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Research Report 1753

Modeling and Measuring Situation Awareness in the Infantry Operational Environment

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14. ABSTRACT *(Maximum 200 words)*:

This report documents the methods and findings of the Infantry Situation Awareness (SA) project, conducted to develop a model and measures of SA for the unique Infantry operational environment. The research team analyzed the complexities of the Infantryman's environment based on the tactical parameters of mission, enemy, terrain, troops, time available, and civilian considerations (METT-TC) at various echelons from the individual soldier to brigade level. The analysis addressed the key factors influencing SA during various stages of operations. Available models of SA were reviewed, and two were adapted and integrated to account for individual and team SA, respectively, in Infantry operations. In addition, the research team reviewed available measures, both direct and indirect, that can be employed to evaluate individual and team SA in different operational situations and at varying echelons. The advantages, disadvantages, and application considerations for these measures were identified. The report recommends future research requirements to address Infantry SA needs related to modernization initiatives and training development efforts. Finally, the report offers suggestions to senior Army leaders concerning the value of considering SA in the development of equipment, doctrine, and training programs.

15. SUBJECT TERMS

Situation Awareness (SA)	SA Measures	Infantry SA Model	Team SA
Research and Development	Infantry Operations	Individual SA	Shared SA

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FOREWORD

The Infantry Forces Research Unit of the U. S. Army Research Institute for the Behavioral and Social Sciences investigates training requirements for the future battlefield under its *Training Modernization for Infantry Forces* research program. This program supports the U. S. Army Infantry Center and School through studies, analyses, and research efforts that examine training needs and issues of importance to Army modernization initiatives.

The Infantry Situation Awareness (SA) project sought to establish a solid foundation for systematic investigation of constructs and dimensions that contribute critically to the Army's capabilities to achieve situational dominance on the future battlefield. The primary goal of the project was to identify and adapt an applicable model of SA to focus on the Infantry environment, and identify prospective measures that would be useful in Infantry operations. Slanted toward the operational Infantry community, this report documents the methods and findings of the study.

The SA model and measurement techniques presented in this report provide a comprehensive underpinning for understanding the individual, team, and battlefield factors that influence the SA of combined arms soldiers and leaders. The products may prove useful to Army training developers working to create innovative training programs for enhancing SA. Equally important, they may lead to enhanced approaches and techniques for determining the SA impact of advanced information technologies. Finally, the recommendations for future research may help Army planners and decision makers faced with the challenge of crafting a realistic strategy for putting in place doctrine and systems enabling the Army to maintain the winning edge on the battlefields of the 21st Century.

The results of this study were briefed to the Director of Bio Systems, Directorate of Defense Research and Engineering, Office of the Under Secretary of Defense (Acquisition and Technology), on October 20, 1999.

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We would like to thank Dr. Robert E. Foster, Director of Bio Systems, Directorate of Defense Research and Engineering, for his support in the planning and funding of this project.

MODELING AND MEASURING SITUATION AWARENESS IN THE INFANTRY OPERATIONAL ENVIRONMENT

EXECUTIVE SUMMARY

Research Requirement:

As a fundamental aspect of Infantry operations, situation awareness (SA) plays a key role in ensuring the Army's capabilities for situational dominance in the 21st Century. Emerging Infantry doctrine and force modernization initiatives, relying heavily on non-linear battlefield tactics and sweeping digitization, place increasing emphasis on superior SA. In the demanding Infantry combat environment, superior SA will bring tremendous advantages by promoting information dominance, improving security and survivability, and optimizing lethality. The future battlefield calls for visionary technologies, leader development, and training concepts targeted at enhancing SA at all echelons. Meeting the Infantry's needs requires a sound framework for understanding and assessing SA in the operational environment.

Procedure:

In response to operational needs, the U. S. Army Research Institute's Infantry Forces Research Unit initiated the Infantry Situation Awareness project. The primary goal was to develop a model and measures of SA as a foundation for developing improved techniques and tools to enhance SA. As a first step, doctrinal and historical documents were reviewed to determine operational Infantry requirements related to SA. An Infantry-focused model of SA was then developed by examining existing models and adapting one for individual SA and a second for team SA, integrating both in a unified framework. Next, existing SA measurement approaches and techniques were reviewed to identify their strengths and weaknesses. The final step was to identify and prioritize recommendations for future SA research and development by analyzing operational needs, knowledge gaps, and high-payoff targets.

Findings:

In the dynamic and complex Infantry operational environment, wide-ranging soldier and leader capabilities, tactical parameters, organizational variables, and environmental factors shape the establishment and maintenance of SA. Often operating independent of a vehicle or crew station, Infantrymen find themselves organized in highly interdependent groups, immersed on foot in their natural environment, and individually responsible for a segment of the battlefield. Each soldier's knowledge and abilities have a critical impact on individual and team SA. By improving SA training approaches, leader development, and information technology, it is feasible to enhance the quality of Infantry SA.

An Infantry-focused model of SA is valuable as a realistic framework for formulating new concepts and approaches for enhancing situational dominance. The model presented in this report leverages a perception-decision-action framework to link task and environmental factors, individual abilities and skills, and Army processes. A major component of the model accounts for team SA at various echelons. The degree to which an Infantryman can draw on his perceptual and cognitive abilities, implicit skills, experience, and motivation to pursue goals in a lethal environment will determine the quality of his SA, and ultimately the quality of the team's collective SA.

Many SA measurement approaches and techniques have been used in diverse performance domains. A process model is provided in this report to account for direct measures, inferred measures, and process indicators of SA. Each type of measure offers advantages and disadvantages for quantifying SA performance and underlying processes. Investigators can adapt the various measures to the challenges of evaluating new Infantry concepts, technologies, and training techniques in simulation and field studies.

To guide the development of Infantry-centered SA tools and techniques, systematic research and development steps are required. Recommended steps focus on extending the SA knowledge base and generating realistic concepts and strategies for enhancing the operational SA of Infantry leaders and soldiers. Application of the results of systematic research can benefit Infantry doctrine, leadership, training, and materiel.

Utilization of Findings

The findings of this project can support the development of usable techniques and technologies for enhancing Infantry SA. By integrating and synthesizing what is known about SA in the Infantry environment, the results provide useful information for Army developers and trainers. The model and measurement techniques should help combat developers, training developers, and researchers "push the envelope" regarding concepts and training approaches for enhancing battlefield SA. They should also guide system designers and developers as they harness and evaluate information age technologies. Finally, the research recommendations will support high-payoff investment strategies for expanding the SA-related technology base.

MODELING AND MEASURING SITUATION AWARENESS IN THE INFANTRY OPERATIONAL ENVIRONMENT

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MODELING AND MEASURING SITUATION AWARENESS IN THE INFANTRY OPERATIONAL ENVIRONMENT

Introduction

Situation awareness (SA) has always been critical to directing and executing Infantry operations. The concept is claiming increasing attention as a key to combat success. Today's appreciation of the role of SA in achieving tactical goals is rooted in the Infantry's combat history, and battlefield anecdotes abound. The following account, summarized by the authors from Moore and Galloway's (1993) book, *We Were Soldiers Once and Young*, is particularly graphic. The vignette sets the stage for this report.

Shortly after 1300 hours on November 17, 1965, two battalions of North Vietnamese Infantry overran the U. S. 2nd Battalion, 7th Cavalry (Infantry) in the Ia Drang Valley. The American battalion survived only after suffering 276 casualties. Its terrible experience stemmed to a large degree from a poor understanding of the situation and is pointedly instructive because so many features normal to Infantry operations—hurried actions, troop fatigue, uncertainty—shaped the outcome.

The 2-7 Cav had air assaulted into the area three days previously. Under a new commander, the unit had exchanged one of its organic companies for another from a sister battalion. On the 17th the battalion was rushed to another landing zone to avoid an imminent B52 strike. In their haste, 2-7 Cav's soldiers had a poor understanding of their mission, the terrain, and the enemy's strength and location. As they moved, the battalion practiced poor tactical security, failing to post flanking observation posts or to adopt a suitable formation.

The soldiers' exhaustion made matters worse. When the North Vietnamese sprung their ambush, the troops of 2-7 Cav had been awake for 60 hours and had been marching with full combat loads through tough terrain for four hours. Indifferent training and poor field discipline also came into play as the battalion fell into casual disarray, stretched out over 500 meters of trail.

The battalion's poor SA contributed enormously to its defeat. The basic conditions of the operation—the rush to move, the lack of clarity about the mission, the fatigue of the troops, and their state of training—illustrate the difficulties of Infantry operations and the obstacles to good SA. The battalion commander's reflections of the fight reinforce the point explicitly: *"In that first hour or so, the situation was so fluid that I was acting more as a platoon leader than a battalion commander.... I was trying to figure out what the hell was going on, myself. I don't think anybody in the battalion could have told you what the situation was at that time."* (Moore & Galloway, 1993, p. 248).

[Authors' summary, based on descriptive material in Moore & Galloway, 1993]

Background

Infantry Operations and Training

Army XXI defines the doctrinal and organizational foundation for future combat operations. Under its umbrella, a challenging picture of the 21st Century Infantry battlefield environment has emerged. Non-linear doctrine will lead to wide dispersion of tactical units operating with expanded mobility, speed, and lethality. The latter factors, combined with information-age command and control (C2), will substantially enlarge the portion of the battlespace controlled by each unit and each level of command. Continuous (round-the-clock) operations will mean more night combat and more frequent decisions about whether decisive engagements should occur during daylight or dark. An overriding emphasis on information dominance will drive faster target acquisition, lightning speed engagements, and shorter decision cycles. Abundant information from sophisticated sensors and tactical networks will demand new techniques for fusing, selecting, interpreting, and disseminating real-time knowledge of the battlefield. Information dominance will enable situational dominance, an expansive concept for overwhelming the enemy. Engaging the enemy on urban/close terrain and dealing with non-combatants, observers, and members of the press will add to the complexities and challenges of the tactical situation. Against this backdrop, certain constants will remain—all-weather operations, frequent movement, rapid change, strenuous physical effort, and ever-present stress. In this demanding combat environment, superior SA will bring strong advantages by reducing uncertainty, improving security and survivability, and enabling highly effective massing of fires.

This picture of future operations spawns compelling implications for training Infantry forces. As the pace of Infantry operations quickens and their scope expands, the tacit perceptual skills of leaders and soldiers will become more important to success. As new warfighting systems and doctrine take their place in the field, innovative unit training programs and training support packages will be required to help Infantry leaders and soldiers achieve situational dominance. At the same time, maintenance of conventional skills will be critical to accommodate system failures. Training researchers and developers must create new training environments and technologies designed specifically to build and hone SA-centered decision making skills. In short, a visionary strategy is needed for Infantry force development and for institutional and unit training that focuses on enhancing SA at all echelons.

Leader Development

The advantages of superior SA depend to a large extent on the preparation and actions of Infantry leaders. The best communications and automation available will improve SA and combat effectiveness only if leaders are prepared to exploit capabilities fully and wisely. Moreover, the mental component of SA will always be more important than the tools Infantrymen employ.

Key leader SA skills include understanding or recognizing: (a) the capabilities and limitations of their own and enemy forces, (b) the specified and implied responsibilities inherent in their missions, (c) the advantages and liabilities created by the environment, (d) dangers and opportunities implicit in tactical circumstances, and (e) the risks they can accept in a particular situation. Leaders' aptitude for and experience in Infantry operations define their needs for external SA support. Leaders will routinely require information specific to the mission and its environment, but their abilities to define information requirements and to recognize patterns, as well as their abilities to sense the need for key elements of SA, will differ between individuals.

There is a clear need to develop innovative, adaptive leaders for future forces. This should involve deliberate screening, training, education, and self-development programs to assure that leaders report to their assignments ready to exploit the advantages that technology and training can provide, consistent with mission requirements and system limitations.

Force Modernization

To meet the challenges of the 21st Century, the Army is pursuing an ambitious program to modernize its combat forces. Under the Force XXI program, numerous initiatives are leveraging information age technologies to boost combat capabilities (Hartzog & Canedy, 1997). Capitalizing on dramatic advances in digital computing capabilities, the Army's efforts to digitize the battlefield are at the center of a sweeping campaign to redesign the service's tactical organizations and warfighting arsenal. Prime examples of Force XXI initiatives include the Land Warrior (LW) program and the Army Battle Command System (ABCS). The LW system promises to equip the Infantryman with advanced capabilities for SA, target acquisition, communication, and survivability. The ABCS is a family of automated battle command systems that is revolutionizing command, control, and communications from the division down to the squad (U. S. Army Training and Doctrine Command [TRADOC], 1998b). In a nutshell, the Army's force modernization efforts are transforming the battlefield, reshaping the character and processes of future warfare.

In the Infantry operational environment especially, superior SA depends on the ability to receive information from diverse sources and evaluate it quickly, then distribute it to dispersed units. As the transformed battlefield emerges, incorporating widespread automation in particular, the sources and forms of information are undergoing dramatic changes. These changes will reshape the information processing demands on Infantry leaders and soldiers, along with the processes for sharing information and achieving individual and team SA. Achieving superior SA will be greatly complicated by the physical and mental demands of the Infantry environment, and by the fact that many of the Infantrymen will be inexperienced junior soldiers. Thus, assessing the impact of battlefield digitization on SA is essential to the eventual success of the Army's force modernization initiatives (see Hartzog & Canedy, 1997).

Situation Awareness

In its pivotal vision of Force XXI operations, TRADOC defines SA as "the ability to have accurate real-time information of friendly, enemy, neutral, and non-combatant locations; a common, relevant picture of the battlefield scaled to specific levels of interest and special needs" (TRADOC, 1994b, p. Glossary-7). This definition leans heavily toward the technology dimensions of SA—digital architectures, systems for capturing and presenting battlefield information, etc. However, the soldier dimensions of SA are equally important (Endsley, 1995b). Among the soldier dimensions are perceptual and cognitive processes, psychomotor skills, individual differences, experience, training, influence of stressors, and information overload/underload. Acknowledging the human dimensions of SA, Endsley (1988) defined SA as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (p. 97). The authors of this report have adopted the latter definition.

While efforts toward battlefield digitization can dramatically affect SA, it is critical to realize that SA does not begin and end with these technologies. Rather, SA is a fundamental aspect of how the Infantryman has always functioned. The utility of new systems must be considered within the context of the ongoing SA processes the Infantryman depends on for effective decision making and combat performance. The ultimate success of modernization efforts will depend on how well they enhance those processes to produce better SA, and how well they avoid interfering with them. By focusing on how the Infantry soldier gathers and evaluates the numerous pieces of critical information in his environment to form operationally relevant SA, approaches for enhancing SA—through both training and technology—become apparent.

Current Army doctrine places great emphasis on SA as a critical determinant of success in combat (e.g., TRADOC, 1994b). Modernization initiatives include extensive work to develop and field automated C2 systems that rely heavily on SA technologies. Advances in these technologies are strongly influencing major Army efforts, most notably Force XXI, to redefine its combat forces, including Infantry forces. The concept of "situational dominance," introduced above, depends on superior SA. Given the growing focus on SA, it is essential that the Infantry community fully understand the nature of SA and how to enhance it under the demanding conditions of highly dynamic, non-linear combat.

Demonstrating or verifying enhanced SA poses serious challenges for the Infantry community, as for the rest of the Army. Many of the challenges stem from the lack of work to define and measure SA in the unique environment of modern Infantry forces. By and large, existing SA measurement approaches and techniques arose in the context of research on piloting high performance aircraft (e.g., Endsley, 1988, 1995a; Taylor, 1990). Designing, developing, and evaluating advanced information systems and SA-focused training programs for Infantry forces demands measures of SA that are valid for the unique ground combat environment.

In September 1998, the U. S. Army Research Institute for the Behavioral and Social Sciences (ARI) organized and hosted a workshop addressing SA requirements for Infantry forces. The workshop gathered together military and scientific experts to consider SA requirements related to tactics, battalion and below operations, and training. The products of the workshop (Graham & Matthews, 1999) established an important foundation and set the stage for the work accomplished in the current project.

Project Overview

The Infantry SA project arose as an initiative to bring a practical focus to diverse efforts addressing the Infantryman's need to understand the immediate combat situation and anticipate near-term developments. Under its *Training Modernization for Infantry Forces* research program, ARI's Infantry Forces Research Unit (IFRU) led the effort to establish an Infantry-focused model of SA along with techniques for measuring SA. The ARI-IFRU orchestrated the research project around real-world problems, emphasizing the demanding, sometimes unique requirements of the ground combat environment typifying Infantry operations.

Statement of the Problem

The Army's force modernization efforts to ensure horizontal and vertical integration of combined arms assets have generated an abundance of pressing questions. Information-age technologies and emerging organizational structures are guaranteed to impose new information processing and decision making challenges on Infantry soldiers and leaders. A key question revolves around how to manage abundant real-time battlefield information in such a way that improves the Infantryman's SA. How much of the information processing challenge can be handled by proper training? How can SA-focused training programs be optimized to meet Infantry requirements? How can we measure SA performance so that we know whether new training programs and advanced systems are part of the "solution"? How do we know which new technologies truly contribute to better SA for Infantry leaders and soldiers at various echelons? Which information technologies provide sufficient value to make it worth changing the soldier's physical load or the unit's mission load? What level of distraction from direct observation of the battlefield is acceptable to harness the benefits of using SA equipment? How do new organizational and operational concepts impact critical SA parameters and decision-making processes?

Of the mounting data resulting from Force XXI Advanced Warfighting Experiments (AWEs) (e.g., TRADOC Analysis Center, 1998), relatively little sheds direct light on SA in the operational Infantry environment. Thus, the existing knowledge base on SA is inadequate to answer the questions stated in the preceding paragraph. New research and development is needed to enable improved techniques and tools for enhancing SA at each tactical echelon. To provide a realistic framework for formulating new concepts and approaches, an Infantry-focused model of SA is required. Equally important is the establishment of valid measures of SA processes and outcomes, tailored to Infantry operations. These needs set the stage for this Infantry Situation Awareness Project.

Technical Objectives

The primary goal of the current project was to establish a comprehensive foundation for advancing the scientific knowledge on SA in the Infantry environment. The scope of the project included individual and team SA, with the collective focus on brigade and below (down to the individual soldier). The following technical objectives guided the planning and execution of the research effort:

1. Survey SA requirements and issues related to Infantry units and operations.
2. Establish a comprehensive modeling framework for SA in the Infantry environment.
3. Survey available SA performance measures.
4. Recommend future SA research and development targets.

Expected Payoff

The principal products of this project include (a) an Infantry-focused SA model, (b) SA measures tuned to Infantry operations, and (c) recommendations for future research and development. The tailored model will provide a valuable tool for understanding battlefield factors that facilitate and hinder SA, yielding insights on SA, generating testable hypotheses, and guiding SA measurement activities. The model may enable more efficient investment of research and development resources by virtue of an integrated, theoretically grounded framework. The Infantry-specific measures of SA processes and outcomes will facilitate design and evaluation of training programs, testing and evaluation of advanced systems, concept evaluation efforts, common assessment across AWEs and Advanced Concept Technology Demonstrations, and derivation of lessons learned. In addition, the measures will support training research programs through systematic SA metrics. The recommendations for future research and development can help shape the planning, resourcing, and integration of high-payoff investment strategies. In the hands of combat developers, training developers, and research investigators, the products of this project will bolster the Army's efforts to boost combat readiness through SA-centered initiatives.

Purpose and Organization of the Report

This report describes the methods and findings of the Infantry SA research project, highlighting the SA model developed for the unique Infantry operational environment as well as practical measurement approaches and techniques. It also presents recommendations—anchored to functional Infantry requirements—for future research to expand the SA knowledge base. By integrating and synthesizing what is known about SA in the Infantry environment, the report provides a useful reference document and guide. The comprehensive framework should help combat developers, training developers, and research personnel to "push the envelope" regarding doctrinal and training approaches for enhancing battlefield SA, and provide direction for systems development and evaluation.

Seven sections organize the contents of this report:

1. *Introduction.* Discusses the background of the project and introduces the concept of SA, then summarizes the project's objectives and products.

2. *Methods.* Describes the approaches and procedures used to achieve each of the project's technical objectives.

3. *Infantry Requirements Related to Situation Awareness.* Analyzes the Infantry battlefield environment, with emphasis on its unique characteristics, considers important variables influencing SA, and discusses the relation between SA and combat performance.

4. *Model of Situation Awareness in Infantry Operations.* Presents an Infantry-centered model of SA, then discusses its utility for focusing effective Army programs.

5. *Measurement Approaches and Techniques*. Constructs an Infantry-focused framework for SA measurement, reviews established measurement approaches and methods, and analyzes their utility in terms of Infantry requirements.

6. *Infantry Situation Awareness Research Requirements*. Offers suggestions for future SA research and development, centering on Infantry issues and requirements.

7. *Conclusions and Recommendations*. Presents the major conclusions of the project based on key findings and their importance to Infantry Forces, then offers recommendations geared to senior Army leaders.

Methods

This section outlines the methods and procedures used to achieve the goals of the project. Given the technical objectives of the study, the research team relied on review and analysis of existing documentation and scientific knowledge, with heavy emphasis on integration and synthesis of information. Throughout the effort, the team focused on operational requirements of Infantry forces. The execution of project activities was organized around the following tasks:

1. Analyze operational Infantry requirements related to SA.
2. Develop an Infantry-focused model of SA.
3. Review existing SA measurement approaches and techniques.
4. Identify and prioritize future SA research needs.

Analysis of Infantry Requirements

The goal of this task was to determine the key characteristics of Infantry operations that influence SA. What mission features and combat tasks shape the battlefield environment of the Infantryman? Which task and environment characteristics are unique to Infantry operations? What dimensions foster or degrade individual and team SA? What SA-related issues and questions are important to Infantry leaders and soldiers? How do SA processes and characteristics vary from the lowest to the highest echelon? How does individual and team SA contribute to combat performance? These questions set the stage for the analysis of Infantry requirements.

The analysis began with a review of U. S. Army, U. S. Department of Defense (DoD), and related documents containing information relevant to Infantry operations. The research team developed a review guide to structure the capture of information from the doctrinal and lessons learned sources. The guide (Appendix B) focused the reviewer's attention on:

1. Infantry issues (e.g., questions, concerns) and their significance
2. Infantry SA requirements (e.g., mission-related tasks, modernization impacts)
3. Other relevant dimensions (e.g., key variables, warfighter insights, future research)

Using the review guide, a senior Infantry subject matter expert (SME) with extensive experience as a doctrine writer examined each of the selected documents, recording pertinent information for later integration and synthesis. (See Appendix D for a listing of documents reviewed.) Much of this effort focused on characterizing the current and future Infantry environment from an SA perspective. In many cases, the reviewer made multiple passes through a given document until all pertinent information had been extracted and clarified. As additional sources of input were identified, they were added to the list for review. The same SME accomplished the primary review activities for all documents, within a two-month period.

In the next step, the SME integrated the cumulative information from the separate reviews. This was initiated by selecting the frequently repeated themes to serve as the global organizing structure for a comprehensive accounting of Infantry SA requirements. These themes included unique operational characteristics, operational features shared with other military environments, human aspects of SA, important variables influencing SA, and echelon. After collating and integrating the separate reviews, the SME prepared a description of Infantry operations with a focus on SA considerations from the warfighter's perspective. Substantial effort was invested in identifying the key variables that influence Infantry SA, organized around the established doctrinal factors of mission, enemy, terrain, troops, time available, and civilian considerations (METT-TC). The resulting description was reviewed by another Infantry SME on the research team and by two ARI experts. The latter reviews involved examination of source documents on a selective basis, where appropriate. The input from those reviews led to revision of the integrated description by the senior SME.

Development of Infantry-Focused Situation Awareness Model

The development of a realistic model of Infantry SA began with a survey to identify the human-centered models available from the scientific and military literature. The models identified in this survey were then reviewed to determine their suitability for the Infantry operational environment. As a first step, the research team generated a list of criteria for a sound Infantry-focused model, based largely on the analysis of operational requirements. These criteria are described later at the start of the *Model of Situation Awareness in Infantry Operations* section. The criteria provided a framework for evaluating the candidate models. They also constituted informal design parameters to guide the development of an SA model tailored to Infantry operations. The following criteria were defined, stating that an Infantry-focused SA model should:

1. Be grounded in the reality of Infantry operations, capturing the factors with which Infantry personnel are familiar (face validity).
2. Account for the full range of individual and collective behaviors that occur in Infantry operations.
3. Systematically consider multiple factors (facilitators and deterrents) that affect SA.
4. Take into account what is known about SA, including realistic independent variables.
5. Represent and accommodate the dynamic nature of SA in Infantry operations.
6. Provide an explanatory framework for both positive and negative SA outcomes.
7. Point to dimensions and approaches for measuring SA.
8. Generate testable hypotheses and directional predictions.

9. Be compatible with established theories of human behavior.
10. Provide sufficient flexibility to accommodate a range of military echelons.
11. Be extendable to other operational environments.

The team developed a review guide to structure the review of the candidate models. The guide (Appendix C) was designed to capture, for each model:

1. A description of the model's basic features and characteristics.
2. A summary of the model's origin/context.
3. The model's strengths and weaknesses.
4. The capability of the model to represent team SA.

Using the guide, a behavioral scientist with extensive experience in SA research reviewed the documentation available for each model. (The candidate models are listed in the *Model of Situation Awareness in Infantry Operations* section.) Once the basic review of the models was completed, the team evaluated each model to determine if it satisfied each of the criteria stated above, yielding a yes-no assessment. Each model was evaluated independently of the others by two behavioral scientists using the same criteria. After both scientists completed their evaluations working alone, they then exchanged their findings and discussed the differences until reaching agreement. The consensus determinations were recorded in simple tabular form. The final step involved counting the number of "yes" determinations for each model to arrive at an index representing a simple sum of unweighted factors. A maximum value for a given model would indicate the existence of a previously developed model fully suitable for the Infantry environment.

When the evaluation of candidate models failed to reveal an existing model fully accounting for Infantry SA, the research team proceeded to develop a model specifically tailored to Infantry requirements. This was accomplished by starting with the existing individual SA model offering the highest criterion-based index and adapting it to meet the full set of criteria. Since no single model adequately accounted for both individual and team SA, the team decided to adapt a second model for the team arena, integrating it with the individual model. The adaptation process entailed modifying or adding model components to account for specific Infantry factors and requirements. A "minimum essential" principle was followed: modification was tried before adding new components, and continuity with respect to the original model was emphasized. The lead scientist performed the primary development work in stages, concluding each stage by submitting the updated model package for review by the other members of the research team. This develop-review-revise cycle continued through four iterations, with the last two iterations including ARI experts. The fourth iteration involved peer review by ARI scientists, culminating in approval of the final model by the ARI technical monitor.

Throughout this task, there was substantial sharing of information with the parallel analysis of Infantry requirements to ensure the model accounted realistically for the Infantry operational environment. In addition, the steps within this task were closely coordinated with those in the following task (SA measurement) to ensure that SA processes and indicators were carefully linked.

Review of Situation Awareness Measurement Approaches

In parallel with the analysis of Infantry requirements and the development of the Infantry-focused SA model, the research team applied literature review methods to identify SA measurement approaches and techniques for the Infantry operational environment. This effort began with a survey of SA measures available from the scientific and military literature. A special data capture guide (see Appendix C, Part III) focused the reviewer's attention on describing:

1. The basic features of each measurement approach
2. The original purpose and context of the approach
3. The strengths and weaknesses of the measurement approach
4. The applicability and ease of use in the Infantry environment
5. Basic psychometric characteristics of specific measures, if known

Using the guide, a behavioral scientist reviewed scientific and military reports from SA-related experiments in a variety of settings. The primary sources included:

- Reports of scientifically controlled experiments and studies conducted mainly in military aviation environments.
- Published reviews of SA measurement techniques.
- Reports of team training and/or decision making involving an SA component.
- Reports of technology-centered development efforts with an SA component.
- Briefing packages representing AWEs and Army Experiments.

Based on the survey of existing literature, the scientist assembled a list of measurement techniques and parameters that have been used in various military environments. He then constructed a framework for organizing the extensive list, built around four types of measures adapted from Endsley (1996): (a) process indices such as eye movements and tactical communications; (b) direct measures of SA, both objective (e.g., on-line queries) and subjective (e.g., self-ratings); (c) overt behaviors such as decisions and verbalizations; and (d) performance parameters typically reflecting tactical outcomes. The scientist next sorted the techniques and measures into these categories, then characterized each technique/measure in terms of advantages, disadvantages, and application considerations for the Infantry environment. A second behavioral scientist reviewed the initial findings and provided input, leading to a consensus characterization based primarily on professional judgment.

Upon completion of the basic review of SA measurement approaches and techniques, the scientist leading this task integrated and synthesized the findings to characterize the Infantry SA measurement environment. This step was organized to address:

- The principal purposes of SA measurement
- Key constructs associated with measuring SA
- Practical considerations anchored to the Infantry operational environment
- Challenges of measuring team SA
- Application of measurement approaches to meet Infantry needs

Throughout this task, there was substantial exchange of information with the parallel task of developing an Infantry-focused SA model. An important goal was to ensure that Infantry-centered measures were carefully linked with SA processes/components.

Identification of Future Research Needs

A key objective of this project was to provide recommendations for future SA research and development. The research team began this task by combing the results of the analysis of Infantry SA requirements to identify gaps and high-payoff targets for extending the SA tools and knowledge. With an emphasis on important questions of interest, the team developed candidate research topics. They then established the following criteria for prioritizing the candidate topics:

- Importance of need, as stated by Infantry leaders
- Immediacy of the need, as indicated by Infantry requirements
- Expected utility, based on previous Army experience
- Expected utility, based on Joint and Army descriptions of future doctrine and tactics
- Adverse impact of "holes" in current SA data and information
- Technical difficulty of accomplishing the recommended research/development

By applying these criteria, the team generated a prioritized list of research and development efforts attuned to Infantry needs of the next several years. The categories of priority were high, medium-high, and medium, with timeframe estimated separately within a 5-year time span.

Infantry Requirements Related to Situation Awareness

This section discusses the dimensions of Infantry operations that directly impact the establishment and maintenance of SA on the battlefield. Doctrinal and tactical trends are reviewed, with an emphasis on those aspects that distinguish the Infantry environment. The discussion includes extensive consideration of the tactical and organizational variables that play key roles in Infantry SA. A final section addresses the linkage between SA and combat performance.

In preparing this section, the authors drew heavily on a variety of sources describing Army and Infantry doctrine, historical combat accounts, and military concepts related to SA. Appendix D lists the various sources reviewed. In brief, the principal sources of information included:

- Army field manuals addressing tactical operations from division to squad
- TRADOC documents presenting concepts for future warfare
- DoD publications dealing with Joint operations
- Books providing historical accounts and perspectives
- Army documents relating specifically to SA

The Battle of Mogadishu on 3 and 4 October of 1993 has come to epitomize the challenges of Infantry combat in urban areas. It also represents some of the sternest tests of SA that Infantry units have faced in the recent past. The combat environment was complicated by segmented command arrangements between United Nations forces, American peace-keepers, and American special operations forces. The U. S. special forces raid to seize leaders of the Habr Gidr clan achieved its objective, but then degenerated into a lethal fight for survival and rescue. In the ensuing battle, confusion and complicated decision-making handicapped U. S. troops in deadly combat.

