TECHNICAL PAPER

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# HSI Top Down Requirements Analysis

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## Abstract

*The major objective of the discipline of human systems integration (HSI) in system development is to ensure that requirements and considerations for the human element of the system will influence design. The system must be designed to facilitate and support human performance capability, safety, reliability, survivability and accommodation. This objective is achieved by addressing human requirements early in system design and development, in fact, at the very outset of the design process. How this is accomplished is through application of the HSI top down requirements analysis (TDRA). This paper describes the TDRA process, discusses applications of the TDRA, and compares TDRA with bottom-up analysis.*


The primary objective of HSI in system acquisition is to *influence design* with requirements and constraints associated with human performance and accommodation. The way in which this is accomplished is through several initiatives:

- identify human performance issues and concerns *early* in system acquisition;
- define the roles of humans in system operations and maintenance *early* in system development;
- identify deficiencies and lessons learned in baseline comparison systems;
- apply simulation and prototyping *early* in system design to develop and assess HSI concepts;
- optimize system manning, training, safety, survivability, and quality of life;
- apply human-centered design;
- apply human-centered test and evaluation.

These initiatives constitute the basis for a standardized and formalized HSI process to address how the system will be designed to ensure that human requirements and considerations are included early in system design and development. The thrusts of the HSI process are to provide the bases for designing human-machine interfaces, developing personnel training systems, providing for human accommodations, and optimizing manning. Optimized manning is defined as the minimum number of personnel consistent with human performance, workload, safety requirements, and affordability, risk, and reliability constraints.

The goal of HSI in early phases of system acquisition is to define requirements for reduced workload and optimized manning, determine requirements for human performance and safety, specify technology requirements to achieve optimized manning, and integrate these requirements into system performance specifications. These issues point to the need to depart radically from the business as usual approach to military system design, to implement an acquisition strategy and developmental approach which is highly innovative, imaginative, creative, revolutionary, and responsive to mission requirements, engineering and operational constraints, and human capabilities and limitations. The foundation for this innovation lies in the early and comprehensive implementation of the top down requirements analysis.

