Employing Cognitive Task Analysis to Define Intelligent Agent System Requirements

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ABSTRACT

Requirements identification is a critical step in the development of any system. When the goal is to develop automation software to offload and augment tasks previously done by humans, the requirements identification challenge becomes one of understanding what experts do, why they do it, and when they do it. To accomplish this, a cognitive task analysis (CTA) was conducted to enumerate the what, when, and why of job performance for trainers at the Joint Warfighting Center (JWFC). The results are being used to help build intelligent agent software to aid trainers associated with Category 3 level training. A total of seventeen interviews were completed and the resultant data provided a wealth of information for compilation and review. This included crucial information that helped to define the intelligent agents software. For example, the CTA revealed types of instructional feedback the trainers give and when they give it. In addition to the knowledge used directly for software development, the results also gave insight regarding the practical considerations of using CTA. The purpose of this paper is to define the CTA problem space, discuss different approaches that were considered, and describe the methodology used for conducting the CTA. The paper will conclude with results and lessons learned that demonstrate the applicability of CTA to the project at hand, as well as to the larger community of training systems.

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INTRODUCTION

Within the military, simulation has been used for many years as a vital training tool. However, research over the past 2 decades has argued persuasively that while the immersive quality that simulation affords is necessary to effective training, it is not sufficient. Structuring the training environment in which simulation is used is essential to ensuring that desired learning takes place and negative training is avoided. Historically this structure has been achieved through the use of expert trainers. As budgets decrease and the military's reliance on simulation-based training increases, there is a corresponding pressure to reduce or eliminate the labor cost associated with expert trainers. Thus, there exists a strong requirement for research and development for automating and augmenting simulation-based training.

Recently, as part of a larger effort to develop intelligent agents to support real-time feedback in scenario based training, a cognitive task analysis (CTA) was conducted at the U.S. Joint Forces Command Joint Warfighting Center. The CTA focused on "trainers" (i.e., those personnel responsible for creating and maintaining the scenario) in order to develop a better understanding of the context in which the software would need to perform. Conducting the CTA proved to be a difficult, labor intensive, and ultimately, very rewarding endeavor. The purpose of this paper is to describe the CTA process and results. To accomplish this, the paper first describes the requirements that drove the CTA and presents different CTA methods that we considered for use in this project. This is followed by a description of the CTA approach used in the current effort and the results. The paper concludes with a discussion of the costs and benefits associated with CTA as a tool to aid training system development.

Background

The US Military has used "wargaming" in one form or another since the 1890's to analyze and train its forces in the art of war/military art. The last twenty years have yielded advances in computer technology that have moved away from the set piece games of World War II and towards sophisticated virtual constructs of the Battlespace.

Levels of War

Conceptually, warfare is conducted at three levels. The highest level is strategic, the middle level is operational, and the lowest level is tactical (Chapter 2, Joint Pub 3-0, "Doctrine for Joint Operations"). Depending on the level of warfare (i.e., the task that ultimately will be performed), the type of required training varies. The types of training, in turn, are categorized into six categories (e.g., Category 1, Category 2, etc.). These categories are determined by the aim or objective of the military force as it applies to the specific task it is performing.

The current effort focused on the operational level of war. The operational level of war requires "Category 3" training. In Category 3 training, a need exists to develop innovative approaches for training the complex skills required by individuals, teams and staffs such as Joint Task Force Commanders, their Component Commanders, and their staffs to make decisions based on the information gleaned from command, control, communications, computers, intelligence, surveillance, & reconnaissance systems (C4ISR). The nature of the command and control tasks and team environment introduces a number of challenges for scenario development, data collection for feedback, and feedback processes.

Requirements for building Intelligent Agents

The objective of the Intelligent Agents (IAGENTS) project is to develop, implement, and demonstrate instructionally sound training strategies and includes a concentration on automating the process of scenario adaptation during runtime (Oser, McCluskey, Blickensderfer, Campbell, and Lyons, 2000). In order to achieve this objective, tools such as software-based intelligent agents, common database structures, human performance modeling, and performance measurement systems will be incorporated within these strategies. The development, implementation, and demonstration will focus on streamlining exercise planning and design in support of real-time control and modification of exercises as a function of training audience performance, as well as the subsequent effect on diagnostic after action reviews and training performance database archiving and management.

