National Technology Alliance

Multi-Source and Multi-INT Fusion Technology Survey and Analysis

Public Release Version 3

October 7, 2009

Rosettex

Prepared for the National Technology Alliance by the Rosettex Technology & Ventures Group and its Partners SRI International and Pennsylvania State University

SRI International

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Publication Number: FR-001-085-052609-538PR

Multi-Source and Multi-INT Fusion

Technology Assessment and Analysis Report

Public Release Version 3

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Report Number:	**FR-001-085-052609-538PR**
Submitted to:	The National Technology Alliance **The National Geospatial-Intelligence Agency (NGA)** 12310 Sunrise Valley Drive Reston, VA 20191
Agreement No:	NMA401-02-9-2001/Task No. 001 (IA&E-085)
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The work performed by Rosettex Technology & Ventures Group and subcontractors was funded by the National Geospatial-Intelligence Agency (NGA) under National Technology Alliance (NTA) Agreement No. NMA401-02-9-2001. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the NGA, the United States Government, or Rosettex. This report has been approved for public release by NGA (Case #09-521, Dated October 1, 2009), distribution unlimited.

Table of Contents

List of Table and Figures

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1.0 INTRODUCTION

The National Geospatial-Intelligence Agency (NGA) InnoVision Advanced Development Office Analysis and Applications Division (IDA) is responsible for developing the *InnoVision Multi-Source and Multi-INT Fusion Portfolio Roadmap*. As part of those efforts, NGA/IDA has been charged with: (1) assessing and documenting the current state of Multi-Source and Multi-INT Fusion, and (2) projecting the development of related technology for the next 5-15 years. Towards these objectives, NGA/IDA tasked Rosettex to conduct a broad, independent assessment of the current state of academic, community, and industry activities in the fusion areas based upon the qualified viewpoints of academic, industry, and community research professionals. The results of this assessment were used to document and evaluate current fusion technology activities in academia, community, and industry to properly identify and define potential applied research and advanced development initiatives.

To accomplish the Multi-Source and Multi-INT Fusion Assessment, Rosettex was tasked to assess current and future industry geospatial intelligence (GEOINT) related activities through a two-step process:

1. Convene an expert panel meeting, point presentations, discussion, and follow-on assignments to provide a starting point for identifying technology and capability shortfalls and for defining further broad Multi-Source and Multi-INT Fusion research and development efforts.
2. Conduct a detailed technology survey centered on critical areas pointed out by judgments of the panel experts to:
   (a) Review information from recent trade shows, conferences, and Intelligence Community (IC) / Department of Defense (DoD) fusion efforts to better understand the current state of affairs.
   (b) Identify key industry actors in the fusion arena.
   (c) Conduct detailed reviews and assessments to characterize pertinent activities and technologies.

In the first step of this process, a panel of distinguished data fusion experts from academia, industry and the government was assembled. The panel included: Dr. David Hall (Pennsylvania State University), Dr. James Llinas (State University of New York - Buffalo), Dr. Craig Knoblock (University of Southern California), Dr. Boris Kovalerchuk, (Central Washington University), Dr. Gail Kucera, (Swiftsure Spatial Systems), Mr. Otto Kessler (MITRE Corporation), Mr. Alan Steinberg, (Independent Consultant), and Mr. Frank White, (Independent Consultant). Members have an extensive history of accomplishments in the DoD data fusion community including participating in the original Joint Directors of Laboratories (JDL) data fusion sub-panel that authored the JDL data fusion process model.

Using the draft NGA/IDA "*Multi-Source, Multi-INT Fusion Portfolio of the InnoVision Research and Development Roadmap*" as a guide, the panel's discussion focused on assessing relevant fusion technology and related operational scenarios. Their aim was to identify potential fusion solutions or shortfalls/gaps, and evaluate the basic, applied, and advanced research necessary and viable in the 5-15 year term related to Multi-Source, Multi-INT Fusion Portfolio research domains. Information gathered from the panel was used to guide the subsequent survey tasks.

In the second step of the process, described in this report, a detailed survey and technology assessment was conducted in five key areas:

1. *Understanding and modeling the new domains* – Development and understanding of models of the observed domains of interest (the physical, human, and cyber landscapes).
2. *Refining and enhancing the data stream, observations, and observation process* – Modeling and understanding the observation and data representation processes.
3. *Net-centric infrastructure* – Characterizing and improving the network centric infrastructure.
4. *Support for improved human-in-the-loop analysis and data understanding* – Investigation of methods to effectively engage the human in the loop to utilize human pattern recognition, semantic level reasoning for contextual understanding and collaborative analysis for improved reasoning and decision-making.
5. *Intelligent systems for automated situational awareness and anomaly detection* – Development of automation methods for data collection and reasoning for automated pattern recognition, computer-based detection of anomalies, and context-based situational awareness.

It should also be noted that the overall effort, including both the Panel focus and the Survey focus, was "Innovision-centric," that is, guided exclusively by the Innovision portfolio provided. The effort did not examine any other organizational roles, technologies, or capabilities within NGA. Further implications of the Survey in this regard are beyond the scope of this report, but may deserve further study.

2.0 PROCESS DESCRIPTION

A two-step process was originally planned to develop recommendations for technology investments. Step 1 involved convening a panel of government, academic and industrial data fusion "greybeards" to discuss the overall state of the art in data and information fusion and provide recommendations for a follow on technology survey and assessment. Step 2 focused on the topical areas defined by the greybeard panel and involved: (1) conducting a detailed technology assessment including literature surveys, (2) identifying on-going programs, (3) surveying open source information including commercial software and practices, and (4) assessing the maturity of the technology areas using the technology readiness level (TRL) concept. By and large, although NGA staff were present and involved in the panel session, the overall thrust of the panel findings and directions of the survey were broad in scope and, while valuable in their own right, they focused mostly on GeoINT users and were not NGA-specific.

2.1 Panel Discussion Process and Results

A panel of distinguished data fusion experts from academia, industry, and the government was assembled at SRI's regional facility in State College, PA on December 2-3, 2008 to identify potential fusion solutions or shortfalls/gaps, and to evaluate the basic, applied, and advanced research necessary and viable in the 5-15 year term related to Multi-Source, Multi-INT Fusion Portfolio research domains. Information gathered from the panel was used to guide the subsequent survey tasks.

Information was provided to the Panel with associated assignments prior to the meeting (See Figure 2.1-1). During the meeting, three sub-teams were formed to conduct parallel sessions to focus on different aspects of fusion related to NGA.

- Team 1 (Dr. Craig Knoblock, Dr. Boris Kovalerchuk, Mr. Alan Steinberg and Dr. Gail Kucera) focused on understanding information needs, visualization techniques, human-in-the-loop fusion and fusion algorithms.
- Team 2 (Dr. David Hall, Mr. Otto Kessler and Mr. Frank White) used the JDL data fusion process model and identified gaps, made recommendations and provided suggestions for the follow-on survey.
- Team 3 (Dr. James Llinas, Mr. David Scott and Mr. Dan Edwards) focused on areas of data analysis and interpretation.

The Panel reviewed the mission and focus areas of NGA, discussed the current state-of-the-art in data fusion, and developed recommendations for follow-on technology assessment, and provided a number of results to assist in guiding the technology survey and assessment.

The Panel results included:

- An overview of data fusion process models and definitions.
- Identification of key operational and threat drivers that motivate the need for multi-sensor data fusion and NGA involvement.
- A summary of the state of the art in data fusion for DoD applications.
- Recommendations by three sub-teams for follow-on surveys and in-depth analysis.
- Creation of a framework for follow-up survey activities.

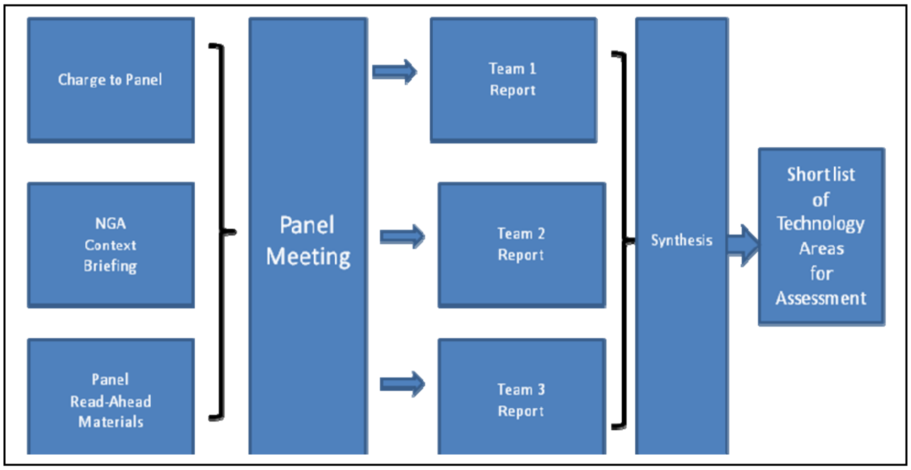

Figure 2.1-1: Panel Discussion Process

The Panel recommended the following technology area framework for follow-up survey and technology assessment under the second (survey) step of the project:

1. *Understanding and modeling the new domains* – Development and understanding of models of the observed domains of interest (i.e. the physical, human and cyber landscapes), including models of the observed "system," prediction models of system evolution and modeling the link between the system state and observable quantities. A particular focus here is on human social networks and the difficulties involved with observing, estimating, and analyzing the behavioral characteristics of typically heterogeneous groups of humans, often in complex urban settings.
2. *Refining and enhancing the data stream, observations, and observation process* – Modeling and understanding the observation and data representation processes (e.g., modeling traditional sensor systems as well as humans acting as observers), meta-data generation and abstraction, and refining the data stream and adding information about the observing process (such as pedigree).
3. *Net-centric infrastructure* – Characterizing and improving the network centric infrastructure (data distribution, access to resources, impact of distributed collection and computing, and distributed collaboration). A particular focus here in on assessing the state of the art in SOAs).
4. *Support for improved human-in-the-loop analysis and data understanding* – Investigation of methods to effectively engage the human in the loop to utilize human pattern recognition (including visual and aural skills), semantic level reasoning for contextual understanding, and collaborative analysis for improved hybrid (human/computer) reasoning and decision-making.
5. *Intelligent systems for automated situational awareness and anomaly detection* – Development of automation methods for data collection and reasoning for automated pattern recognition, computer-based detection of anomalies, understanding of normal versus abnormal conditions and context-based situational awareness.

It can be noted that the recommended survey areas involve many factors besides the numerical and symbolic algorithmic methods for fusing and exploiting the observational and contextual information. They indicate the importance of understanding modern problems and observational techniques, supporting informational infrastructure, and the contributions of human analysts, operators, and decision-makers. Automated algorithmic methods are also important, but only a part of the total architecture and integrated fusion process.

2.2 Technology Survey Process

The survey process began with the framework/technology areas recommended by the panel (see Figure 2.2-1).

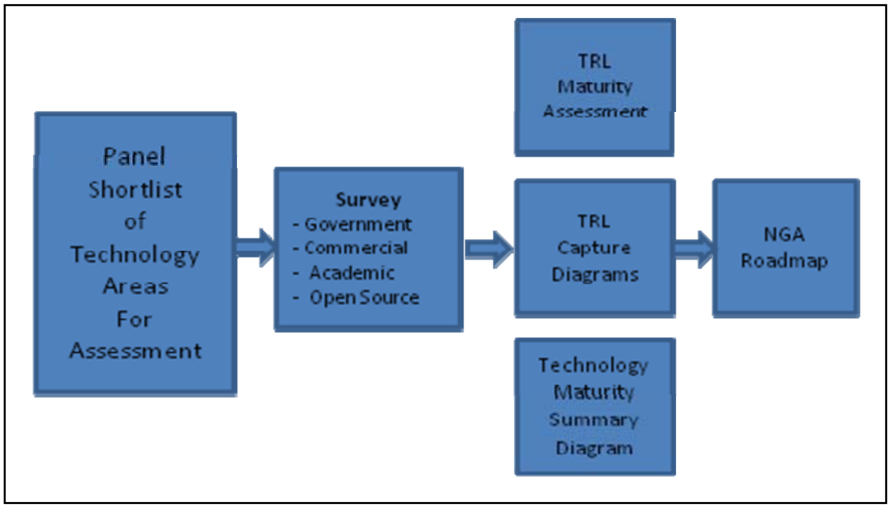

Figure 2.2-1: Overall Survey Process

The investigators were responsible for performing detailed surveys to include but not be limited to: (a) reviewing information from recent trade shows, conferences, and IC/DoD fusion efforts, (b) identifying key industry actors in the fusion arena, and (c) conducting detailed research to characterize these activities and technologies. Each fusion area also had a primary designate responsible for making sure that technology assessments were completed for the support technologies listed in each of the five fusion process areas. The specific survey instruments used by each investigator and any weaknesses/risks inherent in the survey method/data normalization methods selected are documented in a separate Annex to this document.

For each of the five targeted areas recommended by the Panel, survey teams examined a wide variety of information sources to include proceedings from all modern Information Fusion-relevant conferences, especially the conferences of the International Society for Information Fusion and the National Symposia on Sensor and Data Fusion, as well as the SPIE Annual Defense and Security Conference, among others. Additionally, research from ostensibly all the defense Laboratories was examined, and broad internet searches were conducted to retrieve and assess a variety of open-source technical literature.

The concept of Technology Readiness Levels (TRL) was used to capture initial maturity levels for each of the Panel-recommended fusion technologies. The DoD Interim Defense Acquisition Guidebook, dated October 8, 2004, established TRLs as the preferred descriptor of technology maturity for the Technology Readiness Assessments (TRAs) for ACAT ID and ACAT IAM programs. The method is gaining widespread recognition and is the preferred method of communicating technology readiness for large programs. TRL definitions are different for hardware and software – we focus here on software. TRL assessments provide a mechanism to categorize the technical maturity of components, systems, and subsystems. The three components of the assessment include:

1. *Technological maturity* is a measure of performance, reliability, durability, and operating experience, and more technologically mature components (better performing, more reliable, more durable, greater operating experience) are rated higher than experimental or prototype components or systems.
2. *Performance* is the component's or system's ability to perform the task for which it is intended.
3. *Reliability* is a measure of how well the component or system is able to achieve the desired performance upon repeated use. Durability is the ability of the component to withstand stresses and wear without a degradation or failure in performance. Increased operating experience is correlated with higher technical maturity because it provides more data to support more accurate assessments of performance, reliability, and durability.

TRLs provide a common understanding of technology status (maturity), and can be used as a factor in:

- Management of technical risk
- Making decisions concerning technology funding
- Making decisions concerning transition of technology
- Scoping acquisition programs and their requirements

TRLs follow a scale from 1 (lowest level of readiness) to 9 (mature development). For example, a technology assessed at TRL 1 is, by definition, at the lowest level of technology readiness, where scientific research begins to be translated into applied research and development. By the time the technology has reached a TRL 9, the technology has progressed through formulation of an initial concept for application, proof of concept, demonstration in a laboratory environment and realistic environment, and integration into a system. This last state of development, where the technology is operating under mission conditions, is TRL 9.

The recommended actions associated with a TRL analysis fall into six categories as summarized below:

1. *Transition* – The TRL assessment determines that the technologies are relevant to the NGA fusion problem and are ready for transition to operational systems.

2. *Develop* – The assessment determines that the technologies are relevant to the NGA fusion problem and with further development are capable of transitioning to operational systems.

3. *Explore* – The initial assessment indicates that the technologies are relevant to the NGA fusion problem and may provide extensive solutions to the NGA fusion problem with further exploration.

4. *Influence* – The analysis suggests that the technologies provide partial solutions to the NGA fusion problem and with further direction will be capable of providing more comprehensive support.

5. *Track* – The assessment suggests that the technologies are potentially relevant to the NGA fusion problem and may provide solutions at some point in the future. Hence, these technologies should be monitored, but specific investments should not be made.

6. *Ignore* – The assessment indicates that the technologies are not especially relevant to the currently defined NGA fusion problem/requirements.

Figure 2.2-2 shows an example of a TRL summary diagram for the net-centric enabling technologies. This spiral graphic summarizes the TRL maturity assessment for each of the technology/survey areas recommended by the panel. Radial distances capture the overall recommended roadmap status for each contributing technology (Develop, Explore, Influence, Track, Ignore) while quadrants are used to indicate the TRL maturity level. Thus, in Figure 2.2-2, technologies related to data storage, tagging, and identity management are shown in the lower right hand side of the figure, indicating a TRL level 6 which can be developed in the medium term (3-5 year timeframe), and available for transition to fielded operations shortly thereafter.

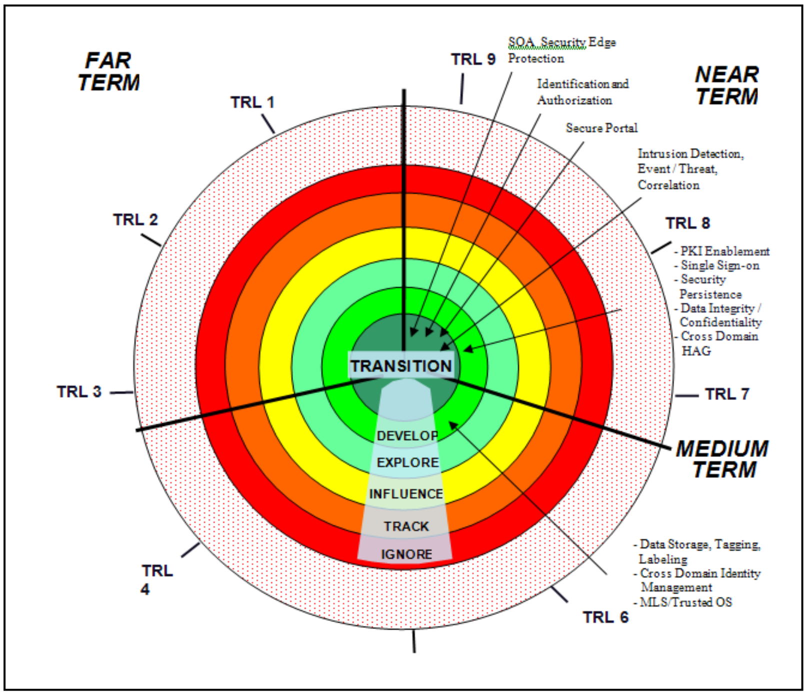

Figure 2.2-2: Sample TRL Diagram for Net-Centric Enabling Technologies (Security Technologies)

By contrast, technologies such as secure portals and identification and authorization are shown on the upper right hand side of Figure 2.2-2, indicating that they are mature (TRL level 9) technologies ready for immediate utilization in fielded systems. Multiple contributing technologies may be included on one graphic summary or, if required, span multiple TRL spirals.

