High Leverage Command and Control Functions with Critical Human Roles

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Abstract

The Command and Control systems of the future must support high quality decisions even when the pace of battle is very fast, the situation is uncertain, and organizations are complex and geographically distributed. This analysis identifies the set of Command and Control functions whose improvement would contribute most to achieving this goal. It identifies three sets of functions: a first set whose improvement will most improve C2 decision making; a second set that would benefit most from improvements in human performance; and a third set where improving human performance will produce the greatest payoff to C2 and operational effectiveness. Five of these functions in this final set support situation assessment, with emphasis on identifying needed information, on situation projection, and on sharing the common picture. The other five functions support planning and execution. These emphasize developing the strategic concept, expressing intent and plan logic, and supporting adaptive control.

1. Introduction

1.1 *Analysis Objectives.*

Command and Control encompasses many complex interacting functions whose goal is to help commanders make decisions of the highest possible quality, despite such impediments as very fast moving operations, considerable uncertainty, complex distributed coalitions, and the opposition of an intelligent adversary intent on thwarting all of the commander's objectives.

Though many of these functions are partially automated, people carry out essential elements of nearly all C2 functions. They assess the situation to determine adversary intent and possible hostile courses of action, they develop plans to accomplish mission objectives, and they continually review execution progress and adjust the plan as required. How well people perform determines C2 effectiveness and the success of the mission.

The objective of our analysis is to determine the functions where improvements to human performance would make the biggest difference to C2 effectiveness. The notional graphs of Figure 1 portray the impact that such improvements might have on decision quality. The vertical

[*] This work sponsored by the Defense Advanced Research Projects Agency and the C4ISR Cooperative Research Program

axis represents decision quality, and the horizontal one represents a mission "stressor." The stressors examined in this analysis were uncertainty, complexity, and rapid mission pace. The two curves represent decision-making quality as a function of the amount of a stressor (e.g., amount of uncertainty). The lower curve is the quality achieved with today's C2 systems while the upper curve is the quality anticipated with a future improved C2 system. The stressor is absent at the vertical axis. This value represents decision quality in high stakes situations against an adversary when there is no uncertainty, no time pressure, and no requirements for coordination. As the stressor increases, decision quality falls, eventually falling to zero when the stressor is high enough.

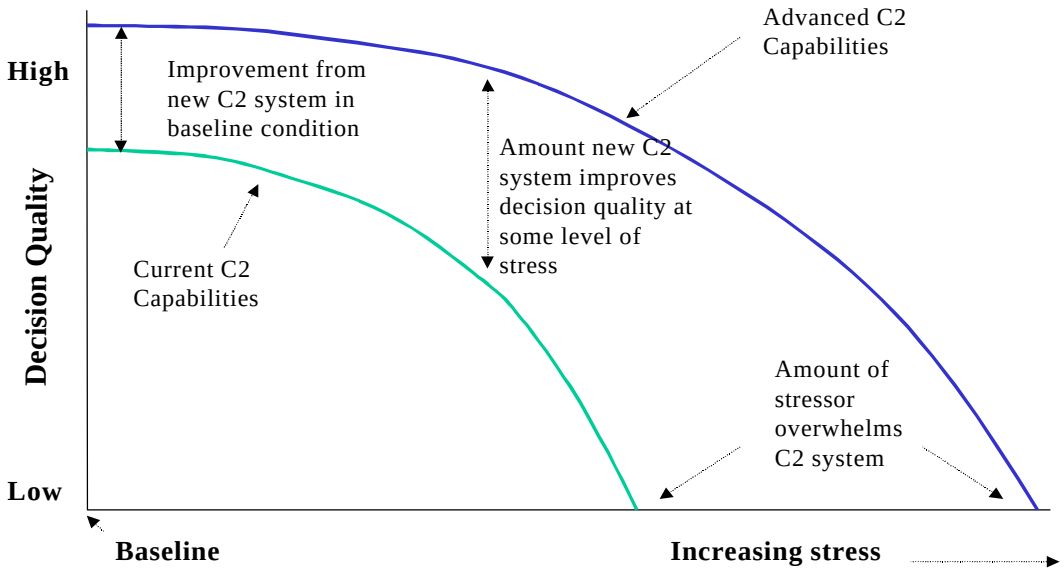

Figure 1. Decision quality as a function of a C2 stressor, for current C2 system and a notional future system

1.2 *Analysis Methodology*

The remainder of this paper will describe the methodology used to identify these desired functions. First, we developed an advanced C2 architecture and operational concept, and identified a comprehensive set of C2 functions within that architecture. Second, we identified the subset of these functions that had highest leverage on decision quality and C2 effectiveness. Third, we determined those functions with significant human performance shortfalls. Last, we identified the functions where improving human performance would have greatest operational payoff.