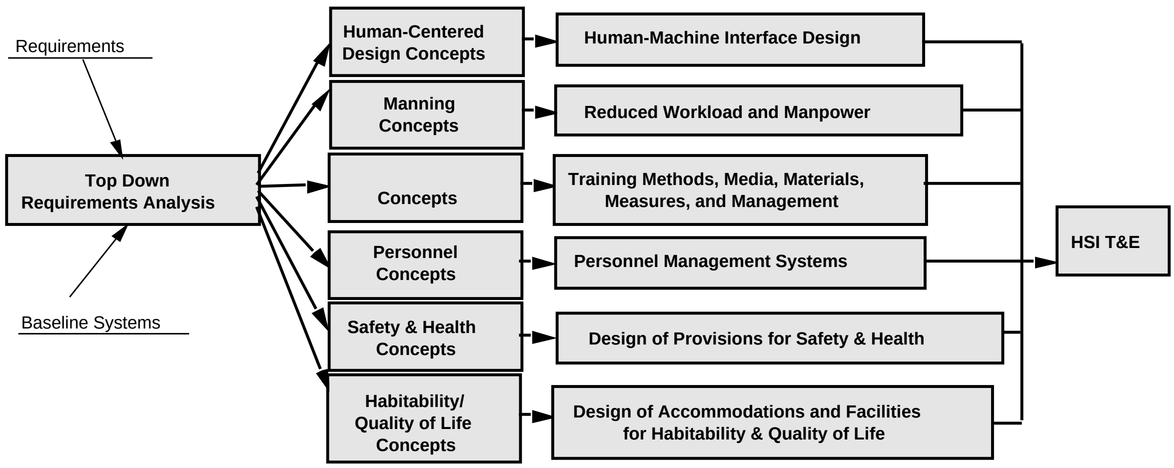



**FIGURE 1:** *Relationship of the TDRA Process to the Total HSI effort*

TDRA represents the front-end of the HSI process. The analytic activities which comprise the TDRA represent an adaptation of the classical front-end analysis, which has always been a pillar of the human factors engineering discipline and which has been described in MIL-HDBK-46855, MIL-HDBK-763, and the DoD Acquisition Deskbook. In addressing approaches to optimize system manning, simply automating system functions will not provide the warfighter with what is needed to monitor, plan, react, understand, maintain situation awareness, supervise, make decisions, make judgments, and modify plans because of changes in the tactical situation. The only viable approach to optimal manning and effective system performance is to develop a system where human and machine synergistically and interactively cooperate to conduct the mission and where the automated system supports human performance with decision aiding, predictive what-if simulation and information integration, data fusion, and knowledge generation.

The critical demand in this HSI approach is to understand the complementary and collaborative roles of human and machine in the performance of system functions and how those roles may change in response to human workload, human availability, and mission changes. That can only be achieved through a top down requirements analysis, which considers the roles and requirements for human and machine performance in each function associated with selected mission scenarios and defines the information, decision, and performance requirements of the associated acquisition strategy.

The overall thrust of HSI in military system acquisition is to address how to optimize ship manning and human workloads (resulting in reduced ship life cycle costs) while at the same time enhancing the performance and safety of the system warfighter. To accomplish this, HSI must define the complete range of requirements for human involvement, human utilization, human performance, human safety, and human accommodation from the earliest stages of military system development. TDRA represents a systems engineering approach to specifying the concerns for the human in ship systems. The relationship of TDRA to the other elements of the HSI design process is depicted in **Figure 1**.

The objective of the TDRA is to provide the analyzed requirements, allocation concepts, workload estimates, human task models, system metrics, and manning models necessary for influencing design with human requirements and considerations. Just as HSI is a systems engineering discipline, TDRA is a systems engineering application. As such, TDRA is requirements-driven, and is focused on defining system interfaces.

In terms of requirements, TDRA is concerned with identifying, analyzing, and integrating requirements for missions, system functions, human involvement in the performance of functions, training, personnel systems, safety and health, and quality of life. These requirements lead ultimately to development of design requirements for human-machine interfaces and human-automation interaction, manpower, personnel and training, safety and health, and quality of life implementations. In terms of a concern for systems interfaces, the scope of TDRA includes the interfaces between the human and other system elements (hardware, software, information, procedures, communications, organizations, and environments).

The TDRA comprises the basis for a disciplined development of innovative, revolutionary design concepts. The TDRA is the initial step in a formalized HSI Process and is an adaptation of the human engineering front-end analysis.

It is human-centered in that it focuses on roles and requirements of humans, defines design concepts in terms of human performance, safety and workload requirements, results in design approaches for human-machine interfaces, and establishes manpower, personnel and training approaches.

It is knowledge-based in that it relies on concepts based on mission, function and system requirements, and in that it is concerned with generation and processing of knowledge as well as information.

Finally, as applied in the early phases of acquisition of a radically new system concept, as in the case of the DD 21, it relies on extensive application of modeling and simulation, for requirements definition, concept development, design assessment, training effectiveness evaluation, and human performance verification.

## TDRA Process

The TDRA process for applying HSI to systems is depicted in **Figure 2**. Descriptions of the activities associated with each process step are featured in Figure 2.

### PROCESS STEP 1: Conduct Top Down Function Analysis

System functions constitute the major activities to be performed by the system at several layers of iteration, short of the level of specificity that requires designation of the means of accomplishing the function. The system HSI function analysis will identify functions to be performed and provide a functional flow block diagram depicting the sequence of functions for the system. The functions will be decomposed to successively greater levels of detail in an iterative manner based on requirements associated with each function.