2.3 NGA Fusion Context

Figures 2.3 1a through 2.3 1d provide context diagrams used to frame potential NGA roles related to data fusion.

NGA Acting as a Data Service Provider - In this role, NGA would not perform any data fusion within its operations. Instead, NGA would provide supporting information (both relevant and timely tactical data based on processing NGA products) as well as foundational data to support contextual analysis; NGA's value-added is in aiding the formation of improved situational estimates (hypotheses "H_{hat}" as shown in these figures) by the external agencies supported. This concept is illustrated in Figure 2.3-1a. In this role, data fusion would be performed external to NGA operations but would require NGA cognizance of the external processing to be effective as a service provider. For example, this role would require developing SOA concepts to support inter-agency data exchanges and development of relevance filters to support the provision of contextual, foundational information to external fusion processes.

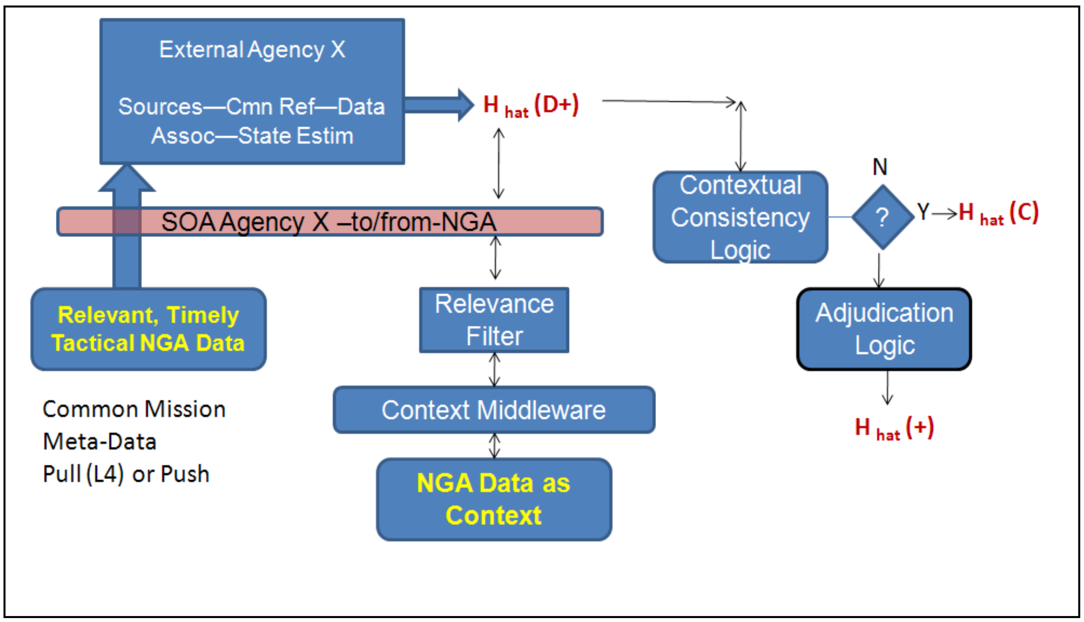

Figure 2.3-1a: NGA as Data Service Provider

NGA as (within NGA) Fusion Agent - In this role, NGA would accept data or fused estimates from other agencies and sources and fuse the external data with NGA evolving products. Hence, the fusion would occur "inside" of NGA based on a combination of NGA data and external source data. This would require development of an SOA to interact with other agencies/sources, establishment of data flow process concepts and protocols, accessibility to the external data (including potential resource tasking), and the design of a robust multi-INT fusion process within NGA. This concept is illustrated in Figure 2.3-1b. NGA value-added is in the improved quality of any internal fusion processes as enhanced by external data sources. Note that the fusion within NGA occurs at the state or estimate level, not the data level, since it is assumed that data level sharing would be prohibitive due to excessive bandwidth requirements and technological complexity at the fusion algorithm level.

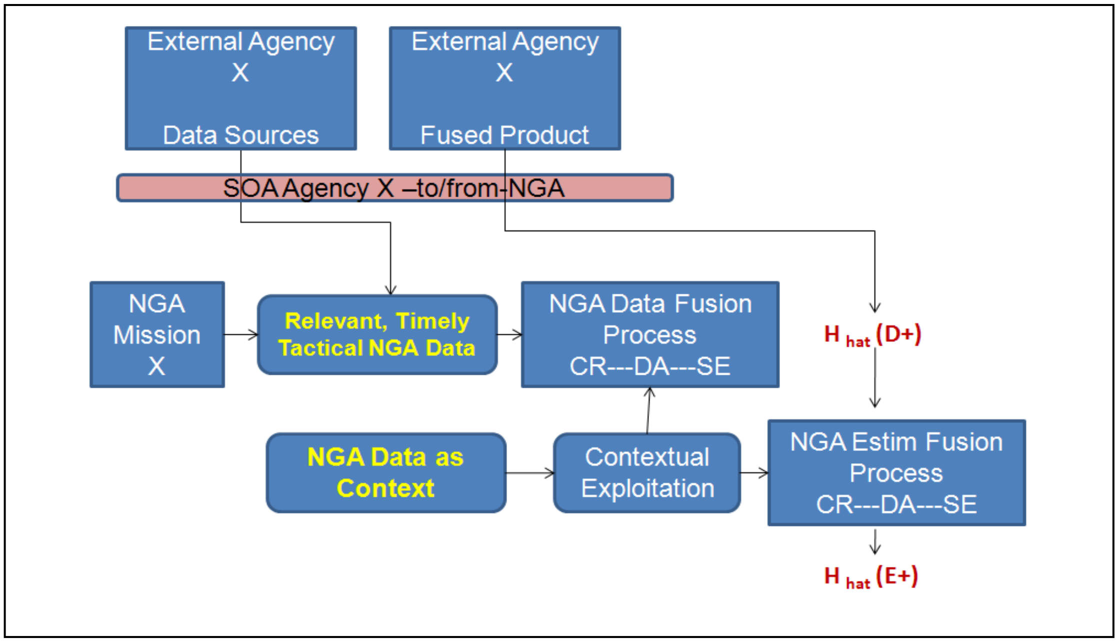

Figure 2.3-1b: NGA as (within) Fusion Agent

NGA as a (Fused-Product) Service Provider - In this concept (shown in Figure 2.3-1c), NGA would perform fusion of its own internal data and products, and then provide the fused results to other agencies or users so they, in turn, can conduct multi-source, multi-INT fusion.

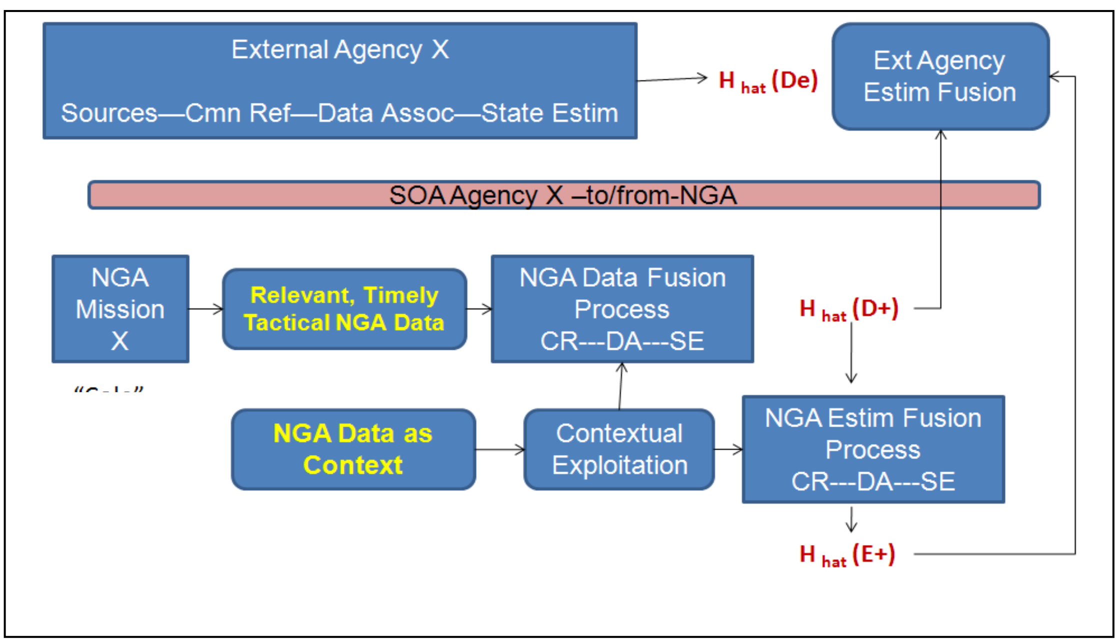

Figure 2.3-1c: NGA as (Fused Product) Service Provider

In this role, the NGA value-added provides a fused product (based on NGA sources and information) to provide external agencies with an improved product. This role requires SOA concepts, interagency coordination; establishment of data flow protocols, development of meta-data to describe the NGA fused products, and creation of NGA data specific fusion architecture and algorithms.

