data use in a short amount of time are shown in Figure 6.

Information Applicability Matrix — Information Content (IC) / Source Reliability (SR)

SR \ IC	1	2	3	4	5
A	9	8	7	4.67	2.67
B	8	7.33	5.67	3.67	2
C	7.33	6	4	3.33	1
D	6	4.33	3	1.67	1
E	4.67	3	2	1	1

Likert Scale
9 Extremely Applicable
8
7 Highly Applicable
6
5 Moderately Applicable
4
3 Somewhat Applicable
2
1 Not Applicable

Figure 4: Averaged SME Information Applicability Ratings

Value Of Information Matrix — Temporal Aspect (TA) / Information Applicability (IA)

IA \ TA	Recent	Somewhat Recent	Old
9			
8			
7			
6			
5			
4			
3			
2			
1			

Likert Scale
10 Extremely Valuable
9
8 Highly Valuable
7
6 Moderately Valuable
5
4 Somewhat Valuable
3
2 Minimally Valuable
1
0 Not Valuable

Figure 5: VOI Likert Survey with Temporal Aspect

Value Of Information Matrix — Temporal Aspect (TA) / Information Applicability (IA)

IA \ TA	Recent	Somewhat Recent	Old
9	10	9.67	9
8	9	8.67	8.33
7	8	7.33	7
6	6.67	6	5.33
5	4.67	4	3.67
4	4	3.33	2.67
3	3	2.33	2.33
2	1.33	1	0.67
1	0.67	0.33	0.33

Likert Scale
10 Extremely Valuable
9
8 Highly Valuable
7
6 Moderately Valuable
5
4 Somewhat Valuable
3
2 Minimally Valuable
1
0 Not Valuable

Figure 6: VOI SME Results Fast Op Tempo

The Likert scales were easy to explain and provided a readily understood scale for rating data values. Data collected via the pilot session with the military analyst SMEs reveals the use of similar trends in analysis and is readily adaptable to the project mathematical model. Further, the inherent flexibility in the collection process seems applicable to additional military contexts that can become the subject of future model applications.

Initial Prototype

The Fuzzy Associative Memory (FAM) model was chosen to construct the prototype fuzzy system. A FAM is a *k*-dimensional table where each dimension corresponds to one of the input universes of the rules. The *i*th dimension of the table is indexed by the fuzzy sets that compromise the decomposition of the *i*th input domain. For the prototype system, three inputs are used to make the VOI decision (source reliability, information content, and timeliness); with three input domains, a 3-dimensional

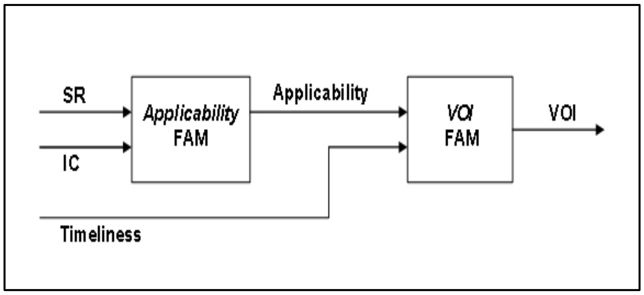

Figure 7: Prototype System Architecture

FAM could be used. However, the decision was made to use two, 2-dimensional FAMs connected "in series" to produce the overall VOI result for several pragmatic reasons (Hammell, Hanratty, and Heilman 2012).

The overall architecture of the prototype fuzzy system is shown in Figure 7. Two inputs feed into the *Applicability* FAM: source reliability and information content; the output of the FAM is the information applicability decision. Likewise, two inputs feed into the *VOI* FAM: one of these (information applicability) is the output of the first FAM; the other input is the information timeliness rating. The output of the second FAM, and the overall system output, is the VOI metric.

The rules elicited from the SMEs are represented in the appropriate FAMs and form the fuzzy rule bases. The number of fuzzy sets, and thus the "language" of the rules, was defined in the knowledge elicitation phase using the two surveys described above. That is, the decomposition of the domains is as shown in Figures 3 and 5. The two inputs to the *Applicability* FAM are divided into five fuzzy sets; the output domain is divided into nine fuzzy sets. Likewise, for the *VOI* FAM, the input domain for information applicability is divided into nine fuzzy sets (as just mentioned), the timeliness input domain three fuzzy sets, and the output domain eleven fuzzy sets.

Figures 4 and 6 actually represent the fuzzy rules bases for the two FAMs resulting from the knowledge elicitation process. For example, Figure 4 demonstrates that one rule in the *Applicability* FAM is "If *source reliability* is reliable (A) and *information content* is possibly true (3), then *information applicability* is highly applicable (7)". Note that the *VOI* FAM shown in Figure 6 applies only to the fast operational tempo (tactical) mission context, while the *Applicability* FAM is constant across all three mission contexts.