### PROCESS STEP 2: Identify High Driver Functions

After completion of the function analysis, HSI high driver functions and subfunctions will be identified. HSI high drivers include functions in legacy systems that impose high demands on manning (are labor intensive) and/or skills, or which are expected to impose high risks, workloads, and performance complexities. The identification of high drivers proceeds from a comparability analysis. This analysis provides indications of high driver functions and mission scenarios, and lessons learned from existing systems. To support the comparability analysis, HSI measures of effectiveness will be developed for each function.

### PROCESS STEP 3: Analyze Mission Requirements/Define Mission Scenarios

The primary objectives of mission analysis are to identify the mission requirements that impact personnel concerns, and to identify mission scenarios which will exercise human performance, workload, and

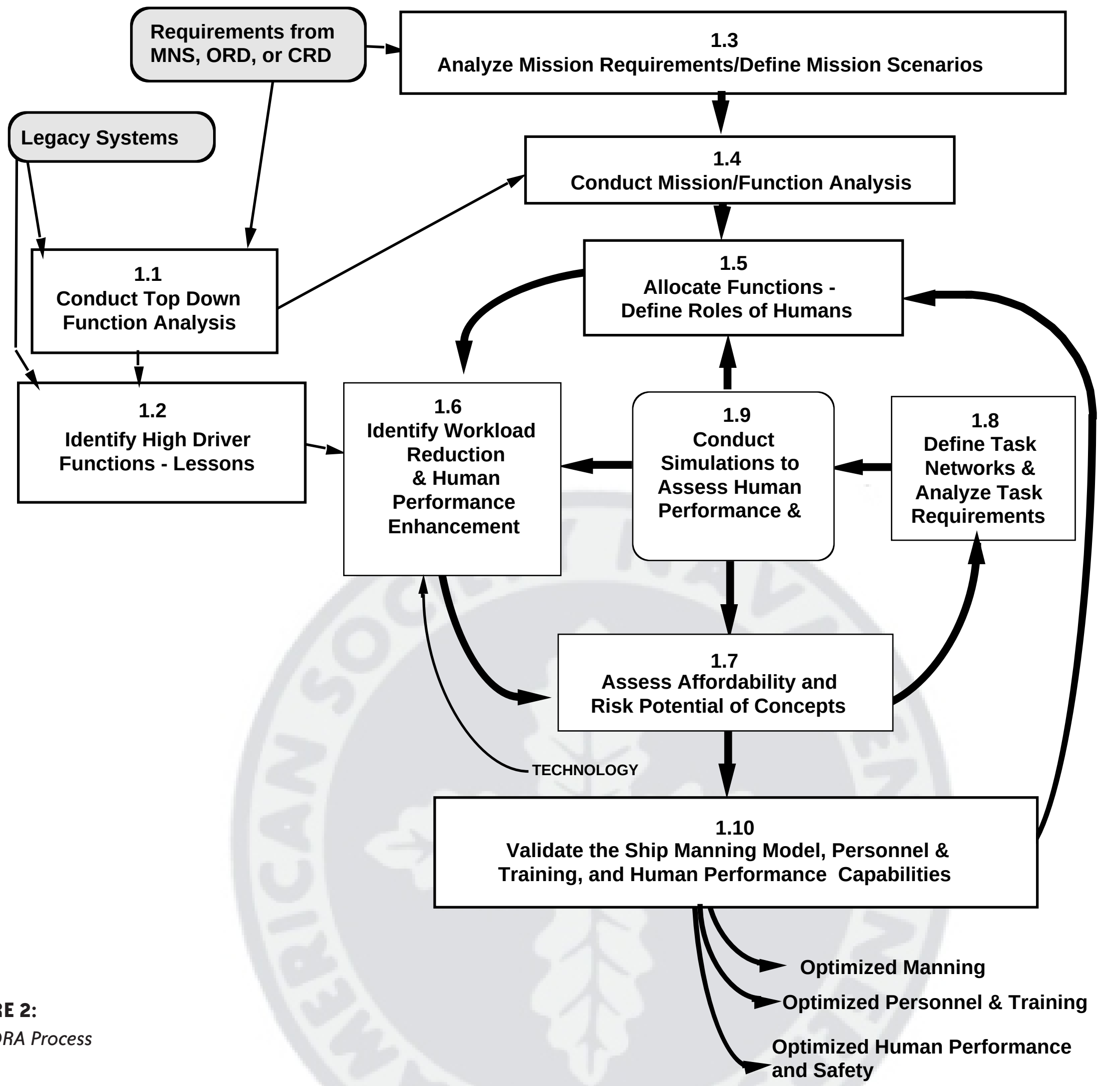



**FIGURE 2:**
*The TDRA Process*

safety requirements, as well as system effectiveness, reliability, and readiness.

Mission scenarios and simulations will be used to model human performance requirements, assess human requirements, and evaluate human performance and workload.

Mission analysis identifies time and performance constraints imposed by the threat and highlights prior decisions concerning system design and the required role of the human in system operation and maintenance.

Mission scenarios comprise a model of the mission in terms of objectives, measures of success, conditions (initial and terminal conditions), events, timelines, and top level functions.

**PROCESS STEP 4: Conduct Mission/Function Analysis**

The mission/function analysis proceeds to a decomposition of functions to successively greater levels of detail based on requirements associated with for each function in the context of mission scenarios.

Requirements include:

1. *information and knowledge requirements* — what the system must know in order to complete the function, and characteristics

of this information, such as source, accuracy, timeliness requirements, etc.;

2. *performance requirements* — performance criteria associated with the performance of functions and subfunctions;

3. *decision requirements* — decisions to be made in the completion of a function, options, and decision rules; and

4. *support requirements* — support needed by the system to enable successful completion of each function.

**PROCESS STEP 5: Allocate Functions and Define the Roles of the Human**

The objective of modeling the role of the human is to identify areas where human performance is mandatory and/or where automation is proscribed, and to define the roles of the human in each system function. The role of the human modeling is used to identify alternative strategies for allocation of system functions and subfunctions to human, machine or a combination of both. The role of the human modeling is also used to select feasible function allocation strategies.