2. Identification of a Comprehensive Set of C2 Functions

2.1 The advanced C2 operational architecture describes the processes and organizations of a C2 system able to support both conventional and emerging military missions. It was specifically designed to support high quality decision making despite situation uncertainty, fast-paced operations, complex spatially distributed coalition forces, and the opposition of an intelligent adversary. The architecture emphasized adaptive control, continuous and integrated planning and execution, and self-synchronization in a network-centric framework.

Figure 2 summarizes the functional integration within the architecture. It shows the principal C2 processes of situation assessment, planning, and execution, bound together with advanced information systems. Situation assessment evaluates the situation, planning identifies actions to be carried out, and execution carries out the plan. Though they interact in complex ways, situation assessment normally occurs first, followed by planning and then by execution.

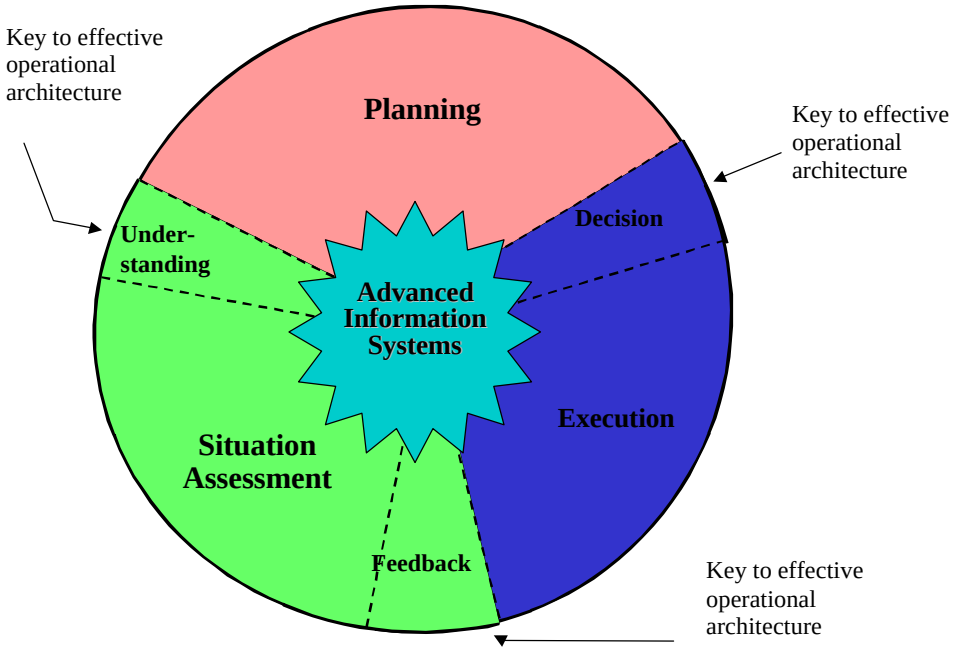

Figure 2. Elements of C2 operational architecture, emphasizing richly coupled, dynamic interfaces

As emphasized in this graphic, the key to an effective operational architecture is the manner in which it integrates situation assessment, planning, and execution. The intersection of situation assessment and planning, labeled "understanding" is the understanding of how the situation impacts the mission. The intersection of planning and execution, called "decision," is embodied in the commander's directive. The clear expression of intent is critical to this interface. Finally, the intersection of execution and situation assessment, labeled "feedback" is the information needed to determine how well the plan is progressing and to identify opportunities and risks.