Mark Bowden's series in the Philadelphia Inquirer and his subsequent best-selling book, *Black Hawk Down*, tell the story of the U. S. Rangers, Delta Force soldiers, Army aviators, and light Infantrymen in Mogadishu (Bowden, 1999). Lack of clarity about the Blackhawk shoot-downs, difficulty in coordinating the actions of separated Infantry units who had erroneous ideas of their locations, and the agonizing misunderstandings that arose in directing wheeled relief columns through the obstructed and confusing city streets all drive home the importance of SA in Infantry combat.

The Ranger-Delta link up at Crash Site 1 exemplifies the difficulties. Late in the afternoon of 3 October, Ranger and Delta units moved separately to secure the downed helicopter. As they approached the crash site, the already mixed formation of Ranger and Delta troops became intermingled at the platoon level. Lacking a common command radio net, soldiers in the mixed platoons couldn't communicate with each other and received conflicting direction from their commanders.

The time that passed as the Delta and Ranger commanders sorted out the situation—determining who held what ground, how many soldiers were present, and who was in charge—was a period of great vulnerability and misunderstanding. Ranger Infantrymen didn't know that Delta troops were in the same area and fired on them at least twice. The threat was disorganized and unconventional—but clearly dangerous. And, as darkness approached without the arrival of relief, the two units faced the problem of defending without night vision equipment or reliable information on the enemy.

The survival of the force and its successful defense of the crash site testify eloquently to the courage and imagination of the soldiers and their leaders. Still, the confusion that haunted the entire operation speaks loudly about the penalties of poor SA. Satisfactory mapping, basic force tracking and strength reporting, and clear understanding of enemy locations and activities would all have made the defense less desperate. Reasonable awareness of the location of the relief column would have lowered stress and facilitated conduct of the defense. And precise knowledge of dispositions at the site would have made external fire support (wholly lacking in the battle) possible. The case both illustrates the resistant conditions in which Infantry combat occurs and explains the interest of senior Infantry leaders in obtaining better SA for dismounted combat.

[Authors' summary, based on descriptive material in Bowden, 1999]

The challenges to and opportunities for Infantry have progressed in tandem over the past decade. While its tactical setting is more lethal, visible and larger than ever before, the Infantry's abilities to exploit superior SA to perceive, decide, and act at greater speed have also grown. Information and weapons technology, global communications networks, automation and sensor effectiveness have changed the battlefield substantially even since Desert Storm.

As the Army's basic combat arm, Infantry fights in all kinds of operations and in all types of terrain and weather. Urbanized or close terrain, novel enemy tactics and arms, intense press scrutiny, the presence of non-combatants, and unprecedented outside observation of events are likely to characterize future conflict. Enemy nuclear, biological, and chemical (NBC) weapons, wide area attack weapons (cluster munitions, scatterable mines), precision guided munitions, and tactical ballistic missiles will enlarge the Infantry commanders' area of interest and reduce his reaction time. Strategic emphasis on fast deployment, prompt employment upon arrival, and short, decisive action is likely to place them in high stakes operations in unfamiliar surroundings on very short notice. National sensitivities about casualties, civilian injuries, and other collateral damage will add to the Infantry commander's concerns.

For soldiers, wide dispersion, great lethality, frequent movement and change, strenuous physical effort, and great mental stress still characterize the Infantry battlefield environment. High-volume, high quality data collection and distribution will give Infantrymen a better appreciation of their physical and demographic surroundings than ever before, although that will come with a requirement to consciously avoid distraction or "overload" (U. S. Army Armor School, 1997). Increased tactical mobility, better reconnaissance and information distribution, and enhanced logistical capabilities will improve economy of force and combat effectiveness of Infantry units. Communications and coordination between levels of command and even between soldiers in platoons and squads will compress the cycle of observation, orientation, decision and action, and thereby accelerate tactical operations.

It is also likely that better orientation and intelligence will permit more effective employment of available troops against well-defined objectives. To division and brigade commanders and staff officers, this means greater economy of force and better efficiency in seeking and engaging the enemy. To smaller Infantry units, it may mean the advent of truly continuous operations or, at least, of engaging in close combat more frequently than in the past. While better SA may lead to shorter fights it may also increase the combat tempo and stress for Infantry battalions and their sub-units.

Force XXI experimentation indicates that better mobility, intelligence, communications and long-range weapons effectiveness of Infantry will greatly expand the size of areas of tactical responsibility (TRADOC Analysis Center, 1998). This development will challenge the competence and comprehension of leaders at all levels as their geographical responsibilities increase. Junior leaders in particular will have to conceptualize more broadly than in the past as their areas of responsibility grow beyond the range of their sight. As fewer soldiers control larger areas, the sense of isolation for individual combatants and small units—already very strong—is likely to grow.

In these circumstances superior SA will confer direct and indirect advantages on Infantry units of all types. Improved training and education and new procedural and technical means of reducing uncertainty, improving security, and supporting more effective maneuver and delivery of fire will be extremely valuable. In the first "digitized" experiments, the addition of ABCS automated C2 equipment—most notably Force XXI Battle Command Battalion and Below (FBCB2) and the prototype LW system—have substantially improved SA capabilities for Infantry units. These and other revolutionary improvements in communications, surveillance and automated information management all represent great operational advantages to today's American Infantrymen.

It is also true that prospective opponents will possess (or have access to) much of the same technology and will employ tactics that counter American advantages. Aggressive, competent adversaries will contest control of the electromagnetic spectrum; vie for advantage in information operations at strategic, operational and tactical levels; adopt tactics that defy anticipated templates; and force the pace of action in ways designed to minimize American advantages. Deliberate deception and the normal confusion of combat will threaten SA in every operation.

Unique and Common Characteristics of the Infantry Environment

Infantry differs from the other combat arms in its ability to fight in all environments and to take and hold ground by dismounted combat action. Infantrymen have operated in swamps, jungles, cities, and the Arctic. They can move by any form of transportation; enter combat by air assault, parachute, or amphibious carriers; and apply force with greater discrimination and precision than any other combat arm. Infantry units can cross terrain that is inaccessible to mounted troops, fight in close terrain, seize and retain positions accessible only to dismounted soldiers.

The Infantry commander's environment embodies a different type of complexity than that of the aircraft flight leader or ship's captain. In addition to the effects of atmospheric and radio-electronic conditions, the Infantryman must account for the effects of ground condition (stability, contour and relief, traction, trafficability, soil type); human construction; NBC contamination; artificial obstacles; and surrounding human, plant and animal life (Builder, 1989). His unit's condition does not present itself on instruments; it is a composite value of individual strengths and energies, dispersion, condition of supplies and weapons, troop morale, and access to external support (artillery, combat engineers, close air support, electronic warfare [EW], etc.).

Infantry units do not normally move in "packaged", communications-equipped, and collectively maneuverable platforms. They maneuver as groups of individuals that are harder to steer than fleets of ships or flights of aircraft. While other fighting entities may depend on fuel for mobility, Infantry depends on human energy—a resource that must be managed much differently. (See Builder (1989) for other basic differences between ground, air and sea operations.)

Unique among the combat arms, the Infantry's principal weapons are its soldiers. Rather than organizing around a system such as a tank, helicopter or howitzer, Infantrymen fight with squads, platoons and companies of dismounted troops.

Informing, directing and coordinating the actions of groups of Infantrymen distributed across the battlefield differs fundamentally from controlling a formation of ships, aircraft or tanks. Response times are longer and communications and force tracking are more difficult. Maintaining a shared, uniform view of the tactical situation in a dispersed, dismounted force and collating the multiple observations of the one hundred soldiers of an Infantry company in contact with the enemy is singularly difficult. It is further complicated by the differing experience and skill levels in Infantry companies, platoons, and squads where every soldier must rely on SA and where key information inputs may originate with agitated, inexperienced junior soldiers.

The relative youth and inexperience of first-line fighters—squad leaders and platoon leaders—also makes controlling, informing and extracting information from Infantry formations essentially different from operating a flight of fighter aircraft or even a tank company. Information distribution, orientation of the command, maneuver, the delivery of fire, and close combat therefore all raise unique SA challenges because every Infantryman contributes to the overall view of the battlefield and each requires information and direction. The time to collect and disseminate information in an Infantry unit, the level of detail needed, and the complexity of Infantry formations are singularly challenging.

Because Infantry units operate by employing soldiers on the ground, they are the most precise forces on the battlefield. Infantry forces can secure or attack highly specific targets: they can move through a community and remove individuals, seize particular places or things, and send soldiers to confirm conditions or circumstances in an area of concern to their commander. On the other hand, the rich variety of their environment requires more time to analyze, teach and learn than the more consistent air and sea venues.

Also unique to Infantry is its close contact with the population in the area of operations (AO). Success often depends on understanding differences in popular outlook and opinion and identifying subtle cues from civilians. The need to filter tactically significant information from a mixed and confusing demographic background makes small unit SA substantially different from that required of other types of organizations and for higher levels of command.

Infantry shares other basic SA aspects of combat organizations (most closely with armor, cavalry, and combat engineer units). As in all fighting units, intangible qualities such as leader quality, attitude and unit cohesion, training state and recent experience have strong effects on the responsiveness of an Infantry force and its ability to generate and absorb the information on which SA depends. Losses exacerbate this problem—especially the leader casualties to which Infantry units are notably susceptible. In other words, SA for an Infantry unit is complex, case-dependent, and variable with the condition of the unit.

The 2d Infantry Division's disastrous withdrawal through "the Gauntlet" in November of 1950 occurred because the division commander misunderstood the strength of the Chinese blocking the Kunu-Sunchon road to his rear (Blair, 1987). Believing the Chinese 113th Infantry Regiment to be no more than a couple of companies, MG "Dutch" Keiser decided against withdrawing by a more westerly route and sent his already depleted regiments into an ambush unprepared and mal-deployed. The 9th Infantry Regiment which led the attack suffered unnecessarily in its first contact with the 113th, when the division staff told regimental operations officers that the Chinese were in fact a newly-arrived South Korean battalion moving to assist 2/9 Infantry.

Largely because of misunderstandings about the enemy's strength and the location of the Commonwealth Brigade that was moving north to link up with and assist the Division, the withdrawal became a mystifying bloodbath. By the end of the action the Division suffered some 3,000 casualties. Ironically, the Division's trains and its wounded from earlier action moved around the roadblock safely by traveling over the western route rejected at the beginning of the movement.

[Authors' summary, based on descriptive material in Blair, 1987]

The 2d Infantry Division's "Gauntlet" experience makes the point that Infantry operations depend essentially on human qualities of leadership, imagination, aggressiveness and courage. Linked and automated command, control, communications, computers, and intelligence (C4I) tools will be of great value to Infantry leaders in maintaining and using SA. Ultimately, however, Infantry leaders will rely heavily on their trained and native abilities and on the training and orientation of their subordinate leaders for both SA and tactical success.

Infantry leaders decide how they will deploy, orient, and direct their units based on their mission, situation and SA. Intangible human skills such as tactical competence, problem-solving abilities, and the capacity to make decisions under the pressures of time and high risk enter into this and are also heavily affected by the state of SA. Their SA is, in other words, a vital component of their initial decision-making and their ability to direct operations.

Infantry leaders bring an important set of embedded preconceptions to each operation. Their prior training, education, and structured professional experience all influence their tactical perceptions and decisions and supplement their natural aptitude for leadership and tactics (U. S. Army Armor School, 1997). Their understanding of Army and Joint force doctrine—the officially sanctioned description of the nature and key relationships of operations—is a highly significant part of this inculcated world view since it establishes the general range of expectations for leaders. Taken together, these implicit and explicit fields of knowledge largely determine the leader's SA (DA, 1999a).

Improving the SA skills of Infantry leaders and soldiers offers great potential payoffs in combat effectiveness. Leaders who can maintain an accurate understanding of their situation and strength vis-à-vis those of the enemy in the chaos of combat will hold a significant advantage. This will be of special importance when tactical events outmode the original plan and require the Infantry leader to act independently within his commander's broad intent. Leaders who can produce units that gain and share accurate information fast will operate more effectively than less well-prepared opponents. Clearly, Infantry training should by design expose leaders to differing levels of information and evaluate their capacity to identify and perceive key SA elements of a tactical situation. Making the quality of SA a standard feature of After Action Reviews seems likely to pay big dividends in force effectiveness.

Similarly, military education of Infantry leaders—officers and non-commissioned officers (NCOs)—should aim to improve their implicit SA abilities. Case studies, simulations, psychological and tactical instruction, and study of C4I capabilities and techniques can be helpful in this professional development. Technical and doctrinal subjects, when properly understood, build leader competence in Infantry operations. Deeper understanding of battle dynamics gained through exercises and historical analyses contribute to the store of vicarious experience that supports seemingly intuitive decision-making.

There is probably room for improvement through aptitude testing and studies as well. Clearly, some traits promote faster understanding and decision-making as well as clearer communications. Experienced soldiers generally acknowledge the central importance of these skills. This warrants focused study of their effects in Infantry operations and possible screening of Infantry leaders for these attributes.

The SA preparation of junior Infantry soldiers is also important because they are the first-line warfighters. Training should instill the ability to recognize key tactical patterns in junior Infantrymen, teach them to note departures from those patterns, and accustom them to aggressively seeking and reporting information that affects the unit's SA. Examples of the SA sensitivities worth developing in junior soldiers are attentiveness to the commander's critical information requirements (CCIR), attention to details of their unit's formation or defensive organization, awareness of threats to their platoon and consciousness of enemy tactics, weapons and habits.

Key Infantry SA Variables

The key variables for Infantry SA depend on the type and size of the unit concerned and on the tactical parameters of each case. All doctrinal tasks from attack to peace enforcement prescribe actions that imply the need for attention to specific concerns. Each level of organization from brigade to squad operates with different time horizons, equipment sets, manning levels, capabilities and vulnerabilities; these characteristics all create differing SA concerns.

For general purposes, Infantry tactical variables can be described using the elements of METT-TC. Requirements for SA information can be defined in each of these areas, as dictated by the mission goals of the unit. Staff specialists preparing for an operation may also review the Battlefield Operating Systems (BOS) to determine narrower SA interests (DA, 1993b, 1999a).

The assigned or deduced *mission* of a unit dictates specific SA information requirements for the unit and its commander. In defense, for instance, a commander will be doctrinally required to maintain a position against an opposing force or to defeat or destroy that force. Completing that task will mean knowing what constitutes success (how much risk to the unit his higher commander will accept, what level of enemy infiltration may be acceptable, what specific conditions must exist after the defense and so on). For example, knowing that the defense will only succeed if a bridge within the battalion sector remains intact creates some very specific information requirements.

Enemy information (strength, location, composition, tactics, morale, equipment, and so on) is a major factor in combat SA. Knowing where the enemy is, what his doctrine specifies, how his troops generally behave in combat, and how quickly they can move is basic to tactical operations. If the commander knows where all the enemy's forces are (an unusual condition despite what simulations suggest), he can act much more confidently and devote far less attention to securing his flanks and rear area. Seeing enemy vulnerabilities in time to exploit them is a powerful advantage. Knowing the movements of enemy reserves helps in preparing for future action and may be the condition for implementing a particular provision of the tactical plan. Understanding enemy capabilities or intentions well enough to guard against them is basic to all operations and knowing the peculiarities and idiosyncrasies of particular opponents can also be of great value.

The *terrain* (or environment) always plays a large part in Infantry SA. The ground over which Infantry units fight constrains their movement and the enemy's, offers varying degrees of protection from observation and fires, presents obstacles that may only be overcome with assistance, and shields or exposes them to air attack. (Notably, an obstacle that is insignificant from the brigade's perspective may strongly affect the options of that brigade's platoons and squads.) Factors such as visibility, cover, concealment, trafficability, urbanization, soil content and gradient may all have considerable effects on operations. Weather conditions may require special clothing or equipment for the troops and may obviate the use of some weapons. Also of note, environmental conditions can change naturally and as the result of human action during an operation. Maintaining accurate SA therefore means monitoring environmental changes as events unfold.

The dimension of *troops available* to the commander also colors SA. Knowing the strengths and weaknesses of friendly forces (their leaders, recent experiences, condition, state of training, and morale) assists the commander in assigning them tactical tasks. Types of Infantry units available—light, mechanized, airborne, air assault, or Ranger—also influence the tasks that the commander assigns and the information that becomes important to his SA. Later, as operations progress, this information helps determine when units must be replaced or reinforced and how long they can be counted on to hold a position or continue an attack. Knowing the movements of friendly forces on the ground enables a commander to assure his general security and to determine what options he possesses at each stage of an operation. The special capabilities of attached troops—combat engineers, scouts, air defenders, snipers—also enter the commander's calculations for employment of his force and affect his options by their location and condition. Past associations with attached units increase or diminish confidence in their abilities and can affect both SA (by sensitizing the commander to reports from a particular unit or raising special concerns about its progress) and tactics.

Time looms large in the tactical consciousness of Infantry leaders. Knowing when an operation commences or transitions to another phase or when friendly or enemy reinforcements will be in position to affect an action can be critical to success. Where information collection and analysis are concerned, commanders must constantly weigh the advantages of waiting for better understanding against the penalties of inaction. Brigade commanders will understand how long a company can defend without support in a particular situation and structure their operations accordingly. Company commanders will know how long their platoons will need to organize and rehearse for a mission and issue their orders against that deadline. Platoon leaders will know with some precision how much time will be required to set up a defense or bring effective mortar fire on a target. Leaders at all levels will remain acutely aware of the duration of an operation in each of its phases, the time remaining to accomplish key tasks, and the effects of passing time on themselves and their enemies.

Civilian attitudes and needs often bear on operations and thus enter into SA considerations. (See Swinton's (1986) classic Infantry tactics primer, *The Defence of Duffer's Drift,* or operations summaries from Panama, Haiti or Somalia for convincing accounts of these effects.) The movements of civilian traffic and refugees may reduce access to road space or areas. The presence of civilians in an area may inhibit the use of fires or mines. The material needs of towns and cities may impose restrictions on the Infantry commander's freedom of action (e.g., he may be required to avoid damaging power grids, reservoirs, bridges, rail lines or airfields that afford some advantages to the enemy). The sympathies of the population and its propensity to sabotage, report on, or interfere with friendly or enemy actions affect the options of both sides and may shape the course of action a commander chooses. As operations proceed, Infantry leaders will in most cases have to follow changes in the location and activities of the population and account for future consequences of their tactical actions. Legal responsibilities of commanders for public safety and well-being may constrain the actions of battalions and brigades and thus become factors in SA.

Levels of Organization (Brigade to Squad/Soldier)

Battalions and brigades are supported with multi-functional staffs and maintain command posts (CPs) that terminate intelligence, operations, fire support and logistics networks. While battalion and brigade commanders fight forward (and must keep their SA current while moving with small command groups) their CPs give them access to extensive databases and outside information throughout an operation. In those headquarters, staff leaders will review the BOS (maneuver, intelligence, fire support, mobility/countermobility/survivability, air defense, NBC defense, logistics, and C2) to spot critical information elements that they must track to assure effective SA. Superior SA will also guide them in exploiting fleeting opportunities and in reacting to changing threats to effect their commander's intent (DA, 1992a, 1999a).

While all units attempt to "see" the situation two levels down, SA considerations vary with the level of command. Brigades must see farther across the battlefield and farther into the future than companies do. The following paragraphs sketch the *general* needs and peculiarities of brigades, battalions, companies, platoons, squads and soldiers.

Brigades

Brigades fight engagements for the purpose of achieving a significant tactical effect important to their divisions. In doing this, they coordinate the actions of their assigned battalions in pursuit of a particular concept of operation. Brigades may operate with two to five maneuver battalions—though increasingly they employ a fixed set of three permanently assigned battalions. The maneuver battalions may include Infantry, mechanized Infantry, armor or cavalry. Normally, divisions assign supporting combat engineers, field artillery (FA), air defense artillery (ADA), military intelligence (MI), military police (MP), chemical defense, signal and other units to brigades as their mission requires (DA, 1999a).

Because they are responsible for semi-independent operations involving close coordination of their subordinates, brigade commanders must maintain detailed SA in actions involving up to 7,000 soldiers. That force will consist of many types of organizations and will operate in a large tactical area against enemy forces as big as divisions. Brigade commanders' combined arms responsibilities mean that they must understand the needs and abilities of artillery, Army aviation, close air support, engineers, intelligence collectors and other specialized units. Infantry officers in command of brigades must be especially expert in employing armor, cavalry and fire support and possess SA appropriate to employing those forces.

Brigade operations may consist of long-term peacekeeping or security missions that last for weeks. In combat operations, brigades typically fight for periods of eight to 24 hours but may be committed and moving between engagements for a period of days. Their SA must therefore extend over a considerable time period and must be especially acute when close combat is taking place. In combat, opportunities, vulnerabilities, and targets commonly appear and disappear within an hour's time.

In coordinating the movement, commitment, and support of their battalions, brigade commanders must know the exact locations of committed companies, the condition of routes and avenues of approach, the time factors associated with air movements, location of obstacles and positions of adjacent friendly units, and much more. When division attack aviation operates in their areas and when air component aircraft transit their airspace, brigade commanders must know of it and control their maneuver, fire support and air defenses accordingly (DA, 1999a).

Brigade operations are also sensitive to some logistical factors which constitute an important part of SA. Shortages or loss of precision guided munitions and missiles, fuel, repair parts critical to weapons and mobility systems, and medical evacuation and treatment assets can affect the brigade's freedom of action significantly. The security of the Brigade Support Area (BSA) and the routes that connect it to the brigade's tactical formations will be a constant concern in the commander's SA.

Time factors affecting battalions are important at brigade level. Brigades must know how long each battalion can continue to defend or attack, how long it takes to commit a reserve battalion or company to any place in the brigade's area, and how long is required to effectively change priority of artillery support. The time necessary to move sensors and communication nodes, secure attack or lift helicopter support, re-fuel mounted units and re-supply Infantry battalions are also components of brigade level SA. The security of the BSA and the routes that connect it to the brigade's tactical formations will be a constant concern in the commander's SA.

Brigades control the land between battalion rear boundaries and the brigade rear boundary (U. S. Army Armor School, 1997). This entails responsibility for positioning reserves, logistical units, signal nodes, FA batteries, CPs, ADA units, forward arming and refueling points (FARPs), MI jammers and collectors and for controlling all routes in the area. This responsibility extends to knowing about the condition of the ground and infrastructure, about chemical or biological contamination, and anything else that influences operations. Importantly, they must follow past movements of supporting elements in order to avoid positioning troops on terrain that the enemy may have targeted because of earlier activity there.

Battalions

Battalions operate within brigades. They may be assigned separate areas of operation in peacekeeping or security operations, but in tactical operations they commonly cooperate closely with adjacent battalions (DA, 1988, 1992a).

The battalion's SA normally extends to the condition, location and situation of platoons and to the enemy forces and environmental factors that affect them. They must also be aware of the strength and condition of their neighboring battalions and the overall condition and progress of the division and their parent brigade. Their field trains commonly collocate with the brigade's in the BSA but, because their access to that support is critical, the battalion must maintain SA of route status between themselves and the BSA.

Within their own areas, battalion commanders track the positioning and condition of their mortar and scout platoons and their CPs. They also monitor the location and capabilities of supporting logistical units and the condition of the routes and vehicle fleets on which their support depends. When assigned sectors or zones, they are responsible for land management of those areas and must remain aware of the location of all friendly, enemy and civilian elements in their AO.

Typically a battalion's internal operations are closely coordinated, requiring the commander to maintain a highly accurate understanding of their spatial relationship. Committed companies must cooperate closely at certain times. Supporting engineers, chemical and ADA elements must remain in supporting distance of the supported companies. Reserve companies must be able to join the fight in less than an hour, so their location and freedom of action are a matter of great concern. Coordinated actions between companies such as relief in place, forward passage, counterattacks and adjustment of zones or sectors demand precise knowledge of friendly locations, state of the terrain and location of enemy forces.

When task organized with armor or cavalry units, Infantry battalions become task forces and assume tactical responsibility for employing their attachments. Their staffs must then follow the specific concerns of those units to achieve task force SA (DA, 1992a).

Companies

Infantry companies engage the enemy in close combat. They forcibly take and hold ground and destroy enemy forces. While companies operate small CPs, these differ materially from the CPs of battalions and brigades. The company CP follows the unit closely and serves mainly as a reporting center and alternate command facility. The executive officer (XO) normally mans the CP and relieves the commander of the duties of receiving and transmitting reports. Assisting the company commander in sustaining accurate SA is part of the XO's duty. Systems such as FBCB2 and LW greatly facilitate maintaining current SA.

Companies generally take about 150 men into action, organized as three platoons, a support element and a command group. Once in contact, companies must commit all their resources quickly in order to generate their full combat power (DA, 1990b). They therefore do not maintain reserves or uncommitted forces for very long and quickly find themselves decisively engaged (that is, in situations where their survival depends on the outcome). To fight most effectively, companies need accurate knowledge of their own strength, dispositions, and weapons status; the best possible understanding of terrain and other environmental effects on their fires and movement; and the clearest possible view of the enemy forces who face them immediately and those who can join or prolong the engagement.

The company commander leads his unit from a position that allows him to see and influence events. While battalion and brigade commanders fight far enough forward to see events, they can very rarely observe their whole zone or sector. Company commanders, on the other hand, can usually see most of their areas of responsibility, talk directly with their chief subordinates, and see the soldiers who are making the company's main effort. This makes SA considerably different for them.

Company commanders get a great deal of their SA from direct observation. In fact, they must deliberately balance their direct impressions with information pushed to them from higher levels of command. Understanding "over the horizon" events described by the battalion staff is useful to company commanders in arranging for future actions, but quite often their direct view of the enemy, terrain or even the neighboring companies differs from what battalion staff understands and communicates about forces in contact.

Company SA concerns center on exact locations of obstacles, objectives and friendly and enemy forces. Position locating devices are a positive boon to Infantry companies and platoons, saving them considerable time in traversing unfamiliar terrain, adding greatly to their ability to complete complicated maneuvers, and reducing fratricide by keeping small units from drifting into each other. Devices that show the company within the battalion and the platoons within the company should add to tactical effectiveness and free commanders from navigation and positioning, allowing them to attend to other important information. They should also improve SA in danger areas (e.g., passage points, breaches in obstacles, last covered positions before an assault) and at night where company formations tend to wander and either "bunch" or become over-extended (DA, 1990b).

Where the battalion commander may need only the location of enemy platoons and squads, the company commander will benefit from knowing where enemy automatic weapons are sited and precisely where enemy obstacles lie. In operating along a boundary or in close proximity to another company, the company commander will need precise information about friendly troops. Linking up with another Infantry unit or making flank contact in close terrain or in a city can be extremely delicate and techniques or devices that help the company distinguish friendly from enemies will be very valuable.

Companies and their platoons also need detailed information about the terrain. Dead space that cannot be observed or swept with direct fire is always of concern. When attacking, the company will want to make the greatest possible use of covered approaches. When defending they will want means of sensing enemy movements out of sight and means of determining the effectiveness of unobserved fire.

Platoons, Squads, and Soldiers

Platoons and squads are composed almost entirely of combatants (medics are the sole exceptions). Their SA needs center on near-term concerns of mobility, protection, weapons effects, combat support and enemy strengths and location. Before being committed to a fight or put into a situation where contact is likely, these soldiers can make good use of SA updates and detailed depictions of their situation.

Platoons are the direct fire, fighting elements of the battalion that accomplish most of the combat tasks. Composed of about thirty men, platoons fight in teams using fire and movement (the alternation of rushes with direct fire suppression of the target area) to reach their assault positions or to adjust their defenses. Platoons may be assigned short-term independent missions such as patrol or outpost duties (DA, 1993a).

Rifle squads consist of nine Infantrymen. There will be three rifle squads in each Infantry platoon once the mechanized Infantry converts to its new design (DA, 1993a). Squads function as the sub-elements of platoons. They control a part of the platoon's position in defense and act together as maneuver elements within the platoon formation in movement and attacks. Squads may perform semi-independent tasks such as reconnaissance, ambush, and combat patrols (DA, 1992b, 1993a).

Platoons depend on drills and other trained responses to stimuli in combat. They learn formations, movement techniques, formatted maneuvers, patterns of fire distribution, and combat shooting techniques to overcome the violence and high tempo of close combat. These standardized actions are trained responses to specific cues or conditions; they depend on general SA and fast, rough estimates of the situation for their effectiveness. Early warning of contact, information on the enemy's precise location with the exact dimensions of his position, the location of his heavy weapons, and cover offered by the terrain are the greatest SA needs of platoons in the crucial early moments of first contact (DA, 1992b, 1993a; U. S. Army Infantry School, 1998).

Once committed or exposed to imminent contact with the enemy, their situation changes. Then, their physical senses become largely devoted to sensing changes in the area around them and external SA promptings must be used very judiciously. The simple TRADOC formula, "where am I, where are my buddies, where is the enemy" is a reasonable guide to requirements for committed forces—if one adds other basic information on terrain and obstacles.

Technical aids that improve their vision, hearing and ability to communicate internally about the situation are welcome. Brief, accurate external updates—short voice alerts or simple visual cues—are generally useful. But a platoon leader, squad leader or rifleman who is straining to see or hear a nearby enemy or adjust fires can be as easily distracted as assisted by external messages. The safest course for supporting Infantrymen in contact with SA information is to rely on them to request updates or specific information at the times they can best absorb it (U. S. Army Infantry School, 1998).

Nonetheless, both training and technology offer some promising opportunities for improved SA in small units. Simulations, structured SA-specific training exercises, and individual user-paced training all may assist in developing greater sensitivity to tactical situations and better skills in identifying and obtaining relevant SA information. Technical progress in position location, target designation, intra-squad communications, image transfer, computer mapping, thermal imaging, and small unit force tracking have shown their value in Force XXI experimentation (e.g., TRADOC Analysis Center, 1998). Future unobtrusive heads-up-displays, voice interfacing with computers, optical and aural aids, and superimposing virtual images ("augmented reality") on direct vision may improve SA in platoons and squads and for individual Infantrymen. At the same time, careful design and testing of new technologies and their impact on SA are warranted to ensure that perceived SA enhancement in one aspect does not adversely impact SA in some other area.

The Role of Situation Awareness in Infantry Operations

In close quarters combat, preserving friendly strength and capability while reducing the enemy's combat power is the *sine qua non*. Infantry commanders harness all forms of combat support to render themselves more effective in the close combat that typifies Infantry operations. Having superior SA powerfully advances the goal of making Infantry combat one-sided.