In simple terms, the IAGENTS effort is focused on mimicking and/or augmenting what trainers in large scale exercises currently do. Though there is ample documentation that addresses doctrine and guidance for joint training, there is little detailed description of how it is done. Thus, the following requirements were identified:

1. Need to identify a set of trainer tasks—to extrapolate functionality for IAGENTS
2. Need to understand what trainers observe about training audience performance—to determine performance measures, and
3. Need to identify what trainers think about and how they provide instructional feedback—to help IAGENTS evaluate options.

While these requirements appear straightforward, in a complex environment such as that represented by Category 3 training, obtaining the "answers" is not a matter of reading a user's manual or even asking the above questions of the trainers. Rather, in light of the cognitive implications of these questions, it was determined that a CTA was needed.

CTA methodologies

Complex man-machine systems have become pervasive throughout the workplace in both military and non-military settings. Thus, the nature of work and tasks has changed and the work place has become more sophisticated. Workers have evolved from being actively engaged in doing tasks to being supervisors and monitors of tasks. While the automation provided by technology has resulted in decreased labor costs and increased production, it has also had the effect of making tasks more cognitively demanding. Understanding and representing how workers accomplish tasks in these environments demands task analysis methods that incorporate the cognitive aspects of tasks—thus was born cognitive task analysis.

The relevance of CTA as a necessary step in developing training for systems and the system itself is evidenced by recent review work. A special issue of Human Factors (Hoffman and Woods, 2000) focused on CTA while Schraagen, Chipman, and Shute (2000) discuss 20 different review papers on the topic in their state-of-the-art review of CTA. In an even more recent effort sponsored by the Office of Naval Research, the CTA Resource Project (http://www.ctaresource.com) has catalogued over 100 techniques for CTA.

While there are a variety of approaches available for conducting a CTA, the common premise shared by all is that complex performance is dependent upon something beyond rote memorization, namely, individuals and teams' ability to access knowledge, assess task requirements, and dynamically make decisions based on the results of these processes. In other words, in order to understand performance in complex environments, we need to understand the cognitive structures and processes that mediate that performance.

When the IAGENTS project began, a CTA of the trainers was planned. During the preparation for the CTA and other initial work on the project, it was realized that a great deal of basic task analysis also was needed, simply because this information was not documented anywhere, yet the project demanded it. Thus, what was labeled as a CTA became much broader than a traditional CTA.

As CTA methods were reviewed, three salient features emerged regarding the state of the art with respect to these techniques. First, though CTA techniques have proven to be integral for both those designing systems and those designing training, typically, these methods emphasize cognitive structures and processes while failing to address the impact of the environment in which tasks take place. As such, CTA fails to address environmental factors that can impact human performance (Potter, Roth, Woods, and Elm, 2000).

A second limitation of CTA techniques is that the state of the art is relatively primitive with respect to ease of use by the non-expert. That is, while there is ample documentation of CTA techniques, the ability to use these techniques is predicated upon years of experience with a given technique.

A final limitation of current techniques that is especially relevant to the current effort is that CTA techniques typically produce written products that do

not easily translate into system design.

In light of these limitations, the current CTA was conducted using techniques and methods developed especially for this effort. A description of the approach is provided next.

METHOD

In order to capture and document the experience of the trainers at the Joint Warfighting Center (JWFC), a series of three interviews were conducted with different JWFC personnel over a period of five months. Questions used for the CTA were developed by a team consisting of a research psychologist, subject matter experts (SMEs), and the computer scientists who were responsible for developing the subsequent IAGENTS software. This was an iterative process that included a review of available Joint Doctrine and, by the final set of interviews, ultimately resulted in a list of 389 questions. To organize the questions, they were categorized by personnel type. The personnel types used and their rough descriptions are shown in Table 1. The questions were also categorized into nine job type categories shown in Table 2.

A total of sixteen interviews were completed with seventeen different people associated with Category 3 level training at the JWFC. This represents approximately 20% of the applicable personnel.

The CTA interviews produced over 804 answers resulting in 120 pages of text in response to the questions. Based on the volume and diversity of the data, it was decided to conduct a further review and breakout of this information to arrive at a more useable format.

This was completed using a four-phase process that reviewed the data and created shorter categorized statements. These statements were reviewed and assigned to sub-categories that led to a meaningful and relational linkage.