The approach to determining the role of the human addresses the issue of establishing the optimum role of the human in a three step process:

1. identifying candidate roles of the human;

2. identifying specific requirements attendant to these roles; and

3. modeling human performance as expected in the selected set of assigned roles.

During this step, alternative feasible roles of the human in system operation and maintenance based on allocations of functions to human, machine, or a combination of the two are identified and evaluated. The human element includes manpower, capabilities, skills available or achievable, forecasted training capabilities, and training burden. An allocation strategy is then recommended.

**PROCESS STEP 6: Identify Workload Reduction and Human Performance Enhancement Concepts**

This step develops alternative concepts for manning, design of human-machine interfaces to enhance human performance capability and safety, personnel management, and training concept definition in a reduced manning environment.

The issues to be addressed are how to develop concepts for manning optimization, and how to ensure human performance effectiveness and safety in a reduced manning environment. The first issue entails applying technology to reduce human workload. The latter issue involves application of human engineering methods and data to ensure human performance and safety. The potential to reduce workloads and manning while improving human performance and safety will be identified in this step. HSI will be improved through function:

1. automation;
2. simplification;
3. elimination; and
4. consolidation.

The potential for *function simplification* to reduce workload entails defining tasks for which increased automation is feasible, identifying the role of the human for these tasks, and determining how automation will modify task sequences and/or reduce the likelihood of human error.

The potential for *function automation* to reduce workload/manning focuses on reducing physical, cognitive, and perceptual-motor function/task demands to reduce: amount of information to be processed, complexity of the information processing, number of decisions and options to be handled, complexity of actions, needs for interactions with other operators, extent and complexity of communications, function/task performance accuracy required, special skills and knowledge required, levels of skills, the level of stress associated with the performance of function/task under representative mission conditions, and time constraints.