NGA as External Data Consumer for NGA Product Quality Improvement - The fourth possible role is for NGA to utilize external data sources to improve its product quality (i.e., by using non-traditional and external sources to improve the foundational data and standards maintained by NGA) as illustrated in Figure 2.3-1d. This role involves fusion within NGA for the purposes of product quality improvement, which is the value-adding paradigm in this model. Requirements include an SOA, interagency coordination, data flow protocols, external source tasking and establishment of a quality improvement process using fusion concepts.

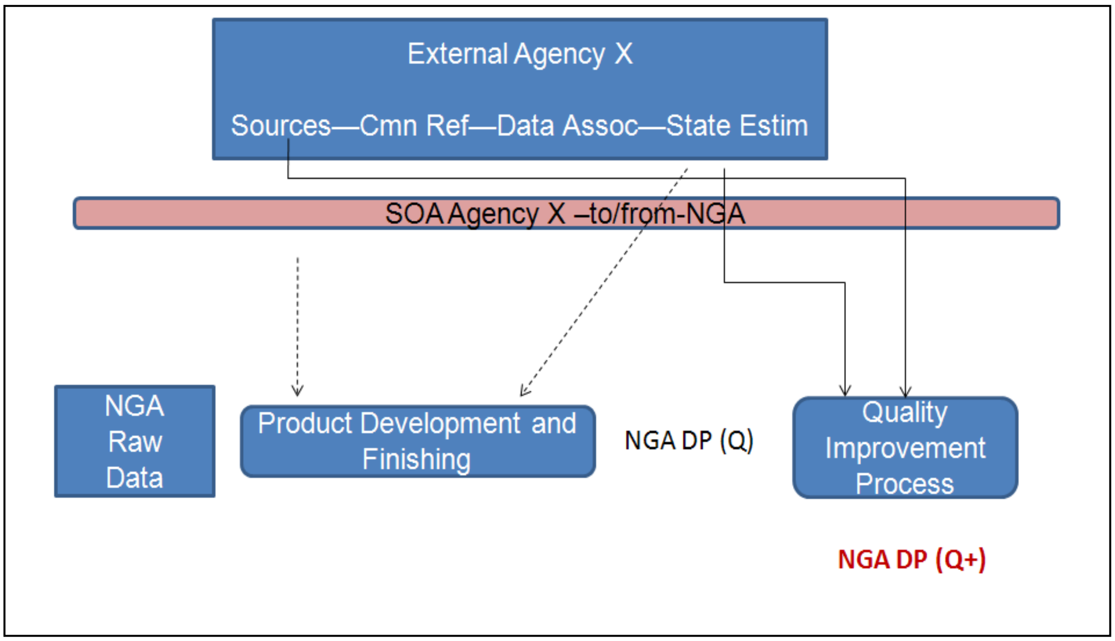

Figure 2.3-1d: NGA as External Data Consumer for NGA Product Quality Improvement

As noted above, sharing and exchanges at the data level in any of these models may generate a bandwidth-capacity issue. The fusion community often assumes that extensive data-level-sharing in the networked/distributed fusion environment would be bandwidth-prohibitive, but this is a case-by-case issue requiring case-specific cost-effectiveness tradeoff analyses. These concepts are not mutually exclusive or an exhaustive list of potential orientations that NGA could adopt for information fusion. Moreover, NGA does not need to “decide” or “choose” among these perspectives; however, they provide a potential framework for understanding and driving technology investment priorities.

Using the four perspectives above, Table 2.3-1 illustrates how the agency's different roles and perspectives would affect interpretation of the technology assessments in the five areas examined. The color code at the bottom of the figure indicates the relative maturity/level of challenge, ranging from green (near-term, low investment) to yellow, red, and orange (with red indicating the most challenging and high investment required).

Table 2.3-1: Implications of NGA Fusion Roles on Technology Assessment Areas

	NGA ROLE			
Technology Survey Focal Topic	**Data Service Provider**	**NGA Fused-Product Service Provider**	**Within NGA All Source Fusion Agent**	**External Data Consumer for Product Improvement**
Understanding and Modeling the New Problem Domain	Need data to problem relevance (no need to model new domain)	Need internal knowledge model for new domains (re: NGA data applicability)	Need internal knowledge model for new domains including state to multi-INT data modeling	Need to understand relevance of internal products & impact on new problem domains (reverse observation modeling)
Refining, enhancing Data Stream Observations and Observation Processes	Limited change to existing NGA process (except to support automation)	Internal infrastructure modifications required to provide efficient input to internal NGA fusion processes	Modifications depend on the complexities and disparities between internal NGA data types & external data types	Unknown
Net-Centric Infrastructure	Interface with external SOA – address external evolving requirements	Interface with external SOA	Internal NGA SOA must address new data types (from external)	Internal NGA SOA must address new data types (from external)
Improve Human in the Loop Analysis and Data Understanding	Focus on internal NGA processes	Some enhancement of HCE to address NGA internal fusion processes	New HCI to address external data types and fusion processes	New HCI to address external data types and fusion processes
Intelligent Systems for Automated Situation Awareness and Anomaly Detection	Focus on automation of existing NGA human intensive processes – dependent on role for contextual exploitation	Contextual exploitation inside NGA requires	Design of full multi-INT fusion process	N/A
NGA Infrastructure Impacts	SOA data models and IT "plumbing" for external interfaces	Infrastructure for NGA data fusion process	Infrastructure for NGA data fusion process	Unknown
Required degree of investment	**Low**	**Low-Moderate**	**Moderate-High**	**High**

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3.0 SUMMARY OF TECHNOLOGY ASSESSMENT

The details of the technology assessment for the five areas involved a detailed literature review, identification of on-going industrial, academic and government research programs, survey of commercial-off-the-shelf (COTS) technology, exploration of standards and reference materials, and discussions with selected experts in the focus areas. The aim was not to provide a complete assessment of general technologies such as data mining or human terrain modeling, but rather to determine how the current state and anticipated evolution of these areas would be applicable to NGA processing. The following sections provide a brief summary of the results of the technology survey and assessment in each of the five areas.

3.1 Understanding and modeling new domains

The increasing interest in observing and characterizing the “human landscape” or “human terrain” using both conventional and emerging information sources motivated the assessment of technologies related to understanding and modeling the new domains. Key technology sub-areas include: (1) human landscape modeling technologies, (2) identifying and representing data imperfections and lineage, (3) modeling object data acquisition and management, (4) addressing moving objects – map merging and tracking, (5) understanding what data needs to be observed or collected, and (6) mapping observables to parameter needs of selected models. Thus, while the traditional domain of observing and characterizing the physical landscape involved observing the physical reference environment (e.g., terrain, roads and vegetation), identifying, characterizing and tracking physical objects such as weapon systems and sensors, and understanding the capabilities and intent of physical weapon systems, the new domains are more focused on the human environment and identifying, tracking and characterizing individuals and groups. Clearly, there is overlap between the physical and human domains (e.g., weapon systems are operated in general by humans); however, the new domains are more focused on the human and cyber landscapes and environments. This is consistent with the directed thrusts put forward by the Department of Defense in the latest (2006) Quadrennial Defense Review that mandates a focus on a new set of “Irregular,” “Catastrophic” and “Disruptive” problem domain challenges A summary of the TRL assessment is provided in Table 3.1-1. The summary is based upon a review of 75 references, 18 government programs, 45 models and commercial products, and 26 research organizations and university programs.

Overall, this area has mixed maturity. Technologies associated with characterizing and modeling the human terrain (issues related to understanding individuals, groups and organizations, and understanding intent) are relatively immature. Even understanding what needs to be observed (the equivalent of the “essential elements of information (EII)”), how these observables are linked to an underlying equivalent state vector or matrix, and how to predict the evolution of the human landscape, are very challenging. By contrast, in the traditional world of data fusion systems, observing and characterizing physical targets using physical sensors (automated target tracking, automatic target recognition), extensive research and theoretical foundations exist. While, this is an important area with major implications for the ultimate goals of NGA situational awareness for this problem class, considerable research is required to bring the level of understanding that would permit exploitation via fusion-based techniques and algorithms. It is likely that these areas will need to be initially tracked with subsequent investments by NGA for capability development as they mature. In particular, new multi-year programs such as the Army Research Laboratory Collaborative Technology Alliance (CTA) program for Network Science (Solicitation No. W911NF-08-R-0013, Jan, 27, 2009) are expected to foster major technology advancements in this area.