During Phase I, all 804 answers were reviewed independently and statements of thought were pulled from the long answers and placed into four categories. The four categories used were:

1. Responsibility—responsibilities are what I do or am required to do in my job
2. Techniques—techniques are the how I do what I do in my job, including who I meet with, what tools I use, how I communicate, how I make decisions, how I present my information to others
3. Products—products are the things (e.g., Master Scenario Event List (MSEL), Collection Management Plan, Checklists, Opposing force(s) Campaign Plan, etc…) that I produce, use, or interact with in doing my job, and
4. Interactions—interactions are the people, systems, or products that I interact with to do my job

To ensure that information was captured and coded appropriately, during coding it was intended that a single statement could be formatted to fit into all four categories. The statement creation and coding process resulted in generating 3126 statements (824 Responsibilities, 1315 Techniques, 503 Products, and 484 Interactions).

Table 1: Personnel types used for question categorization

Quests.	Category	Definition
259	After Action Review (AAR) Analysts	Civilian contractors that work with the Observer/trainers to document the training audience performance and prepare the AAR debriefs. Involved in developing standards for evaluating training audience performance.
273	Exercise Controller	Military Exercise Controller or civilian Deputy Exercise Controller that provides runtime control of the exercise.
129	Intelligence Control Cell	Provides control for the Intelligence functions that provide information to the training audience and ensure the intelligence requests for information are handled appropriately.
136	M&S Response Cell	Modeling and Simulation (M&S) response cell, group that receives inputs from the training audience and inputs these items into the models and monitors the models for correct output.
266	MSEL Director	Directs the MSEL control group that develops the MSEL for the exercise and then monitors its execution and changes.
342	Observer/Trainer (O/T)	Military observers of JWFC exercises who directly interface with the training audience used for July 2001 interviews
75	OPFOR	Opposing force controllers, involved in development and execution of exercise working in the White Cell to control OPFOR
78	Role Player	Group that provides feedback and response directly to the training audience in support of the scenario, represents News Agencies, State Department, Red Cross, etc.
216	Senior Mentor	Senior Observer of the commander of the Joint Task Force usually retired 4 star General or Admiral.
76	Training Objective Development	Group that interacts with the training audience to develop the training objectives for a given exercise, not involved during runtime or in MSEL development.

Table 2: Job types used for question categorization

Questions	Answers	Type	Description
16	12	After Action Review	How the results of the exercise are presented during runtime (midcourse AAR) and post exercise to show the training audience, trainers, and others how the exercise went. How the exercise is presented to show the completion of required training goals.
46	59	Data Collection	How the plan for collection of information throughout the exercise is developed. How the data is collected. How the plans are changed as the exercise changes in real time. How the collected information is archived for storage between exercises.
104	203	Exercise Control	How the exercise is controlled during runtime. What must be done prior to exercise start to ensure the exercise will work as planned. How decisions to change the flow of the exercise are handled and how exercise flow is maintained.
29	67	Exercise Creation	How the exercise scenario is developed prior to runtime. How training objectives are integrated into the scenario and how instructional requirements are built into the exercise.
55	76	Instruc-tional Control	How the trainers control the flow of the scenario to ensure that the training objectives for the exercise are achieved. How changes are made to account for training audience actions and how learning is achieved through control of the exercise.

Questions	Answers	Type	Description
38	72	Training Assess-ment	How the training audience is assessed during the exercise. How the collected data is analyzed and how decisions are made regarding the completion of training objectives.
8	17	Training Audience Actions	Actions taken by the training audience that may impact the exercise.
23	40	Training Objectives	How training objectives for the exercise are developed. What resources are used and how training objectives are selected for a specific exercise.
70	259	Work Environ.	General working conditions of the subject and the training audience. Including communications and how things are done in the area.
389	805	Total	Total of answers removing the 4 O/T's individual answers and leaving the Consensus

Once ten percent of Phase I was completed, a Phase II sub-categorization coding test was conducted. Using ten percent of the generated statements in each of the four major categories, two evaluators independently reviewed the statements and developed sub-categories for the statements. Once these sub-categories were developed, the evaluators reviewed their sub-categorization scheme and developed a consensus scheme and definitions for each of the sub-categories. Inter-evaluator agreement in terms of the number of sub-categories was consistently high as was agreement with respect to coding of specific statements within the sub-categories. This resulted in developing 7 sub-categories for Responsibilities, 7 sub-categories for Techniques, 8 sub-categories for Interactions, and 4 sub-categories for Products.