Superior SA permits Infantry units in combat to avoid hazards, to move efficiently, to apply combat power in mass against targets that hurt the enemy most, and to transition quickly to subsequent tasks. There are direct and indirect inputs to battlefield SA. Direct inputs are situation-specific and become more refined and less complex as a unit approaches commitment to combat. Indirect inputs are embedded in the force before and after combat by training, education and systematic exploitation of experience. Indirect elements of SA lay the foundation for interpreting the direct observations of combat.

In Stability and Support Operations (SASO), SA is equally important. Whether the mission calls for support of civilian authorities or peace enforcement, accurate SA is essential to efficiency and can make the difference between success and failure. Usually, SASO missions call for great discretion in use of force and for exceptional sensitivity to local conditions. In such conditions, the orientation of the unit toward its surroundings and quick feedback from its actions can be especially important.

For general discussion, SA in operations can be considered under the five broad headings of staging, deploying, pre-operations movements, during operations, and post-operations activities. These categories apply to Infantry units from squad to brigade in ways appropriate to the levels of organization.

Staging

Staging is the deliberate preparation of a unit for movement to an AO. Informal preparation begins when a commander or Infantry leader anticipates receiving a mission. He will at that point begin preparation of his soldiers and subordinate leaders for all the events of mobilization and movement. Where SA is concerned, he will review his own status in the broadest terms. He will consider his unit's leadership; its proficiency in the tactics, techniques and procedures he expects to use; its capability for teamwork and reaction to combat stimuli; its ability to receive and process information; and its ability to understand the activities of its subordinate, superior, adjacent and supporting units. More pointedly he will assay his unit's familiarity with the environment, general situation, mission, and enemy it will face (U. S. Army Armor School, 1997; TRADOC, 1994b).

During staging there is still a considerable opportunity to conduct remedial training or to introduce new information that will assist in SA later. Environmental training (coping with physical conditions, recognizing adverse effects of the environment on soldiers and equipment), enemy and friendly force familiarization (learning cues and indicators of anticipated behaviors or weapons effects), mission familiarization (reviewing the essentials of missions by type), and personal introduction of new leaders/soldiers are all candidates for SA improvement during staging. Necessarily, this effort takes place in the midst of other activities associated with moving troops to the theater of operations. While sound staging can lay the groundwork for fast and efficient SA in operations, improper staging can lead to significant misinterpretation and delays in processing information in actual operations.

Reasonable SA goals during staging include obtaining rough focus on information requirements, orienting soldiers and leaders on the broadest essentials and identifying gaps in SA which may reasonably be filled before the unit is committed.

Deploying

Deployment consists of moving the unit from its staging area to the theater of operations. This phase can be short and lead directly to commitment as in the case of air-landing or a parachute drop. It may also be an extended phase of operations involving sea transport and separation from and reunion with mission equipment. Considerable advantages can be secured by sharpening SA during deployment, especially if the deployment leads directly into the movement to contact (U. S. Army Armor School, 1997; TRADOC, 1998b).

Squads, platoons, and companies normally move intact. Battalions and brigades may move incrementally, depending on the type of transportation in use. In any case, today's communications allow commanders to obtain and distribute critical information to their subordinates throughout deployment. They will be able to follow the course of operations in the theater to which they are bound, learning about the enemy's and allies' abilities and practices, charting changes to the terrain caused by operations, and assessing the effectiveness of tactics and doctrine employed by units already engaged.

Staff officers will be able to improve their knowledge of supply, transportation, popular attitudes, geography and climatology and just about anything else of interest to the commander. Additionally, deploying troops will remain in contact with their force projection base which will permit Joint and Army trainers to send them timely orientations, updates and special training programs.

In-transit visibility of materiel and units will also open options for adjusting the order of force arrival to take advantage of recent developments in the theater. Infantry commanders may find their units' ports of debarkation, marshalling areas and tactical assembly areas changed during their movement in order to facilitate future operations. In short, where deployments of the past essentially represented a period of limited communications and training, future deployments will allow for continued preparation for operations and will be fully integrated parts of the land component operation (U. S. Army Infantry School, 1998).

Pre-Operations Movements

Once in theater, Infantry units usually move from ports of debarkation through forward assembly areas to their areas of operation. Further movements normally take them from tactical assembly areas or reserve positions into action. Air, airborne and amphibious assaults reduce this movement considerably, essentially limiting it to the short move from airhead or beachhead into contact.

In any case, these movements before commitment are a combination of administrative and tactical moves. Once contact with the enemy is anticipated, Infantry units maneuver as committed or reserve forces (DA, 1990b).

During this pre-combat movement, SA plays a vital role. Knowing the locations of friendly and enemy forces and the state of the environment affects the security of the unit as it moves, its ability to move at the expected rate, and its ability to join the fight under favorable terms. Detecting newly created hazards such as chemical contamination, destroyed bridges, groups of moving refugees and scatterable minefields and adding them to the unit's SA also reduces the friction of movement to contact (DA, 1990b, 1992a; U. S. Army Infantry School, 1998).

The dangers of premature and/or inadvertent involvement of uncommitted units and of late arrival as a result of disorientation, obstacles or mal-positioning are the chief threats to effective use of uncommitted units. The use of dynamic obstacles, interdiction fires, and unconventional forces in the depth of a brigade or battalion formation (enemy deep operations) can also break up the coherence of friendly operations. Good SA based on aggressive reconnaissance and strong communications can reduce the effects of these enemy actions.

It also permits the force commander to adjust his movement and dispositions to assure the most advantageous terms possible upon commitment. Good SA is critical to these dynamic shifts to the operational plan. Finally, accurate SA distributed throughout the unit reduces the risks of fratricide between committed and uncommitted units and supports the safest possible movement of troops through danger areas.

During Operations

Obviously, the value of knowing friendly and enemy situations and the condition of the environment is vital during combat or in other operations. In conditions where detailed information is readily available, Infantry commanders will have to make conscious decisions about how SA is maintained during combat. They will base these decisions on the balance between the value of new information and the penalties of distracting committed units. Decisions made in advance about information needs during combat and the practiced judgment of supporting staff officers will help in maintaining SA during combat.

The CCIR are the doctrinal means of establishing priorities and of managing information flow. Good tacticians limit their information requirements to absolute essentials once their units are committed. These vary with each operation but commonly concentrate on enemy forces that can affect the unit within a given time; friendly strength, location and condition of key weapons; and environmental changes that affect the commander's plan or freedom of action.

Enemy information is particularly sensitive during combat and demands special attention. The output of division, brigade and even battalion intelligence sections usually lags far enough behind the true situation to make technical displays of the enemy in contact inaccurate. The first soldiers to train with digitized C4I (the Experimental Force at Fort Hood) learned to discount enemy information that was more than a few minutes old and, once committed, tended to ignore enemy force displays in their immediate area (TRW Inc., 1997b). In addition to problems of timeliness, deliberate deception, electronic countermeasures and the errors and uncertainty of friendly analysts will obscure the enemy situation.

Post-Operations (or Inter-Combat) Activities

In the intervals between phases of an operation or at an operation's end, SA concerns move to regaining a broad view of the situation and, in particular, to assessing the effects of the just-completed action. Brigades and smaller units will sharply re-orient their view from the immediate circumstances of the completed fight to a wider perspective aimed at determining the next requirement. They will pay particular attention to damages to the enemy, to their own condition and to changes in the environment that will limit or support their next anticipated actions.

In practice, these intervals feature intense efforts to collect and confirm critical information. Commanders urgently seek exact locations of their units and their neighbors; information on casualties, equipment and weapons losses, and amounts of critical material on hand; and revised information on the enemy. They will also press to pass their estimate of the situation to their superior commanders and to learn what their next mission is to be. Normally, they will re-organize or re-deploy their units in order to resume operations in the optimum configuration. They will also adjust all of their staff estimates to reflect the changed conditions after an operation.

Re-distributing scarce supplies and replacing lost leaders also claims a lot of a commander's attention following operations. When they must make changes to the chain of command (moving staff officers into commands and reassigning junior leaders to positions of greater responsibility to replace lost leaders) and assign replacement soldiers to the squads, efforts to restore high levels of SA by informing newcomers assume great importance.

Technical aids to post-operations SA include position-reporting equipment, automated material diagnostic equipment, automated inventory reporting systems, sensor imagery, and elements of the "total asset visibility" logistical system. Platform reporting systems such as FBCB2 make understanding friendly dispositions far easier than in the past. Ammunition inventory features of the Advanced Field Artillery Tactical Data System and the Combat Service Support Control System are also helpful. Unmanned aerial vehicles and other overhead sensors can be useful in sorting out enemy adjustments and movement of the population following an action as well.

Even with this sort of technology, however, Infantry units must act aggressively to fill gaps in their SA. Commanders visit their units and make personal reconnaissance on the ground. They send patrols to confirm imagery or to conduct long range observation of areas of interest. They dispatch liaison teams and contact teams to adjacent units and to lower and higher headquarters to gain a fuller understanding of the consequences of an action just-completed and of the direction of future operations. Such actions have a large effect on the commander's confidence in collected information—a critical factor in SA.

In transitioning to post-combat operations, good SA usually demands close contact with the population of the area and stronger emphasis on civil-military operations. North Atlantic Treaty Organization forces moving into Kosovo after the Serbian capitulation had to acquaint themselves with details of local government and conflicts between civilian groups, find and mark mines and duds, locate and secure evidence of war crimes, and obtain basic knowledge about public order. These difficult tasks get minimal attention in basic leadership courses because they are secondary. Nonetheless, the experiences of World War II, Korea, Vietnam, Grenada, Panama, and the Gulf War all testify that this kind of SA becomes important to combat units between episodes of fighting, at the end of conflicts and in all peace-keeping efforts.

Summary of Key Battlefield Factors

The issues and variables that play important roles in Infantry SA form a complex array of interacting dimensions. Table 1 summarizes the foregoing discussion to portray the situation elements of immediate interest to Infantry leaders and soldiers as one moves across phases of combat operations and also from higher echelons to lower. The table illustrates the complexity encountered in Infantry operations.

Table 1

Summary of Representative Situation Elements for Infantry Situation Awareness

	Phases of Infantry Operations				
Echelon	***Staging***	***Deploying***	***Pre-Operations***	***During Operations***	***Post-Operations***
Brigade	♦ Mission, enemy, area of operations (AO) ♦ Weather ♦ Status of battalions (Bns), brigade (Bde) staff ♦ Division's concept for deployment, operations ♦ Task organization changes ♦ Strengths/limitations of assigned units and leaders ♦ Time remaining before first movement ♦ Time required to fully deploy the Bde ♦ Time when Bde must/can assume control in AO	♦ Location/status of subordinate Bns, companies (COs) ♦ Tactical developments in AO ♦ Enemy actions and condition ♦ Capabilities, limitations and past experience of US/friendly Bdes ♦ Changes to division plan ♦ Changes to division order or concept ♦ Status and availability of support units ♦ Condition of forward assembly areas	♦ Changes to availability/condition of routes ♦ Changes affecting air movement or C4I ♦ Status of division and adjacent Bde formations, movements ♦ Vulnerability to enemy action ♦ Changes at the line of contact ♦ Changes to time of commitment ♦ Availability and condition of attached or supporting forces	♦ Location/condition of assigned forces ♦ Location/activities of enemy units in area of interest ♦ Changes to air situation ♦ Location/progress of adjacent, reserve Bdes ♦ Division appreciation of situation ♦ Combat support (CS) or combat service support (CSS) constraints ♦ Conditions that trigger changes to plan ♦ Location of command posts (CPs) and key leaders	♦ Time until next mission ♦ Nature of next mission ♦ Condition, location and status of assigned forces ♦ Enemy location, condition, and activities ♦ Time until resupply or reorganization complete ♦ Need to replace leaders ♦ Status of morale and key systems ♦ Changes to task organization ♦ Battle damage to AO that affects future operations

(table continues)

Table 1 (continued)

Echelon	*Phases of Infantry Operations*				
	Staging	***Deploying***	***Pre-Operations***	***During Operations***	***Post-Operations***
Battalion	♦ Mission, enemy, AO ♦ Weather ♦ Status of COs, staff, and special platoons ♦ Bde movement plan ♦ Time available to prepare and train ♦ Special requirements for advance parties/debarkation details, time to provide them	♦ Location and status of COs, other Bns ♦ Changes to enemy situation ♦ Changes to friendly position in theater ♦ Availability of transportation and supply at destination ♦ Changes to Bde or division plans ♦ Changes to deployment of attachments or supporting units	♦ Conditions of routes or avenues of approach ♦ Status and coherence of Bde formation ♦ Location of enemy forces ♦ Susceptibility to enemy fire or air attack ♦ Imminence of commitment ♦ Exact location of passage points or lanes ♦ Location of obstacles and defenses around them	♦ Location/conditions of COs, platoons ♦ Location/status of other Bns ♦ Enemy location, activities ♦ Condition of C4I links/sites ♦ Activities of Bde's supporting FA and engineers ♦ Changes to terrain that affect operations ♦ Location of hazards in sector or zone ♦ Location/status of trains and CPs ♦ Location of key leaders	♦ Time until next mission ♦ Nature of next mission ♦ Location/status of COs, other Bns ♦ Enemy location, activities ♦ Time until refitting/resupply complete ♦ Need to replace leaders ♦ Morale/energy of Bn ♦ Status of key systems ♦ Changes to Bde's allocation of CS ♦ Condition of CS, CSS units
Company	♦ Mission, enemy, terrain ♦ Time to move ♦ Availability and condition of assigned soldiers and leaders ♦ Location and nature of transportation ♦ Special staging, movement and equipment requirements ♦ Soldier training and morale readiness	♦ Changes to the situation ♦ Changes to orders or organization ♦ Destination weather ♦ Location of CO supply trains ♦ Enemy location/activities ♦ Status of attachments ♦ Location of key Bn leaders ♦ Sequence of unit arrivals	♦ Changes to orders or to battlefield conditions ♦ Conditions at destination ♦ Timing of commitment to action ♦ Location and status of other COs ♦ Access to supporting fires and engineers	♦ Location and condition of platoons and squads ♦ Location and situation of other COs ♦ Enemy location, activity, and condition ♦ Enemy use of air, artillery, nuclear/biological/chemical (NBC) ♦ Location of obstacles/hazards ♦ Conditions limiting use of wpns ♦ Time left to accomplish mission	♦ Time until next mission ♦ Disposition of Bn/Bde ♦ Strength of personnel, equipment ♦ Time needed to resupply ♦ Location/activities of adjacent COs ♦ Enemy location/activities ♦ Availability of artillery and engineer support

(table continues)

Table 1 (continued)

Echelon	Phases of Infantry Operations				
	Staging	*Deploying*	*Pre-Operations*	*During Operations*	*Post-Operations*
Platoon, Squad	♦ Mission, enemy, terrain ♦ Time until departure ♦ Availability and condition of assigned soldiers ♦ Condition of equipment and supplies ♦ Determination of equipment to move separately ♦ Soldier readiness ♦ Individual training needs and opportunities	♦ Changes to the situation ♦ Unit destination and first mission ♦ Ammunition and supply status ♦ Communications status ♦ Sources of supply ♦ Location and arrival times of other squads and platoons	♦ Objective ♦ Conditions at the objective ♦ Location of subordinate elements ♦ Location of other squads and platoons	♦ Location of all unit members and attachments ♦ Losses and their medical needs ♦ Enemy strength and location ♦ Status of/ access to heavy weapons support ♦ Strength and disposition of next two higher levels of command ♦ Loss of leaders	♦ Time/nature of next action ♦ Disposition of next level of command ♦ Location of adjacent and supporting teams ♦ Supply status, time of resupply ♦ Enemy location and activities ♦ Availability of mortar support ♦ Access to/arrival of special support (NBC decon, etc.)
Soldier	♦ General situation (mission, enemy, terrain) ♦ Time until deployment ♦ Technical and tactical knowledge deficiencies ♦ Environmental conditions	♦ Changes to the situation ♦ Exact destination and conditions there ♦ Initial tasks ♦ Imminence of combat ♦ Adequacy of weapons, supplies, medical support	♦ Destination and conditions there ♦ Location of teammates and other friendly units ♦ Status of critical supplies ♦ Location of enemy	♦ Orientation ♦ Location of teammates and objective ♦ Specific enemy locations including major wpns ♦ Presence/status of support units ♦ Availability of ammunition and medical support ♦ Location of squad leader ♦ Location and status of hazards	♦ Time/nature of next action ♦ Location of teammates, other friendly units ♦ Location of enemy ♦ Location of squad and platoon leaders ♦ Adequacy of critical supplies ♦ Safety/condition of unit members

Better understanding of conditions and opportunities promises great tactical advantages to battalions, companies and platoons. By removing some of the uncertainty from operations, improved SA fosters more precision in planning, greater efficiency in operations, and, sometimes, reduced stress on soldiers. It also enhances the use of time, an advantage that has commonly provided a tactical edge of great value.

Better knowledge of the situation with a high level of confidence reduces commanders' misperceptions and their need to hedge or "safe-side" in tactical planning. If a commander or leader knows the time and place of an enemy attack or the design of his defense, his own actions will be more effective. If he understands the enemy's true situation, he may free himself from the need to withhold forces from the fight to cover contingencies such as exposed flanks or the possibility of counterattack from a particular direction. Moreover, he gains the advantages of being able to decide and act faster if he understands his situation earlier and can brief his subordinate leaders and soldiers faster and in greater detail.

The leading battalion commanders of the 1st Infantry Division (Mechanized), for instance, profited from exquisitely precise intelligence on Iraqi defensive positions in the first phase of their Desert Storm attack. According to a brigade commander, their high levels of SA and detailed schemes of maneuver and fire support contrasted strongly with their comparative lack of information and SA when they moved to rejoin the battle on the night of 26-27 February 1990, four days later (Maggart & Hubal, 1999).

A clearer view of circumstances also facilitates the full use of all available combat power. Full visibility of the battalion's platoons facilitates coordinated maneuver and more effective application of force. It also gives the battalion commander the ability to detect and correct errors in maneuvering or positioning and thus avoid some of the penalties of poorly coordinated operations. Knowing the location, condition and availability of supporting FA, engineer, EW, ADA and chemical defense units also adds to combat effectiveness.

Knowing where the enemy is and is not or what maneuver the ground will support greatly enhances the effectiveness of battalion operations. If the battalion commander knows such things as exact enemy dispositions, the location of enemy obstacles, the availability of supporting artillery and the true location of his platoons he will enjoy considerable fighting advantage. As a result, he will be able to "push the envelope" of possibilities, employing every supporting weapon or system as it becomes available. He will also have a better, earlier appreciation of the results of supporting fires, EW, or engineer effort that can be translated into better exploitation of tactical advantages. Understanding when to break off an attack or when persisting can lead to significant gains is also a major advantage of superior SA.

At the Infantry soldier's level, superior SA represents a huge combat multiplier. Understanding the location and condition of friends and adversaries, knowing the best sites for defense or paths for attack, and being able to avoid enemy fires and obstacles permits soldiers to accomplish more at lower costs in time, material and casualties. Intangible but critical morale advantages—confidence, aggressiveness, and optimism—usually accrue to a force with a firm grasp of the situation.

The effects of uncertainty, the unknown, and surprise create enormous stress in combat. To the extent that improved SA reduces uncertainty, fills information gaps, and reduces the likelihood of surprise, it may relieve some of the anxiety of fighting, diminish the number of stress casualties, and therefore prolong a battalion's effectiveness. On the other hand, when a battalion, company or platoon finds itself in exceptional danger, seeing that clearly and well in advance may add to the stress of an already bad situation.

Model of Situation Awareness in Infantry Operations

Requirements for an Infantry-Focused Model

The previous section described the importance of SA for success in Infantry operations and the many factors with which soldiers and leaders must deal to gain and maintain SA. In order to focus the examination of SA on developing useful strategies for improving SA, a model of the factors and processes that affect the establishment and maintenance of SA in Infantry operations is needed. The criteria that such a model should meet were outlined in the *Methods* section.

The ultimate utility of an Infantry-focused SA model is to provide a foundation for developing strategies for improving SA. By clearly understanding the perceptual and cognitive processes involved in achieving SA, and the many task and environmental factors that influence the SA of the Infantryman, effective tools, processes, and training strategies can be identified for aiding soldiers in Infantry operations. The model also can provide a framework for developing measures that can be employed to assess the impact of new programs or tools on Infantry SA.

While the factors and challenges that make SA difficult in the Infantry environment are somewhat unique, the cognitive processes and mechanisms that all human beings use to arrive at a mental representation of their situation are essentially the same across many different domains. The basic features of SA have been widely studied for the past decade in combat aviation, air traffic control, nuclear power plant operations, vehicle driving, and maintenance operations. These domains differ in some significant ways from Infantry operations, such as the degree to which the latter must rely on very detailed analyses of terrain or the degree to which civilian considerations must be taken into account. However, they also share many common aspects, such as reliance on multiple team members for information, assessment of environmental and system information, challenges of information complexity, and information overload.

Several models of SA have been developed that discuss how people achieve SA in complex domains, as summarized in Table 2. These models were reviewed to determine their suitability to represent Infantry SA, based on the criteria outlined in the *Methods* section. The results of the review appear in Table 3, which indicates whether the various models satisfy each criterion. The criterion-based evaluation process yielded the highest index value for the model of Endsley and Jones (1997), which satisfied 10 of 12 criteria. However, their model is specialized for team SA, relying on Endsley's (1995b) model for individual behaviors. Geared to individual SA, Endsley's model satisfied 9 of 12 criteria. For the operational environment of the individual Infantry soldier, Endsley's model provides the closest fit while retaining a tie to accepted cognitive theory. It provides the basic foundation needed for understanding how soldiers achieve SA under the challenges of Infantry operations. It establishes the appropriate framework, detail, and theoretical soundness for determining methods for measuring SA and generating research solutions. Similarly, Endsley and Jones' model forms a solid foundation for modeling team SA in the Infantry environment. Neither model satisfied all of the criteria for an Infantry-focused SA model, indicating a need for further development.

Based on the criterion-centered evaluation of candidate models, the team adapted Endsley's (1995b) model to account for individual SA in Infantry operations. To address team SA, they adapted Endsley and Jones' (1997) model. The basic framework of both selected models was retained, while dimensions characterizing the operational Infantry environment were incorporated. Five categories of factors structured the basic model: (a) individual capabilities, goals, and actions; (b) the external world, including task and environmental factors; (c) Army doctrine and tactics; (d) Army processes such as mission planning and preparation; and (e) real-time cognitive processes. The extension of the selected models incorporated the current state of knowledge on SA and the factors affecting SA in Infantry operations (see the preceding section). The resulting model takes into account both the cognitive processes and environmental factors that affect the development and maintenance of SA in the dynamic domain of combat. Shown in Figure 1, the Infantry-focused model incorporates the unique features of Army operations and the Infantry environment. Where specific factors and aspects are itemized in Figure 1, the lists are meant to be illustrative, rather than exhaustive. The model will be described first at the level of the individual soldier or commander, and then at the collective levels of squad through brigade. While discussed primarily in terms of the soldier, the model is intended to be applicable at all echelons of Infantry organizations.

Table 2

Summary of Candidate SA Models

Model	Description	Strengths	Limitations
Adams, Tenney & Pew (1995)	• Describes SA as a dynamic perception-action cycle • General model of cognition • Includes role of memory, expertise and task management	• Emphasizes dynamic nature of SA • Explains some SA processes	• Only partially includes factors relevant to SA • Not extendable to team SA • Does not focus on operational Infantry • Confounds SA processes and products
Endsley (1995b)	• Describes individual cognitive processes and external system and environment factors affecting SA • Defines 3 levels of SA • Based on information processing theory • Includes role of attention, memory, cognitive processes, expertise, goals, expectations, and stressors	• Forms comprehensive model of SA • Contains explanatory and predictive components • Provides for SA measurement • Generalizable to many environments	• Does not focus on operational Infantry • Does not address team SA
Endsley & Jones (1997)	• Describes team SA including factors that affect team SA	• Links to model of individual SA • Provides descriptive and predictive components • Provides for measurement of SA at the team level	• Does not focus on operational Infantry • Does not explicitly discuss organizational echelons.

(table continues)

Table 2 (continued)

Model	Description	Strengths	Limitations
Fracker (1988)	• Describes SA in terms of memory structures • Includes role of attention and memory structures	• Provides for SA measurement • Generalizable to many environments	• Only partially includes factors relevant to SA • Does not focus on operational Infantry • Does not address team SA
Maggart & Hubal (1999)	• Describes various factors impacting SA	• Emphasizes Infantry factors & terminology	• Not consistent with psychological theories or models • Only partially includes factors relevant to SA • Does not provide for SA measurement
Salas, Prince, Baker & Shrestha (1995)	• Describes team SA • Emphasis on team processes	• Provides for measurement of team processes • Describes features of team SA	• Only partially includes factors affecting team SA • Does not address individual SA • Does not focus on operational Infantry • Does not explicitly discuss organizational echelons.
Smith & Hancock (1995)	• Describes SA as externally directed consciousness arising from adaptation between environment and individual • Based on ecological psychology • Emphasizes role of goals on SA	• Generalizable to many environments	• Only partially includes factors relevant to SA • Not extendable to team SA • Does not focus on operational Infantry • Confounds SA processes and products • Does not provide for SA measurement
Taylor & Selcon (1994)	• Describes SA in terms of supply and demand on attentional resources & understanding • Based on surveys of pilots	• Based on systematic analysis • Provides for SA measurement • Explanatory model	• Confounds SA and workload • Not generalizable to Infantry environment • Does not include predictive components • Does not address team SA

Table 3

Criterion-Based Assessment of Candidate Models of Situation Awareness

Required Characteristics	**Adams, Tenney, & Pew (1995)**	**Endsley (1995b)**	**Endsley & Jones (1997)**	**Fracker (1988)**	**Maggart & Hubal (1999)**	**Salas et al. (1995)**	**Smith & Hancock (1995)**	**Taylor & Selcon (1994)**
Representation of operational Infantry factors					√			
Incorporation of individual behaviors	√	√		√	√		√	√
Incorporation of collective behaviors			√			√		
Systematic consideration of factors influencing SA		√	√		√			√
Integration of current SA knowledge		√	√					√
Representation of SA's dynamic nature	√	√	√	√	√	√	√	√
Explanatory power	√	√	√	√	√	√		√
Suitability for quantification of SA behaviors	√	√	√	√		√		√
Capability for comprehensive, directional prediction		√	√	√				
Compatibility with recognized theories of behavior	√	√	√	√		√	√	√
Flexibility to account for organizational echelons			√			√		
Extendability to other operational environments	√	√	√	√	√	√	√	

Description of the Model

Because the model incorporates a large number of factors relevant to SA in Infantry operations, it will be described in segments to facilitate the reader's understanding. Each segment will be linked to a break-out figure representing a portion of Figure 1. The sequence of figures representing the model segments is progressive and cumulative, so that each figure builds on its predecessor.

What is Situation Awareness?

As stated in the *Introduction*, Endsley (1988) formally defined SA as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (p. 97). The construct therefore involves perceiving critical factors in the environment (Level 1 SA), comprehending what those

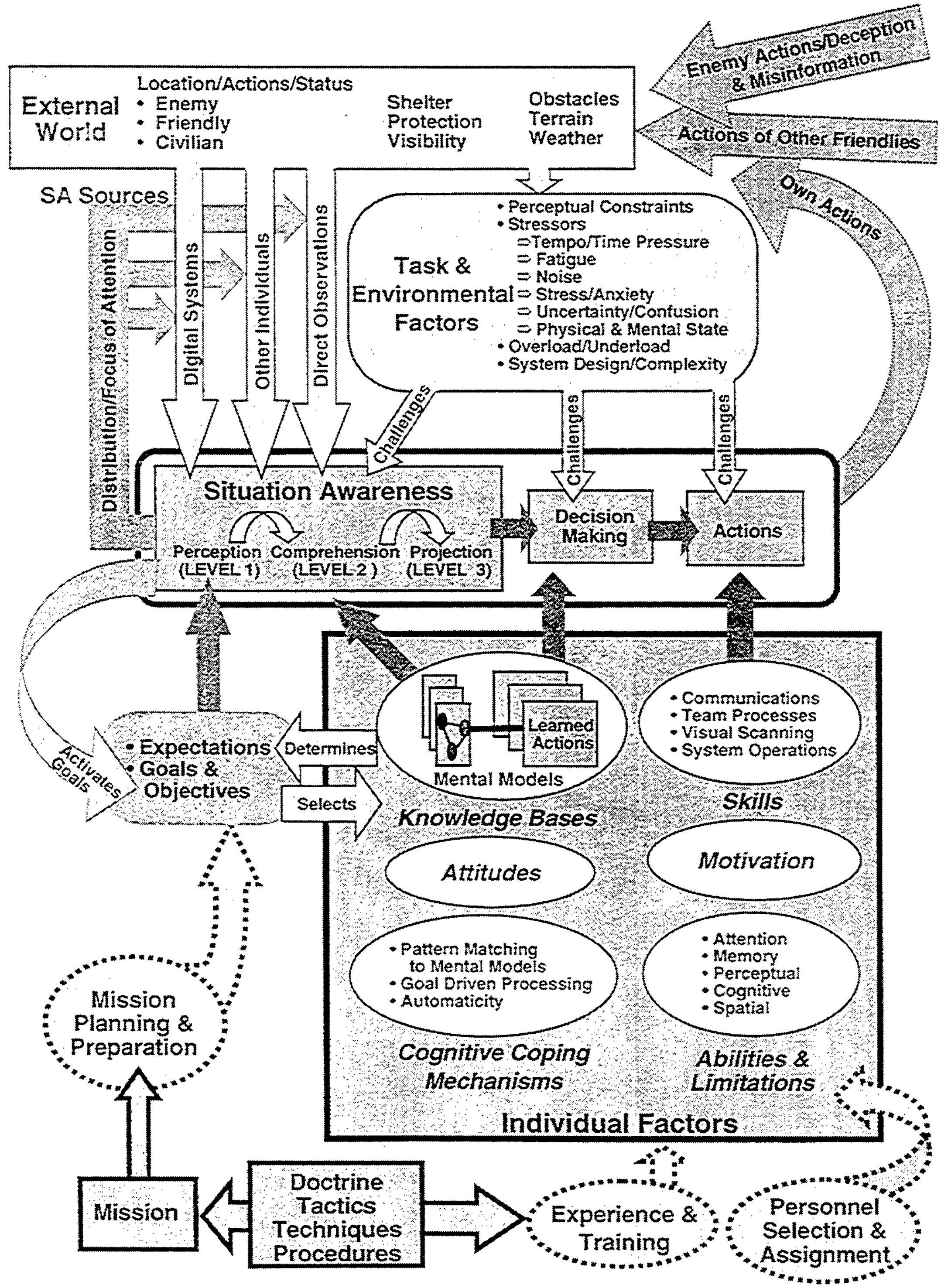

Figure 1. The Infantry-focused model of individual situation awareness.

factors mean, particularly when integrated together in relation to the soldier's goals (Level 2 SA), and at the highest level, projecting what will happen in the near future (Level 3 SA). The higher levels of SA allow soldiers to function in a timely and effective manner. The three levels are depicted in Figure 2.