Table 3.1-1: Summary of TRL Assessments for Understanding & Modeling the New Domains

TRL Area	Technology Area	TRL	Ignore	Track	Influence	Explore	Develop	Transition
Understanding and modeling the new domains	Human landscape modeling technologies	3				●		
	Identifying and representing data imperfections and lineage							
	• Sensor calibration/registration	9						●
	• Uncertainty representation	8						●
	• Pattern learning from SNA	5				●		
	• Pedigree maintenance	4			●			
	• Human source characterization	2				●		
	Models objects data acquisition and management							
	• Georeference moving objects from video	7		●				
	• Point location data model	6	●					
	• Extract moving objects from video	5			●			
	• Trajectory data model(TC211);Trajectory database system	4			●			
	Moving objects map merge and tracking							
	• Off-line map merge/tracking; good data quality of map and object	7					●	
	• On-line map merge/tracking; good data quality of map and object	6					●	
	• Off-line map merge/tracking; low data quality of map or object	3					●	
	• On-line map merge/tracking; low data quality of map or object	2					●	
	Understanding what data needs to be observed or collected and what transformational processes are required							
	• Information needs decomposition	8			●		●	
	• Needs satisfaction modeling	7			●		●	
	• Adaptive collection / process management	6					●	
	Mapping observables to parameter needs of selected models							
	• Information theoretical methods	8			●			
	• Genetic Algorithms	6					●	
	• Adaptive evidence accrual	5					●	
	• SEM methods	4				●		

Highlights include:

- *Human landscape technologies* - The near-midterm state of affairs for human landscape technologies is judged to be immature, but deemed critical since the technology is absolutely necessary in the far-term as the problem-defining engine for other fusion capabilities.
- *Sensor calibration and meta-data generation* - Sensor calibration/registration and uncertainty elements of data lineage technology space are well represented in fully realized programs and ready for NGA transition; pedigree maintenance and human source characterization are fairly immature with very few opportunities to exploit technologies.
- *Moving objects technologies* - Significant differences exist in the maturity of moving-object, map-merge/tracking technologies based on the quality of map/object data in both online/offline fusion scenarios.
- *Geo-referencing objects* - Geo-referencing objects from video and image data is a maturing technology. However, extracting objects from video is still immature, but well-represented in current research efforts.
- *Translating information needs into tasking* - Methods for decomposing high-level needs into actionable intelligence and information models are mature; however, this decomposition becomes more challenging when addressing the human landscape (linking decision needs to essential elements of information and collection sources). Technologies that adapt exploitation processes are less mature with partial solutions in standalone programs.
- *Observables selection* - Technologies supporting systematic selection of observables to meet information needs are maturing, but highly dependent on the maturity of related data alignment, association, and estimation fusion technologies.

3.2 Refining and enhancing the data stream, observations and observation process

Fundamental to automated information fusion is the process of refining and enhancing the data stream, observations and the observation process (as a process automated in software, fusion is still subject to "garbage-in, garbage-out" constraints). In traditional NGA processing, this primarily has entailed focusing on image processing, from the fundamentals of pixel-level processing to object recognition, geo-registration, conflation and related areas. A lot of effort has been expended in the area of automated image exploitation and target recognition. A basic tenet in fusion processing is that one must understand and control error at all steps in the fusion process (from energy detection, signal/image condition, to association and correlation, state vector estimation and ultimately to automated reasoning for situational awareness and threat assessment), so these efforts do have a payoff in eventual fusion processing, but they are pre-processing steps, not fusion *per se*. Technologies associated with signal and image processing and characterization are very mature; however, powerful new techniques are actively being developed and need support. Further, many standard approaches are lacking for want of UAV collection. The entire field needs standard data bases from which to evaluate new methods and algorithms. This technology area has an extensive history of research and practice, especially for traditional "hard" sensors (physical sensors observing physical objects). However, the situation becomes much less mature when dealing with human observations (so-called "soft sensor" reports) and requires translating language-based reports into scalar quantities. Further, characterizing the performance of human observers is immature.

A summary of the TRL assessments is provided in Table 3.2-1. The analysis included consideration of 400 references, six commercial vendors, and twelve research organizations.

Highlights include:

- *Signal and image processing and conditioning* – Traditional signal and image processing is a very mature technology, with numerous sophisticated commercial tools such as MATLAB, Mathematica, and others. Many new techniques are outlined in Appendix B, but their value requires demonstration. As more sophisticated mathematical techniques become available, they will be transitioned to support NGA product development.
- *Automated semantic labeling of image and signal data* – While processing at the signal and pixel level of many hard-sensor data streams has matured considerably, a serious deficiency has existed in automated methods for semantic labeling of image content, necessary to reduce the extensive cognitive workload of human analysts that need to post-process much of the imagery collected and processed today. However, an increasing tidal wave of data and the emergence of methods for automated semantic labeling of images (e.g., tools such as ALIPR (http://alipr.com/about.html) and SIMPlicity) may provide a basis for exploring a generation of semantic meta-data to support rapid retrieval, sorting and characterization of huge data sets.
- *Characterizing "soft" sensors* – The mathematics of characterizing the performance of traditional "hard" (physical) sensors is very mature and well understood. A much less mature area is the characterization of the performance of humans acting as "soft" sensors. This is an increasingly important area not only due to the increased importance of human-based observational data but also to the huge increase of relevant information from sources such as Twitter and on-line blogs.

Table 3.2-1: Summary of TRL Assessments for Refining and Enhancing the Data Stream, Observations and Observation Process

TRL Area	Technology Area	TRL	Ignore	Track	Influence	Explore	Develop	Transition
Refining and enhancing the data stream, observations and observation process	Conflation technologies	8					●	
	Map text/feature extraction							
	• Text	7					●	
	• Features	8		●				
	Image processing/feature extraction/pattern recognition							
	Current Technologies							
	• Registration	9					●	
	• Pan sharpening	9					●	
	• End member extraction	9					●	
	• Data reduction	9					●	
	• Classification	9					●	
	• Feature extraction	9					●	
	• Production support	9					●	
	• Change/anomaly detection	9					●	
	• Subpixel analysis	8					●	
	• Persistence surveillance apps. from those above	2					●	
	Emerging Technologies							
	• Image Fusion	7					●	
	• Noise Filtering							
	• Bilateral Filtering	6					●	
	• Non-iterative, feature preserving mesh smoothing	5					●	
	• Real-time video abstraction	5					●	
	• Diffusion Processes							
	• Partial differential equations in image processing	5					●	
	• Continuous diffusion filtering	5					●	
	• Semi-discrete diffusion filtering	5					●	
	• Differential geometry and the scale-space approach	4					●	
	• Registration							
	• Elastic model based deformations	6					●	
	• Elastic registration	6					●	
	• Diffeomorphic-Non-linear image registration	3					●	
	• Riemannian elasticity	3					●	
	• Non-Rigid Transformations	5					●	
	• Linear elastic transformations	6					●	
	• Fluid flow transformations	6					●	
	• Transformations based on basis function expansion	6					●	
	• Adaptive irregular grids	4					●	

Table 3.2-1: Summary of TRL Assessments for Refining and Enhancing the Data Stream, Observations and Observation Process

TRL Area	Technology Area	TRL	Ignore	Track	Influence	Explore	Develop	Transition
	• Segmentation						●	
	• Normalized cut graphs	5					●	
	• Level Sets	5					●	
	• Action volumes	4					●	
	• Manifold learning	4					●	
	• Tensor voting	3					●	
	• Visual Cortex Modeling	4					●	
	• Semantic labeling	6					●	
	Source Characterization – human soft sensor	1				●		

3.3 Net-centric infrastructure

Improved connectivity for data distribution, access to resources, distributed computing and collaboration provide enabling technology for net-centric operations (both for own-force resources as well as adversary operations). The focus of this technology area assessment involves understanding how rapid changes in technology both enable improved information fusion as well as provide challenges to the fusion process. Specific areas of focus included security technologies (SOA) security edge protection, identification and authorization, intrusion detection, public key encrypted concepts, and data storage, tasking, labeling and related concepts, as well as service-relevant fusion services such as presentation, meta-data, reliability and messaging, security and authorization, workflow and orchestration, and repository and grid concepts. The commercial world and web 2.0 technologies are leading this area. A key for NGA is tracking these changes and adapting their own cyber infrastructure as appropriate. The rapid evolution of net-centric infrastructure technologies acts as an enabler for distributed data collection, dissemination and analysis. However, it also provides challenges related to data integrity, pedigree, understanding the evolution and origin of products, and establishing standards and methods for the overall analytic process.

A summary of TRL levels is shown in Table 3.3-1. The analysis included a review of 350 COTS products, evaluation of 55 standards, and evaluation of 11 security standards.