Once Phase I coding and Phase II testing were completed for each category, the full set of data was reviewed and assigned to the sub-categories developed. This process was completed by the two evaluators who developed the sub-category definitions for each category to improve consistency and repeatability across the full set of data.

As each group finished the full sub-categorization of their set of the data, each sub-category was reviewed to determine if further categorization was required. Where required, this further categorization was completed on each of the four major categories. This resulted in a further 59 sub-categories for Responsibilities, 56 sub-categories for Techniques, 31 sub-categories for Interactions, and 30 sub-categories for Products.

RESULTS

Table 3 provides a broad overview of the type of information that was gleaned from the CTA. Within each of the broad functional areas that we identified earlier (i.e., responsibilities, techniques, products, and interactions), we collected extremely valuable information about exercise creation, exercise control, data collection, assessment, and instructional feedback—the key areas that we felt our intelligent agents needed to address. While the volume of this information precludes detailed reporting in this paper, key findings relevant to training objectives, the simulation, trainer's emphasis, the job of the Observer/Trainer (O/T—the most important trainer for the current effort), performance measures, and the cognitive underpinnings of diagnosis are presented below.

Training Objectives and Measures

Analysis of interview responses indicated that while tactical like training objectives (specific and measurable) exist for the JTF staff, the training objectives for the CDR of the JTF are not as well defined. With respect to measures, the CTA provided a critical result—namely the validation of the measurement model developed by the IAGENTS program. This model is presented in Figure 1 and it displays the relationship between training requirements and the Category 3 training environment. Also shown are the categories of performance measurement with examples of the types of specific measures and how they relate to training and exercise objectives. Examples are provided for training and exercise objectives. This figure presents a simplified view of the overall model that guides the IAGENTS project.

Table 3: CTA results within categories.

Exercise Creation—includes efforts focused on the development of the exercise prior to or during runtime	**Exercise Control**—includes efforts focused on maintaining the exercise prior to or during runtime	**Data Collection**—the gathering of information about training audience performance for the purpose of assisting assessment or the process of exercise control	**Assessment**—using collected data to make assessments regarding training audience performance or exercise progress	**Instructional Feedback**—information related to training audience performance provided via direct interaction or through the simulation; pre-exercise, during the exercise, or following the exercise
1. Exercise planning: Information relevant to planning considerations, meetings, and planning tools used in exercise	1. Organization 2. Procedures for decision making/conflict resolution, exercise	1. Data collection management—the mechanics of collecting data for performance	1. Assessment procedures—based on the expertise of the trainer and accomplished by	1. Pre-exercise—can be thought of as "feed forward" 2. Run-time feedback—3

tools used in exercise development 2. Master Scenario Event (MSE) development: Driven by training commander's guidance and training audience requirements 3. MSE modification: Based on feedback from O/Ts, white cell, determine which joint mission essential tasks (JMETs) are not getting the required exercise support 4. Development / selection of training objectives: Actions and issues associated with the development of the higher order measurable training objectives 5. Exercise rehearsal: Actions or issues associated with wargaming or crosswalking the exercise events prior to execution	flow, context maintenance, technical / model control 3. Situational awareness: maintaining currency with the exercise to ensure smooth presentation of training opportunities, correct sequencing of events, pace, credibility of exercise events	performance 2. Data collection for exercise state 3. Data collection for performance assessment	accomplished by senior mentors and members of the Deployable Training Team (DTT) at daily meeting (DTT Roundup) 2. Assessment of performance—heavily oriented toward process 3. Assessment of exercise progress—global assessment of the training audience to support decisions regarding instructional actions	types identified: direct, indirect, and simulation feedback 3. Post exercise: Information presented to senior mentor, information presented to training audience, information presented in facilitated debrief

In tactical training, a simplified timeline is as follows: prebrief, exercise (tactical unit simulation), results. In contrast, in operational level training the timeline is as follows: JTF develops a plan and gives the orders, tactical unit simulation occurs, and results follow. At the same time, measuring the effectiveness of those plans and orders via the results of the simulation is much less direct than measuring performance of the tactical unit during the tactical training simulation. The emphasis of training for the JTF is on process (e.g., planning, communication, and review of plans). This is an interesting contrast with tactical training which typically focuses on outcomes (e.g., did they shoot down the missile).