2.2 *C2 Functions*

The operational architecture functions define the processes performed by people and organizations that employ this architecture. The architecture documentation describes these functions at different levels of aggregation. At the highest level are the three principal categories of situation assessment, planning, and execution. These are decomposed into eleven high level functions, fifty mid level ones, and 225 detailed activities. Our analysis focuses on the fifty mid level ones. Table 1 lists these fifty functions, grouped first by situation assessment, planning, and execution and then organized under the eleven high level functions.

Table 1. The Fifty Mid-Level C2 Functions

SITUATION ASSESSMENT FUNCTIONS

S-1 Understand situation assessment requirements
- a) Identify elements of requested information
- b) Review context of requested information

S-2 Gather the information
- a) Identify *information* to be gathered
- b) Formulate and make requests
- c) Retrieve requested *information*
- d) Assess *information* quality
- e) Screen, organize, and forward *information*

S-3 Estimate the situation
- a) Assess and track environment (weather/ terrain, social/ economic/ political situation)
- b) Project environment
- c) Estimate and track threat location and identity
- d) Estimate and track adversary force, ISR, logistics, communications, and facility status, and organization, activity, and beliefs
- e) Estimate adversary objectives, vulnerabilities, COAs/ plans
- f) Project the threat, including possible COAs
- g) Estimate own force location and capabilities, and status of own ISR, logistics, communications, and facilities
- h) Estimate own force vulnerabilities and opportunities
- i) Project own forces, including strengths and vulnerabilities

S-4 Manage, integrate and distribute situation picture
- a) Provide information assurance
- b) Manage uncertainty
- c) Assemble and integrate *information* for situation picture
- d) Manage inconsistencies among geographically distributed pictures
- e) Tailor picture to support decision making
- f) Share the picture

Table 1. The Fifty Mid-Level C2 Functions (con't)

PLANNING FUNCTIONS
P-1 Prepare for planning
a) Understand missions and tasks
b) Form planning team
P-2 Develop strategy
a) Understand objective trade-offs
b) Understand the situation
c) Develop concepts for achieving goals
d) Identify subgoals, assets, constraints, phases, and contingencies
e) Select Course(s) of Action
P-3 Make/revise tentative plan
a) Decompose strategy to task & ID success conditions
b) Identify needed assets: equipment, *information*, consumables, and organizations
c) Determine boundaries (geographic, ROE)
d) Schedule tasks and assets (time, order)
e) Plan for automated and contingent decisions
f) Plan for execution monitoring and success forecasting.
g) Evaluate plan: suitability, feasibility, acceptability, and robustness
P-4 Deconflict, finalize, and promulgate
a) Review and coordinate with operational echelons and resource managers
b) Articulate intent
c) Develop directive
d) Promulgate directive/ share plan

EXECUTION FUNCTIONS
E-1 Understand directive
E-2 Identify needed future adjustments
a) Continually monitor and understand the situation
b) Continually monitor progress of plan execution
c) Continuously forecast task and plan outcomes
d) Determine need for adjustments to plan
e) Specify, coordinate, and promulgate adjustments
E-3 Employ resources
a) Implement as specified by plan
b) Respond immediately and flexibly to new opportunities and risks
c) Assess and report

Table 2 is an example of the most detailed functional decomposition for the function "Tailor Picture to Support Decision Makers." This most detailed level of specification recommends specific actions for accomplishing the function.

Table 2. Example of Highest Level of Function Specification:
Actions to Tailor a Picture to Support Decision Makers.

Actions to Tailor Picture to Support Decision Makers
A. Determine those elements of the situation able to provide the situation understanding needed to support specific decisions.
B. Depict those elements needed to promote sound decision making under uncertainty. Provide information that helps decision makers consider alternative possibilities and avoid tunnel vision.
C. Emphasize elements of the situation to help decision maker recognize opportunities and risks. Include depiction of missing information.
D. Provide means to view the situation from different perspectives.
E. Remove or de-emphasize elements not relevant to decision task.
F. Represent the quality of the information. Provide drill down so that user can review basis of information. Include supplementary information required to promote correct interpretation of the information.
G. Provide alternative ways to view situation through time. These could include static displays showing the situation as a selected time, and time-oriented progress maps, trends lines, animation of the situation over time, or other advanced displays
H. Update situation picture to reflect reported situation changes as quickly as possible

With the identification of a set of C2 functions completed, the task now shift focus to identifying the "highest leverage" functions; e.g., those that contribute most directly and most strongly to C2 effectiveness and mission success.