The potential for *function elimination* to reduce workload is based on a determination of the potential with which system functions performed onboard can be offloaded to shore-based elements, to other ships or platforms, or to other ship systems.

Finally, the potential for *function consolidation* and cross training to reduce workload entails determination of functions and tasks for which consolidation and cross training is feasible; identification of the role of the human for functions and tasks for which consolidation/cross training has been implemented, and determination of how consolidation/cross training will modify function and task sequences and/or reduce the likelihood of human error.

This step will also address the integration of the elements of HSI into the system acquisition process. Essentially this will involve developing concepts for insertion of technology, integration of humans and automation, and development of approaches for human-machine interfaces that will support and enhance the development of human capabilities, through training, and human utilization, through personnel management.

### PROCESS STEP 7: Assess Affordability and Risk Potential of Concepts

The objective of this effort is to assess the impact of manpower reductions on system affordability, risk, reliability, performance effectiveness, and safety. Manning concepts must be based on assumptions about the workload reducing potential of automating technologies, function simplification, elimination, and consolidation. Evaluation requires the generation of measures of effectiveness (MOE) that can be applied to concepts to assess potential impacts on affordability, risk, reliability, performance, and safety.

HSI MOEs are derived from system requirements, and existing standards, specifications and data such as ASTM-1166. Where top level requirements arise from the mission need statement, ORD, or other documents, which specify performance in terms of operability, maintainability, survivability, etc., then corresponding HSI MOEs will be defined in terms of the time and accuracy of performance of critical personnel tasks. Human response time and error rates will generally drive or affect total system performance. Design MOEs, as opposed to performance MOPs, generally assess the degree to which the human machine interface (HMI) design conforms to applicable design criteria arising from standards in the areas of human factors, training, maintainability, safety, habitability, and survivability.

Data from which MOEs and MOPs are quantified are obtained during evaluation, although HSI efforts early in the acquisition process must frequently rely on simulation or on analysis of legacy systems. The equipment used for valid optimized manning evaluation can include static mockups, functional mockups, and rapid prototyping software products. Functional system prototypes can be used to support evaluation. Data used to quantify performance MOEs that assess personnel performance speed and accuracy may be obtained throughout the detailed design and construction process and continue into the deployment phase.

### PROCESS STEP 8: Define Task Networks and Analyze Task Requirements

This step will develop task requirements for manning and design of human-machine interfaces to support human performance capability and safety in a reduced manning environment.

Task analysis is conducted to further the understanding of human task performance requirements and to establish task sequences and dependencies that result in task networks to be used in network simulations of human workload and performance. Task analysis data also further the development of design concepts by serving as the basis for human-machine interface design approaches.

Task analysis data are derived from functional analysis, from systems requirement data in the MNS or ORD, and from the technology features of a specific design concept.

**PROCESS STEP 9: Conduct Simulations to Assess Human Performance and Workloads**

HSI simulations identify the plausible outcomes of specific design assumptions and performance parameters (e.g., workload, high driver tasks). The simulation is critical in early stages of system development since it enables the analyst to assess alternate design approaches without committing resources or losing design decisions.

The interactive nature of task network simulation affords the HSI analyst the flexibility to tailor the configuration of task sequences and operator assignments to realistically model system operations. This simulation provides the analyst with a transcript of task completion status and operator availability for additional tasks as well as a summary of workload distributions by operator and task. These data can be used by system designers to evaluate, predict and identify:

- system manning level requirements;
- training and cross-training requirements;
- critical task sequences;
- critical nodes;
- reiterative task sequences;
- minimum, median and maximum task completion times;
- redundant and/or unnecessary task sequences;
- critical personnel;
- overextended resources/personnel;
- underutilized personnel and personnel resources.