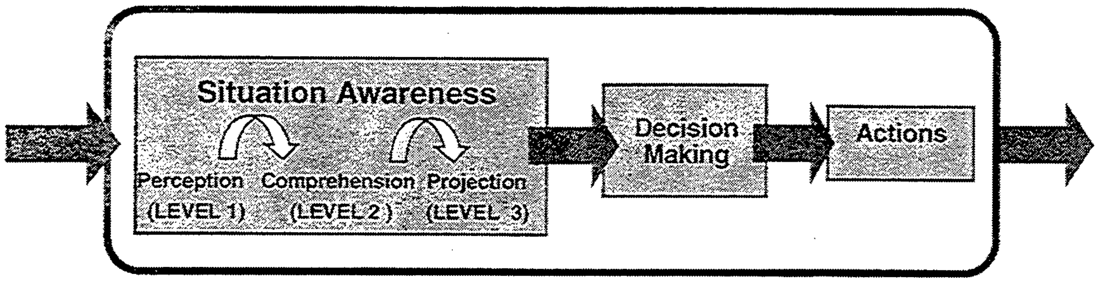

Figure 2. Model of situation awareness levels and decision-action process.

Level 1 SA—perception of the elements in the environment. The first step in achieving SA is to perceive the status, attributes, and dynamics of relevant elements in the environment. As discussed earlier, this will include important elements such as enemy, civilian and friendly position and actions, terrain features, obstacles, and weather. In Infantry operations it may often be difficult to assess all the needed aspects of the situation due to obscured vision, noise, smoke, confusion and the dynamics of a rapidly changing situation. Numerous sources of information may all vie for limited attention and processing resources. This information may come from direct observation of the environment (which is the main source below company level), from verbal and non-verbal communications with others at squad level, or from electronic systems and enhanced sensors that are increasingly becoming a part of Infantry operations. Each of these sources of information is associated with different levels of reliability. Confidence in information (based on the sensor, organization, or individual providing it), as well as the information itself, forms a critical part of Level 1 SA for the Infantryman.

Level 2 SA—comprehension of the current situation. Comprehension of the situation is based on a synthesis of disjointed Level 1 elements. Level 2 SA goes beyond simply being aware of the elements that are present, to include an understanding of the significance of those elements in light of the soldier's or leader's goals. The Infantryman assimilates Level 1 data to form a holistic picture of the environment, including a comprehension of the significance of objects and events. For example, upon seeing a disturbed section of terrain (vehicle tracks or boot marks), an experienced soldier may understand that means other units have passed through the area and consequently adopt a stealthier posture in scouting ahead. A less experienced soldier may see the same cues (Level 1 SA), but not be able to comprehend the situation as well. Similarly a brigade logistician must understand the consequences of operational developments for his support of the unit and know when circumstances in the support elements become significant to the tactical situation. Typically Level 1 SA (perceived data) must be interpreted (with reference to goals or plans) in order to have meaning as Level 2 SA. For example, comprehension could mean knowing the significance of discovering that a particular squad is in a given location, e.g., realizing that they are half a mile away from their intended position.

Level 3 SA—projection of future status. The third and highest level of SA is the ability to project the future actions of the elements in the environment, at least in the very near term. This is achieved through knowledge of the status and dynamics of the elements and a comprehension of the situation (both Level 1 and Level 2 SA). Commanders with a very high level of SA are able to project where and when the enemy will strike. Soldiers with Level 3 SA are able to project how much time they have until reinforcements arrive or until a second volley of artillery fire is brought to bear. This gives them the knowledge and time necessary to decide on the most favorable course of action to meet their objectives.

Situation Awareness Requirements

Understanding SA in the Infantry environment rests on identifying which things the soldier needs to perceive, understand and project. Examples of these elements were provided in Table 1. Certain classes of elements are needed, including geographical SA, spatial/temporal SA, environmental SA, and tactical SA. These are specific to different types of missions and to different roles within the mission (e.g., the company commander versus the squad leader). As such, they must be determined separately for each mission and role. Thus, SA requirements are the aspects of the external world that are important for SA (as shown in Figure 3) and are driven by the mission goals prescribed for each individual role. A methodology for determining SA requirements based on mission goals has been developed (Endsley, 1989, 1993; Endsley & Rodgers, 1994). That methodology can be applied to establish a more complete understanding of SA in the Infantry environment. Identifying the specific SA requirements for each mission type and Infantry role is critical to the development of useful tools for supporting SA and for developing appropriate measures of SA in Infantry operations.

Situation Awareness Sources

Individuals derive SA through various sources, as shown in the upper left portion of Figure 3. First and foremost is direct observation of the external world using all of the soldier's senses: sight, hearing, smell, tactile/kinesthetic senses and even taste. A second major source of information is through communications with other individuals. This may be verbal communication (directly or through radio connections), but also may include non-verbal communications (facial gestures or hand and arm signals) that can occur when individuals are co-located in the same environment.

Increasingly, Infantry operations will also be privy to electronic systems and sensors designed to aid SA or boost soldier performance. Night vision goggles (NVG), global positioning systems (GPS), laser range finders, and various forms of digital information sharing systems are but a few of the technologies that are being used or proposed for Infantry operations. All of these sources of information vie for the soldier's limited attention. Increased attention directed toward one source may well result in less attention directed toward another source, and therefore a compromise of SA on certain critical elements. For example, the soldier who is engrossed in analyzing information from a display may miss important information around him. It is essential that the effect of any new system proposed for Infantry operations be evaluated within the context of all the sources of information that are available and vying for attention, so that potential tradeoffs in information attended to can be identified. The design of these systems, in terms of the way in which information is integrated and presented and the degree to which that presentation is compatible with the capabilities and tasks of the user, will be a critical factor in how well it supports SA.

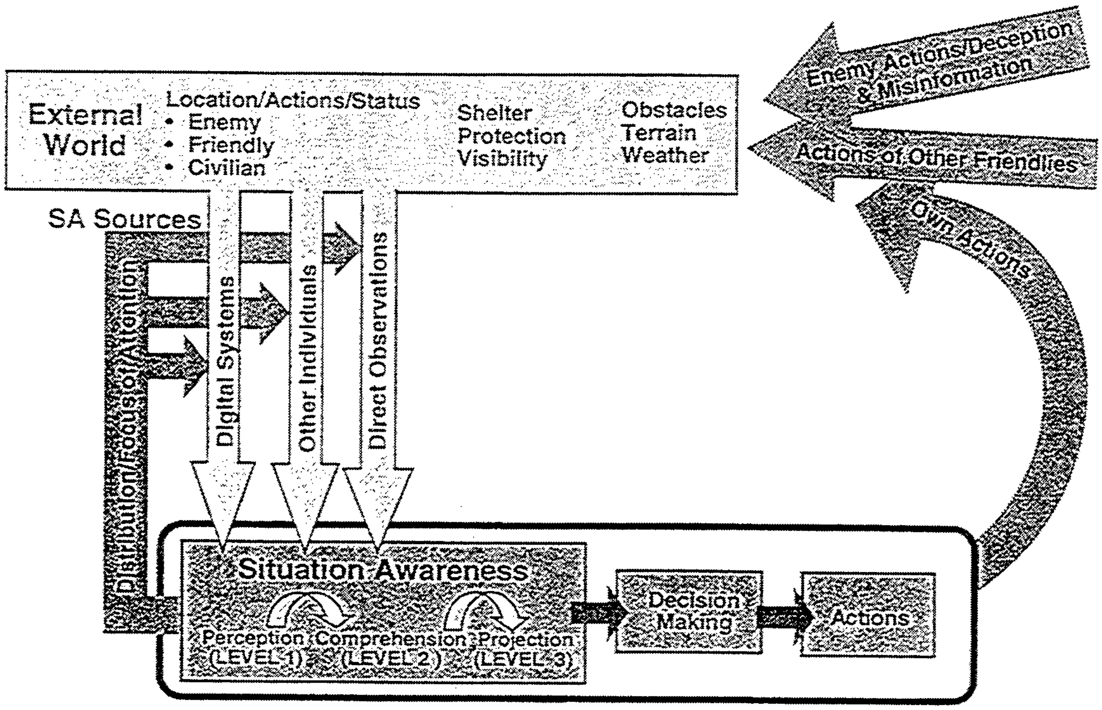

Figure 3. Model of Infantry situation awareness sources and requirements.

The individual soldier or leader will develop SA based on a synthesis of the information derived from all these sources. His ability to derive the needed information through these various sources and to turn that information into the needed situational understanding and projection will be largely affected by task and environmental factors and by individual capabilities. Each of these classes of factors will be described separately in the subsections that follow.

External Factors Influencing Situation Awareness

Many task and environmental factors will have a large impact on SA, as shown in the upper right portion of Figure 4. Each factor can seriously challenge the ability of the soldier to maintain a high level of SA, and each can affect decision making and action performance. Some of these factors are features of the natural environment (e.g., noise, heat, rugged terrain) or of the Infantryman's condition (e.g., fatigue and physical or mental stress). These factors also can be greatly influenced by the enemy, who can alter the tempo of the battle and greatly affect the conditions under which a battle may be fought. Thus, Infantry operations must be conducted under the challenges of a number of factors, naturally occurring, task or enemy induced, that can all act to seriously degrade SA.

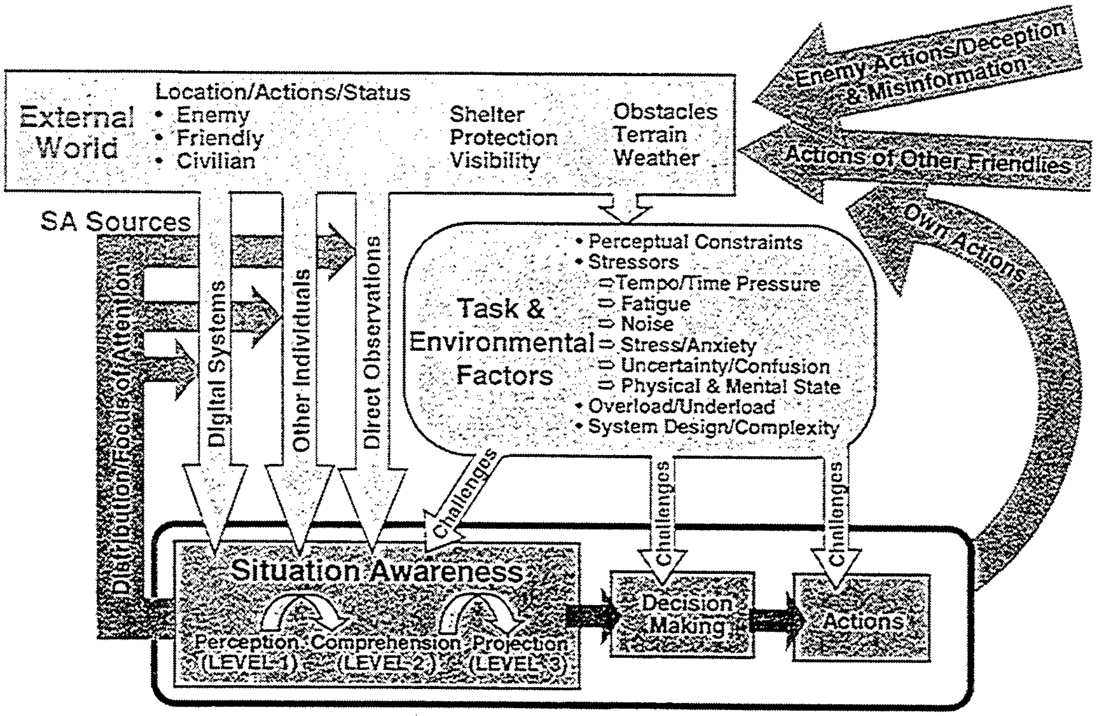

Figure 4. Model of task and environmental factors as they relate to Infantry situation awareness.

Perceptual Constraints

Unlike many domains (e.g., an aircraft cockpit), the Infantryman does not have a narrowly confined space or system that constitutes his world. The soldier must traverse widely disparate terrain and deal with highly varied conditions. The constraints on simple perception of information are many. Obstacles, noise, poor weather and visibility, smoke—all of these factors will act to reduce the soldier's ability to perceive the information that is needed. Due to hazardous enemy actions (such as direct fire), even directly viewing the critical area may be impossible. Uncertainty and confusion (the antithesis of SA) can further reduce the SA of others. Problems with perception of information also exist at higher levels in the Infantry structure. Simply gathering the needed information across a widely dispersed operation is a challenging activity that takes considerable effort. Commanders often must struggle to obtain needed information if they are physically distant from the direct AO. The enemy may act deliberately to conceal critical information or provide misinformation. These factors work to directly limit Level 1 SA, and thus higher levels of SA (comprehension and projection), due to incomplete or inaccurate perceptions of critical environmental cues.

Stressors

Several types of stress factors in the Infantry environment may affect SA. These include (a) physical stressors—noise, vibration, heat/cold, lighting, atmospheric conditions, boredom, and fatigue, and (b) social/psychological stressors—fear or anxiety, uncertainty, importance or consequences of events, self-esteem, career advancement, mental load, and time pressure (Hockey, 1986; Sharit & Salvendy, 1982).

The physical and mental condition of the individual can affect SA. Fatigue (due to lack of sleep or rest or simply prolonged mental or physical exertion) may negatively affect the soldier's individual capabilities to derive SA from the environment. (A summary of work on the effects of sustained operations can be found in Krueger, Cardenales-Ortiz, and Loveless, 1985.) The tempo and time pressures of combat operations can make maintaining SA in the face of rapid change very difficult.

Often stress may result from the natural anxiety that affects the body due to the dangers inherent in Infantry operations. A certain amount of stress may actually improve performance by increasing attention to important aspects of the situation (e.g., sniper fire or booby traps). A greater amount of stress can have negative consequences, however, as accompanying increases in autonomic functioning and aspects of the stressors can demand a portion of the soldier's attentional capacity (Hockey, 1986).

Stressors can affect SA in various ways, including attentional narrowing, reduction of information intake, and reductions in working memory capacity. Under stress a decrease in attention has been observed for peripheral information, those aspects which attract less attentional focus (Bacon, 1974; Weltman, Smith, & Egstrom, 1971), and there is an increased tendency to sample dominant or probable sources of information (Broadbent, 1971). This is a critical problem for SA, leading to the neglect of certain aspects of the situation in favor of others. In many cases, especially emergency situations, it is those factors outside the person's perceived central task that prove to be lethal.

Premature closure, arriving at a decision without exploring all information available, has also been found to be more likely under stress (Janis, 1982; Keinan, 1987; Keinan & Friedland, 1987). This includes considering less information and attending more to negative information (Janis, 1982; Wright, 1974). Several researchers have also found that scanning of information under stress is scattered and poorly organized (Keinan, 1987; Keinan & Friedland, 1987; Wachtel, 1967). A lowering of attention capacity, attentional narrowing, disruptions of scan patterns and premature closure may all negatively affect Level 1 SA under various forms of stress.

A second way in which stress may negatively affect SA is by decreasing working memory capacity and hindering information retrieval (Hockey, 1986; Mandler, 1979). Under stress, the soldier or commander may simply have fewer processing resources (working memory) for combining information into a meaningful picture and making decisions. It may be harder to retain detailed information that is essential. The degree to which decrements in working memory will impact SA depends on the resources available to the individual. In tasks where achieving

SA involves a high working memory load (such as a battle captain managing the information flow in a fast-paced operation), a significant impact on SA Levels 2 and 3 (given the same Level 1 SA) would be expected. If long-term memory stores are available to support SA, however, as in more practiced situations, less influence will be expected (see later discussion).

Overload/Underload

High workload is a stressor of particular importance that can negatively affect SA. If the volume of information and number of tasks are too great, SA may suffer as only a subset of information can be attended to. The soldier or leader may be working actively to achieve SA, yet suffer from erroneous or incomplete perception and integration of information. In some cases, SA problems may occur from an overall high level of workload or a momentary overload in the tasks to be performed or in information being presented.

Poor SA can also occur under low workload. In this case the soldier may have little idea of what is going on and not be actively working to find out due to inattentiveness or vigilance problems. This could easily occur during periods of low activity. Relatively little attention has been paid to the effects of low workload that may be present in extended duty situations or on night tactical operations center (TOC) duty, for instance. Low workload and operations that occur during the slow stage of diurnal rhythms (early morning hours) have been related to vigilance problems that can directly affect Level 1 SA (Matthews, 1985). In addition, these conditions may also negatively affect higher level SA through reductions in cognitive processing of the information that is perceived. This condition can pose a significant challenge for SA in Infantry operations and deserves further study.

System Design/Complexity

The capabilities of the systems provided at each echelon (brigade through squad) for acquiring needed information and the way in which they present that information will have a large impact on soldier SA. While a lack of information can certainly be a problem for SA, too much information poses an equal problem. Associated with improvements in the electronic systems provided to Infantrymen and commanders will be a dramatic increase in the sheer volume of available information. Sorting through these data to derive the desired information and achieve a good picture of the overall situation is no small challenge. Overcoming this problem through better system designs that present integrated data is an important goal.

The complexity of the digital systems will also act to degrade SA, as complexity can significantly increase workload. System complexity may be somewhat offset by the degree to which the soldier has a well developed mastery of the system to aid in directing attention, integrating data, and developing higher levels of SA. These mechanisms may be effective for coping with complexity, but developing mastery may require a considerable amount of training.

Although it has not been a major feature in Infantry systems to date, various forms of automation or decision aids are being proposed and developed for TOC functions. These efforts should be viewed with great caution. A soldier's SA may be negatively impacted by the automation of tasks that put her/him "out-of-the-loop". As the Army increases its use of electronic support systems in Infantry operations, careful testing will be imperative to ensure that the systems effectively support SA and do not diminish it by redirecting the soldier's attention or overloading his cognitive processing. For instance, the use of NVGs has been associated with decrements in other senses (e.g., hearing) that could inadvertently reduce SA (Dyer et al., 1999). More serious effects may be found with other devices (e.g., helmet mounted displays or electronic systems similar to the LW system) that interfere with soldier vision, hearing, or attention (National Research Council, 1997).

Individual Factors Influencing Situation Awareness

Each individual soldier possesses certain abilities, skills and knowledge bases that will largely determine the quality of his SA in a given situation (as shown in the lower portion of Figure 5). It has been noted at least anecdotally that some leaders and soldiers are better at obtaining and maintaining SA under adverse conditions than others. This finding has been confirmed empirically in other domains (Endsley & Bolstad, 1994; O'Hare, 1997). Some of these factors may be inherent to the individual, and thus can only be affected through careful selection and assignment processes, although many may be trainable and can be developed through experience (as will be discussed in a later subsection). Understanding the individual factors that are important for SA begins with understanding the cognitive processes that any individual must use to gather and process information to form SA.

In general, SA is challenged by the limitations of human attention and working memory (shown in the lower right portion of Figure 5). The development of relevant long-term memory stores (knowledge bases) for pattern matching to observed environmental information, goal-directed processing, and automaticity of actions through experience and training are seen as the primary mechanisms used for overcoming these limitations (as shown in the lower central portion of Figure 5) to achieve high levels of SA and successful performance. The model suggests that the Army can have a large effect on soldier SA by influencing these individual and team capabilities—through training, leader development, mission planning and preparation activities, etc. (discussed later in this section). In theory, it is even possible to select and assign personnel on the basis of their SA capabilities, although this would involve complex considerations. Each of the individual factors influencing SA will be discussed, providing a framework for developing strategies to improve soldier SA.

Processing Limitations

Attention. The development of SA and the decision process are restricted by limited attention and working memory capacity. Direct attention is needed for perceiving and processing the environment to form SA, for selecting actions and executing responses. In the dynamic Infantry environment, scattered information from multiple sources, multiple tasks and the rapid rate of change in the situation can exceed the soldier's limited attention capacity. Add the effects of fatigue, noise and stress to the picture, and attention capacity can be even more limited. Because the supply of attention is limited, more attention to some information may mean a loss of SA on other aspects of the situation. The resulting lack of SA can result in poor decisions and suboptimal performance.

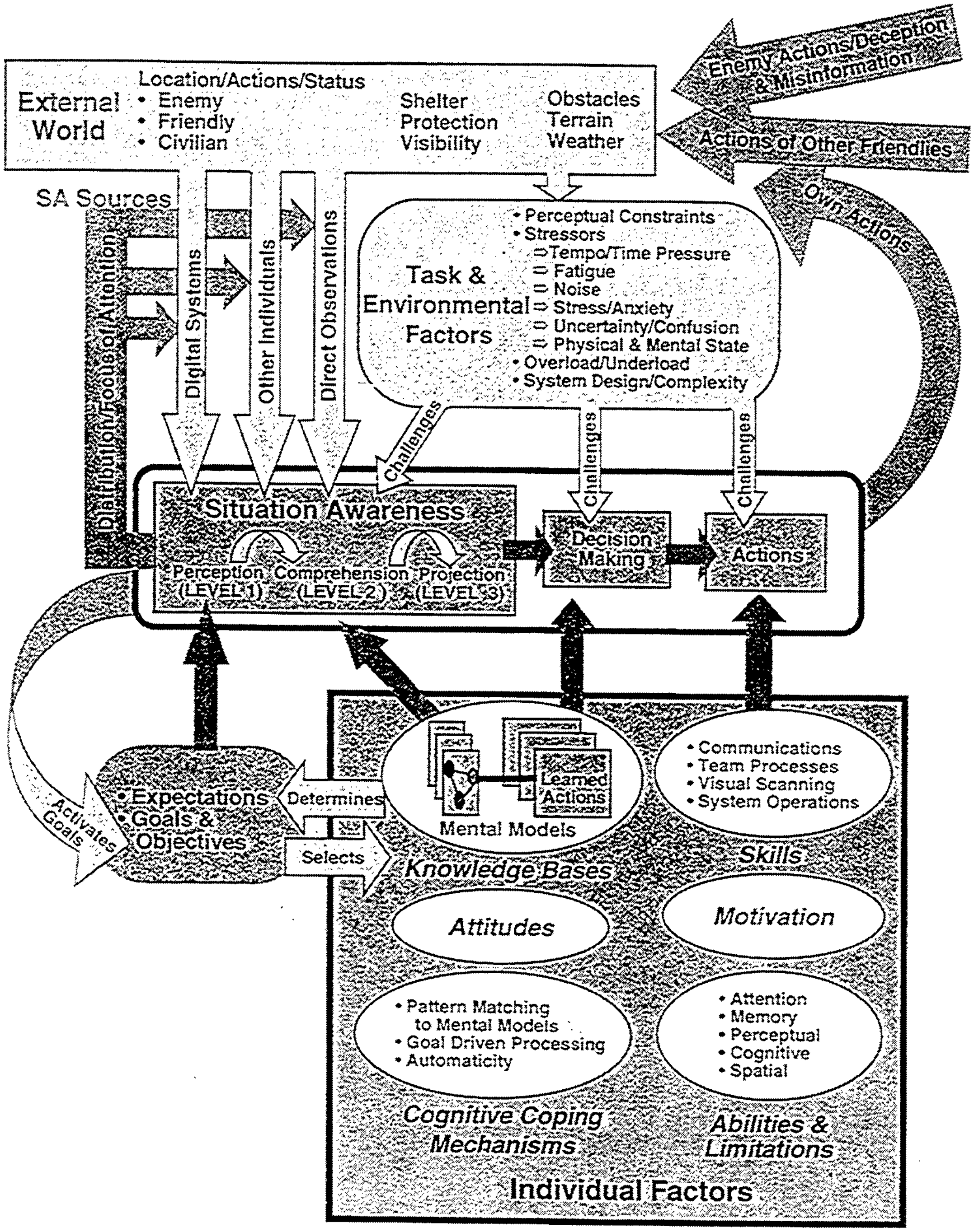

Figure 5. Model of individual factors as they relate to Infantry situation awareness.

Soldiers typically employ a process of information sampling to circumvent attention limits, attending to information in rapid sequence following a pattern dictated by long-term memory concerning the relative priorities of information sources and expectations regarding where relevant information might be found. Working memory also plays an important role in this process, allowing the soldier to modify attention deployment on the basis of other information perceived or active goals. In the dynamic and varied arena of Infantry operations, however, having a good basis on which to prioritize attention (knowing where to look for critical information and what can be neglected) is a serious challenge. With a highly varied number of places to look for information, and potentially multiple auditory cues competing for the soldier's limited attention, achieving a high level of SA across the many SA requirements of the soldier can be quite difficult.

In the presence of information overload, a frequent occurrence, soldiers may choose to attend to certain information, to the neglect of other information (attentional narrowing). If the selection is correct and sufficient, all is well. However, in many instances this is not the case, and information that is not attended to is of critical importance. This leads to a very important point. In order to know which information to focus attention on and which information can be temporarily ignored, the soldier must have some level of understanding about all of it—"the big picture." In many cases, however, the dynamically changing big picture has not been communicated across echelons. This may lead to suboptimal allocation of attention and insufficient understanding of the information being processed by the individual.

Working memory. Working memory capacity can also act as a limit on SA. Working memory is a limited capacity system for temporarily holding and manipulating information mentally (Baddeley, 1981). In the absence of other mechanisms, most of a person's active processing of information must occur in working memory. The second level of SA involves comprehending the meaning of the data that are perceived. New information must be combined with existing knowledge and a composite picture of the situation developed. Achieving the desired integration and comprehension in this fashion is a very taxing proposition that can seriously overload the commander's and soldier's working memory and will draw even further on attention, leaving even less capacity to direct toward the process of acquiring new information.

Similarly, projections of future status (Level 3 SA) and subsequent decisions as to appropriate courses of action will draw upon working memory. Wickens (1984) has stated that the prediction of future states imposes a strong load on working memory by requiring the maintenance of present conditions, future conditions, rules used to generate the latter from the former, and actions that are appropriate to the future conditions. In other words, achieving higher levels of SA, formulating and selecting options, and carrying out subsequent actions may severely challenge Infantry leaders and soldiers. Although cognitive mechanisms exist for reducing some of this load (discussed below), the limitations of cognitive processing dictate that any equipment designed for this environment should impose minimal attention and working memory demands.

The way in which information is perceived (Level 1 SA) is affected by the contents of both working memory and long-term memory in the form of *expectations*. Advanced knowledge of the characteristics, form, and location of information, for instance, can significantly facilitate the perception of information (Barber & Folkard, 1972; Biederman, Mezzanotte, Rabinowitz, Francolin, & Plude, 1981; Davis, Kramer, & Graham, 1983; Humphreys, 1981; Palmer, 1975; Posner, Nissen, & Ogden, 1978). This type of knowledge is typically gained through experience, training, and pre-mission planning and analysis. One's preconceptions or expectations about information can affect the speed and accuracy of the perception of information in operations. Repeated experience in an environment allows people to develop expectations about future events that predispose them to perceive the information accordingly. They will process information faster if it is in agreement with those expectations, but they will also be more likely to make an error if it is not (Jones, 1997). Expectations therefore create a two-edged sword. There is a noted tendency to make perceived information fit expectations, even when it does not, creating a significant misperception of the situation. Breaking people out of such an incorrect mindset, even in the face of clearly conflicting information, has been found to be very difficult (Jones, 1997). For this reason, the veracity and realism of the training and mission planning experiences the Army provides can directly affect the accuracy and completeness of the soldier's SA in later Infantry operations. It is critical for building accurate expectations.

Cognitive Coping Mechanisms

Pattern matching to mental models and schemata. In practice, experienced soldiers and commanders may use long-term memory stores, most likely in the form of schemata and mental models, to circumvent the limits of attention and working memory, as shown in Figure 5. Schemata are general knowledge structures used to organize information into meaningful frameworks (Mayer, 1983). Much of the detail of new information is lost, but it becomes more coherent and organized for storage as perceived information is interpreted into understood concepts. Mental models are "mechanisms whereby humans are able to generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future states" (Rouse & Morris, 1985, p. 7). They are very complex schemata that are used to model the behavior of systems. Schemata and mental models provide for the integration and comprehension of information and the projection of future events without loading working memory. They also allow for decision making where incomplete information and uncertainty are involved.

Experienced soldiers often have internal representations of the environment they are dealing with—a mental model. A well developed mental model provides:

- Knowledge of the relevant "elements" of the environment that can be used in directing attention and classifying information in the perception process.
- A means of integrating elements to form an understanding of their meaning (Level 2 SA).
- A mechanism for projecting future states of the environment based on the current state and an understanding of its dynamics (Level 3 SA).

During active decision making, a soldier's perceptions of the current state of the environment may be matched to related schemata in memory that depict prototypical situations or states of the mental model. These prototypical situations provide situation classification, understanding, and projection of what is likely to happen in the future (Level 3 SA). For example, the observed pattern of troop movements may be matched to known maneuvers for that enemy, to very quickly classify and understand what tactics are being employed, and thus what actions they may be predicted to take. These mental models and schema are what allow experienced Infantry commanders to almost automatically understand what is happening, even on the basis of few key cues.

A major advantage of mental models and schema is that the current situation does not need to be exactly like one encountered before, due to the use of categorization mapping (a best fit between the characteristics of the situation and the characteristics of known categories or prototype schemata). The matching process can be almost instantaneous due to the speed of human pattern matching mechanisms. When an individual has a well developed mental model for the behavior of particular groups, systems or domains, it will provide:

- For the dynamic direction of attention to critical environmental cues.
- Expectations regarding future states of the environment (including what to expect as well as what not to expect) based on the projection mechanisms of the model.
- A direct, single-step link between recognized situation classifications and typical actions, providing very rapid decision making.

The use of mental models also provides useful default information. Default values (expected characteristics of elements based on their classification) may be used by soldiers to predict events even with incomplete or uncertain information, yielding more effective decisions than novices who are more hampered by missing data. For example, experienced soldiers are able to predict within a reasonable range how fast a particular convoy is traveling just by knowing the types of vehicles in the convoy. This allows them to develop good projections of arrival times, based on very limited information. Default information may furnish an important coping mechanism for experienced soldiers in forming SA in many situations where information is missing or they are unable to acquire all the information they need.

Well developed mental models and schema can enable the comprehension and future projection required for the higher levels of SA almost automatically, thus greatly off-loading working memory and attention requirements. A major advantage of these long-term stores is that a great deal of information can be called upon very rapidly, using only a very small amount of attention (Logan, 1988). When sets of actions have been mastered and tied to these schema, the entire decision making process can be greatly simplified, and working memory will be off-loaded even further. The development of robust mental models and schema of prototypical situations through training and experience is a hallmark of unit training at the CTCs. It may be feasible to exploit this avenue further as a means to improve SA.