3. Identification of High Leverage Functions

All of the functions in Table 1 are important, and under the right circumstances, any of these can be decisive. The high leverage functions are the most important ones because they make the greatest contribution to high quality decisions and hence to mission success. Because the relative contributions of different functions vary under different circumstances, the analysis evaluated function contributions separately for five different conditions. These were a baseline case corresponding to the y-axis of Figure 1, three stressors, each corresponding to a possible x-axis label in Figure 1, and one multi-stressor case. For each of these cases, Evidence Based Research, Inc. (EBR) first identified the major reasons for poor quality decisions, and then identified those functions that most directly addressed these causes. The result is five lists of high leverage functions, one for each of the evaluation conditions.

3.1 *Mission Conditions: Baseline and Stressing Cases*

The five conditions are a baseline, the three stressing conditions of complexity, uncertainty, and rapid change, and a final multi-stressor.

- In the **baseline** conditions, there is only a single decision maker, possibly tasked by someone else, acting against an adversary in a high stakes mission. There is no uncertainty, no time pressure, and because there is only a single decision maker, no organizational complexity. The baseline conditions of high stakes and active adversary apply to each of the four stressor conditions.

- In the **complexity** stressor condition, there are multiple stakeholders, coalition forces, and geographically distributed diverse forces. There is no uncertainty or time pressure.

- In the high **uncertainty** stressor condition, information is incomplete, imprecise, ambiguous, not current, and of unknown accuracy and reliability. There is no complexity or time pressure.

- In the **rapid change** stressor condition, mission activities occur rapidly. Rapid changes to the environment or fast paced actions by the adversary require fast-paced decisions, which will be ineffective if made too late. There is neither uncertainty nor complexity, however.

- In the **multi-stressor** case, uncertainty, rapid change, and complexity may occur together. Such combinations can impose additional stress, beyond what each stressor imposes separately. This case requires a robust architecture. It can represent the mix of conditions that arises most commonly in military mission.

3.2 *Causes of Poor Quality Decisions*

Most C2 decisions are satisfactory. Though these can often be improved, doing so usually contributes only marginally to decision quality and overall mission success. Occasionally, however, commanders will make a serious mistake (Hayes, 1978). Eliminating these will have a much more significant impact on decision quality and mission success. This analysis focuses on elimination of such errors by addressing their causes. Table 3 summarizes some of these causes in the baseline and stressing conditions (Hayes, 1993)

Table 3. Causes of Poor Quality Decisions

Baseline	Cause of Poor Quality Decision
Baseline	1. Objectives misunderstood 2. Situation misdiagnosed[1] 3. No good alternative identified 4. Incorrect evaluation of alternative quality[1] 5. Failure to make corrections when decision is not working[1]
Complexity	1. Stakeholders and implementers have dissimilar understanding of the situation[1,2] 2. Participants understand the plan differently and are not clear about the roles, relationships, tasks, and success criteria 3. Implementers misunderstand commander's intent 4. Difficulty of orchestration and synchronization[1,2]
Uncertainty	1. Failure to consider the different situation possibilities[1] 2. Information able to resolve among these possibilities not identified[1] 3. Failure to extract the maximum amount of information from the data, or reaching conclusions that go beyond the data[1] 4. Failure to know how long it's safe to wait for situation to clarify 5. Failure to have multiple options that hedge for the different uncertainties[1]

[1.] Impacted by information overload
[2] Impacted by number of actors and layers

Fast-Paced	1. Opportunities and risks identified too late to respond[1,2] 2. Not enough time to identify a good action[1,2] 3. Time available not used effectively 4. Not enough time to determine what's happening[1,2] 5. Not enough time to adjust plans[1,2]
Multi-stressor	1. Complex organizations impose coordination and approval processes that impede quick response 2. Fast paced operations don't allow sufficient time to resolve uncertainties 3. Stove-piping in complex organizations impede collection and receipt of information needed to resolve uncertainty

3.3 *High Leverage Functions*

The high leverage functions are those that most directly address these causes of poor quality decisions. For example, the very important function, "Project the threat, including possible COAs," directly addresses six causes of low quality decisions: two in the baseline, two for handling uncertainty, and two for handling fast-paced operations. Table 4 summarizes the contributions of this function, explaining how the function addresses each of the problems. Note that this function contributes to each of these in a different way and for a different reason. The function is also important for the "complexity" condition. Complexity is not listed on the table, however, because it imposes no additional requirements for this function than the baseline case imposes.