HSI simulation addresses the verification of design approaches and function allocations. Simulations involve modeling of functional and task sequences for individual operators/maintainers and for crews. The simulation receives input from the role of the human and the task analysis.

**PROCESS STEP 10: Validate the Manning Model, Personnel and Training, and Human Performance Capabilities**

The manning model development process starts with an analysis of the mission and required operational capabilities and projected operational environment along with the design and systems configuration. This establishes the basis for both the system operating stations that must be manned under various conditions, as well as the support manning needed. Regulations, policy constraints and applicable staffing standards are also applied. The manning analysis attempts to project the most manpower intensive scenario. For surface combatants this is at-sea, forward deployed in the littoral environment, with designated joint/allied/combined forces.

Independent workload analyses are conducted to determine the total workload, expressed in average man-hours per week, in the areas of operational, maintenance and own unit support manning. The data developed for the workload elements then become the source of workload for performing workload calculations to determine the number of individual billets required. The specific workload elements used are operational manning (OM), planned maintenance (PM), corrective maintenance (CM), facilities maintenance (FM), and own unit support (OUS). Figure 2 graphically depicts the process.

To determine manpower requirements, the workload requirements which had been allocated to human performance are assigned to the various personnel ratings in accordance with the rating and skill level requirements specified in the planned maintenance (PMS) cards and/or in accordance with the Navy rating qualifications manual. To calculate the number of billets required in each rating, the workload is mathematically divided by the number of hours representing the productive workweek available.

Billet requirements are minimized by selection of the minimum skill levels needed for the work and watch requirements and by cross-utilization. Work not requiring a specific skill is reallocated from billets with excess work to billets that are not fully used in accordance with CNO rules. Rounding of partial billets produced by the calculations is performed in accordance with staffing standards to produce whole billets.

After the minimum billet requirements are calculated, based on the allocated workload, the number is then compared to the requirements of other conditions and scenarios to determine the total billets needed to satisfy all manning requirements. The total number of personnel required for any one condition of readiness or evolution must be provided.

Future manning models need to provide an integrated system for development of a manpower requirements that can assimilate and retain data and provide appropriate support for a design from the beginning of concept formulation through to completion of system construction and delivery to the Fleet. The system should interface with the front-end mission and function allocation model described earlier and be able to "grow" with progress of the design, adding detail with increasing levels of accuracy as design and configuration decisions are made. It should be able to aid the decision process with quick-response manning impact and cost assessments of alternative concepts and configurations. The system should produce a continuum of data accumulation and automated reports for feedback to the Fleet and to other users of the MP&T process throughout development of the manning document, resulting in an end-product of sufficient quality to provide the information needed to make accurate, universally accepted training requirements and personnel assignment plans. Finally, the future manning model should document, in sufficient detail and in an easily interpreted form, the workload allocated to and within the system organization as well as the work required to be performed off the ship by support activities.

## Applications of TDRA

The TDRA methodology has been applied to a number of naval systems. The DD 21 program has highlighted TDRA in order to achieve the magnitude of manpower reduction required.  The requirements for HSI in systems acquisition, and the TDRA approach to integrating HSI into system acquisition have been described in a number of recent publications, such as: Bost et al. 1999a; Bost et al. 1999b; Bush et al. 1999; Bost et al. 1998; Anderson et al. 1998; Malone et al. 1998; Malone et al., 1997a; Malone et al. 1997b; Malone et al. 1997c; Anderson et al. 1997; Malone et al. 1996b; Malone et al., 1996c; Bost et al. 1996.

The TDRA was employed in the application of HSI to reduce manning and enhance human performance on the *Fast Sealift*. As a result of the TDRA, *Sealift* function analysis and allocation resulted in reduction of required manning levels from 47 to 12.