Job of the O/T

The job of the O/T is cognitively complex and performed under time constraints. For example, a major task of the O/T is to develop an understanding of the training audience's understanding of how the particular JTF they are a part of operates (e.g., who talks to whom, hierarchy of decision making, roles and responsibilities, communication and coordination patterns, etc.). Each JTF operates differently

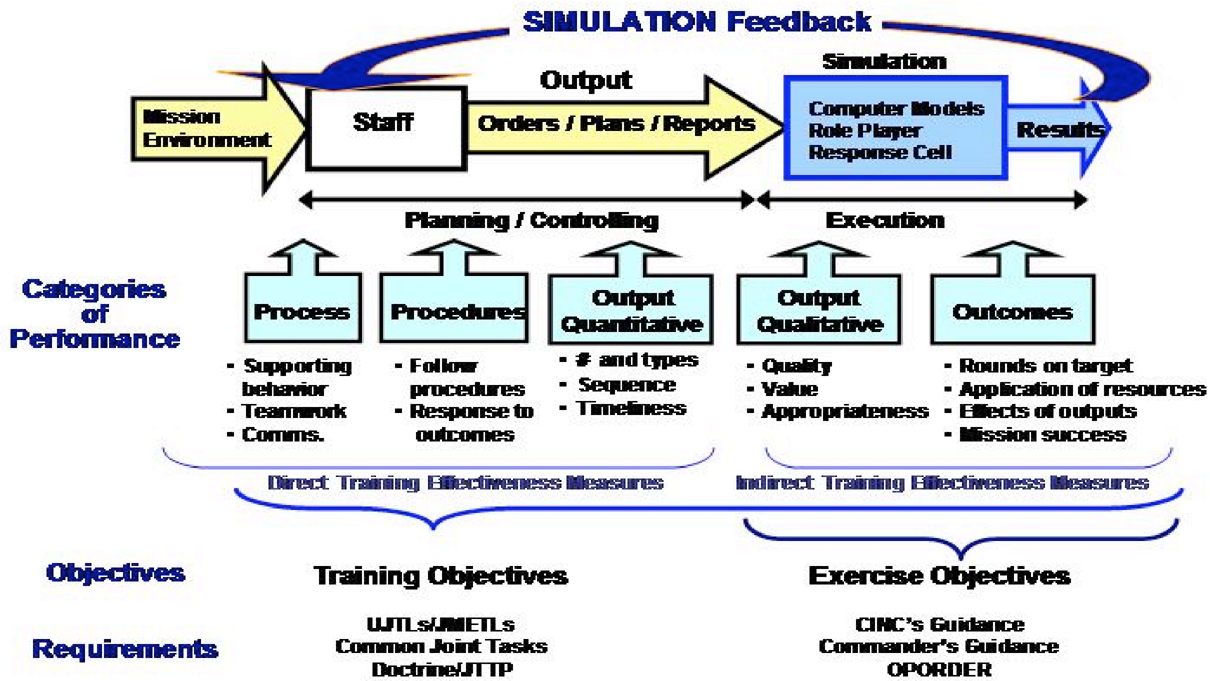

Figure 1: Performance measures related to requirements.

depending on Doctrine, standard operating procedure (SOP), and the guidance from the particular JTF CDR. In JTF training exercises, the JTF arrives with differing degrees of knowledge of how they (the JTF) will operate. The O/Ts must first figure out how that particular JTF is operating and how much the respective JTF members understand about the JTF operation. The O/Ts do this by listening to conversations among the JTF, observing actions the JTF staffers take, etc.

Cognitive Underpinnings of Diagnosis

In terms of "what trainers observe" we elicited some of the cues for which trainers look. For example, we learned that they rely extensively on their personal expertise in performance assessment. This can involve making a judgment that there is an anomaly in operational activity such as overuse of an asset or significant attrition of an asset. Alternatively, an OT may make note of a dysfunctional or marginally functional staff organization. In making this assessment, the OT will take into consideration the situational awareness of the staff keying in on their process as well as their products. Trainers indicated that lack of situational awareness as reflected in marginal or dysfunctional staff organization often predicts trouble for the training audience in that they will experience difficulty in achieving their operational objectives.