Goal-driven processing. In the processing of dynamic and complex information, such as can be found in Infantry operations, soldiers will need to rapidly switch between data-driven and goal-driven processing. In a data-driven process, various environmental features are detected whose inherent properties determine which information will receive further focalized attention and processing. In this mode, cue salience (features that naturally attract attention due to their perceptual qualities such as artillery explosions, sounds of aircraft, movement, etc.) will have a large impact on which portions of the environment are attended to and thus SA.

Soldiers and leaders can also operate in a goal-driven fashion. In this mode, SA is affected by the soldier's goals and expectations, which influence how attention is directed, how information is perceived, and how it is interpreted. The individual's goals and plans direct which aspects of the environment are noticed. That information is then integrated and interpreted in light of these goals to form Level 2 SA. On an on-going basis, there are trade-offs between top-down and bottom-up processing. Rapid switching between goal-driven and data-driven processing is necessary for good performance because it allows the soldier to process information effectively in a dynamic environment.

While the inexperienced soldier will be mainly data-driven, with experience soldiers will develop a better understanding of their goals, which goals should be active in which circumstances, and how to acquire information to support these goals. The increased reliance on goal directed processing allows the environment to be assessed more efficiently than with purely data-driven processing. An important issue for achieving successful performance in Infantry operations lies in the ability of soldiers to dynamically juggle multiple competing goals effectively. They need to rapidly switch between pursuing information in support of a particular goal and responding to perceived data activating a new goal, back and forth. This capability is greatly affected by training and experience.

Automaticity. An Infantryman's SA can be affected by automaticity of information processing and psycho-motor behaviors. Automaticity may be useful in overcoming attention limits, but may also leave the soldier susceptible to missing novel stimuli. Over time, it is easy for actions to become habitual and routine, requiring a very low level of attention. In general a high level of automaticity is desirable for psycho-motor tasks (such as rifle firing or hand-to-hand combat). At the same time, automaticity may have both positive and negative effects on the cognitive aspects of tasks (such as directing attention to external cues and making decisions as to the best course of action).

Developed through experience and a high level of learning, automatic cognitive processing tends to be fast, autonomous, effortless and unavailable to conscious awareness in that it can occur without attention (Logan, 1988). Automatic processing is advantageous because it provides good performance with minimal attention allocation. While automaticity in cognitive processing may provide an important mechanism for overcoming processing limitations, thus helping soldiers to achieve SA and make decisions in complex, dynamic environments, it also creates an increased risk of being less responsive to new stimuli as automatic processes operate with limited use of feedback. When something is slightly different than the habitual pattern, the soldier may miss the new cue and carry out the habitual action. For example, a radio operator in a TOC is accustomed to receiving and recording radio messages and logging their receipt in a journal, as a matter of routine. He may not consider the relative importance of the content of a particular message and continue his routine, rather than alerting others to the receipt of this important information. When using automatic cognitive processing, a lower level of SA can occur in non-typical situations, decreasing decision timeliness and effectiveness.

Individual Abilities and Skills

In summary, SA can be achieved by drawing upon a number of individual factors, as depicted in Figure 5. Due to limitations of attention and working memory, long-term memory may be heavily relied upon to achieve SA in the highly demanding Infantry environment. The degree to which these structures can be developed and effectively used in the Infantry environment, the degree to which soldiers can effectively balance goal-driven processing with data-driven processing, and the degree to which soldiers can leverage the benefits of automaticity (while avoiding its pitfalls) will ultimately determine the quality of their SA.

Based on this model, we can argue that critical abilities for SA in Infantry operations may include attention sharing capacity, working memory capacity, perceptual abilities (including perceptual speed), cognitive analytical skills (including pattern matching), and spatial abilities. While many of these factors have been found to be important to SA in other domains, including piloting and driving (Endsley & Bolstad, 1994; Gugerty & Tirre, 1997; O'Hare, 1997), no studies have yet been conducted to extrapolate these findings to the Infantry arena. Further investigation of those abilities to distinguish great commanders and Infantrymen who possess high levels of SA from others should be conducted so those abilities that are trainable can be fostered in others. In addition, it might be appropriate to examine personnel assignment and selection procedures in light of the findings.

Some factors are known to be trainable, either through carefully developed training programs and exercises or through actual combat experiences. This includes the development of a rich set of knowledge bases (in the form of mental models and schema of prototypical situations connected to well learned actions) upon which SA is dependent in complex and dynamic operations. The Army has long recognized the crucial role of such experiences in building a capable fighting force. Perhaps more can be done to exploit these training arenas for developing the robust and varied knowledge bases that are critical for SA.

Finally, SA in individuals is dependent on certain critical skills. In Infantry operations these may include:

- communicating with other members of the squad, subordinates and commanders;
- team processes present in the unit, including factors such as leadership, teamwork, and information sharing norms;
- observation and surveillance skills that are taught; and
- the ability to operate the sensors and systems that are provided.

Individual motivation and attitudes can have a direct impact on the effectiveness of training in developing and employing these critical skills. The skills that are critical for SA in Infantry operations need to be identified and carefully developed in the training process.

An Iterative Process

Finally it should be emphasized that SA comprises an iterative and dynamic process, as indicated by the arrows in Figure 5. Individuals will make decisions and take actions based on their SA. Those actions will in turn affect the state of the environment itself (along with the action of other agents, such as enemy, friendly or civilian forces).

The movements and actions of the individual, other friendlies, and civilians will continually change the external world state, as will natural changes (e.g., weather patterns). These dynamic changes must in turn be processed by the individual in order to maintain an accurate picture. The active deception and misinformation introduced by the enemy must also be ferreted out and taken into account in future-oriented assessments of the external world. This is a very important aspect of SA on the military battlefield. Much information cannot be taken at face value. In some cases this is due to intentional deception or subterfuge on the part of the enemy. In other cases it may be due to the inherent limitations of electronic systems or intelligence operations. As such, the actual source of information is often important because it enables the decision maker to form an understanding of the reliability or confidence level associated with bits of information. Confidence level regarding information has been found to be a major element of SA in most domains (Endsley, 1993; Endsley & Rodgers, 1994; Endsley & Robertson, 1996). It is probably a key component in Infantry operations.

The processes used to assess the environment (the distribution of attention, communications and team processes, scan patterns, and system operations) will be determined by the individual's state of SA. The situation assessment processes then lead to the state of SA, in a dynamic cycle (Adams, Tenney, & Pew, 1995). Poorly formed SA can lead to the wrong situation assessment processes, which can reinforce poor SA. Breaking out of such a cycle depends on the development of situation assessment processes designed to detect SA problems, rather than reinforce them. Thus, situation assessment and SA form an integrally linked and ongoing dynamic process/product. The resulting SA forms the foundation for decision making and action throughout this cycle, whether it is to gather more information or to take some decisive action, or to take no new action but to carry through with well learned routine behaviors.

Army Mechanisms for Achieving Situation Awareness

Achieving high levels of SA during Infantry operations will always be difficult. However, the Army can increase the SA capabilities of Infantrymen through several mechanisms, as indicated by the elements around the bottom of Figure 6. (Please note that Figure 6 is a duplicate of Figure 1, repeated here for ease of reference.) The first mechanism involves selection and assignment of personnel to duty positions that are suitable for their unique individual capabilities. As more is learned about the factors that allow some individuals to have superior levels of SA, such factors can be taken into account, at least theoretically. Only limited intervention through selection may be possible or desirable, however, due to the constrained pools of soldiers that are available.

The second major mechanism is in the area of training and experience. This is a major approach for improving the SA capabilities of Infantry leaders and soldiers under the duress of combat operations. Current training exercises do much to help develop the skills and abilities that are needed for SA and performance in combat. These mechanisms can be even further exploited to build high levels of SA in Infantrymen. Mission planning and preparation procedures have a major impact on the more dynamic goals and expectations that soldiers and leaders take to the field. The realism and veracity of these pre-mission experiences is critical. It

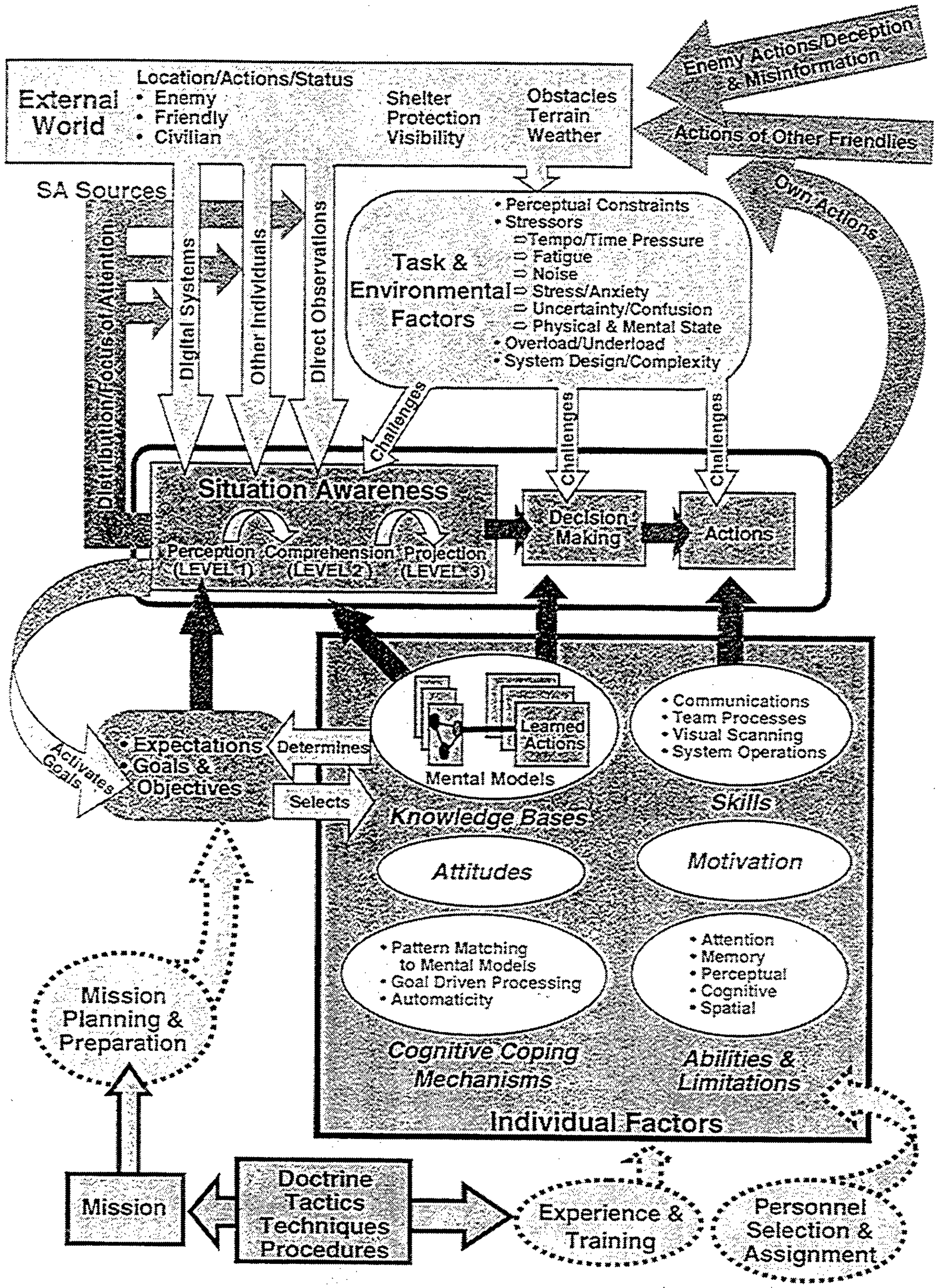

Figure 6. The Infantry-focused model of individual situation awareness (repeat of Figure 1).

has been found that when individuals are reliant on expectations, and those expectations are false, they are far more likely to miss critical cues and omit processes for detecting their SA failures (Taylor, Endsley, & Henderson, 1996). Army doctrine, tactics, techniques, procedures, simulations, realistic field exercises, and mission plans are but some of the factors that will directly affect SA in the field through these mechanisms.

Finally, while the Army cannot control all the aspects of the environment it might wish to, it can significantly affect SA through digital systems for representing the environment. It is true, however, that the digital systems themselves will never "deliver" SA nor will they comprise SA. They can only provide one source, along with other important sources, of SA for the Infantryman. The actual state of SA achieved by the soldier will depend on the numerous individual and environmental factors that are operating within the bounds of a very dynamic and complex environment.

Situation Awareness in Multiple-Distributed Teams in Infantry Operations

The model presented thus far identifies the many factors that will affect the SA of a given Infantry soldier or leader. This is important because SA only exists within the individual, as an internal representation of the environment. In Infantry operations, however, most activities are conducted in well developed teams: squads, platoons, companies, battalions and brigades. (The term "team" will be used very broadly here to represent collectives of individuals involved in pursuing a common goal. As such it can incorporate a small team—such as a squad—or the much larger brigade, which can be considered a team of teams.)

Examining SA as it exists within and between these teams lends an important perspective to understanding SA in Infantry operations. In general, the issue of team SA has received little direct research attention, compared to individual SA. More recently, however, team SA has begun receiving more focused attention. The only general model of team SA was found in the scientific literature (Endsley & Jones, 1997), which forms the basis for the discussion here. Other work, however, has discussed issues associated with team SA (e.g., Cannon-Bowers, Salas, & Converse, 1993; Endsley, 1989; Endsley & Robertson, 1996; Mosier & Chidester, 1991; Orasanu, 1990; Prince & Salas, 1998; Robertson & Endsley, 1995; Salas, Prince, Baker, & Shrestha, 1995; Wellens, 1993). This work was used to expand the information presented in the model of team SA.

Team Situation Awareness

A team can be defined as "a distinguishable set of two or more people who interact dynamically, interdependently, and adaptively toward a common and valued goal/objective/ mission, who have each been assigned specific roles or functions to perform, and who have a limited life span of membership" (Salas, Dickinson, Converse, & Tannenbaum, 1992, p. 6). Critical features that define a team therefore include a common goal, interdependence, and specific roles. This definition has several implications for the concept of team SA.

The factors relevant to SA in teams will be explained in terms of the squad. However, each of these factors can be extrapolated to understanding team SA at the other echelons as well.

In a squad, each soldier has a subgoal pertinent to his specific role that feeds into the overall squad goal. For instance, some soldiers may be assigned to conduct reconnaissance of an objective while others provide security at the objective rally point. Other soldiers may have the responsibility of-maintaining communications with other squads and company headquarters. One will serve as squad leader, coordinating and directing the actions of the others. Associated with each squad member's subgoal is a set of SA elements about which he is concerned.

The SA for a squad can be represented, therefore, as shown in Figure 7. As the members of the squad are essentially interdependent in meeting the overall squad goal, some overlap of subgoals and their associated SA requirements will be present. So, in the previous example, there will be pieces of information that need to be in the SA of those performing reconnaissance and those providing security at the rally point. It is this subset of information that constitutes much of intra-squad coordination. That coordination may occur as a verbal exchange, through gestures and signals, as a duplication of displayed information (audio or video), or by some other SA device.

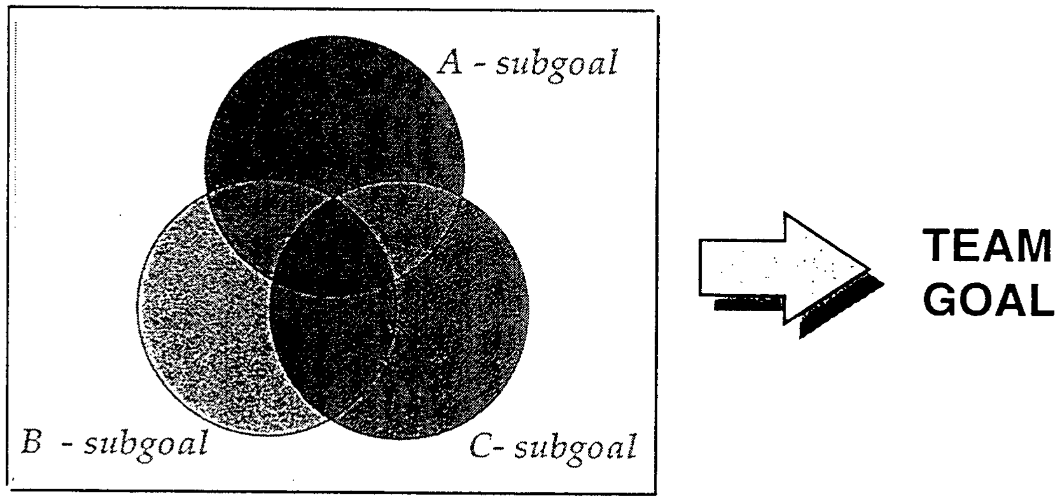

Figure 7. Team situation awareness concept (adapted from Endsley & Jones, 1997).

Overall team SA for the squad can be conceived of as "the degree to which every team member possesses the SA required for his or her responsibilities" (Endsley, 1995b, p. 39). This is independent of any overlaps in SA requirements that may be present. If each of two squad members needs to know a piece of information, it is not sufficient that one knows it perfectly but the other does not. Each and every squad member must have SA for all of his own SA requirements or become the proverbial chain's weakest link.

Shared Situation Awareness

A major part of teamwork involves the area where these SA requirements overlap—the shared SA requirements that exist as a function of the essential interdependency of the squad members. While two squad members may be assigned different tasks in executing a mission plan, they must also operate on a common set of data. The assessments and actions of one can have a large impact on the assessments and actions of the other.

In a poorly functioning squad, two squad members may have different assessments of these shared SA requirements and thus behave in a non-coordinated fashion. For example, if a soldier has one picture of where a target is relative to the ambush site, but this is not properly communicated to the others, suppressive fires may not be initiated at the right time or in the right direction. In a smoothly functioning squad, each member shares a common understanding of what is happening on those SA elements that are common—shared SA. This refers to the overlap between the SA requirements of the squad members as presented in Figure 7. Not all information needs to be shared. Clearly, each squad member is aware of much that is not pertinent to the others in the squad. Sharing every detail of each soldier's job would only create a great deal of chaff to sort through to get needed information. It is only that information relevant to the SA requirements across squad members that is needed. Thus, shared SA can be defined as "the degree to which team members possess the same SA on shared SA requirements" (Endsley & Jones, 1997, p. 47). Shared SA constitutes one important component of team SA, along with the level of SA possessed by individual team members.

Different possible states of shared SA exist. The SA of two squad members on these shared elements may be the same and both be correct. Or, their SA may be the same with both being incorrect. That is, they may share a common but erroneous picture of the situation. Alternately, they may have different pictures of the situation, with one being correct and one incorrect, or they could be both incorrect in different ways. (Because shared SA is only concerned with the SA elements that are common to both squad members, it is essentially impossible for both to be correct but different.)

Obviously the goal is for both squad members to be correct in their SA. With good communications and supporting technologies, cases in which there are different pictures of the same situation will be revealed so that the soldiers can take steps to gather additional information or work to resolve differences. The most dangerous situation is when multiple members share common but incorrect SA. In this case, no immediate dissonance will occur between squad members that indicates there is a problem to be resolved. Often in such a case the entire squad may remain locked into its incorrect picture of the situation until some external event occurs to alter it—for instance, walking into an ambush because no one detected the enemy presence.

An examination of how squads (and teams in general) develop high levels of SA across its members can be undertaken by determining the primary factors that underlie team SA. Developing shared SA within a squad and between squads can be extremely challenging, especially where those squads are distributed in terms of space, time or physical barriers. Endsley & Jones (1997) described this process as a function of four components:

- Shared SA requirements
- Shared SA sources
- Shared SA mechanisms
- Shared SA processes

These four components effectively determine the quality (completeness and accuracy) of the SA of the unit (and each of its members) at each level of the organization.

This model applies to the distributed and hierarchical units of Infantry forces, as shown in Figure 8. At each level, each individual will form his own distinct picture of the world based on the section of it that is observable to him by means of available SA sources, including digital devices. The individual interprets that information through the filter of his own individual goals and internal mental models to arrive at his own state of SA. This may vary significantly from his fellow squad members if they are observing different cues through possibly different SA sources and interpreting those cues through different mental models and in accordance with slightly different goal states. The resolution of those differences can be achieved through shared SA sources or through direct communication using the SA processes established either explicitly or implicitly for the team.

Shared Situation Awareness Requirements

The degree to which the squad members know which information needs to be shared is critical. Often they may be unsure of which information others do or do not know or what information others really need. While they may communicate lower level information (data), they often may fail to convey their higher level assessments and projections, which are usually not otherwise available to fellow squad members. The assumption that others will arrive at the same comprehension and projections based on the same input is often false, because each individual will interpret the information in the context of his own goals and mental models. Information on each squad member's task status and current capabilities is also an important component of shared SA requirements.

Each person's SA requirements (at any level of the organization) are essentially a function of his mission goals and can be specified as such. Shared SA requirements between any two individuals are essentially a function of the degree of overlap between those goals. This is true within a unit, between units (which would have less overlap between goals than within units), and between different levels of the organization.

A set of shared SA requirements exists between a battalion commander and his subordinate company commanders, for instance. While a high degree of overlap can be speculated, it is also true that the company commander may be aware of much that is too detailed and situation specific to be of interest to the battalion commander, and the battalion commander may be aware of many details in the big picture that are outside the scope of a company commander. Knowing just where to draw this line, what to pass on and what to leave out of a report or briefing, is critical for achieving successful SA within Army units. The omission of critical information (either up the chain of command or down) can lead to catastrophic SA failures. The inclusion of too much information can strain limited communication channels and be impossible under time constraints. Resolving this dilemma depends on each person, at every level in the organization, having a clear understanding of the actual SA requirements of the others. If a company commander does not have enough of the "big picture" he may not realize that certain information is critical to share with other unit commanders.

The need for a big picture is also fueled by the fact that in combat, attrition occurs and subordinates may need to rapidly assume the role of a higher level member (e.g., a platoon leader who must assume the role of a company commander), or another team member. This factor only serves to accentuate the need for a high level of shared SA within Infantry operations.

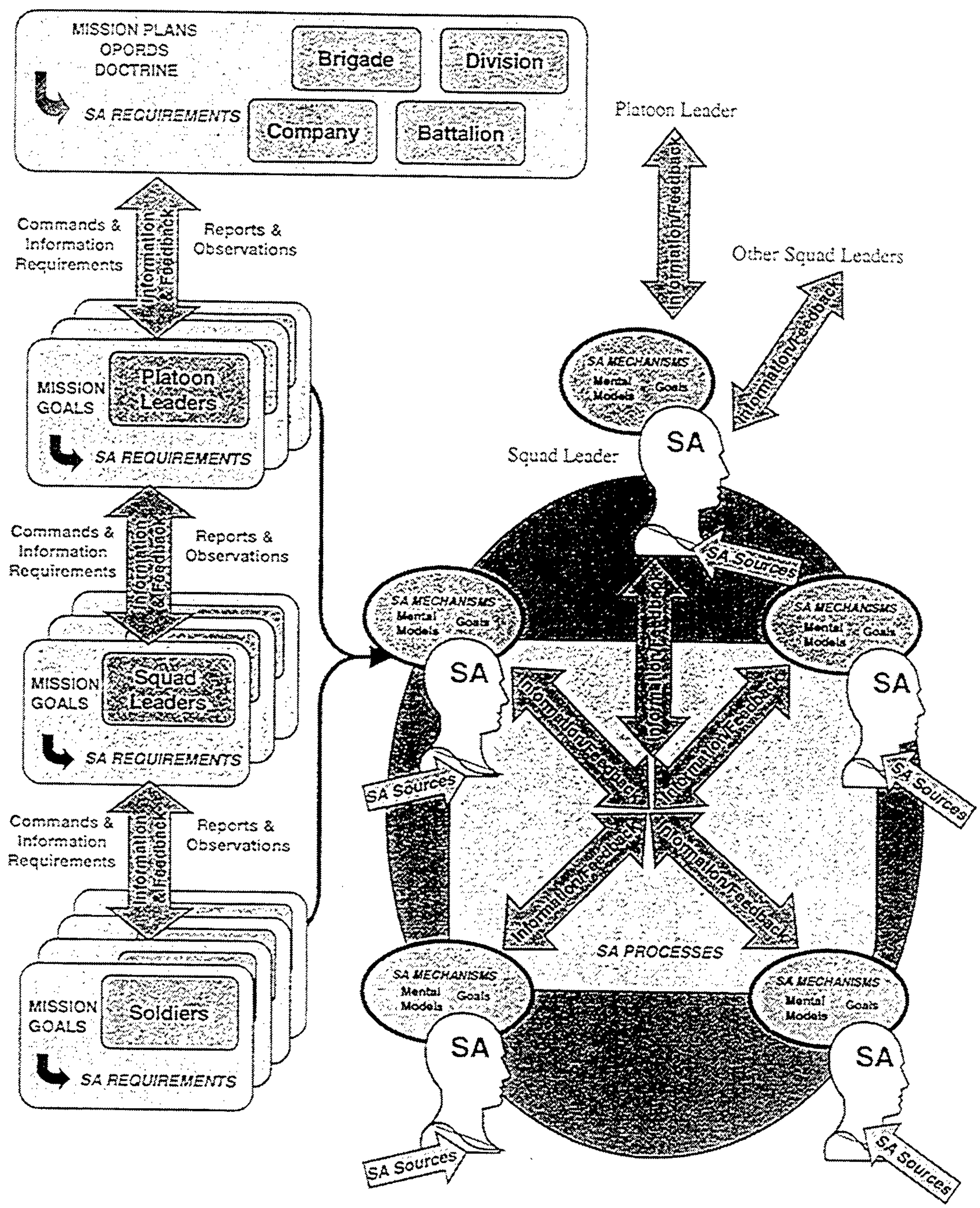

Figure 8. An Infantry-focused model of team situation awareness.

Some general elements that appear to be common for promoting good team functioning are displayed in Table 4. Information needs to be shared at each of the three levels of SA:

perception (basic data), comprehension, and projection. Certain basic data about the environment, enemy, civilian and friendly actions and status, weather and terrain features will generally need to be shared. In addition, information about other team members may need to be shared. For instance, information regarding actions other squad members have taken and their current capabilities (e.g., as affected by fatalities, injuries, fatigue or stress) may be important to another squad member's SA.

Table 4

Shared Situation Awareness Requirements for Teams

- Data
  - Enemy, friendly, civilian
  - Terrain, obstacles, features
  - Environment
  - Other team members
- Comprehension
  - Status relevant to own goals/ requirements
  - Status relevant to others' goals/requirements
  - Impact of own actions/changes on others
  - Impact of other's actions on self and mission
- Projection
  - Actions of team members and leaders

Beyond this basic data, higher level assessments of the situation are also extremely important and need to be shared among squad members. A shared understanding of the impact of the other squad members' task status on one's own functions, and thus the overall mission, is important. Similarly, all squad members need to know how their own task status and actions impact on other squad members so that they can coordinate appropriately. Finally, in a highly functioning squad, members are able to project not only what enemy actions will occur (e.g., toss a grenade into a room before entering), but also what fellow squad members will do. For example, members of effective squads will intuitively know what other members will do in a given situation, where they will be, and with what tasks they will have difficulty. This information is extremely important for operating efficiently as a team because it allows each squad member to plan actions effectively.

Shared Situation Awareness Sources

Each individual will gather information directly and from others. The SA sources that each soldier has will determine the information gathered and the perspective on that information. These include the factors in Table 5. Each member of the squad may have slightly different SA sources available, and may be in a different position and orientation, and therefore will start from a slightly different perspective. The degree to which two individuals have shared SA sources determines the degree to which these perspectives will promote a common or shared picture of the environment. Traditionally, direct communication (both verbal and non-verbal) has been the main source available for achieving a common shared picture of the situation.

In addition, the degree to which two people share the same environment is also very important for achieving a common understanding. When squad members are collocated, much information does not need to be shared explicitly, as they will all be informed by the same events occurring before them. With distributed teams, however, this common thread is lost. Far more information must be communicated verbally to a squad member or battalion commander who is not in the same environment. This can be both taxing and time consuming and many important details may be lost or miscommunicated. This has implications for tactics and doctrine that rely on greater dispersion of troops.

Table 5

Team Situation Awareness Sources

- Communications
  - Verbal
  - Non-verbal
- Shared Displays
  - Visual
  - Audio
  - Other
- Shared Environment

Shared displays are therefore a third major avenue for achieving shared SA, particularly for distributed teams. These shared displays may take the form of audio displays or visual cues. New technologies for datalinking video and digital information from the battlefield to the CP, or between units, is an example of how such shared displays might be applied. Such devices, if they provide a common picture, will help to promote shared SA. It is critical, however, that such displays do not overload individuals with too much information about the operations of their teammates, or SA and performance can actually suffer (Bolstad & Endsley, 1998, 1999). The development of effective shared displays poses many challenges on which more research is needed.

In considering the devices that are available within units, between units and between levels of the hierarchy, it is important to realize that all of these sources will contribute to shared SA. Any one device that becomes unavailable in a given situation (e.g., loss of radio communications or shared display information) will place a higher load on the other devices. If shared displays or a shared environment are not provided, more interaction will have to be accomplished through limited communication channels. Therefore to maximize shared SA, increasing the number of sources available for conveying a common picture will be desirable in general, provided information overload does not cause a reduction in SA.

Shared Situation Awareness Mechanisms

The degree to which team members possess mechanisms, such as shared mental models, that support their ability to interpret information in the same way and make accurate projections regarding each other's actions will also have a large effect on the degree to which they develop a common picture, even when provided with the exact same data. The possession of shared mental models can greatly facilitate communication and coordination in team settings. The higher levels of SA will most likely not be directly available. Each person must process the available data in order to understand what it means relative to the mission goals and to project what will happen in the future. These higher levels of SA, therefore, may be very divergent for different squad members if they have independent mental models with which they process information. The degree to which the squad members share a common mental model (as developed through common training and experience) will greatly enhance the ability of the squad to develop shared SA without necessitating extra verbal communication or other information sharing. For this reason, squads (or other elements) that have trained and worked together possess a distinct advantage over those that are organized ad hoc. They have been able to form shared mental models of not only the environment, but also of each other. This allows them to more quickly arrive at a common understanding and interpretation of critical information and achieve superior team coordination. Shared mental models were found to be even more important than shared displays for promoting high levels of performance in teams (Bolstad & Endsley, 1998, 1999).

Individuals from different units (e.g., Infantry vs. armored battalions) may have very different mental models. Without shared mental models, it will most likely require a great deal of real-time coordination and communication to ensure that their mutual activities are carried out properly, thus creating opportunities for lapses. Combined arms and Joint exercises and familiarization with the goals, processes and requirements of other units that need to be coordinated with should do much to improve shared mental models and shared SA in combined arms operations. The development of shared mental models has not received much attention to date, but it most likely occurs through:

- Shared training (e.g., Joint training or cross training on different job functions).
- Shared experiences (e.g., experience in working together as a team and similar experiences which may occur either together or individually).
- Direct communications between team members to build up a shared mental model in advance of operations.