Another representative application of the TDRA process to system development was the aviation system of the DD 21. As described by Carson and Malone (2000), a TDRA was conducted for both helo operations and UAV operations in support of DD 21 missions. The top level functions which comprised the basis for that analysis are depicted in **Figure 3**. The effort resulted in an identification of information and knowledge requirements, decision requirements, and performance requirements for each function, and decomposition of the functions on the basis of these requirements. While the complete TDRA was not completed for DD 21 air operations, the requirements for such conducting the complete analysis were specified and these included the following:

**Top Level Function Analysis – DD 21 Air Operations**

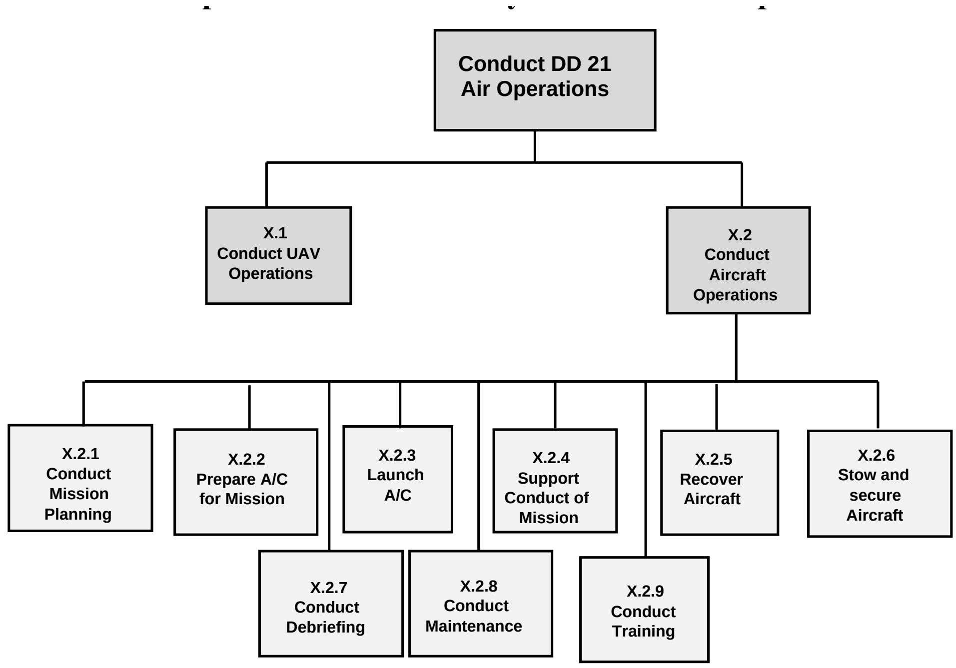
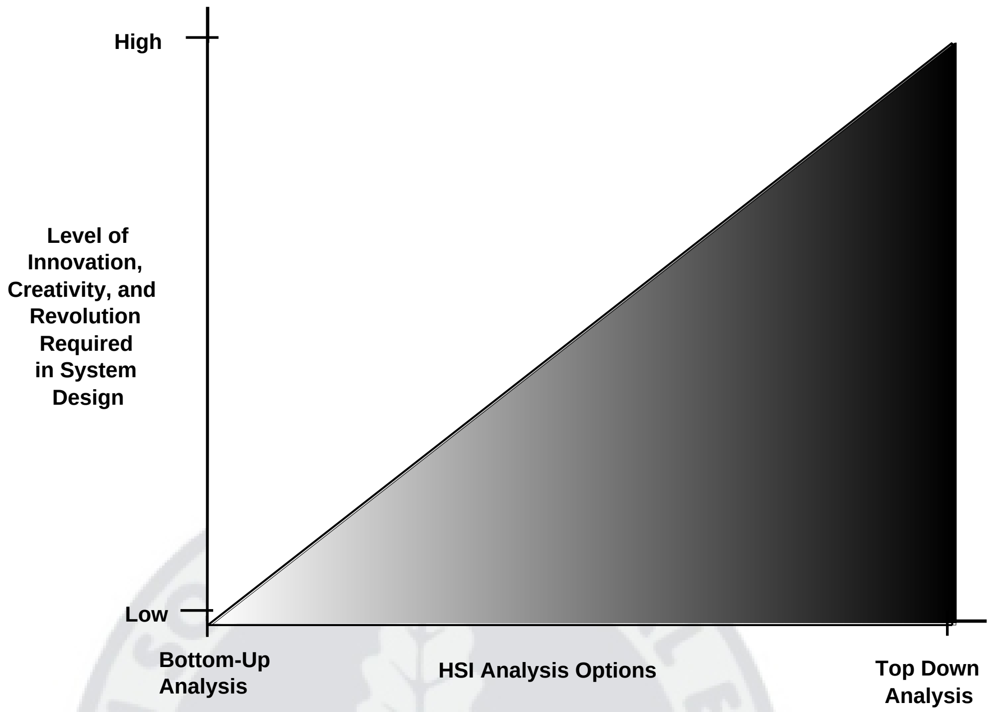