Table 4. Contribution of "Project the Threat" Function to High Quality Decision Making

Condition	Problem Addressed	Why Important
Baseline	• Situation misdiagnosed	• Understanding adversary intent and possible COAs is key to understanding the nature of the military problem
	• Incorrect evaluation of alternative quality	• The estimated outcomes from adopting an alternative may be very inaccurate if predictions of hostile counter-actions are incorrect.
Uncertainty	• Failure to consider different situation possibilities	• Coping with uncertainty requires hedging for all important situation possibilities. Possible hostile COAs are among the most important of these possibilities.
	• Don't know how long it's safe to wait for situation to clarify	• Commanders often must decide whether to act now, despite being uncertain of the situation, or to wait for more information. Predicting when key adversary actions will take place helps the commander know how long he may wait.
Fast-paced	• Identifying opportunities and risk too late to respond	• Opportunities and risks are forecast by projecting the threat.
	• Not taking full advantage of time available	• The pressure to make decisions quickly produces stress and can prevent adequate consideration of alternatives. Knowing how much time is available alleviates both of these problems.

Table 5 lists the high level functions. About half of those, the ones on the left hand side of Table 5, address the baseline and at least one of the stressing conditions. The half listed on the left side of the table addresses only one of the conditions.

Table 5. High Leverage Functions

Address Baseline and One or More Stressors	Addresses Only a Single Condition
• Identify information to be gathered • Project the threat, including possible COAs • Share the picture • Understand objective trade-offs • Develop concept for achieving goals • Plan for automated and contingent decisions • Promulgate directive/share plan • Continually forecast task and plan outcomes • Specify, coordinate and promulgate adjustments	• Project environment • Project own force, including strengths and vulnerabilities • Manage uncertainty • Select Course(s) of Action • Decompose strategy to task & ID success conditions • Articulate intent • Understand the directive • Continually monitor progress of plan execution • Determine need for adjustments to plan • Respond immediately and flexibly to new opportunities • Assess and report

4. Identification of Functions with Significant Human Shortfalls

People perform most of the activities needed to accomplish the functions of Table 1, performing more proficiently in some functions than in others. This part of the analysis identifies those functions where people have often not performed well enough. It is based on recent analyses of C2 performance. The analysis has four steps. First EBR examined the cognitive functions important in two Army exercises. We then identified those having significant shortfalls in a Marine Corps exercise. Third, we placed these in the context of past research and historical cases. In the final step, we mapped the shortfalls to the C2 functions where these shortfalls occur.

4.1 *Important Cognitive Functions*

A recent Army Research Laboratory study [Adelman et al, 1998], investigated cognitive functions important to Command and Control. This study described these important functions in terms of four descriptive models of "naturalistic" decision making. It then analyzed exercises to determine the extent to which these models can explain observed behaviors. The observed behaviors supported three of the cognitive models. The fourth model, which dealt with human strategies for handling uncertainty, could not be evaluated because uncertainty was not featured in these exercises.

The four cognitive models were consistent with each other, with each emphasizing a different aspect of decision making.

- Klein's **Recognition-Primed Decision Model** described a decision making process frequently used by experienced people, particularly when under time pressure. It emphasizes

situation assessment. People often pick an alternative that they know from experience will work in a particular type of situation. They usually do not explicitly consider more than one alternative.

- The **monitoring function** stressed in Rouse and Vasulek's research describes addresses behavior over time. It describes how people continually monitor their plan's progress to determine if it is working if expected, and discusses ways to adjust or replace the plan if it is not.

- Beach's concept of **"images"** emphasizes the three frames of references that people use to judge the quality of an action. These values include stable long term personal and organization values, the mission goals and basic strategy, and the actions specified by a plan.