The role and efficacy of each of these mechanisms for developing robust shared mental models needs to be explored.

Developing good shared mental models can be most easily accomplished with units that train and prepare together. This allows them to develop accurate expectations regarding the capabilities, strengths, weaknesses, and behavior patterns of their teammates. They will learn more about what to expect from each other and develop a shared set of expectations regarding behaviors, tasks, and information sharing within the team. The reality, however, is that combat units often must cope with ad hoc teams as individual members are lost through attrition, separated, or reassigned to meet dynamic mission goals. New leaders may take over and new specialists may join the unit to perform new tasks. These changes will decrease the degree to which the team can rely on shared mental models and will make the team far more reliant on other factors (e.g., more direct communication and good team processes) to achieve SA. These factors may not be as efficient, however, without shared mental models. Mechanisms for rapidly creating shared mental models within ad hoc teams need to be determined.

Shared Situation Awareness Processes

All team interaction takes place within a context of group processes. A considerable amount of research has been conducted on factors affecting group decision making and performance. The applicability of much of this work to the combat environment is limited, however, as it has for the most part been conducted with small, artificially constructed groups performing a single, relatively simple task under controlled laboratory conditions. As such, it neglects the important role environmental, organizational and social context has on group processes. These contextual factors are very important for understanding how teams function in complex settings like military operations.

A number of studies of team processes conducted under relatively realistic conditions are applicable to the issue of team SA (Bolstad & Endsley, 1998, 1999; Chidester, Kanki, Foushee, Dickinson, & Bowles, 1990; Christ, McKeever, & Huff, 1994; Citera et al., 1995; Duffy, 1993; Hirokawa, 1983; Klein, Zsambok, & Thordsen, 1993; Orasanu, 1990; Orasanu & Salas, 1993; Pepitone, King, & Murphy, 1988; Prince & Salas, 1993; Taylor et al., 1996; Torrance, 1953; Young & McNeese, 1995). A full review of team processes is beyond the scope of this report. From these studies, however, some team processes that may affect the quality of team SA are summarized in Table 6.

Many of these observations are drawn from teams outside the Infantry sphere. While such characteristics provide an interesting window into possible differences in processes that may affect team SA, they need to be investigated in the context of Infantry operations. The Army has developed its own process of team interaction for Infantry operations over many years of experience. It faces particular stressors, including harsh operational conditions and the necessity to carry out tasks under very real and present danger. The requirement for a cohesive unit operating under the direction of strong leadership must be reconciled with the requirement for the development of a high level of SA within the team. While it is possible for both requirements to be met simultaneously, this requires special leadership traits and practices. Establishing effective SA processes within each team, from the squad up, and between teams, forms the fourth major linchpin determining the quality of SA in Infantry operations.

Situation Awareness at Various Infantry Echelons

The team SA model describing the four factors affecting shared SA in Infantry operations (Figure 8) applies equally to the squad, platoon, company, battalion, and brigade. The presence of a good understanding of shared SA requirements, shared mental models, shared displays, and shared SA processes will affect the degree to which shared SA is developed at each level of the organization, and between levels of the organization. At the same time, SA tends to change in certain ways as it flows through the different levels of the organization.

Table 6

Factors Affecting the Quality of Team Situation Awareness

Effective Team SA Processes	*Ineffective Team SA Processes*
Team is self-checking, verifies picture against each other at each step	SA black hole—one member leads others off in wrong direction
Team actively coordinates to get information from each other	Does not share pertinent information as a group norm
Prioritizes tasks, prepares for contingencies (forming a shared mental model), plans for rejoining if separated	Failure to prioritize, each member goes in own direction, loses track of main goal
Group norm of questioning self and others	Reliance on expectations—not prepared for violations of assumptions
Leaders create environment for all to share information; explicitly state plans, intentions and strategies; consider more options; and provide more warnings or predictions to the group	"Group-think"—reluctance to question consensus of group or of a powerful leader, causing critical information and perspectives to go unshared
Group develops shared understanding of the situation before looking for solutions	Reluctance to offer novel information in an effort to maintain group cohesion
The team acts to ensure all members understand goals, plans, roles, and functions of each other (explicitly defined)	False assumptions that others share one's opinions, goals, or teamwork values
Team members act to compensate and help other team members who are overloaded or having trouble	Rejection of relevant information offered by lower ranking individuals
The team is able to avoid fixation on a particular focus or perspective by looking at both near and long term issues	Shared misconceptions based on similar, but incorrect experiences

The flow of information up through the organization's hierarchy is critical to informing higher echelons, providing feedback on the status of events and state of the ongoing dynamic situation. Only selected information is reported up, however, as exhaustive reporting would quickly overload any information channel. Reports up the chain of command are carefully formulated to pass on the information that is *believed* to be important for those above. As such, a fair amount of information filtering takes place (either consciously or unconsciously). In general, the information passed up will become coarser (having less resolution) than the detailed information on the ground. A description of muddy terrain received at a higher level, for example, will not contain the level of detail that is in the awareness of those in the field who understand the degree of muddiness, consistency of the mud, pervasiveness of the mud, and the effect of the mud on options for troop and vehicular movement.

As a tradeoff for the loss in granularity, however, the SA of those at higher levels in the organization tends to encompass a far greater field-of-interest. Instead of being very detailed and narrow in scope (such as at the squad level), it will cover information aggregated across many squads from subordinate platoons, companies, and battalions. That aggregation of information is important and contributes to the higher levels of SA of those operating up the chain of command. An important shift from tactical to operational thinking also pervades the way in which information is used and the needs that exist for it at higher echelons.

As information moves up the chain of command, it may also become less recent. The age of information is important for determining the level of confidence one should have in it in a dynamic environment. Finally, the SA at higher levels of the organization may be influenced by transmission error.

Information, of course, does not move only one direction in the Infantry hierarchy. Orders and information flow down the hierarchy to lower echelons. Specific requests for information may also be passed along. In general, as one moves down the hierarchy, SA tends to be more granular, directed at a smaller field-of-interest, and more focused on the tactical rather than operational picture. Those at lower levels may also suffer from the problems of information filtering and transmission error. Not all information gets passed down the chain of command. Thus those at lower levels may lack the context of the big picture that allows them to dynamically deal with situational changes in an optimal manner. They may not immediately understand the importance of cues perceived or which information should be passed up the line. As the Army moves toward greater use of information systems for supporting SA, these characteristics need to be taken into account to build the types of systems that will support shared SA vertically and horizontally.

Summary

Many factors act to impact the quality of a soldier's SA on the battlefield and his commanders' SA in the CP. Various task and environmental features will always act to strain the ability of an individual to form coherent, complete and accurate mental representations of the situation upon which to base sound decision making and performance. There are many mechanisms available for combating these challenges, however. These include intrinsic abilities and the skills and knowledge that can be developed through sound Army training and experience. The mission planning and preparation process is also an important means. While SA in Infantry operations has long been dependent mainly on direct observation of the environment and on communications with others, new digital systems are now coming on the scene which may also boost soldier SA. These systems should be designed and evaluated carefully to ensure that they are compatible with the basic cognitive mechanisms soldiers rely on to keep their SA accurate and up-to-date in the rapidly changing combat arena. The model of SA presented here can shed light on important SA processes, as well as help develop suitable strategies to enhance SA in Infantry operations.

Measurement Approaches and Techniques

The measurement of SA is as complex as it is formidable in the Infantry combat environment. This dynamic environment creates a myriad of tasks and environmental challenges for SA: information complexity, rapidly changing information, uncertainty of information, information overload/underload, tempo, fatigue, noise, and stress. Traditionally, soldiers have relied on very subtle cues from the environment and from fellow combatants for information. In addition, new information systems (e.g., ABCS, GPS, range finders, video links) are capable of producing huge amounts of data. The problem with these systems is not a lack of information, but finding what is needed when it is needed. The individual soldier may be called upon to perceive and comprehend a dazzling array of data that can change very rapidly.

As discussed in previous sections of this report, collective training should foster SA preparedness among Infantry forces. Consequently, we need to know how well the training program supports the Infantrymen's ability to get the needed information under the chaotic and dynamic operational constraints of combat. Valid, reliable measurement techniques will allow us to determine whether the new training techniques and digital systems actually enhance SA and warrant fielding.

Focusing the Measurement of Situation Awareness

The direct measurement of SA (i.e., measuring the actual state of a person's situational knowledge rather than inferring it) can provide great insight into how soldiers and commanders piece together the disparate bits of available information to form a coherent operational picture. Such measurement provides a useful index for evaluating new information technologies and training techniques and for better understanding decision making in Infantry operations. It provides a greater analysis and examination capability than is typically available from performance measures alone, and greater detail regarding the types of effects a given system or training program may have on SA. It allows the designers of new Army systems and training programs to determine whether sub-optimal outcomes are the result of poor SA or of poor tactics and execution. While either is undesirable, the remediation techniques for addressing each component of performance are quite different. While a given system or program may affect some parts of SA positively, it may also decrease SA on other aspects of the situation. Consequently, measures that are sensitive to such changes are needed to detect this possibility, thus guiding future system or program changes.

Evaluation of System Designs

To date, the primary reason for measuring SA in most other domains has been to evaluate system and interface designs. To assess the degree to which new technologies or design concepts actually improve (or degrade) SA, it is necessary to systematically evaluate them based on a measure of SA. This enables a determination of which ideas have merit and which have unforeseen negative consequences. Explicit measurement of SA during design testing illuminates the degree to which design objectives have been met.

The Infantryman's SA and workload can be directly measured during design testing. High level performance measures (as collected during the limited conditions of simulation or field testing) are often too coarse to reveal differences in system designs. Thus, while one system design concept may be superior to another in providing the soldier with needed information in a format that is easier to assimilate, the benefits of this may go unnoticed during the limited conditions of field testing, perhaps due to extra effort on the part of soldiers to compensate for a design concept's deficiencies. From the standpoint of evaluating new systems, this may mask the design deficiencies that should be corrected during the design phase.

If SA is measured directly, it should be possible to select design concepts that promote SA, and thus increase the probability that soldiers will make effective decisions and avoid poor ones during the harsh conditions of real operations. Problems with SA are frequently brought on by the chaos of combat (e.g., information overload/underload, non-integrated data, complex systems that are poorly understood, excessive attention demands, fatigue, information uncertainty, noise, stress). The degree to which a new system or technology helps to reduce these problems and promote good SA needs to be established. Even more importantly, if it fails to improve SA, or actually degrades SA (due to shifts in attention away from the environment toward the system, or high task load associated with its operation), this needs to be detected early in the design process and changes made to improve the system.

Evaluation of Training Techniques

Infantry training programs are being developed to ensure that soldiers understand how to use and employ the new systems being developed for enhancing SA in battlefield operations. In addition, new programs for training soldiers in skills that will directly enhance their SA may be developed. In either of these cases measures of SA can be useful for evaluating the impact of training techniques on Infantry SA.

Many factors work to enhance and degrade SA in the combat environment, so significant attention should be paid to evaluating the impact of new training concepts on SA. Only by evaluating new concepts carefully in planned studies can their impact be identified. The development of training techniques should include a consideration of the type of support Infantry leaders and soldiers really need in achieving better SA and what factors hinder it in the combat environment. Evaluations should include not only how training concepts affect such things as soldier performance, but also how SA is affected. Infantry scenarios employing new training techniques and paradigms can be used to assess the effect of the new training by carefully measuring performance, workload, and SA. Direct measures of SA are recommended to provide sufficient insight into the effectiveness of such training.

Investigations of the Situation Awareness Construct

The measurement of SA is essential for conducting studies to empirically examine factors that may affect SA, such as individual abilities and skills. A sensitive and valid measure of SA can be applied in combat simulation to better assess the processes and strategies for acquiring SA that are used by successful soldiers and leaders as compared to those used by less successful individuals. This information may be very useful for better delineating the critical skills, abilities and strategies for achieving high levels of SA under the stresses of Infantry operations. Such studies are also needed to investigate the nature of the SA construct itself. Information from these types of studies would be very useful for refining and building on the SA model presented in the preceding section. It would also promote fruitful work in the area of new technologies and training programs for enhancing Infantry SA.

Determining Measurement Requirements

In order to derive benefits from measuring SA in combat operations, the veracity (i.e., accuracy, truthfulness) of the measures used must be assured. Without this safeguard, the measures may provide little benefit or even misleading indications. Ultimately, validity and reliability must be established for any SA measurement technique that is used. Additional criteria such as ease of use and soldier acceptance should be considered only when choosing between two or more measures that are equally reliable and valid. *Reliability* concerns whether a measure will remain consistent if the same quantity is measured at different times under the same conditions. *Validity* mainly concerns whether the measure actually measures what it is supposed to measure. Both are important. On one hand, the validity of a measure cannot exceed its reliability. On the other, there is nothing to prevent a highly reliable measure from being invalid. For example, measuring the length of soldiers' noses is likely to provide highly reliable but completely invalid assessments of their combat skills. It is necessary to establish that a metric (a) indeed measures SA and is not a reflection of other processes or factors, (b) provides the required insight in the form of sensitivity (e.g., the likelihood that the true effect of a new SA training program will be detected), and (c) does not substantially alter SA in the process, which can provide biased data and altered behavior. In addition, it can be useful to establish the existence of a relationship between the measure and other constructs as would be predicted by theory. (For more information on measurement issues, see Cook & Campbell, 1979.) Several implications can be drawn from the Infantry SA model (preceding section) with significant ramifications for potential measures of SA.

Processes versus States

First, SA as defined here is a dynamic *state* of knowledge and understanding about an ever-changing environment. This is different than the *processes* used to achieve that knowledge. Different Infantrymen may use different processes (information acquisition methods) to arrive at the same state of knowledge. Or they may arrive at different states of knowledge based on the same processes due to differences in comprehension and projection of acquired information or different mental models and schema. Measures that tap into SA processes, therefore, may provide information of interest in understanding how Infantry leaders and soldiers acquire information; however, they will only provide partial and indirect information regarding an Infantryman's resulting level of SA.

Situation Awareness, Decision Making, and Performance Disconnect

Just as there may be a disconnect between the processes used and the resulting SA, there may also be a disconnect between SA and the decisions made. With high levels of expertise in well-understood environments, there may be a direct SA-decision link. In this case understanding the situation leads directly to selecting an appropriate learned action or behavior. This is not always the case, however. Individuals can still make poor decisions with good SA.

The relationship between SA and performance, therefore, can be viewed as a probabilistic link. Good SA should increase the probability of good decisions and good performance, but does not guarantee it. Conversely, poor SA increases the probability of poor performance, although, in many cases a poor outcome may not occur. For instance, Infantrymen who are fatigued and disoriented in an unsecured area are more likely to encounter enemy troops and suffer severe casualties, than if they are disoriented in a secured area. Lack of SA about one's enemy may not be a problem if the enemy also lacks SA. In relation to SA measurement, these issues indicate that behavior and performance measures are only indirect indices of Infantry SA. They also include the effect of strategy and tactics in decision making, the ability of soldiers to carry out desired actions, and the effects of enemy actions and tactics. Direct measurement of SA is therefore needed in most cases, in addition to performance measurement.

Attention

The way in which an Infantryman allocates his attention in acquiring and processing information has a fundamental impact on SA. Particularly in complex and chaotic environments where multiple sources of information compete for attention, which information soldiers attend to has a substantial influence on their SA. New technologies or training programs that shape attention distribution (intentionally or inadvertently) can have a big impact on SA. Similarly, measurement techniques that artificially influence attention distribution should be avoided, as they may well change the construct that is being measured in the process.

Memory

Direct measures of SA tap into an Infantryman's knowledge of the state of the dynamic environment. This information may be resident in working memory for a short period of time or in long-term memory to some degree and under certain circumstances (Endsley, 1990a, 1995a). A significant issue for measures that attempt to tap into memory is the degree to which people can report on mental processes to make this information accessible.

Time affects the ability of people to report information from memory. With time there is a rapid decay of information in working memory, so that only long-term memory access may be available. Nisbett and Wilson (1977) demonstrate that recall of mental processes after the fact tends to be over-generalized, over-summarized, and over-rationalized, and thus may not be an accurate view of the actual SA possessed in a dynamic sense. Direct retrospective access of a person's memory can be problematic, therefore, and careful strategies for obtaining this information *during* Infantry operations must be employed.

Workload

In the individual SA model (Figure 6), both task overload and underload are shown to be a problem for SA in combat operations. When workload demands exceed maximum human capacity, SA may suffer. Problems may also occur under low workload (due to vigilance problems) or when workload is in a moderate region. Although inter-related in certain circumstances, SA and workload are essentially independent constructs.

Infantrymen can make tradeoffs between the level of effort expended and how much they feel they need to know. Thus, it is important that both SA and workload be measured independently in the evaluation of a training or design concept. A particular training technique or system design may improve (or diminish) SA, yet workload may remain stable. That is, Infantrymen may be putting forth the same amount of effort while achieving more (or less) in terms of SA. With other systems, it may be that Infantrymen are able to maintain the same level of SA, yet may have to work much harder or much less. For a complete understanding of the effects of a particular training and/or design concept, therefore, both SA and workload need to be measured during testing. Measures of SA that are confounded with workload measurement (e.g., that equate low SA with high workload and high SA with low workload) should be avoided for Infantry operations.

Constraints of the Operational Environment

The constraints of the Infantry environment will affect the ability to measure SA during Infantry operations. While the demands of the combat environment make the acquisition and maintenance of SA challenging for the Infantryman, these demands also provide a formidable challenge for assessing SA. At any given time Infantry leaders and soldiers have many tasks in various stages of completion. Others are anticipated in the near future. This task regimen has an explicit, but very dynamic priority structure. The urgency associated with individual tasks changes with the passage of time or with the acquisition of new information. Environmental and enemy initiated events intervene, sometimes predictably, but often unpredictably. In either case they can change the task priority structure—some tasks increase in priority while others become optional. The pace with which these changes take place depends on the time factors of the situation. Infantry leaders and soldiers communicate in order to share awareness, to disseminate changing priorities, or to request action or information from one another.

It is this dynamic environment in which SA plays a critical role. Information and status updates are required to support all the currently active tasks (such as reconnaissance or navigation) as well as those that may be added soon (for instance, response to enemy fire). With constantly changing priorities, information requirements are also constantly evolving. In addition to seeking out and gathering information in this rapidly changing environment, it must be interpreted and related to other information and to the task requirements.

The demands of the operational domain indicate that in many situations, soldiers will have limited attention available for addressing SA measurement needs, along with their ongoing tasks. Measures that require soldier input during ongoing operations will need to be carefully scheduled, and techniques for minimizing intrusiveness employed. In Infantry operations, leaders and soldiers will be deployed, each with different SA, each mobile and separated from other key elements. Measurement techniques will need to determine the SA of multiple personnel simultaneously to get an accurate picture of SA across and within Infantry units, a challenging task logistically. Noise and limited visibility in some cases may also interfere with the administration of SA measures. Finally the tempo or pace of operations can be low or intense. Measurement of SA during rapidly changing operations can be very difficult, but this often is the most informative time to collect such measures. It should also be noted that those tasked with observing and measuring performance in Infantry training exercises suffer from high workload (e.g., Brown, Nordyke, Gerlock, Begley, & Meliza, 1998), a fact that should be taken into account in designing SA measures.

As an alternative venue, SA may be assessed within soldier-in-the-loop simulation environments. While current virtual simulators provide less environmental realism and team interactions, they also provide certain advantages for detailed measurement of soldier behavior and SA. These systems may be used to carefully augment the information that can be gained from less controlled field exercises.

These issues are presented here because assessing measurement alternatives requires an understanding of the character of the dynamic informational context in which Infantrymen operate. It helps to explain the context dependence, scope and transience of SA requirements in the combat environment.

Measuring Team Situation Awareness

In keeping with the nature of Infantry operations, it may be desirable to investigate SA as it exists between multiple soldiers in a squad, or within the company, battalion or brigade. Much can be learned about the dynamic nature of SA and how it is shared (or not shared) among individuals within a unit or across echelons of the organization. In addition, the degree to which new information technologies or training programs affect the SA of the team as a whole may need to be determined. Shifts in SA knowledge from one team member to another, gaps in the transmittal of SA from one team member to another, the effects of casualties on team SA, or the development of inconsistencies in the common relevant picture need to be detected.

Team SA has seldom been measured, but it can be directly examined in experimental studies. Using a direct measure, an assessment of each team member's SA can be made simultaneously during Infantry exercises. Determining the degree to which each team member is aware of the factors required for his specific job will enable the identification of SA weaknesses across the team.

In addition, it can be very useful to make a direct comparison of the SA of any two team members to determine the degree to which they have shared SA (as a critical component of effective team functioning). A direct comparison of the SA of any two team members on those elements which they both need to know (e.g., their shared SA requirements in the areas of perception, comprehension and projection) provides a clear indication of their shared SA. Differences in their perceptions of the situation can be systematically compared to determine the degree to which the squad (or other unit of interest) possesses a shared common picture. This information can be especially enlightening in conducting studies that compare the effectiveness of different team processes and sources (including information technologies that may actually serve to make SA more disparate within the team).

Types of Measurement Approaches

To better represent the issues involved in selecting measures of SA, the process model in Figure 9 is presented. This model shows the stages involved in the perception-action sequence. While they are shown as separate stages for simplicity in narration, these stages may be very closely coupled. Moderating factors common to the Infantry environment that may influence each stage are shown along the bottom of Figure 9. Along the top, classes of measures appropriate to each stage are shown. Some of these will be indirect indices of SA and others will be more direct. The measures for each stage are discussed, including the advantages and disadvantages of each.

Each class of measures shown in Figure 9 may be used to assess the SA of Infantry soldiers and leaders at various echelons and in various mission types. The measures may be applied, with suitable tailoring, to any of the echelons and missions found in Infantry operations. The class of measure used for a particular study should be based on the objectives of the study (e.g., to examine general SA abilities or processes, or to measure the impact of a new piece of equipment) and the type of tasks affected (e.g., combat activities).

Process Indices

Basic characteristics of Infantry leaders and soldiers will influence the processes used in acquiring information from the environment. There is evidence that some people are better at developing SA than others (Endsley & Bolstad, 1994). Differences in underlying abilities have been shown to contribute to this finding, including spatial, attention, memory, perceptual and cognitive abilities. With experience and training, soldiers will also acquire strategies, skills and knowledge that will contribute to their selection of assessment processes and to the SA they derive from those processes. Process measures tap into these factors to assess and understand the various types of processes that different individuals (with varying capabilities, experience levels, and skill types) use to achieve SA in different types of settings (e.g., in performing certain tasks, or in conjunction with certain types of equipment).

An examination of processes used for acquiring SA may be useful in some contexts. It can provide information about how Infantrymen allocate their attention across a complex and demanding environment. This may yield information about the relative priority of different types of information or the relative utility of information sources. It also can provide information about individual differences in these processes that may be useful for developing training strategies. Process measures of SA will be useful for examining these types of test objectives. They will provide only an indirect indication of soldier SA as a state of knowledge, however, as different individuals can arrive at different assessments (comprehension and projection) even when they seemingly use the same processes. This is because of the effects of the moderating factors—shown in Figure 9—that will cause perceived information to be interpreted and synthesized differently. Process measures, therefore, are indirect measures of SA. Several SA process measures may be considered, many of which may be useful in conjunction with each other. Table 7 presents the advantages and disadvantages of various types of measures for assessing the processes used to achieve SA.

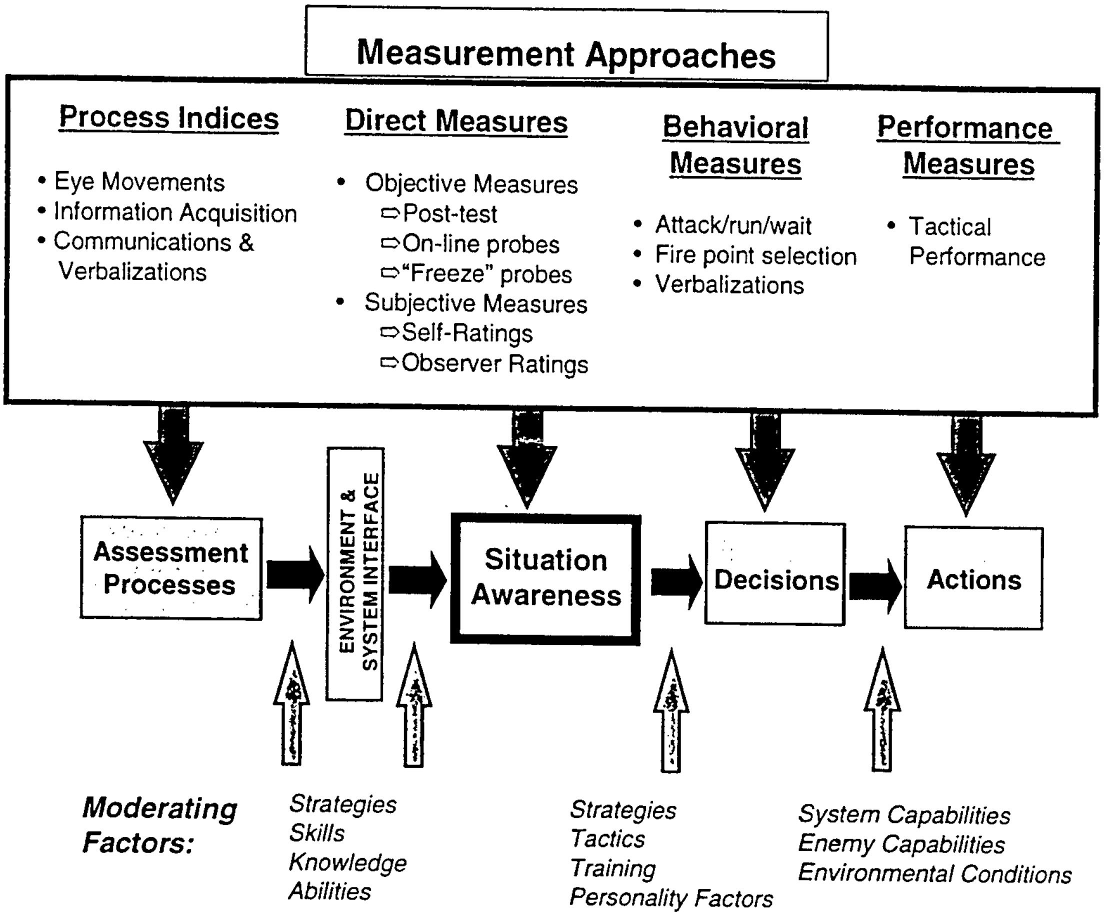

Figure 9. Process model of situation awareness measures (adapted from Endsley, 1996).

Eye Movements

Eye movement recordings have frequently been used to assess information seeking. It cannot be argued conclusively that simply directing the eyes toward a specific object means that it is seen. However, the correlation between looking and seeing is likely to be quite high. Eye movement recordings for assessing information acquisition may provide useful indicators of how attention is allocated (or not allocated) in the process of acquiring SA. Visual search patterns and relations between elements can be assessed (Smolensky, 1993). This information may provide useful insights into the process of acquiring SA or into the types of mental models directing this process. The technique will not provide information on how the perceived data is interpreted and used, and thus will not provide a direct indication of SA. Eye movement recording equipment is quite finicky. While it is suitable for controlled laboratory conditions, it is difficult to use in field settings. In addition, it requires considerable effort to process and interpret eye movement data.

Table 7

Process Indices of Situation Awareness

Advantages	Disadvantages	Application Considerations
	Eye Movements	
➢ Provides indicators of how attention is allocated	➢ Not conclusive that an object is seen and processed ➢ No information on how information is used or combined	➢ Equipment is difficult to calibrate in field ➢ Data analysis is problematic ➢ Will not assess team SA
	Verbal Protocols	
➢ Provides partial information on data that is used or lacking ➢ Provides information on SA strategies and processes ➢ Provides partial insight into how information is integrated and used ➢ Identifies SA concepts needing more systematic measurement	➢ Does not provide a complete representation of what is attended/processed ➢ Can slow performance when responding	➢ Data analysis is problematic ➢ Noisy environments may interfere with data collection ➢ May provide partial assessment of team SA
	Communications	
➢ Provides information on: • Unavailable information • Verbal processes • SA strategies • Feedback on actions • Communication types • Soldier interactions	➢ Does not provide a complete representation of what is attended to/processed ➢ Provides partial insight into information integration and use	➢ Data analysis is problematic ➢ Noisy environments may interfere with data collection ➢ Useful for assessing team SA processes
	Scenario Manipulation	
➢ Can yield direct observations of processes that may lead to correct assessments or mis-assessments of situations	➢ Affects attention ➢ Affects SA ➢ Should not be used during concurrent testing of workload or performance ➢ Measures awareness of specific scenario features, not global SA	➢ Uses realistic scenarios ➢ Manipulations must be mission relevant ➢ Useful for assessing team SA ➢ Need to use with other SA measures

Communications

The effects of poor communication on acquiring and maintaining SA are obvious. Communications below the platoon level have historically relied on visual and auditory contact with members of the unit. However, combat environments may involve dense jungle and mountainous terrain, which makes it difficult to acquire and maintain visual and auditory contact. Military operations on urbanized terrain (MOUT) scenarios similarly may make direct contact difficult, as the effects of buildings and other obstacles must be taken into account. In these environments radios or other devices may be used to enhance direct communications. These challenges place increased emphasis on the importance of communication processes for maintaining SA and cohesion across the squad.

Communication practices usually include orders and instructions flowing down from headquarters to lower units, and information about the combat situation flowing from Infantry leaders up to headquarters. The overall communication process in the combat environment is based primarily on the success of Infantry leaders and soldiers in (a) gathering information, (b) assessing the validity of the information, (c) determining the relative importance of the information, (d) communicating effectively with unit members, and (e) assimilating information into a comprehensible form that others can understand and utilize in their decision process.

Studying the communication process between Infantry leaders and soldiers may shed light on (a) the types of information lacking in available resources, (b) the verbal techniques used for acquiring SA, (c) the differences in SA strategies between Infantrymen, (d) the feedback information available about the adequacy of an action, (e) the nature and type of communications, and (f) interactions among leaders and soldiers. Recording and analyzing the communications between soldiers provides a direct and objective source for measuring SA processes. Collection of such data is usually non-intrusive, since it is part of the naturally occurring process. Although communications may be difficult in Infantry operations (due to noise or obstacles), these challenges are normal and soldier behavior in the face of such problems should also be studied. Analysis of soldier communications can be time consuming and may often be cryptic. In Infantry operations at squad and platoon levels, it must include consideration of non-verbal signals (standardized hand-and-arm signals and non-standard gestures) that complement (or replace) verbal messages. Communications can provide partial information on processes of acquiring SA in squads and above, from which many inferences about team SA processes may be possible.