Table 3.3-1: Summary of TRL Assessment for Net-centric Infrastructure

TRL Area	Technology Area	TRL	Ignore	Track	Influence	Explore	Develop	Transition
Net-Centric Infrastructure	Security Technologies							
	• SOA Security Edge Protection	8					●	
	• Identification and Authorization	8					●	
	• Secure Portal	8					●	
	• Intrusion Detection, Event / Threat Correlation	8					●	
	• PKI Enablement, Single Sign-on, Security Persistence, Data Integrity /Confidentiality, Cross Domain HAG	7					●	
	• Data Storage, Tagging, Labeling, Cross Domain Identity Management	6					●	
	Service-Based Relevant Fusion Services						●	
	• Presentation	7					●	
	• Meta-data	6					●	
	• Reliability and Messaging	6					●	
	• Security and Authorization	6					●	
	• Workflow and Orchestration	6					●	
	• Repository	6					●	
	• Grid	6					●	

Highlights include:

- *Net-centric infrastructure* - Net-centric infrastructure inward/outward facing fusion service technologies (Presentation, Meta-Data, Reliability and Messaging, Workflow and Orchestration, Repository, Grid) are mature and ready for transition within NGA applications. Risk of transition is low; performance is acceptable to good with good to excellent supportability.
- *Security-based services* - Security-based net-centric services are mostly mature and ready for transition within NGA fusion applications. MLS/Trusted OS technologies and data storage tagging/automated labeling technologies are somewhat less mature, but well represented in program/research efforts.
- *Standards* - Standards integral to the GEOINT Service Reference Architecture are mature, stable, and well-represented in COTs products.
- *Interoperability* - Interoperability is well demonstrated across core standards suites.
- *Evolving web technologies* - The commercial world and web 2.0 technologies are leading this area. A key for NGA is tracking these changes and adapting their own cyber infrastructure as appropriate.

3.4 Support for improved human-in-the-loop analysis and data understanding

It is common in information fusion research and development to focus on the incoming data and subsequent data processing. Fusion systems start at the sensing and data ingestion side of fusion and proceed to development of data bases and visual displays that are (typically) passively observed by a human analyst in most of today's systems. This approach focuses the fusion process on "serving the sensors" rather than supporting a human decision-maker/analyst. This technology area takes the viewpoint that humans can become very active in the fusion process, leveraging their visualization, pattern recognition skills, semantic reasoning abilities, and collaboration skills to participate in a hybrid human/computing fusion process. To that end, an analysis was conducted of technologies aimed at improving human in the loop analysis and data understanding. Subareas of interest included: (1) data mining, knowledge and pattern discovery, and hypothesis generation techniques, (2) visualization for geo-spatial data, intelligence browsing and data understanding, (3) ontology query, integration and navigation, (4) autonomous workflow management, (5) multi (human) sensory human computer interaction, and (6) collaboration and virtual world technologies.

The review included evaluation of 25 research organizations, 33 ontology tools, 11 ontology frameworks, and several reference texts. A summary of the TRL assessment for this area is shown in Table 3.4-1. This is an important area for enhancing synergistic analyst-system performance. The increasingly overwhelming collection of data from traditional hard sensors and new information sources such as the web and human soft sensors threatens to significantly reduce analyst performance and capability. Data overload can result in what McNeese *(Cognitive Systems Engineering in Military Aviation Environments: Avoiding Cogminutia Fragmentosa*, M. D. McNeese and M. A. Vidulich ed. 2003) has termed "cogminutia fragmentosa" (effectively making analysts perform in a fragmented way about trivial issues). Progress in this area can simultaneously enhance current analysis while providing a basis for addressing increasing data rates and new data sources. Progress has been made along many lines of technology that can improve the human-system composite performance, but the ability to dynamically and specifically integrate human intelligence with machine processing remains a distant goal.

Highlights include:

- *Data mining, pattern discovery and intelligent algorithms* - Extensive research has been conducted in data mining, pattern recognition, machine learning and related areas. Numerous commercial tools exist and can be readily applied to support improved analysis. This is a mature technology area that can be adapted to NGA processes.
- *Hypothesis generation* – Currently, hypothesis generation is primarily a manual process that can be augmented by cognitive aids such as logical templates, team-based intelligent agents, and gaming techniques. This is anticipated to be a fertile area for exploration, especially when considering decision-driven processing concepts.
- *Geospatial data interaction* – Geospatial information systems (GIS) have become very mature with sophisticated commercial tools such as ArcGIS and others. Rapid progress in this area is driven by commercial enterprises such as Google Earth.
- *Ontology query, integration, navigation* - Basic theory and standards for ontology query, integration and navigation are rapidly evolving, spurred in part by DARPA funding and by commercial needs. These techniques are very necessary for semantic-level fusion of heterogeneous data. Extensive background work will likely be required to perform the requisite knowledge engineering to populate the ontological models.

Table 3.4-1: Summary of TRL Assessment for Improved Human-in-the-Loop Analysis/Data Understanding

TRL Area	Technology Area	TRL	Ignore	Track	Influence	Explore	Develop	Transition
Support for improved human in-the-loop analysis and data understanding	Data mining knowledge, pattern discovery, feature extraction, intelligent algorithm technologies	8						●
	• Anomaly discovery technologies, self-assessment self refusal technologies	7				●		
	• Hypothesis generation technologies	5				●		
	Visualization for Geo-spatial data intelligence browsing adaptive display technologies	8					●	●
	• GIS Systems	8					●	
	Ontology query, integration, navigation; ontology integration	5				●		
	• Ontology standards and data base tools	6		●				
	• Knowledge engineering and ontology population	5				●		
	Autonomous workflow management human cognition technologies	7		●				
	• Understanding workflow and performance optimization	5		●				
	Multi (human) sensory human-computer interaction							
	• Immersive, 3-D visual displays	8						●
	• Sonification	4				●		
	• Haptic interfaces	2		●				
	Collaboration and visual world technologies	5			●			
	• Virtual world tools (e.g., 2nd Life, etc.)	6		●				
	• Virtual world collaboration and analysis	3				●		

- *Multi-sensory human computer interaction* – This area has mixed maturity. Full immersion, 3-D environments have become sophisticated and have been deployed at various operational locations, as well as in other agencies. The tools provide impressive interaction and significantly enhance analysis capability. Less work has been done for displaying information along the various dimensions of the human landscape. The area of sonification (use of sound to interact with data) appears promising, especially for assisting in focus of attention and anomaly detection. Haptic (touch-based) interfaces and gesture recognition techniques are intriguing bur relatively immature.
- *Collaboration and virtual world technologies* – The digital natives (younger generation of analysts) are quite familiar with emerging virtual world technologies such as 2ndLife, Olivia and other tools. The development of the tools is driven by the commercial world (in part spurred by the computer gaming industry). However, the tools have not achieved standard use, are often "stand-alone" and highly proprietary, and their utility for collaborative analysis has not yet been proven.

3.5 Intelligent systems for automated situational awareness and anomaly detection

Extensive work has been conducted over many years to achieve the “holy grail” of automated situational awareness and anomaly detection. Clearly this is applicable to information fusion to assist human operators and analysts in sorting through huge data sets for improved understanding of an evolving situation or threat. Over a multi-decade period, a great deal of research in information fusion and artificial intelligence (AI) has been conducted on automated reasoning and seeking to perform computer based inferencing to achieve the equivalent of human analyst situational awareness and data understanding. Given the increasingly huge data overload of analysts, this is a natural area to explore for assisting the transformation from energy and data to actionable knowledge. However, the results frequently have been disappointing. The early excitement of expert systems (e.g., utilizing rule-based systems, templating, case-based reasoning, Bayesian belief nets, and other techniques) gave way to a realization about the challenges of knowledge elicitation and representation, efforts to obtain a priori information and probabilities, and the brittleness of automated reasoning systems. Despite these challenges, there are emerging techniques that can support information fusion for NGA.

A review in this technology area included assessing: machine learning, the application of models against incoming data for anomaly detection, evidential reasoning across diverse digital data, uncertainty management for situation and threat assessment, ontology languages, and ontologies for situation and threat assessment. The review included 196 technical papers, 7 university research centers, 5 government and industrial programs, 6 COTS software applications, 6 commercial research organizations, 13 separate evidential reasoning approaches, and 4 situational awareness models A summary of the TRL assessments is shown in Table 3.5-1.