- Lipshitz and Strauss' model of **tactics for coping with uncertainty** emphasizes methods for managing the situation when the uncertainly is too great to predict confidently that a particular course of action would be appropriate.

The processes described in these models generally paralleled those in the operational architecture reviewed in Section 2. It confirmed that the cognitive processes, described in the four models and observed in the exercises, map reasonably into the architecture functions. For example, both cognitive models and architecture functions emphasize the importance of situation assessment, monitoring, and having a clear understanding of commander's intent.

While the Army Research Lab report confirmed that the functions in the architecture do parallel those performed by commanders during exercises, it did not assess where people did well or poorly. The lessons learned from the Marine Corps MAGTF Staff Training Program (MSTP 1999) exercise provided the data for that assessment.

4.2 *Identification of Shortfalls in Human Performance*

The "Lessons Learned" summary did not explicitly specify cognitive shortfalls or shortfalls in human performance. Instead, it documented operational shortfalls observed in the exercise and recommended corrections. Most of the operational shortfalls, however, were due to human performance limitations. Consequently, most of the recommendations were remedies to shortfalls in human performance. Using the ARL analysis described above as a guide, EBR identified those recommendations intended to improve human performance, and then organized these recommendations into four groups.

The four groups of recommendations were 1) building and sharing a consistent common picture; 2) developing mission strategy/concept and identifying needed tasks; 3) establishing conditions needed for adaptive control; and 4) expressing intent in a clear directive. Table 6 lists the specific recommendations associated with each of the groups. The shortfalls may be inferred directly from the list of recommendations; e.g., a recommendation to articulate intent implies a human failure to articulate intent adequately.

Table 6. Recommendations in MTST Lessons Learned
to Correct Human Performance Shortfalls

Build Situation Picture
a. Staff incorporates information and assessments, not raw data. b. Staff filters information flow so that the commander receives useful focused information. c. Staff evaluates terrain to support logistics activities and operations. d. Staff bases evaluation on enemy, environment, and blue capabilities and limitations. e. Staff performs both long-term assessment (trend analysis) and short term analysis (recognition~~,~~/ pattern analysis requiring large amounts of intuition). f. Staff scrubs and deconflicts briefings to avoid contradiction and duplication.

Develop Strategy and Tasks
a. Commander's priority should be developing his vision for decisive action. b. Shaping (creates) the conditions for decisive actions and takes all lethal and non-lethal activities into account. c. Commander should employ friendly COG as source of strength to be used asymmetrically. d. Commander organizes reserve tasks in anticipation of being employed to achieve the decisive action. e. Staff analyzes time and battlespace required to accomplish tasks and activities. f. Planners link decisive and supporting actions to the main and supporting efforts.

Prepare for Adaptive Control
a. Commander/staff must express tasks, objectives, goals, end states, etc. in measurable qualitative or quantitative terms to facilitate assessment. b. Commander articulates conditions for preplanned shifting of main effort. c. Commander/staff must establish Critical Intelligence Requirements (CCIR), which are vital to the commander's decision making process. d. Commander/staff must update CCIRs to reflect commander's current concerns.

Express Clear Intent
a. He clearly articulates the overall purpose of the operation. b. He uses accepted and clearly defined military terms from doctrinal publications, c. He makes plans understandable, definable, achievable, and measurable. d. He identifies the single action critical to him for mission success. e. He makes clear MSC commander roles in achieving or supporting decisive actions. f. His planning guidance to force staff addresses shaping and decision actions.

4.3 *Functions with Significant Human Shortfalls*

The final step of this analysis phase associated the human shortfalls (as implied by the recommended corrective actions) with the functions of Table 5. For example, The shortfall implied by the recommendations "Staff bases evaluation on enemy, environment, and blue capabilities and limitations" and "Commander should employ friendly COG as source of strength to be used asymmetrically" were both associated with the architecture function "estimate own force vulnerabilities and opportunities." Table 7 lists the seventeen functions associated with significant shortfalls in human performance, as assessed from the MSTP Lessons Learned. Five of these functions addressed shortfalls from more than one category. The other twelve functions addressed shortfalls from only a single category.