Scenario Manipulation

Scenario manipulation methods involve altering a simulated exercise by changing displayed or communicated information in some way (Sarter & Woods, 1991). For example, an information display failure, unexpected enemy fire, or an unexpected civilian disturbance could be introduced. These techniques are then combined with the use of video tapes, direct observation, or verbal protocols to examine the processes used by soldiers to piece together cues to detect the problems and develop a new understanding of the situation (correctly or incorrectly). While intrusive to other performance measures, the use of planned scenario manipulations, in conjunction with other measures, can be valuable for investigations of SA processes employed by successful and unsuccessful units.

While the manipulation of parameters in such scenarios may influence soldier SA too much to provide an accurate quantification of SA (it will artificially affect their attention and SA), it may provide useful insights into the SA process. By systematically manipulating events or information, one may discover patterns of the factors that lead directly to correct assessments or mis-assessments of situations. Due to its intrusiveness and artificial impact on SA, scenario manipulation should not be used during tests in which simultaneous assessments of SA, workload or performance are to be made.

Direct Measures of Situation Awareness

Objective Measures

The most common approaches to measuring SA as a state of knowledge have been direct objective measurement techniques, summarized in Table 8. These techniques use queries or probes to collect detailed information on the soldier's knowledge and understanding of the situation. The queries can address detailed aspects of SA across all three levels—perception, comprehension and projection. Probes can be introduced during on going task performance if the pace of the task allows it. However, it is more common to suspend the task—to freeze the exercise—and ask a set of detailed questions about the individual's perceptions of the state of the environment before resuming the action. This method has been formalized by Endsley (1988, 1995a) as the Situation Awareness Global Assessment Technique (SAGAT) and applied in many situations. It, and variants of it, are now widely used.

Table 8

Direct Objective Measures of Situation Awareness

Advantages	Disadvantages	Application Considerations
Post–Test Queries		
➢ Less intrusive ➢ Ample time to respond ➢ Does not disrupt mission tempo	➢ Memories not reliable ➢ Early misperceptions may be forgotten ➢ Captures SA only at the end of an exercise	➢ Requires detailed analysis of SA requirements ➢ Uses mission relevant queries ➢ Data collection easily achieved ➢ Administer immediately after exercise completion ➢ Useful to assess team SA
On–Line Queries		
➢ Overcomes memory problem associated with post-test queries ➢ Queries embedded in task	➢ May intrude on concurrent task performance ➢ May alter SA by shifting attention ➢ May increase workload ➢ Assesses limited SA requirements	➢ Requires detailed analysis of SA requirements ➢ Mission relevant queries occur as part of normal events ➢ Requires careful synchronization with mission tasks and events ➢ Noise may interfere with data collection ➢ Assessing team SA is limited
Situation Awareness Global Assessment Technique (SAGAT)		
➢ Assesses global SA ➢ Objective, unbiased assessment ➢ Avoids retrospective recall ➢ Minimizes biasing of SA ➢ Good psychometric qualities ➢ Performed in realistic, dynamic environments ➢ Allows assessment of shared SA within teams	➢ Requires freezes in the scenarios ➢ May negatively impact the pace and flow of real-time scenarios	➢ Requires detailed analysis of SA requirements ➢ Uses mission relevant queries ➢ Multiple data collectors for teams ➢ Freezes can last 2-3 minutes ➢ Freezes should not be predictable ➢ Freezes may be problematic in field operations

Query or probe techniques collect detailed information about individual perceptions, some of which can then be evaluated against reality, thus providing an objective assessment of SA on a detailed level. This type of assessment provides a direct measure of SA and does not require individuals or observers to make judgments about situational knowledge on the basis of incomplete information, as subjective assessments do. All three levels of SA (perception of data, comprehension of meaning, and projection for the near future) can be addressed. Because these measures collect detailed information on each SA component (e.g., knowledge of own location; knowledge of enemy location; understanding of relative tactical advantage) they provide detailed diagnostic information that is useful for evaluating system design and training concepts. This can include consideration of system functioning and status as well as relevant features of the external environment. These measures also support detailed comparisons of the SA of different individuals between and within teams, allowing for an assessment of shared SA in team settings such as Infantry operations.

In order to provide a clearly objective measure, ground truth (the actual state of the situation) must be assessed by the researcher for comparison to the individuals' perceptions. In simulation settings, making this determination is fairly straightforward since such information can be collected from the simulation network. In Infantry field exercises, however, determining ground truth may be more challenging. In such settings, researchers may need to rely on closed circuit cameras and recording devices, GPS devices, or well positioned observers to assist in collecting this information.

This class of measures suffers a major limitation: it provides little direct information on the SA processes used to arrive at the state of knowledge reported. Direct queries are most useful for making relative comparisons of SA processes, training programs or systems designs on the SA possessed by individuals. They measure SA as a state of ongoing, dynamic knowledge. Query or probe techniques are not without some costs, since a detailed analysis of SA requirements is required in order to develop the battery of questions to be administered. On the positive side, this analysis can also be extremely useful for guiding training and design efforts.

Direct objective measures of SA can be gathered in one of three ways: post-test, during scenario exercises or during interruptions in the scenarios. Each of these techniques will be discussed, in turn.

Post-test queries. A detailed set of questions can be administered after the completion of each exercise in a scenario, allowing time for Infantry leaders and soldiers to respond to a detailed list of questions. Memories of dynamic changes in SA will be less reliable with time, however. Early misperceptions during the exercise may be quickly forgotten as the situation unfolds over time. Therefore, post-test questionnaires will reliably capture SA only at the very end of an exercise. Kibbe (1988) used this technique to evaluate SA as affected by automation of a threat recognition task. She found a retrospective recall measure to be insensitive to the automation. While such queries can be easily applied in Army field settings, reliability and validity are questionable. Post-test queries can be administered to a wide range of soldiers, allowing for both inter-group and intra-group SA comparisons.

On-line queries. One way of overcoming the problem of retrospective memory found with post-test queries is to ask Infantry leaders and soldiers about their SA while they are carrying out their tasks. For instance, "What is your azimuth and range to the target?" "Are there any enemy units in your AO?" These queries could be provided at various points in the exercise over the normal communication channels or dedicated ear-phones in order to examine SA as it evolves across the mission. Such a measure would probe for their awareness of specific pieces of information, as gleaned from the environment or systems provided. On-line queries may alter SA, however, by directing attention to items of interest, and may be intrusive in ongoing task performance if individuals need to answer questions on top of their normal duties.

It might also be possible to measure reaction time to such probes as an index of SA (Durso et al., 1998). It is difficult, however, to tell whether such reaction time approaches measure SA or whether they provide an index of workload, as a secondary workload task technique would (Endsley, Sollenberger, Nakata, Hough, & Stein, 1999).

SAGAT (queries during exercise freezes). The SAGAT is a global tool developed to assess SA across all of its elements based on a comprehensive assessment of domain SA requirements (Endsley, 1988, 1995a). To overcome the limitations of reporting on SA during or after the exercise, the simulated exercise is frozen at randomly selected times, information sources (e.g., new digital technologies) are blanked, and the exercise is suspended while participants quickly answer questions about their current perceptions of the situation. Soldier perceptions can then be compared to the real situation (as determined by experienced observers who are running the exercise and have knowledge about the actual state of events) to provide an objective measure of SA. The collection of SA data in this manner provides an objective, unbiased assessment of SA that overcomes the problems incurred when collecting SA reports after the fact, yet minimizes biasing of soldier SA due to secondary task loading. The approach minimizes possible biasing of attention, as soldiers cannot prepare for the queries in advance since they could be queried over almost any aspect of the situation to which they would normally attend. The primary disadvantage of this technique involves the temporary halt in the exercise. Freezes typically last around 2-3 minutes.

The SAGAT has thus far been shown to have a high degree of validity for measuring SA. It has good predictive validity, with SAGAT scores indicative of pilot performance in a combat simulation (Endsley, 1990b). Content validity was also established, showing the queries to be relevant to SA in a fighter aircraft domain (Endsley, 1990c). New queries would need to be similarly established for the Infantry domains. Studies have shown that a temporary freeze in the simulation to collect SAGAT data did not impact performance and that such data could be collected for up to 5 or 6 minutes during a freeze without running into memory decay problems (Endsley, 1990a, 1995a). A certain degree of measurement reliability has been demonstrated in a study that found high reliability of SAGAT scores for four individuals who participated in two sets of simulation trials (Endsley & Bolstad, 1994).

The technique has most often been used within the context of virtual simulations, and is more difficult to implement during field operations. Applying SAGAT in field environments is rich with challenges. Probes administered during the exercise may be difficult due to the pace and distributed nature of the exercise. Post-exercise queries would be easiest to administer in field exercises, but the technique is problematic due to the unreliability of retrospective memory.

A modified SAGAT methodology may need to be created for Infantry operations involving field tests to deal with these challenges.

Subjective Measures

Like objective direct measures, subjective measures of SA can be collected from multiple individuals within a unit, allowing for examination of team SA. They also try to directly assess SA, rather than infer it from related factors (e.g., processes or performance). Unlike objective measures, subjective measures provide a rating or opinion of the quality of a person's SA. Subjective estimation of SA may be made by individual soldiers or by experienced observers (e.g., peers, commanders or external experts). These measures are summarized in Table 9.

Table 9

Direct Subjective Measures of Situation Awareness

Advantages	Disadvantages	Application Considerations
	Self-Ratings	
➢ Assesses own degree of confidence in SA	➢ Soldiers may not know what information they are unaware of ➢ May be influenced by self assessments of performance	➢ Data are easily collected in uncontrolled field settings after or during exercises
	Situational Awareness Rating Technique (SART)	
➢ Measures general constructs ➢ Widely used ➢ Correlates with performance and workload measures	➢ Workload elements in scale confounded with SA ➢ Not correlated with objective measures ➢ Limited resolution of individual SA elements	➢ Easily administered in laboratory or field settings ➢ Use with other SA measures ➢ Useful to assess team SA
	SA–Subjective Workload Dominance (SWORD)	
➢ Good sensitivity and inter-rater reliability ➢ Good face validity ➢ Provides rating of SA for different design features	➢ May reflect subjective preferences rather than SA ➢ Limited for broader SA construct investigations	➢ Easily administered in laboratory or field settings ➢ Use with other SA measures ➢ Use to compare design features or concepts
	Observer Ratings	
➢ Observers may have more complete knowledge of reality than soldiers/participants	➢ Observers have limited knowledge of the soldier's concept of the situation ➢ Correlated with observer ratings of performance and experience ➢ For teams, multiple observers are needed	➢ Need observable behaviors to anchor ratings ➢ Multiple raters and opportunities are needed ➢ Scenarios must allow behaviors to be exhibited ➢ Observers should not interfere with task ➢ Confederate observers may be used in the field ➢ Peer ratings may be problematic in the field

The subjective assessment of SA for Infantry operations is very attractive in that it is fairly inexpensive and easy to administer. In addition to allowing evaluation of design concepts in simulation studies, subjective techniques can be easily applied in Infantry field operations. Certain limitations, however, constrain the interpretation of subjective evaluations of SA. In particular, individuals making subjective assessments of SA have no objective basis for their judgments. Subjective measures also tend to be global in nature, and as such do not provide the detailed diagnostic resolution that is available with objective measures.

Self-ratings. Self-ratings of SA involve a subjective estimation of how much SA a particular soldier feels he has (along a pre-defined scale) when using a given set of information technologies or during a particular training exercise. Self-ratings of SA do not necessarily provide an accurate quantification of SA, however, as soldiers may not know about their own inaccuracies or of what information they are unaware. They have a limited basis for making such judgments. In Infantry exercises, soldiers can sometimes demonstrate such poor SA that they engage friendly forces with fire, suspecting that they are enemy. In addition, subjective self-ratings may be highly influenced by self-assessments of performance, and thus become biased by issues beyond the SA construct. If a soldier feels he is performing well, he may rate his SA as high, even though in reality he has mainly been lucky so far.

These self-ratings may still be useful, however, because they can provide an assessment of a soldier's degree of confidence in his SA (Endsley, Selcon, Hardiman, & Croft, 1998). Such assessments may provide a unique and complementary picture to that provided by more objective measures.

Situational Awareness Rating Technique (SART). One of the best known subjective SA scales is the SART developed by Taylor (1990). This technique has individuals make ratings of the amount of demand on attentional resources, supply of attentional resources, and understanding of the situation they feel they experienced in a particular situation or exercise. As such, it considers an individual's perceived workload (supply and demand on attentional resources) in addition to their perceived understanding of the situation. High workload is considered detrimental to SA in calculating the SART score and low workload is considered good for SA, which may not be the case for Infantry operations.

While SART ratings have been shown to be correlated with performance measures in aircraft scenarios (Selcon & Taylor, 1990), it is unclear whether this is due to the workload or the understanding components. Selcon, Taylor, and Koritsas (1991), for instance, showed SART to be sensitive to changes in task demands, correlating with the NASA-task loading index measure of workload. Crabtree, Marcelo, McCoy, and Vidulich (1993) examined the sensitivity of SART to various display manipulations. They found SART to be sensitive to most of the manipulations, particularly the attentional demand subscale.

In another study, SART was directly compared to SAGAT to examine the comparability and validity of these techniques (Endsley et al., 1998). No correlation between the SAGAT scores (either individual query accuracy or combined accuracy) and the SART scale (or its subscales) was found. The SART measures correlated highly with a subjective measure of performance and a subjective measure of confidence level, however. This indicates that subjective and objective measures of SA may be assessing very different things.

SA-Subjective Workload Dominance (SA-SWORD). Vidulich and Hughes (1991) modified a workload dominance rating technique to obtain subjective evaluations of the SA provided by different system displays. The SA-SWORD procedure asks individuals to provide a comparative preference for two displays on a nine-point scale, based on their beliefs about the amount of SA provided by each. The investigators found the technique discriminated between two display formats and had inter-rater reliability.

Observer ratings. Outside observers may assess SA via subjective ratings. As an advantage, trained observers may have more information about what is really happening than the soldier who is participating in an exercise, so their knowledge of reality may be more complete. As a shortcoming, observers will have only limited knowledge of the soldier's internal concept of the situation. Soldier actions and verbalizations may provide useful diagnostic information on explicit SA problems (misperceptions or lack of knowledge) and provide an indication that certain information is known, supporting observer judgments. Actions and verbalizations cannot be taken as a complete representation of a soldier's SA, however. They may know many things they do not mention immediately as they are performing other tasks, for instance. Observer ratings therefore provide only a partial indicator of soldier SA. Efforts to elicit more information (by asking questions or providing artificial tasks) may augment natural verbalizations, but this may influence the soldier's distribution of attention, thus altering SA. To improve reliability of observer ratings, Bell and Lyon (in press), recommend that (a) observer ratings be anchored to an established list of observable behaviors, (b) multiple opportunities for observing the individuals be provided, (c) multiple raters be used, and (d) scenarios create opportunities for good or poor SA to be exhibited.

Summary

The ease of implementation, ease of administration, low cost, and non-intrusiveness, as well as the ability to utilize these scales in controlled real-world settings, make subjective SA assessment techniques a popular choice. Although numerous subjective scales have been proposed, few of these scales have been subjected to extensive evaluation for validity and sensitivity. Scales that take into account the multidimensionality and complexity of SA are more likely than single factor scales to illuminate the SA construct. Nonetheless, the problems inherent in subjective metrics demand that caution be employed when interpreting the data gained from these scales. Further, even under ideal circumstances, subjective scales only provide a partial picture of SA—that is, the warfighter's self assessment may not reflect the true situation. For this reason, subjective SA data may most effectively be used in conjunction with objective SA measures.

Proponents of subjective measures suggest that utilizing them is advantageous because they are more closely related to higher order psychological constructs than are other forms of measures (Bell & Waag, 1996). Undoubtedly, utilizing subjective measures provides insight into the operator's subjective experience that cannot be gained from other techniques. Thus, the strength in utilizing subjective assessment metrics is that of a complement to rather than a replacement for other forms of SA metrics.

Behavioral and Performance Measures of Situation Awareness

Infantry leaders and soldiers might be expected to act in certain ways based on their SA. Therefore, some information about SA may be inferred from examining behaviors on specific subtasks of interest. Such behavioral indices might include time to make a response (verbal or non-verbal) to some event, and correct or incorrect SA as identified from soldier verbalizations and appropriateness of a given behavior for a particular situation. Observations of decision making in certain controlled scenarios may be used to infer the SA that underlies the decision. For instance, if a company commander decides to establish an ambush site at a particular location in his AO, it may be inferred that he believes the enemy will be traveling down a certain path.

Inferences of SA based on these types of behavioral measures need to be viewed with caution, however, as they assume what appropriate behavior should be, given the soldier's SA. These assumptions may not be warranted. For instance, different soldiers may respond very differently to the same situation understanding if they choose different combat procedures. They may prioritize tasks differently than expected, or not act in an overt way, even though they recognize and understand the information at hand. This makes the use of behavioral measures to infer SA challenging. Because such measures are objective and readily observable as a natural part of exercises, they are advantageous in some situations. The pros and cons of this class of measures are summarized in Table 10.

Table 10

Behavioral and Performance Measures for Inferring Situation Awareness

Advantages	Disadvantages	Application Considerations
	Behavioral Measures	
➢ Objective and observable measures that are usually non-intrusive	➢ Assumes what appropriate behavior will be for a given level of SA ➢ Behavioral indices may reflect other processes, such as decision strategy, rather than SA	➢ Requires operationally realistic scenarios ➢ Behavioral indices must be specific and task relevant ➢ Should be used in conjunction with other measures of SA
	Performance Measures	
➢ Objective and observable measures that are usually non-intrusive	➢ Global performance measures (e.g., success in meeting a goal, kills in a battle) suffer from problems of diagnosticity and sensitivity ➢ Identifying unambiguous task performance measures may be difficult.	➢ Should be used in conjunction with other measures of SA ➢ Requires operationally realistic scenarios ➢ Performance indices must be specific and task relevant ➢ Subtask performance outcomes should be clearly specified and utilized instead of global performance outcomes

Some investigators have used measures of performance as indicators of SA (Table 10). While behavioral and performance measures are similar, in general, performance measures also reflect the ability of the soldier to carry out the desired action (e.g., his marksmanship in hitting the desired target) as well as his choice of behaviors (e.g., shoot at that target). Inferring SA from performance measures may be especially problematic, because the relative advantage of enemy troops (e.g., who may be better equipped or in a better position) may also affect outcomes.

Like behavioral measures, performance measures provide the advantages of being objective and usually non-intrusive. Several limitations exist in using performance data to infer SA, however. Global measures of performance (e.g., success in meeting a goal, kills and losses in a battle, etc.) suffer from problems of diagnosticity and sensitivity. While global measures of performance are very important, they are somewhat limited as measures of SA. Many moderating factors can influence the link between SA and performance, so global performance measures will only provide an indirect indication of SA.

While discrete task measures may readily present themselves for some investigations of SA, for others, determining appropriate measures may be more difficult. A new information system, for instance, may influence many factors in a global, not readily predictable manner. The major limitation of this approach stems from the interactive nature of SA sub-components. A new system or training technique enhancing SA on one factor may simultaneously reduce SA on another, unmeasured, factor. Unless performance measures are chosen carefully, these problems may not be detected. Wickens (1995), for instance, found that a particular type of navigation display improved performance for staying on course, but decreased performance in emergency situations when a new safe course needed to be determined very quickly. If only one of these measures had been used in the study, very misleading inferences about SA would have been made.

In addition, it is quite easy for participants to bias their attention to a single issue which is under evaluation if they know or suspect the purpose of the study. For instance, if a new information display is provided, soldiers will do very well at performing tasks related to that system, but may do so at the neglect of overall SA that may be needed for other tasks.

One way of dealing with these issues has been the careful development of scenarios that incorporate a "testable response" (Pritchett & Hansman, in press). An example would be to provide soldiers conflicting or inaccurate information concerning enemy location. The measure of SA would be the time required to detect the discrepancy. Another example would be to introduce a critical event into a scenario, such as a friendly call for support, and measure the amount of time taken to locate the appropriate friendly force. These measures allow for very specific measurable performance outcomes that can be predetermined to be correct, given a particular level of SA. Researchers must be prepared for anomalous outcomes, however, because individuals may not react as expected to events and interpretation of their actions can sometimes be ambiguous. It can also be difficult to ensure that planned events occur within a simulated exercise, since the soldiers may bypass the event (e.g., they may choose to change course and never encounter a planned obstacle).

Overall, improved SA in one area may easily result in decreased SA in others. Thus, relying exclusively on the measurement of performance on specific parameters can yield misleading results, and should be viewed within the context of other measures of SA.

Infantry-Focused Measurement Techniques

In addition to evaluating overall performance, Infantry SA should be measured directly in order to better ensure that new systems and training programs act to enhance and not degrade SA in combat settings. In addition, by measuring SA during Infantry operations, the factors that lead to the development of good and poor SA will be more fully understood.

Multiple types of SA assessments may be desirable for different research questions and objectives. At the most basic level of research, part-task studies under well controlled laboratory conditions are preferred. This type of testing is performed to determine potential problems with perceptual tasks (information seeking and detection), motor tasks (entering data, range of motion, physical interference with the environment), and information processing tasks (decision making and problem solving). Very simple and direct measures of task performance (e.g., errors in performing a task, or time on task) are available in these situations.

Soldier-in-the-loop computer simulations provide a more realistic task setting than simple laboratory tasks. They allow an examination of detailed soldier SA under controlled conditions (e.g., stressors, fatigue, high or low workload) and with different types of aids. This approach probably allows for the most detailed measurement of SA under fairly realistic task conditions. Direct objective and subjective measures of SA can be employed, as can performance based measures.

An even more critical level of testing for SA involves simulation and gaming activities, or mission vignettes carried out in realistic field settings. Scenarios for these exercises should incorporate realistic environmental characteristics and requisite soldier task loadings. The scenarios should establish a dynamic setting for expected and unexpected events and factors, for example, enemy movements, enemy ambush, loss of friendly forces, fragmentary orders, and civilian interference on the battlefield. Noise and visual obscuration must be accurately portrayed to replicate combat conditions. The obvious objective is to provide a realistic testing environment that accurately depicts the features of actual operations. Such a setting provides the most representative environment and the potential for valuable, practical data. Unfortunately, while providing the highest form of realism, it also affords the least control over environmental and measurement factors.

An investigator must judiciously choose both the measurement context and the appropriate SA measures. The choices should be made with full understanding of the classes of situations that are to be measured and some thought about what will index transitions from one situation to another. Each class of measurement techniques discussed in this section is readily applicable to the Infantry environment, each for different sorts of research questions. In addition, it may be desirable to create a new set of measures to deal with the unique aspects of Infantry operations. For example, a series of real-time queries based on an in-depth SA requirements analysis can be created for different types of Infantry missions. They can then be administered during the flow of the exercise to soldiers and commanders over radios, as on-line probes. Such queries could be phrased as requests from the battalion or brigade commander, and thus would be a natural component of the exercise.

Objective SA measures such as SAGAT can provide a far more complete picture of soldier SA. They allow for the collection of far more information on SA across a wide range of SA requirements and have been found to be highly sensitive to a wide range of independent variables. As such they are highly desirable for a wide range of Infantry needs. Although easily applied in real-time soldier-in-the-loop simulations, the direct application of SAGAT to the distributed and less controlled nature of Infantry operations in field settings is problematic.

A variation of this technique for field operations would take advantage of combat casualties through two possible methods. The "St. Peter Technique" would take advantage of naturally occurring casualties. Once "killed" in the exercise, the soldiers could immediately be administered a series of questions concerning their perceptions and understanding of the events prior to being killed. This would enable detailed information on soldier SA to be collected and evaluated, providing an objective measure of SA without incurring the problems of instituting a freeze in the exercise. It may provide a biased measure of SA, however, because the casualties of the exercise could be expected to have lower SA than the more successful combatants. Conversely, if unit leaders are targeted strategically by the enemy and killed first, these individuals may have higher SA than others, providing a potential bias. Even though casualties in simulated (and real) combat may not occur randomly, information collected through such a technique could prove to be very useful.

Another related approach could be conceived of as the "Angel of Death Technique". This technique would similarly involve querying those killed in the simulated exercises, but in this case the researcher would designate randomly selected individuals as casualties during different stages of the exercise. Once selected by the researcher and removed from the battle, they would then be administered a series of SAGAT-like queries. This technique would avoid the potential problem of measurement bias in the St. Peter technique created by using only naturally occurring casualties who would likely have poorer SA. It also provides better control over the sampling of participants at various stages during the exercise. As a disadvantage, however, such an approach would also be more intrusive and could affect the force ratios and potentially the information flows within units. This disadvantage may be acceptable, however, in the quest to obtain accurate measurements of SA in complex, real-world Infantry settings. These concepts should be developed and tested, to determine their relative benefits in investigating SA in Infantry operations.

Because each class of SA measure will provide information on different characteristics of the issue, it may be desirable to employ many measures within the same exercise. As an example, we will discuss the application of SA measures to the evaluation of a new system for navigation and position location, a GPS unit. The GPS undoubtedly will provide soldiers with better SA, particularly in terrain that is limited in identifying features or whose features are ambiguous. It is important to test these assumptions, however. Many GPS systems have interfaces, which are confusing and hard to use and may result in gross errors in determining position. The differences between systems need to be determined, so that the best system interfaces can be selected. The systems may be unreliable or could get knocked out by enemy actions, leaving the soldier with the necessity to revert to manual navigation. This is a task that may be difficult if the GPS has left him too reliant on it. These sorts of problems need to be detected in testing so that design or training solutions can be developed.

Applying the model in Figure 6, a number of SA assessment measures could be used to examine how soldiers use the new systems. Video recordings or eye track recorders could be employed to determine how much time the soldiers spend in viewing the information on the GPS. If more time is spent viewing the information in one GPS system as compared to another, this may indicate a poorly designed interface (given that other performance is the same). Does the soldier use the GPS while moving or must he stop to operate and read the display? A system that can be used while mobile would be more versatile in meeting the soldiers' demands. Such an analysis should also seek to determine just which information was used on the displays and in what order. This information would be useful in making recommendations for display modifications to simplify the use of the system (thus leaving the soldier's eyes and brain free for his other tasks, such as monitoring for enemy activity). These are a few examples of the type of information one could gather about SA processes that would provide useful diagnostic input into an evaluation of the suitability of the new system. These assessments could be conducted under fairly simple and controlled laboratory conditions, using a computer simulator, or in the field in simple experiments.

In the next stage, direct measures of SA would be collected. The GPS systems under evaluation could be employed in realistic exercises and mission scenarios. The same scenarios should be used to access traditional methods for navigation and position location, as a basis of comparison. Scenarios depicting typical use conditions (varied terrain, enemy jamming, noise, sunlight glare, etc.) should be created. Within these scenarios, soldiers could be interrupted at selected intervals and asked to report key pieces of information that are relevant for SA. For example: (a) What is your current position? (b) What is the correct azimuth to your next point? (c) What is the best path to take to provide cover and tactical advantage? (d) What is the location of your squad? (e) What is the location of enemy combatants? (f) Where is there terrain offering cover? (g) How confident are you in this information? By assessing the soldiers' accuracy in answering the questions (across many individuals using a given GPS system), it will be possible to detect whether the system actually provides better SA than when soldiers navigate by traditional manual methods, or whether trade-offs have taken place. For instance, it could be that they have much better awareness of current location and bearing, but become attuned to blindly following the system without regard to terrain. Their knowledge of information not on the displays may be decreased due to shifts in attention or in how they are performing the task.

Soldiers using the system could also be asked to subjectively rate their SA. For an assessment of equipment, such as this one, SA-SWORD would provide a suitable measure for providing subjective impressions of the degree to which competing systems enhance SA.

Finally, soldier behavior and performance with the GPS systems should be analyzed to detect SA problems. They could be confronted with new challenges that require a specific action (testable response method). For instance, a new command could be relayed to the soldiers at some point in the scenario to change course and head for a new location. The amount of time taken to determine the new course (and accuracy in this process) and start toward it could be measured as an objective indicator of the SA provided by the system. The main scenario would also lend itself to a number of objective performance measures. The time required to reach the designated point, degree of adherence to the optimal route, speed over that route, time spent exposed to enemy fire, and dispersion of the unit are all objective performance measures that may infer the amount of SA provided by the system.

The ability of soldiers to recover from system failures (either due to equipment or power problems or due to damage from combat operations) is a very real concern with new information technologies. Therefore, special scenarios should be created in which the system fails at unpredicted times. The amount of time taken to recover (determine one's location and the correct bearing to the desired point) and resume manual navigation activities should also be investigated to determine soldier SA with such systems.

Likewise, the SA effects of casualties (especially leader losses) deserve study. Infantry operations commonly involve losses, detachment of soldiers, and addition of new team members. Infantry commanders will gain tactical advantages by knowing how and when SA is affected by these changes.

Obviously the specific measures used will vary for different research objectives. Evaluation metrics appropriate for each system or training program will be unique. The use of SA metrics to investigate the nature of SA in Infantry operations will necessarily be broad in scope. This example does demonstrate, however, the ways in which each class of SA measures can be useful in answering different types of questions.

Summary

There are many SA measurement techniques that are being used in a wide variety of domains. We are beginning to understand which measures are good for which purposes. Since each type of measure provides information on a different aspect of SA, it is recommended that multiple measures be employed.

The think-aloud verbal protocol techniques are probably best suited to preliminary research to understand Infantry SA requirements and processes. Eye-tracking measures also provide information on SA processes, but are better suited to controlled conditions, such as those found in a laboratory or simulator, rather than field operations. Each of these techniques produces vast quantities of data that can be time consuming and difficult to interpret, so their use should be restricted to very specific research questions dealing with information acquisition strategies.

Objective measures of SA provide the most detailed and direct measures. Such measures yield detailed diagnostic information on the level of SA soldiers possess on each element of the situation (e.g., enemy location, weather impact). They have been extensively validated, but may be more challenging to use in Infantry field operations. Query and probe techniques, such as

SAGAT, are best for examining global SA across experimental treatment conditions. These measures can be applied readily in simulation settings.

Subjective measurement approaches will be useful for providing information on the perceived SA of individual soldiers. These approaches can be highly related to the degree of confidence Infantrymen have in their own understanding. Both objective SA and subjective SA may act in combination to indicate how an individual will act (Christ et al., 1994; Endsley & Jones, 1997). Those whose confidence is high (high subjective SA) may choose to act, where those whose confidence is low (low subjective SA) may behave more conservatively. The results of their choices will depend on the objective quality of their SA. In addition to the objective measurement of SA, subjective measures may be relevant for determining an important aspect of behavior in combat operations.

Behavioral and performance measures offer objective and generally non-intrusive measures of SA. They only infer SA from observable behaviors and actions, so they must be treated with caution. Carefully constructed testable response measures are best for evaluating a soldier's ability to meet scenario-specific SA requirements in response to very narrowly defined mission tasks. The tasks or scenario events should require a timely and accurate response from the soldier. One advantage of these techniques is precise measurement. Another advantage is that such implicit probes are part of the normal task and are not intrusive to the realism of the exercise. Because distinct SA tradeoffs can occur, however, a wide range of performance measures across a broad spectrum of scenario possibilities should be collected.