Triangular membership functions are used within the system, wherein the triangles are isosceles with evenly spaced midpoints. The output from each FAM is determined by the standard centroid defuzzification strategy. More detailed description of the FAMs, the fuzzy rule bases, the domain decompositions, and other implementation aspects of the prototype system can be found in (Hammell, Hanratty, and Heilman 2012).

The prototype system has been exercised across numerous scenarios (that is, various combinations of input values) to produce VOI determinations. These preliminary system results have been demonstrated to the SMEs and the system performance has been validated in principal and concept. That is, the system output has been judged to be consistent with what the SMEs would expect, and the prototype has demonstrated the feasibility to both elicit rules from experts in this domain as well as to use the extracted knowledge in a meaningful way.

Note that there is no current system against which the results can be compared. As such, the system has not been tested comprehensively due to the human-centric, context-based nature of the problem and usage of the system. Thus, the system performance will need to be validated by providing the SMEs with various scenario-based VOI results for their examination and feedback. In some cases the output of the system is an exact application of the rules provided by the SMEs which should permit easy judgment; in other instances, the system output is less clear and will require more detailed examination.

Conclusion and Future Work

Information drives action and for the military that is facing an unprecedented increase in the types and amount of information available, the ability to separate the important information from the routine is paramount. This paper presented an approach used for gathering the parameters to calculate the VOI for military analysis and allow the subsequent development of a fuzzy-based prototype system.

The obvious next step for this effort is to seek validation of the system from the SMEs by producing a comprehensive, well-designed set of scenario-based VOI results for their examination and feedback. It is entirely possible that the concepts and relationships captured through the conceptual method of knowledge elicitation would require modification. If so, further iterations of the knowledge elicitation process will occur. As the program matures, the capability to accommodate inconsistent or contradictory information will be investigated. For the military, the ability to efficiently and effectively calculate VOI and separate the wheat from the chaff is paramount. This program is an important step towards that goal.

References

Addis, T.R., "A Framework for Knowledge Elicitation", University of Reading, Department of Computer Science, 1987.

Alberts, David S., John J. Garstka, Richard E. Hayes, and David T.Signori. *Understanding Information Age Warfare.* Washington, DC: CCRP, 2001.

Cooke, N.J., “Knowledge Elicitation”, in *Handbook of Applied Cognition*, F. Durso, ed., Wiley, pp. 479-509, 1999.

Daintith, J, “Knowledge Acquisition”, A Dictionary of Computing, *Encyclopedia.com*, 20 Feb 2012, <http//www.encyclopedia.com>, 2004.

DoD (Department of Defense), “Quadrennial Defense Review”, January 2010.

FM 2-22.3 (FM 34-52) Human Intelligence Collector Operations, Headquarters, Department of the Army, Sept 2006.

FM 6-0 (US Army Field Manual 6-0), Mission Command: Command and Control of Army Forces, US Army, August 2003.

Hammell, R.J. II, T. Hanratty, and E. Heilman, “Capturing the Value of Information in Complex Military Environments: A Fuzzy-based Approach”, *Proceedings of the IEEE International Conference on Fuzzy Systems 2012 (FUZZ-IEEE 2012)*, 10-15 June 2012, Brisbane, Australia, accepted.

Hanratty, T. P., et. al., “Counter-Improvised Explosive Device (IED) Operations Integration Center (COIC) Data Fusion Operations and Capabilities: An Initial Assessment”, US Army Technical Report, December 2011.

Hoffman, R.R., N.R. Shadbolt, A.M. Burton, and G. Klein, “Eliciting Knowledge from Experts: A Methodological Analysis”, *Organizational Behavior and Human Decision Processes*, vol. 62, no. 2, pp. 129-158, May, 1995.

James, John, “Military Data”, presentation, Network Science Center, West Point, Oct 2010.

Liou, Y.I., “Knowledge Acquisition: Issues, Technologies and Methodology”, *ACM SIGMIS Database*, vol 23, no. 1, pp. 59-64, Winter 1992.

Martin, J. and S. Oxman, *Building Expert Systems: A Tutorial.* Englewood Cliffs, New Jersey: Prentice Hall, 1988.

Moskal, Michael D., Dr. Moises Sudit, Dr. Kedar Sambhoos, “Providing Analytical Rigor in Intelligence Analysis Processes Utilizing Information Fusion Based Methods”, CUBRC/University at Buffalo, Sep 2010.

North Atlantic Treaty Organizaiton (NATO) Standard Agreement 2022 (Edition 8) Annex, 1997.

Sagheb-Tehrani, M., “A Conceptual Model of Knowledge Elicitation”, *Proceedings of Conference on Information Systems Applied Research (CONISAR) 2009*, §1542, pp. 1-7, 5-8 Nov, 2009, Washington, D.C.

Waterman, D.A., *Building Expert Systems*. Reading, MA: Addison Wesley, 1983.