Table 7. Functions with Significant Human Performance Shortfalls

Addresses Shortfalls from Multiple Categories	Addresses Shortfalls from only a Single Category
• Estimate own force vulnerabilities and opportunities • Project own force, including strengths and vulnerabilities • Decompose strategy to task & ID success conditions • Articulate intent • Continually forecast task and plan outcomes	• Identify information to be gathered • Screen, organize and forward information • Assess and track environment • Project environment • Project the threat, including possible COAs • Assemble and integrate information for situation picture • Manage inconsistencies among geographically distributed situation pictures • Tailor picture to support decision making • Develop concept for achieving goals • Plan for automated and contingent decisions • Plan for execution monitoring and success forecasting • Develop directive

5. Synthesis

The analysis synthesis produced a list of ten high leverage functions with significant human performance shortfalls. These ten functions were the ones on common to two lists: the "High Leverage Functions" list of Table 5 and the "Functions with Significant Human Performance Shortfalls" list of Table 7.

Figure 3 depicts these functions, linked to the C2 processes that they contribute to most directly. Eight of the ten functions are associated with the interfaces between the situation assessment, planning, and execution categories. Only two of the functions are not associated with an interface. This result is not surprising, for the functions in these overlaps are both those that people have the most difficulty with as well as the ones that tend to be most critical to effective command and control.

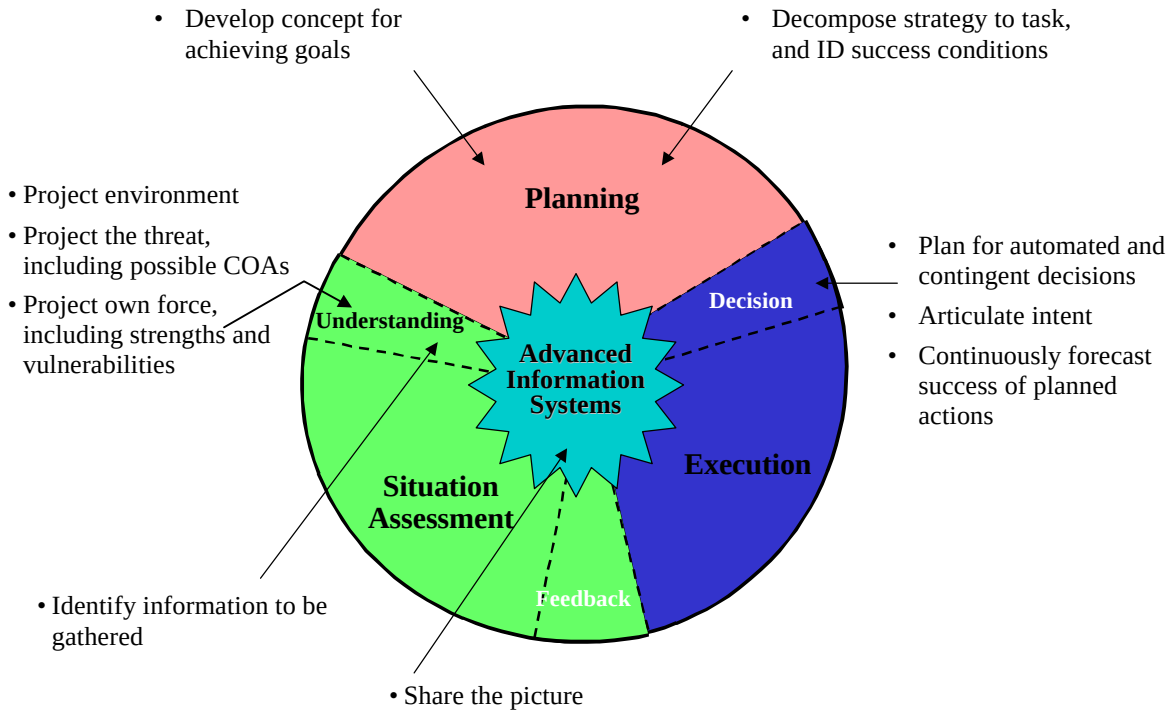

Figure 3. High Leverage Functions with Shortfalls in Human Performance

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