In terms of "what trainers think", we elicited some of the reasoning process that trainers use. For example, when making a determination to provide feedback during exercise runtime, trainers told us that intuition and judgment are key to their process and that they take into account the training audience's response to previous instructional actions. In deciding to provide feedback during runtime, trainers indicated that they decide between corrective feedback (providing specific prescriptive guidance as to what a training audience member should do) or instructional feedback. With respect to instructional feedback, we documented a consistent theme in the use of the "Socratic" technique. That is, we learned that when a trainer makes a determination that the training audience can and should work through a problem, they (the trainer) often facilitate this process by asking a question of the trainee such as:

- "Why did you do this or that?"
- "What would happen if you did this or that?"
- "Here is what you said and here is what I am seeing. Based on my observation here is what I think might happen."

This type of feedback could be provided directly (trainer to trainee) or indirectly (trainer to the supervisor or leader of the trainee or Senior Mentor to the JTF Commander).

The use of this approach is reflective of another theme that emerged from our CTA, namely that the tasks of assessing performance and providing feedback are cognitively demanding. While the simulation is used to both help in the diagnosis process and as a means of providing "feedback", face-to-face interactions are the preferred method for both assessment and feedback. We heard repeatedly that the trainers view their job as one of "getting inside" the heads of the training audience. That is, diagnosis and feedback are predicated on the trainers understanding that the training audience has a SOP and a specific plan for the exercise—the trainers clearly indicated that one of their responsibilities was to understand what the training audience was trying to do and then to support them in effecting their plan.

In general, significant differences exist between tactical level of training and operational level of training. These have implications for training science and technology (S&T).

CONCLUSION

As was indicated earlier, at the outset of the IAGENTS effort, it was felt that a CTA of the trainers at JWFC would provide specific guidance regarding the development of the software that would aid and augment dynamic scenario management. Early on however, it was realized that the project's requirements were broader than that encompassed by traditional CTA techniques. Thus, the effort reported here provides information related to both traditional task analysis and to CTA. The detailed interviews that comprised the CTA produced an enormous amount of information regarding what the trainers at the JWFC do and think relative to their responsibilities, the products they use and produce, the techniques they use, and the people and systems that they interact with in doing their job.

Indeed, during this analysis we uncovered and documented a wealth of information on functions, positions, and the relationships amongst those. At the same time, we also elicited crucial cognitive information. For example, two of the major objectives for the analysis were to determine what trainers observe about training audience performance (to determine performance measures) and "what trainers think about" and how trainers provide instructional feedback. We met these objectives.

Again, if we had not had to expend our resources documenting the less cognitive but important aspects of joint training, we could have identified an even greater degree of information specifically relating to the cognitive processes of the controllers and have more extensive models of their thought processes and knowledge. However, even without a more extensive, purely cognitive analysis, we have acquired enough information to build our agents.

While the CTA proved invaluable to the IAGENTS effort, the present effort underscored several limitations of the current state-of-the-art for those who need the type of information that a CTA provides, but are not expert in one of its varied methods.

First, for all the variety of techniques that have been described, there does not exist comprehensive guidance that would aid in matching project CTA needs to the most appropriate CTA technique.

In a related vein, and reflective of the maturity of CTA as a set of technologies, there is a paucity of tools for actually conducting a CTA. In the present effort, it was necessary to build custom MS Access databases for both question construction and for subsequent data reduction. While absolutely necessary and very useful, this was labor-intensive work that took a significant investment of time.

Perhaps most important, the present effort revealed the challenge of translating CTA results into a product that is useful to system design and to software developers. Here, we concur with Roth, Gualtieri, Easter, Potter, and Elm (2000) who note that as useful as CTA has been in systematically describing complex human performance, all too often, the results of CTA are only weakly linked to design. In large measure, this can be attributed to the lack of a formalism for representing CTA results. There is a real need for the creation of an abstract and algorithmic model of intelligent systems based on CTA results (Casey, Giebenrath, Burns, Shearouse, and Cohn, 2001).

We concur with Roth et. al., (2000) that CTA must become a practical, repeatable, high quality engineering methodology that is on par with the Software Engineering Institute's efforts for software engineering processes. Only when this is achieved will the results of the CTA seamlessly integrate with the software engineering and overall system development processes that are required for complex aiding and augmentation systems such as IAGENTS.

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