Table 3.5-1: Summary of TRL Assessment for Intelligent Systems for Automated SA and Anomaly Detection

TRL Area	Technology Area	TRL	Ignore	Track	Influence	Explore	Develop	Transition
Intelligent systems for automated situational awareness and anomaly detection	Machine Learning							
	• Regression Methods	4		●				
	• Automatic Neural Network Methods	4			●			
	• Support Vector Machines	3			●			
	• Relevance Vector Machines	3			●			
	Application of models against incoming data for anomaly detection							
	• Matched Filter-Based Methods	5					●	
	• Multi-level, Multi-look	2				●		
	• Hybrid	2				●		
	• Active Decision Scheme	2				●		
	• Invariant Subspace Algorithm	2	●					
	Evidential Reasoning across Diverse Geospatial Data							
	• Matched Filter Based Methods	6	●					
	• Model-Based Fusion	5					●	

Table 3.5-1: Summary of TRL Assessment for Intelligent Systems for Automated SA and Anomaly Detection

TRL Area	Technology Area	TRL	Ignore	Track	Influence	Explore	Develop	Transition
	• Genetic Algorithms	4		●				
	• Multi-level, Multi-look	4				●		
	• Hybrid Methods	2		●				
	Uncertainty Management for Situation / Threat Assessment							
	• Probabilistic Methods	5					●	
	• Fuzzy Methods	4			●			
	• Evidential Methods	3		●				
	• Graph Theoretic Methods	3				●		
	• Pixel/Region Multilevel Methods	3				●		
	• Joint Registration/Tracking Multilevel Methods	2		●				
	Ontology Languages							
	• OWL	5		●				
	• Protégé	5		●				
	• PR-OWL	4			●			
	• CASL	4		●				
	• SNePS	3			●			
	• IDEF5	3				●		
	Ontologies for Situation/Threat Assessment							
	• Core SA Ontology	2				●		
	• Ontology of Threat and Vulnerability	2				●		

A brief summary:

- *Machine learning* - State of the art for relevance vector, support vector, automatic neural network, Bayesian and regression machine learning technologies is immature, but well-represented in current research work.
- *Model-based anomaly detection* - With the exception of matched filter-based methods and model-based anomaly detection approaches, model-based anomaly detection technologies are very immature with active pockets of research in industry and academia.
- *Evidential reasoning* - With the exception of matched filter-based methods, and model-based fusion approaches, evidential reasoning technologies are somewhat immature, but research is very active in academia and commercial industry. However, such research is narrowly focused, with very little emphasis on integrated solutions.
- *Uncertainty Management* - Joint registration, pixel/region multi-level methods, graph theoretical, evidential, fuzzy, and probabilistic methods provide increasing levels of

uncertainty management maturity, with significant active research in industry and academia. Research is primarily targeted at point solutions.

4.0 RECOMMENDATIONS

Based on the panel presentations and discussions, survey-based technology assessments, and subsequent analysis, a number of recommendations were developed for the near-term, mid-term and far-term time frames. A summary of the recommendations is shown in Figure 4.1. Each of the recommended actions is described further in table 4.0-1 which provides for each project a brief description and identification of rationale and potential payoff.

The overall strategy for developing the recommendations involves several basic principles:

1. *Optimize analyst attention units* - Recognize and address the fundamental limitation in the "system of systems" involving tasking, data collection, distribution, and analysis (namely the limited number of analysts and limited "human attention units" available).
2. *Balance technology with human capability* - The recommendations reflect having a human in the loop process, rather than seeking complete automation. The use of experienced analysts leverages human capabilities for pattern recognition and context-based reasoning.
3. *Serve the users* - Work from both a data driven and a hypothesis driven approach so that the overall system serves not only the collection resources, but also the human user/analyst.
4. *Seek low hanging fruit* - Identify areas for near-term projects that involve mature technologies readily applicable to the NGA analysis process.
5. *Leverage on-going programs and rapidly evolving commercial technologies* - Selectively monitor funded programs and commercial technology developments to use "other people's technologies."
6. *Assess the evolving problem* - Continue to assess the new domains of interest and the evolving culture of the digital natives to ensure that the NGA investments address the rapidly evolving digital world.

It is beyond the scope of this study to provide specific statements of work and cost estimates for the recommended tasks. As described above, some of the tasks must be performed internally by NGA (or support) personnel, and some efforts will likely or necessarily be contracted externally. For example, the recommended development of case studies and assessment of NGA operational concepts and cyber-infrastructure require access to internal NGA operations. By contrast, monitoring ARL CTA projects, analysis of asymmetric intelligence operations, and other areas could be outsourced.

In addition, we have not prioritized the recommendations within the technology areas (nor prioritized the technology areas among themselves). The recommended projects have a range of potential cost, effort, and payoff. For example, monitoring the ARL CTA or various other important fusion technology projects may involve attending annual review meetings or reviewing annual technical documents, while developing and evaluating new methods for signal semantic labeling could require multiple man years of effort. After review of these recommendations, additional analysis could be conducted to estimate the potential level of effort as well as the potential payoff.