Measures of SA that have been validated in other domains are applicable to the Infantry's needs. Most are broad approaches (e.g., process measures or performance measures) that can be readily applied, but which must be tailored for the individual research objectives, missions, and conditions of the particular testing situation. The direct measures of SA, including objective and subjective measures, must be modified to fit Infantry operations. This can be accomplished by conducting an SA requirements analysis to determine appropriate SA queries for the broad range of Infantry operations. These queries could be applied as post-exercise surveys or as real-time probes (over radios). To provide the best validity, sensitivity, and diagnosticity, they should be implemented as scenario interruptions (as in SAGAT) or through one of the SAGAT variants described above. This approach will also provide much needed information on shared SA within and between units. Of particular note, the scenario interruption technique is also well suited to examining SA across the different types of units (armor, cavalry, engineers, etc.) that may be involved in Infantry operations. Notably, the use of performance-based testable responses will provide objective data in line with the requirements of Infantry testing. It is important that these scenarios be carefully constructed, however, in order to produce unambiguous responses.

Finally, much research is still needed to investigate the nature of SA in Infantry operations. We need to better understand the factors that impact Infantry SA and the individual and team processes that can successfully achieve and maintain SA under these demanding conditions. Addressing these research objectives will depend on a combination of process and direct measures of SA.

Infantry Situation Awareness Research Requirements

In order to provide effective input to training initiatives and system design efforts that are seeking to improve SA for Infantry soldiers, new information on the nature and measurement of SA is needed. This section presents a number of research needs which the authors recommend as relatively high priority in the near and intermediate timeframes. These recommendations are based on the major issues and variables that emerged in the preceding sections of this report. The presentation begins with an outline overview of the recommendations, followed by discussion of each item.

Outline of Research and Development Requirements

Table 11 outlines the basic research requirements, setting the stage for discussion of each recommendation. The recommendations are grouped by priority, based on the criteria listed in the *Methods* section. In addition, the table indicates timeframes reflecting the relative urgency of the various requirements. Implicit in the hierarchy of priorities are sequential dependencies, where many of the later efforts depend on at least partial completion of earlier efforts.

Table 11

Outline of Research and Development Recommendations

Priority	*Recommendation*	*Timeframe*
High	Validate and refine Infantry SA model	Immediate
	Identify SA requirements for Infantry operations	Immediate
	Develop and validate Infantry SA metrics	Immediate
	Investigate competition among SA sources	1-2 years
Medium-High	Analyze upward/downward flow of SA information	1-3 years
	Assess effectiveness of current Infantry SA strategies	1-3 years
	Identify key SA skills and abilities	1-3 years
	Analyze effective team SA processes	1-3 years
	Assess SA content of current training programs	2-3 years
	Assess SA capabilities of current training technologies	2-3 years
Medium	Assess SA doctrine and approaches of foreign armies	2-3 years
	Analyze SA errors in Infantry operations	2-4 years
	Develop improved SA strategies for Infantry operations	2-3 years
	Develop and validate SA aids and devices	3-5 years
	Develop training programs to improve SA	3-5 years

Discussion of Recommendations

The following paragraphs discuss the general framework and approach for each of the recommendations outlined in Table 11.

Validation and refinement of Infantry SA model. The model presented in this report should be validated to determine how well it fits the operational Infantry environment and explains observed performance. One approach would involve submitting the model for review by Infantry SMEs, possibly to include interactive panel sessions. It would also be desirable to test the model under operational conditions with realistic Infantry scenarios, using either explanatory or predictive criteria, or both. The results of the validation efforts would then form the basis for refining the model.

Identification of SA requirements for Infantry operations. An analysis of SA requirements should be conducted for Infantry operations over a wide range of missions and battlefield functions. Key differences in the SA needs of Infantry (light, Ranger, air assault, airborne, and mechanized) and Special Forces should be determined. These analyses would form the basis for developing direct measures of SA and for providing meaningful design guidance for systems development efforts. Goal-directed task analysis has been found to be successful for performing such analyses (e.g., Endsley, 1993).

Development and validation of Infantry SA metrics. Based on the SA requirements analysis, direct measures of SA for Infantry operations need to be developed and validated. This would include a set of queries for assessing SA during operations, post-exercise, or through variations of the SAGAT technique. The requirements analysis should also be used to develop objective testable response performance metrics for different Infantry functions. Finally, because existing subjective measures are not really suitable for Infantry needs, a behaviorally anchored observer rating scale and a self-rating scale should be created for assessing subjective confidence in SA. The validity, reliability and sensitivity of these measures needs to be determined, so that they can be used for a wide range of research initiatives and system evaluation activities. Their utility in a variety of combined arms environments and in Joint exercises should be assessed.

Investigation of competition among SA sources. An understanding of the way in which various sources of SA information compete for the Infantryman's attention would strengthen substantially the foundation for meeting the challenges of the Infantry operational environment. Of particular interest is the competition between the soldier's natural observation of the battlefield and his monitoring of SA devices. The basic mechanisms or processes involved and the characteristics which influence relative salience of SA sources should be analyzed. Also of interest are the basic parameters of intuitive information display that might facilitate obtaining critical information from SA devices. The results of laboratory and field research would help improve Infantry SA strategies and approaches.

Analysis of upward/downward flow of SA information. Because of the influence of echelon on individual and team SA, an evaluation of the transformation of information as it flows upward or downward is needed, from the perspective of the Infantry leader and soldier. This should be accompanied by analysis of the differences in SA requirements found between organizational echelons and elements. This analysis would likely focus on important dimensions such as granularity, aggregation, filtering, and integration of information, as well as scope of interest, spatial perspective, temporal characteristics, and operational orientation (e.g., procedural vs. tactical). Selective verification of analytical findings in a field setting may be valuable. An important outcome of these efforts would be an understanding of how critical dimensions combine to shape effective display of information as well as SA strategies.

Assessment of effectiveness of current Infantry SA strategies. The model of Infantry SA presented in this report provides a foundation for directing research on SA, and it also points to numerous areas where more information is needed. Among these, a number of task and environmental factors that affect SA in Infantry operations have been posited, including visibility problems, noise, anxiety, fatigue, battle tempo, enemy deception, information overload and underload, complexity, and time pressure. The effects of each of these factors on the processes used by Infantrymen to achieve SA should be determined. The strengths and weaknesses of current strategies and processes for maintaining Infantry SA under such challenges could then be ascertained to identify shortcomings that need to be remedied. Input from Infantry SMEs would be important to this effort.

Identification of key SA skills and abilities. Individual differences in SA abilities within Infantry soldiers and commanders should be studied. While anecdotally we know that some people are much better at deriving and maintaining SA than others, very little information exists on the inherent abilities or learned strategies that underlie these differences. An identification of the critical abilities and skills that allow some people to excel at being situationally aware can be used to better guide training and perhaps even personnel selection/assignment systems. This could include efforts to survey SA capabilities among Infantry leaders and soldiers.

Analysis of effective team SA processes. Very little analysis has been done on the level of team SA present within and between Infantry units (e.g., different squads, companies and battalions) and different force components. An investigation should be conducted to determine the team processes that best contribute to a high level of shared SA within and between squads, as required for coordinated actions. Differences in SA that exist between the different echelons of the organization need to be examined and problems in achieving shared SA identified. The way in which Infantry assignment to armor- or aviation-led task forces or brigades can affect SA needs to be considered. Processes for maintaining SA in cooperative operations with civilian authorities, non-governmental organizations, and private volunteer organizations should be addressed. Effective team processes need to be identified and training programs for promoting high levels of team SA created.

Assessment of SA content of current training programs. A review of the SA content and quality of existing Infantry training programs would help pave the way for design and development of improved SA training tools. This effort would survey current institutional and self-development programs required for or available to Infantry officers and NCOs, focusing on course components or modules that teach SA techniques and procedures in one way or another. Analytical methods would be used to characterize and/or classify existing instructional techniques and tools. Data on the relative effectiveness of the various programs would be sought, to include pertinent measurement procedures. Further, existing capabilities would be compared against functional requirements to determine gaps and shortcomings. Finally, recommendations for improving SA instruction and measurement methods could be developed.

Assessment of SA capabilities of current training technologies. Modern Army training programs rely heavily on virtual and constructive simulation technologies to meet operational training objectives. The extent to which those technologies can support Infantry SA training is unknown. A review of existing training technologies is needed to determine the capabilities of simulation-based training programs to impart required SA skills to Infantry leaders and soldiers. The review would focus on the technical capabilities of simulation suites such as the Close Combat Tactical Trainer as well as the structure and content of training support packages built for those environments. Performance measurement procedures would be studied, and training effectiveness data would be sought. A comparison of current capabilities against functional requirements would illuminate shortcomings and unmet needs. The effort would culminate in recommendations for improving simulations/simulators, exercise design, and training support packages.

Assessment of SA doctrine and approaches of foreign armies. The importance of SA in Infantry operations is not unique to the U. S. Army. A review of the SA doctrine and approaches being used in foreign armies would be instructive. This review would encompass doctrine, TTP, individual and collective training approaches, leader development programs, design of SA devices, and measurement of SA performance. Information on the relative success of the various programs would help gauge their potential for adaptation to the U. S. Army Infantry environment. It would be important to assess the role of cultural differences as they influence foreign programs and their potential value in this country. By examining the current SA practices and lessons learned of other armies, it may be possible to derive insights into improving the SA practices of U. S. Infantry.

Analysis of SA errors in Infantry operations. While analyses of factors leading to SA errors have been conducted for other domains (e.g., aircraft piloting, air traffic control), such a study has not yet been undertaken for Infantry operations. An analyses of causal factors associated with degraded SA (or inaccurate SA) in Infantry operations needs to be conducted so that an assessment can be made of which factors are associated with the greatest problems in this domain. The analysis should consider both the external factors that cause problems (e.g., weather, poor visibility) and the soldier's internal processes (e.g., failures in attention or working memory) that led to the errors, using previously developed SA error taxonomies. This effort should include examination of existing historical databases, as well as observational field studies and other techniques (e.g., verbal protocols and surveys).

Development of improved SA strategies for Infantry operations. To complete the foundation for improving SA strategies, the ways in which the higher levels of SA (comprehension and projection) are developed from low level data need to be better understood. The evolution and role of mental models and schema in the development of SA need to be further validated and understood, so that the strengths and weaknesses of these mechanisms can be better dealt with. In particular, the role they play in creating expectations and future projections needs to examined. Since false expectations and incorrect mental models can be particularly hard to dismiss, methods for avoiding these pitfalls while maintaining the benefits need to be determined. Drawing on the cumulative knowledge of SA requirements, processes, and capabilities, this effort would lead to recommendations for improving Infantry SA strategies.

Development and validation of SA aids and devices. Research and development efforts should be directed at developing innovative, high-impact aids and devices to support the establishment and maintenance of SA in Infantry operations. These efforts would build on the improved strategies resulting from research to be performed under the preceding recommendation. The results of these efforts would arm Infantry leaders and soldiers with tools enabling them to track changing conditions easily during all phases of tactical operations. A list of anticipated requirements for such tools is included in Appendix E. Testing and validation of new SA tools would be an essential component of these efforts.

Development of training programs to improve SA. Because SA is critical to effective decision making and performance at all levels of the Infantry organization, methods for optimizing SA between and within each level of the organization need to be identified, both with and without new information technologies. There are a number of approaches to explore for improving SA in Infantry operations, including (a) training programs for building the meta-cognitive skills that build good SA, including attention sharing, task management, contingency planning, and self-checking; (b) pre-mission SA analysis modules for intensive pre-mission briefings to build up mental pictures of the route and tasks, supporting mental model development, hazard assessment, and contingency planning; (c) SA-oriented training that focuses on developing higher level SA (comprehension and projection) from low level information; and (d) the use of structured feedback based on objective measurement of soldier SA to help fine tune information acquisition strategies and schema. These and other approaches for improving the skills and knowledge of Infantrymen should be explored, based on empirical studies of SA within the Infantry domain. Evaluation techniques should be employed to identify the most effective forms of training and their relative value, using validated measures of Infantry SA.

Summary

The research and development recommendations presented in this section represent a systematic approach to expanding the foundation for ensuring effective SA among leaders and soldiers during Infantry operations. The identified requirements encompass modeling and measuring SA, creating new SA strategies and approaches, and designing and developing new systems and programs, with the ultimate goal of enhancing SA on the battlefield. The authors provide a framework for addressing prioritization, sequencing, and timing of the proposed efforts. The set of recommendations provides a basis for crafting an Army investment strategy designed to bring high-payoff returns in a logical, mutually supportive progression.

Conclusions and Recommendations

Achieving SA under the fog of war has always been difficult, but highly critical to effective direction and execution of Infantry operations. This core fact will only become more important as the Army adopts new doctrine and new information technologies. Infantrymen have always relied on SA. As this report details, SA for Infantry forces is a crucial factor that influences the outcome of battles and plays a vital role in successfully executing peacetime operations worldwide. As the Army fields new equipment and doctrine, the service will also need innovative training programs and training support packages to ensure that Infantry leaders and soldiers can gain their full potential for situational dominance. Given the growing focus on SA and fielding digitized systems to enhance information flow and C2, it is essential that the Infantry community fully understand the nature of SA and how to enhance it under the demanding conditions of highly dynamic, non-linear combat. The following paragraphs present the major conclusions of this research project based on key findings and their importance to the Infantry, and also offer recommendations to senior Army leaders.

Conclusions

A major issue revolves around how to manage abundant battlefield information in such a way that it improves SA for Infantry leaders and soldiers. New research and development is needed to identify improved techniques, processes and systems for enhancing SA at each tactical echelon from the individual soldier through commanders and staffs at the brigade level. Creating a realistic framework for formulating new concepts and approaches calls for an Infantry-focused model of SA. This report offers such a model. Establishing valid, quantifiable SA measures that are tailored to Infantry operations is equally important. The report discusses a variety of measures, along with their advantages, disadvantages, and implementation considerations. These measures can be applied in simulation or field studies of new concepts and technologies to determine their advantages and disadvantages for Infantry SA and ensure that problematic technologies are not adopted.

Although the Infantry's tactical environment is more lethal, dynamic, and expansive than it has ever been, the capability to exploit superior SA has also grown. Information and weapons technology, global communication networks, automation and sensor effectiveness have changed the battlefield substantially in recent years. High-volume, high-quality data collection and distribution will give Infantrymen a better appreciation of their surroundings. Communications and coordination between levels of command and even between soldiers in platoons and squads will compress the cycle of observation, orientation, decision and action, thereby accelerating tactical actions. It is also likely that better orientation and intelligence will permit more effective employment of available troops. While superior capabilities may contribute to Infantry forces being better informed, and increased combat power will likely lead to shorter duration battles, the consequence may also increase the combat tempo and stress for Infantry leaders and soldiers, producing a negative effect on SA. Such consequences need to be examined and strategies developed for dealing with them.

While the Infantryman's "world" may seem simplistic to the uninitiated observer, the environment in which Infantry soldiers operate is extremely complex. In addition to the obvious impacts of weather and terrain, Infantrymen must understand and follow all the factors that could influence operations. These include such volatile factors as NBC contamination, radio-electronic interference, artificial obstacles, plant and animal life, noncombatants that may move freely throughout the area, interface with other soldiers and units, capabilities and readiness of supporting units, just to mention a few. Rather than centering their focus around a platform (e.g., tank, ship, aircraft), Infantrymen organize into squads, platoons and companies of dismounted soldiers who each process information and respond in an independent manner. These small units suffer losses in the midst of their missions and function under stress that has no parallels outside of combat. Without proper training and conditioned experience, attaining and maintaining adequate team SA will not be possible.

In the dynamic and varied arena of Infantry operations, having a good basis on which to distribute attention (knowing where to look for critical information and what can be neglected) is a serious challenge. Only through an organized and studied approach can leaders ascertain what factors are the key determinants in maintaining Infantry SA, and hence assist Infantrymen in focusing their attention. Using a systematic and iterative process, leaders can evaluate the applicability, veracity and realism of these determinants in the training and experiences the Army provides and how that directly affects the accuracy and completeness of the soldiers' SA in later Infantry operations.

The combat environment creates a myriad of challenges for Infantry soldiers to manage in order to attain and maintain SA: information complexity, rapidly changing information, uncertainty of information, information overload/underload, tempo, fatigue, death and injury, change of leaders, noise, and stress. An Infantryman's attention, as well as his preparation, implicit skills, and working and long-term memory will be critical to achieving SA in this type environment. The degree to which these structures can be developed and effectively used, the degree to which soldiers can effectively employ goal driven processing in conjunction with data driven processing, and the degree to which soldiers can avoid the hazards of cognitive automaticity will ultimately determine the quality of their SA.

Numerous SA measures that have been used and validated in other domains are applicable to the Infantry's needs. However, to identify a universal measure of Infantry SA is not practical. Multiple types of SA measures will be needed for different investigative questions and objectives. Most of these measures reflect broad approaches (e.g., process measures or performance measures) that can be readily applied, but which must be tailored for the individual objectives, missions, and conditions of the particular testing situation.

Once validated, SA measures provide a useful index for evaluating new information technologies and training techniques. They offer a better understanding of decision making in operations. These SA measures present a greater analysis and examination capability than is typically available from performance measures. Finally, they render greater detail regarding the types of effects a given system or training program may have on SA. In sum, SA measurement techniques will allow us to determine whether new training techniques and technologies actually enhance SA or become a hindrance.

Determining which SA measures to employ and then implementing procedures to obtain data is a difficult challenge. First, direct retrospective access to a soldier's memory stores can be problematic. Careful strategies for obtaining this information during simulated combat events must be followed. Second, the demands of the combat environment impose a formidable challenge for assessing SA. The demands of the operational environment mean soldiers will have limited attention available for addressing SA measurement needs, along with their ongoing tasks. Finally, multiple personnel will need to be assessed simultaneously to obtain an accurate picture of SA across and within Infantry units. Given the noise of battle, the "fog of war," and limited visibility in some cases interfering with the administration of SA measures, conducting measurements could be quite demanding.

Recommendations

A visionary strategy must emerge for institutional and unit training that focuses on enhancing SA at all echelons. Training researchers and developers must create new training environments and technologies designed specifically to build and hone SA-centered decision making skills. This is possible by focusing on how Infantry soldiers and leaders gather and process the numerous pieces of critical information in their environment. One component of this effort should focus on incorporating SA feedback as a matter of routine in Infantry training exercises.

The Army is continually exploring force modernization initiatives to enhance operational effectiveness. One key area currently being evaluated is the use of battlefield digitization. As already noted by some senior Army leaders, it is essential to assess the impact of these modernization initiatives on SA if they are to achieve their technological potential.

Specific SA measures must be developed, validated, and refined as necessary to address the data gathering requirements in the Infantryman's environment. With a library of these measures available, exercise planners and organizers, as well as training and doctrine developers will be able to select the appropriate measures for inclusion in test and evaluation plans for their specific efforts.

Testing has demonstrated that certain attributes contribute to a person's ability to achieve and maintain SA, depending on the particular environment. The Army should determine the desirable attributes for Infantry leaders at different echelons. Using this information, the Army might consider screening potential Infantry leaders for assignments based on their SA attributes.

Given the ever-changing battlefield environment, coupled with the advent of evolving modern technologies, Army leaders need regular opportunities to assess the synergistic impact of these areas on SA for the Infantry. Recurring workshops, similar to the one organized and hosted by ARI-IFRU in September 1998, should become a matter of routine.

This report has identified several fruitful areas for future research (see Table 11). These proposed efforts should be reviewed by senior Army leaders and supported with the appropriate funding and oversight, to include robust Infantry participation and input.

The SA model and measurement techniques presented in this report provide a comprehensive underpinning for understanding the individual, team, and battlefield factors that influence the SA of combined arms soldiers and leaders. The products may prove useful to Army training developers working to create innovative training programs for enhancing SA. Equally important, they may lead to enhanced approaches and techniques for determining the SA impact of advanced information technologies. Finally, the recommendations for future research may help Army planners and decision makers faced with the challenge of crafting a realistic strategy for putting in place doctrine and systems enabling the Army to maintain the winning edge on the battlefields of the 21st Century.

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Appendix A
Acronyms

ABCS	Army Battle Command System
ADA	Air Defense Artillery
AO	Area of Operations
ARI	U. S. Army Research Institute for the Behavioral and Social Sciences
AWE	Advanced Warfighting Experiment
Bde	Brigade
Bn	Battalion
BOS	Battlefield Operating System
BSA	Brigade Support Area
C2	Command and Control
C4I	Command, Control, Communications, Computers, and Intelligence
CALL	Center for Army Lessons Learned
CCIR	Commander's Critical Information Requirements
CO	Company
CP	Command Post
CS	Combat Support
CSS	Combat Service Support
DA	U. S. Department of the Army
DoD	U. S. Department of Defense
EW	Electronic Warfare
FA	Field Artillery
FARP	Forward Arming and Refueling Point
FBCB2	Force XXI Battle Command Brigade and Below
FKSM	Fort Knox Supplemental Manual
FM	Field Manual
GPS	Global Positioning System
IFRU	Infantry Forces Research Unit
LW	Land Warrior
METT-TC	Mission, Enemy, Terrain, Troops, Time Available, and Civilian Considerations
MI	Military Intelligence
MOUT	Military Operations on Urbanized Terrain
MP	Military Police

NBC	Nuclear, Biological, and Chemical
NCO	Non-Commissioned Officer
NVG	Night Vision Goggles
SA	Situation Awareness
SAGAT	Situation Awareness Global Assessment Technique
SART	Situational Awareness Rating Technique
SASO	Stability and Support Operations
SWORD	Subjective Workload Dominance
TOC	Tactical Operations Center
TRADOC	U. S. Army Training and Doctrine Command
TTP	Tactics, Techniques, and Procedures
XO	Executive Officer

Appendix B
Review Form: Infantry Issues and Requirements

Reviewer's Name ______________________________ **Date** ____________

Purpose: This form captures project-relevant information from DA documents regarding infantry SA requirements.

I. Source ID:

Author(s):
Date:
Full Title:
Type of Document (e.g., FM 100-5, CALL Bulletin):
Publisher:
Publisher's Location (City, State):

II. Infantry Issues:

A. What SA-related questions, concerns, and issues are stated explicitly?

B. What SA-related questions, concerns, and issues are implied?

C. Is echelon considered significant for SA questions, concerns, and issues? If yes, explain.

D. Is type of unit (e.g., mounted vs. air assault) considered significant for SA questions, concerns, and issues? If yes, explain.

E. How does the combined arms or Joint setting influence infantry SA questions and issues?

F. Why does this source consider the SA-related questions and issues important?

III. Infantry Requirements:

A. What mission-relevant tasks are highlighted? List by echelon, as appropriate.

B. What development-related needs (any aspect of DTLOMS) are mentioned? (e.g., training assessment, doctrine validation, T&E)

C. What infantry requirements are specialized or unique compared to other military components?

D. What Army modernization impacts among infantry forces are discussed? (e.g., digitization effects, fire-and-forget weapons, non-linear battlefield dynamics)

E. What SA products (models, measures, data, etc.) are indicated as needs or goals?

IV. Other Relevant Observations

A. What variables (e.g., echelon, type of mission) are suggested to be important?

B. What does this source say about characteristics of an infantry SA model?

C. What future research is suggested?

D. What other observations may be of value to the ISA study?

V. Follow-Up:

A. What points from this source need clarification?

B. What sources referenced in this document should be examined?

Appendix C
Review Form: SA Models and Measurement Methods

Reviewer's Name ______________________________ **Date** ____________

Purpose: This form captures project-relevant information from scientific and military literature regarding current SA models and measurement methods.

I. Source ID: Bibliographic citation in APA format.

II. SA Models

A. Summarize the model(s) described in this source (include input, process, output, and enabling variables).

B. In what context did the model(s) originate?

C. What questions, concerns, or issues did the originators intend to address?

D. How does each model represent shared SA?

E. What kind of performance (e.g., group decision making) does each model represent well?

F. What are the strengths of each model?

G. What are the weaknesses of each model?

H. What independent variables does each model accommodate?

III. SA Measurement Approaches and Methods

A. What SA measurement approaches and techniques were used?

B. What measures of performance were defined? At what level of detail?

C. Which of the measures represent individual SA? Shared SA?

D. In what context did the approaches and/or measures originate? (e.g., individual vs. group, maneuver element vs. staff, planning vs. crisis management)

E. What questions, concerns, or issues did the originators intend to address?

F. What are the intended conditions for using the approaches and/or measures?

G. What are the strengths of the approaches and/or measures?

H. What are the weaknesses of the approaches and/or measures?

I. To what extent are the approaches and/or measures applicable to infantry SA?

J. How easy is it to implement the approaches and/or measures?

K. What is known about key characteristics of the measures, to include:
- Reliability
- Construct validity
- Predictive validity
- Sensitivity

IV. Other Relevant Observations

A. What independent variables were examined using the SA measures?

B. Where else have the SA models and measurement approaches/measures been used?

C. What future research is suggested?

D. What other observations may be of value to the ISA study?

V. Follow-Up

A. What points from this source need clarification?

B. What sources referenced in this document should be examined?

Appendix D
List of Sources Reviewed for Infantry Doctrine and SA Requirements

1. Doctrinal publications
   - FM 100-5, *Operations* (U. S. Department of the Army [DA], 1993b)
   - FM 71-100, *Division Operations* (DA, 1990a)
   - FM 71-3, *Brigade Operations* (DA, 1999b)
   - FM 71-3FD, *The Armored and Mechanized Infantry Brigade* (DA, 1999a)
   - Fort Knox Supplemental Manual (FKSM) 71-3-1(A), *The Digitized Heavy Brigade* (U. S. Army Armor School, 1997)
   - FM 71-2, *The Tank and Mechanized Infantry Battalion Task Force* (DA, 1988)
   - FM 7-20, *The Infantry Battalion* (DA, 1992a)
   - FM 7-7, *Mechanized Infantry Platoon and Squad (APC)* (DA, 1985)
   - FM 7-7J, *Mechanized Infantry Platoon and Squad (Bradley)* (DA, 1993a)
   - FM 7-8, *Infantry Rifle Platoon and Squad* (DA, 1992b)
   - FM 7-10, *Infantry Rifle Company* (DA, 1990b)
   - Special Text (ST) 7-7J, *Mechanized Infantry Platoon and Squad* (U. S. Army Infantry School, 1998)
   - TRADOC Pam 525-200-1, *Battle Command* (TRADOC, 1994a)
   - TRADOC Pam 525-5, *Force XXI Operations* (TRADOC, 1994b)
   - Special Text (ST) 100-40, *Tactics* (U. S. Army Command and General Staff College, 1999)
   - *Land Combat in the 21st Century* (TRADOC, 1998b)
   - *Army Division XXI* (TRADOC, 1998a)
   - *Division XXI Advanced Warfighting Experiment (DAWE) report* (TRADOC Analysis Center, 1998)
   - *Strike Force Organizational and Operational Concept* (TRADOC, 1999)
   - Joint Pub 3-0, *Doctrine for Joint Operations* (DoD, 1995)
   - Joint Pub 3-13, *Joint Doctrine for Information Operations* (DoD, 1998)
   - *National Security in the 21st Century* (DoD, 1997b)
   - *Concept for Future Joint Operations* (DoD, 1997a)
   - *Joint Vision 2010* (DoD, 1996)

2. Historical references
   - *Infantry in Battle* (Marshal, 1982)
   - *A Perspective on Infantry* (English, 1985)
   - *We Were Soldiers Once and Young* (Moore & Galloway, 1993)
   - *The Defence of Duffer's Drift* (Swinton, 1986)
   - *Masks of War* (Builder, 1989)

3. Army documents related to SA
   - *Papers from the 1998 Infantry Situation Awareness Workshop* (Graham & Matthews, 1999)
   - TRADOC Pam 525-70, *Battlefield Visualization* (TRADOC, 1995)
   - Center for Army Lessons Learned (CALL) Operations Database
   - TRADOC briefings on Army Experiments 5 and 6
   - *Army Experiment 5 Assessment Report* (Mitre Corporation, 1998)
   - Unpublished analysis of Task Force XXI AWE (TRW Inc., 1997b)
   - Unpublished analysis of Division XXI AWE (TRW Inc., 1997a)

Appendix E
Infantry Situation Awareness Requirements and Issues

The following lists of SA requirements and issues were derived from analyses discussed in the body of the report.

A. Infantry SA Requirements

1. SA aids and devices that permit commanders to change parameters, thresholds, and basic organizational and mission data easily.
2. Accurate information on location of friendly, enemy and civilian entities in the AOs distributed to everyone affected.
3. Accurate information on the condition of friendly and enemy forces in all matters of tactical significance (strength, mobility, weapons status, supply, morale, leadership, state of training, etc.). Insertion of cues or prompts into battle tracking when significant changes to condition occur.
4. Accurate information on the environment including timely updates on changes. This includes condition of weather, the ground, infrastructure, electromagnetic spectrum, air and space factors, and civilian attitudes.
5. Accurate appreciation of time factors including time limits on mission accomplishment, and time for attached and support unit functions. Means of understanding the tactical effects of accelerating and delaying key actions.
6. Reliable, flexible methods for updating Infantry soldiers *en route* to an operational area during their movement and just prior to their arrival.
7. Simple, dependable means of updating SA by soldiers in committed squads and platoons. Means of orienting replacement soldiers or attached specialists to the situation during operations.
8. Simple, dependable means of conveying essential SA information to leaders who assume positions of greater responsibility during operations.
9. Methods for metering external information flow to the unit's ability to receive it.
10. Methods for assuring commonality of SA within a unit. (In particular, ways of confirming that junior soldiers understand the meaning of information intended to add to their SA.)

B. Infantry SA Issues

1. How will SA measurement efforts address differing combat environments?
2. How will inclusion of armor, FA, combat engineers and other branch elements in Infantry-based task forces and brigades affect SA measurement?
3. How will Infantry assignment to armor- or aviation-led task forces and brigades affect their SA support and operation?
4. How will Infantry battalions and brigades maintain comprehensive SA in cooperative operations with civilian authorities, non-governmental organizations and private voluntary organizations?
5. To what extent can SA support be automated? To what extent can SA support to brigades and their components be provided from remote sites or sanctuaries?

6. How well can standard training tools and events support the full complexity of Infantry SA? Will training events present enough data and deliver enough information to support measurement of SA for experimental or training purposes?
7. What forms of training and education are most effective in improving subjective or intuitive SA abilities of Infantry leaders? How can the relative value of training and educational alternatives be measured and evaluated?
8. What will SA support equipment add to the load of dismounted Infantrymen and Infantry units? What trade-offs in combat load make most sense?
9. What are the meaningful differences in the SA needs and capabilities of regular Infantry, Ranger Infantry and Special Forces? Are there doctrinal, materiel, training and leadership consequences of these differences?