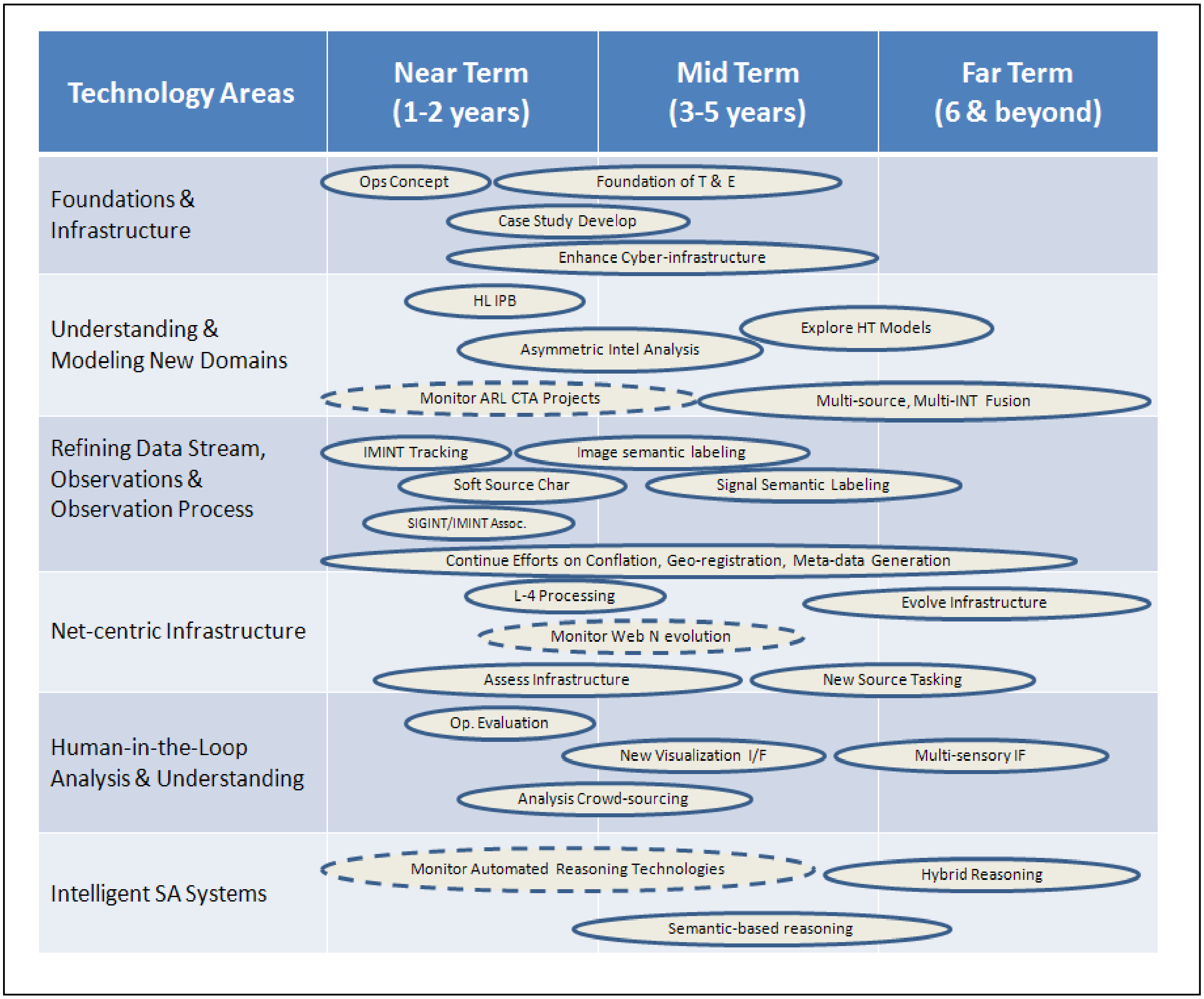

Figure 4.0-1: Summary of Recommendations

Table 4.0-1: Summary List of Recommendations

Time Frame	Description	Benefit/Payoff
Foundations & Infrastructure		
Near Term	*Ops Concept:* Develop an operational concept and reference model framework for NGA fusion perspectives	Establishes a basis for the fusion perspective and interaction with other agencies; develops user perspectives & priorities
Near Term/ Mid Term	*Enhance Cyber infrastructure*: Using SOA methods and web 2.0 evolution, enhance the NGA cyber infrastructure to allow data interaction with other agencies; including development of baseline ontologies, standards, etc.	Required for effective fusion interaction with other sources and agencies (regardless of role selected)
Near Term/ Mid Term	*Case Study Development* – Obtain historical information on “success stories” related to NGA utilization of data to support operations; collect “ground truth,” data collected & processed, and OPINT available at the time	Provides a baseline for test and evaluation of new techniques; guides new operational concepts & investments
Near Term/ Mid Term	*Foundations of T&E:* Establish formal foundations for rigorous test & evaluation of end-to-end data to knowledge process (including metrics, approach for human in the loop evaluation, etc)	Establishes a firm basis for evaluation of tools & techniques as well as investment decisions
Understanding & Modeling New Domains		
Near Term	Monitor the Army Research Lab Collaborative Technology Alliance (CTA) IRC, INARC & SNARC programs (anticipated Aug, 2009). More generally, identify and monitor DoD programs addressing “new domain” problems.	Leverage 5-year, $ 50 M ARL CTA program, as well as others
Near Term	*HL IPB*: Establish Intelligent Preparation of the Battlespace for human landscape concepts; work with U. S. Army programs to identify essential elements of information, observables, etc.	Baseline for addressing the new problem domains
NearTerm/ Mid Term	*Asymmetric Intel Analysis:* Using case studies such as Mumbai incident and terrorist use of technologies such as Twitter, etc., develop an understanding of how asymmetric intelligence and C^2 affects dynamic and diminish U. S. capabilities; How can these asymmetric techniques be incorporated into traditional processing/collection roles?	Provides basis for determining how our capabilities may be countered or undermined by COTS/Web N “technological judo”
Mid Term	*Explore human terrain (HT) models*: assess the viability of models to link observations to HT “state vector” equivalent and predictive models – implement baseline models	Basis for HT predictive models (viz., “left of boom”)
MidTerm/ Long Term	*Multi-source, Multi-INT fusion*: Based on HLIPB and HT models develop a framework and fusion models for fusion of multi-source, multi-INT HT related data	Establishes potential for major new capability in situational awareness via multi-source, multi-INT fusion

Table 4.0-1: Summary List of Recommendations

Time Frame	Description	Benefit/Payoff
Refine Data Stream, Observations & Observation Process		
Near Term	Establish association/correlation approach for SIGINT/IMINT at report level	Basis for rapid data association to enable SIGINT/IMINT fusion
	Develop IMINT automated target tracking (e.g. report level tracking using image data)	Improved automation, reduced analyst workload
	Characterize soft sources (how to transform fuzzy semantic terms into scalar observations; how to characterize uncertainty)	Prepares the way for utilization of soft sensors and fusion with hard sensor data
Near Term/ Long Term	Continue efforts on refining the NGA products via improved geo-registration, conflation, etc.	Enhanced baseline products
Near Term/ Mid Term	Explore automated semantic labeling of image data using ALIP type methods	Provides basis for semantic level image retrieval, sorting & reasoning
	Explore automated semantic labeling of SIGINT & related data	Provides basis for semantic level signal data retrieval, sorting & reasoning
	Explore and monitor ongoing research in human observational modeling (e.g., ARO Hard and Soft Fusion MURI program)	Provides basis of understanding for role and placement of NGA data and algorithms in these "New domain" systems
Net-centric Infrastructure		
Near Term/ Mid Term	Monitor web 2.0 & beyond technologies for implications for NGA cyber-infrastructure	Provides leverage of commercial developments for NGA
Near Term/ Mid Term	*Assess infrastructure*: Assess the current and planned network centric infrastructure (especially the information architecture concepts) as it relates to selected NGA fusion role	Provides basis for planning and evolving infrastructure to support distributed fusion approach
Mid Term	*L-4 Processing:* Assess the tasking and control of collection resources; develop metrics for optimization based on information utility (for enhanced decision-making) and implement resource allocation/tasking using user-centered metrics	Optimizes the use of resources to "serve the decision-maker/analyst rather than the collection system
	New source tasking: Develop approaches for tasking new types of resources such as soft sensors and open-source (Web-based) data to augment tasking of traditional sources	Provides enhancement of overall information tasking and collection

Table 4.0-1: Summary List of Recommendations

Time Frame	Description	Benefit/Payoff
Long Term	*Evolve infrastructure:* In the long term, it will not doubt be necessary to evolve the net-centric infrastructure to account for new sensor types, sensor platforms, new OPINT sources, soft sensors, crowd-sourcing of observations and analysis, etc. This task should systematically prepare for that evolution.	Provides basis for next generation net-centric infrastructure.
Human-in-the-Loop Analysis & Understanding		
Near Term	*Ops Evaluation*: Conduct ethnographic studies of current NGA analysis methods and analysts (especially vis a vis digital natives vs. digital immigrants); evaluation emerging techniques at KRSOC, JIATF South, etc.	Improves understanding of actual analyst needs and practices
Mid Term	New advanced visualization techniques for Human Landscape information & data analysis	Enhance analyst interaction with models & data sets
Long Term	Multi (human) sensory interaction with complex data sets (includes haptic, sonification, visualization, gesture recognition, etc)	Enhanced analyst productivity (reduces human-data impedance "mismatch")
Mid Term	*Analysis crowd-sourcing*: Explore use of virtual world and related collaborative aids for distributed, ad hoc, dynamic problem solving and analysis	Potential for improved analysis solutions (more creative, less "brittle") and enhanced experience for digital native analysts
Intelligent Situation Awareness Systems		
Near Term/ Mid Term	*Automated reasoning technologies*: Monitor the progress in automated reasoning techniques (viz. evolution of ontological methods, Bayesian Belief nets and hybrid reasoning)	Establishes a basis for MT/LT investments in automated context-based reasoning
Mid Term	*Semantic based reasoning*: Using the results of the semantic labeling of image & signal data, develop semantic level fusion and reasoning systems	Increased automation and improved robustness for situational awareness
Long Term	*Hybrid reasoning*: Based on maturity of human terrain models, explore hybrid based reasoning methods that combine data mining and machine learning methods with model-based prediction models	Automation and fusion for situational awareness and threat analysis

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5.0 SUMMARY

Extensive reviews, analyses, and assessments of the data/information fusion technology and application arena were conducted to help develop a roadmap for future investment decisions by NGA. These efforts are summarized in this document. Perhaps even more important than technology forecasts and assessments, however, is the need for NGA to develop its own perspectives and focus on what roles are most feasible and desired for them in a multi-source fusion-capable environment. Implementation will depend upon how NGA balances their joint missions of developing fundamental data and information for foundational data bases versus their need to support tactical operations and missions. The changing focus on the human landscape (versus the traditional physical landscape) will affect how NGA's response. Rapid changes in information technologies provide both opportunities for increased net-centric operations and use of new information sources such as ad hoc human observers and information on the web, as well as increased threats from asymmetric information collection, dissemination and command and control.

Finally, we suggested that the following represents some "low hanging fruit" that could be addressed to obtain very near term improvements in NGA data fusion operations and preparation for more substantial follow-on improvements:

1. *Automated tracking of moving targets* – A straightforward application would entail automating the tracking of moving objects using image data (e.g., frame-to-frame images) by using a simple approach such as an alpha-beta filter in "observation space" to assist users. This would allow characterization of target tracks and prediction capabilities. Such a capability would be relatively easy to implement and would provide supporting automation for NGA operations.

2. *Correlation/association of IMINT/SIGINT* – In order to assist automated fusion (or even manual fusion) of SIGINT and IMINT data, general correlation/association techniques could be developed (e.g., using a generalized measure of correlation/association at the report level). This would allow rapid sorting of SIGINT and IMINT data to determine what could/should be fused.

3. *Level*-4 *processing for resource planning* – Some improvements could be readily made to the problem of allocating collection "resources" for mission planning (level-4 refers to the Joint Directors of Laboratories (JDL) data fusion process model focusing on the meta-problem of dynamically improving collection and processing). The current approach (viewed as a 3-way assignment problem) could be readily augmented with optimization, with an emphasis on quantifying the value of collected information to meet decision-maker/analyst needs.

4. *Automated Semantic labeling of images* – While a bit challenging, there are existing methods for automated semantic labeling of images that could be applied to NGA products to support rapid data retrieval, cataloging, filtering, etc. This would require access to sample products and analysts to support the generation of appropriate sample labels and training data.

5. *Analyst Fly-away kit* – For analysts who are deployed to support specific operations or areas of interest, it could be useful to develop a cyber "fly-away" kit that would be a pre-configured analyst environment containing information (e.g. open source information, RSS feeds, etc.) that would support the analysis process. This would enable experienced analysts to develop "lessons learned" from deployments (i.e., " if only I had known this information, or included this tool…") to help other analysts.

6. *Digital Native Analysis* – The newest generation of analysts is considered to be comprised of “digital natives,” who interact with data and each other in a different way than older, more traditional “digital immigrant” analysts. It would be useful to talk with new analysts, observe their analytical and collaborative methods (and contrast them with traditional methods) and develop tools to support their perspectives and working styles.

7. *Development of sample use cases* – It would certainly be valuable to develop a few “use cases” based on historical examples of successes and not so successes to guide near term investments. The use cases would contain a description of the problem addressed by NGA analysts, the data they had available, what could have been obtained from open sources (viz., what could they have learned at the time from open sources, but may not have had available), what types of analysis worked well, what were challenges, etc.

NTA

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