**FIGURE 3:** *TDRA for Air Operations*

### *Identify Helo Det HSI Issues and Evaluation Criteria*

1. Conduct DD 21 Helo mission analysis
   - Identify DD 21 Helo missions, mission objectives, and measures of mission success
   - Identify mission characteristics — frequency and duration
   - Identify top level functions for each mission
   - Identify conditions under which functions are to be performed
   - Identify requirements associated with each top level function
   - Generate mission scenarios
2. Conduct DD 21 Helo function analysis
   - Identify functions
   - Analyze and decompose functions
   - Analyze system requirements
3. Develop a task network and task analysis for each mission
   - Identify operators involved
   - Develop a network of tasks
   - Conduct a task analysis to identify and assess task performance requirements
4. Conduct task network simulations for scenarios to assess workloads
5. Identify alternate design approaches to reduce workloads:
   - Identify workload reduction potential through function automation, function consolidation, function elimination, and function simplification
   - Assess technologies to describe alternate design concepts
6. Identify function allocation strategies
   - Automate functions
   - Consolidate Helo Det functions with ship's crew functions
   - Cross train aviation personnel
   - Telemaintenance to offload maintenance skills off the ship
7. Identify task networks associated with alternate function allocation strategies and workload reduction concepts
8. Conduct task network simulation to assess workloads for reduced workload concepts

**FIGURE 4:**
*The relationships between Bottom-up and Top Down Analyses and the Innovation, Creativity and Revolution Required for System Design*




## Top Down or Bottom Up

It should be noted that some analysts have proposed using a bottom-up analysis in lieu of top down. Bottom-up analysis is a reengineering process concerned with modifying and improving existing, legacy systems. Bottom-up analysis is constraint-driven in that the results of the analysis are constrained by the design of the existing system. Therefore, bottom-up analysis in and of itself will not result in optimal manning reduction or optimal human performance, since it is too dependent on the existing system, and will not provide the bases for the innovative and creative engineering insight needed to significantly and effectively reduce manning levels. Bottom-up analysis is evolutionary while top down analysis is revolutionary. The relationships of bottom-up and top down analyses to the needs for innovative and creative design are depicted in **Figure 4.**

The strengths of bottom-up analysis are it's relative low cost and low risk. The weakness of bottom-up analysis is that it is based totally on the existing system and does not support the derivation of the complete set of design requirements and concepts beyond the existing system. The strength of top down analysis is the ability to begin with a clean sheet of paper, to identify, analyze and integrate requirements without being constrained by existing system design implementations. The weaknesses of top down analysis are the time and costs associated with conducting the analysis, and the higher risks associated with failing to address all requirements.

Bottom-up analysis does however support TDRA in identifying functions in existing systems and identifying high driver functions. TDRA results in mission requirements and scenarios, functions, and requirements. Rather than addressing all possible missions, scenarios and functions, TDRA should be based on *high driver* missions, scenarios, and functions. These have resulted in high cost, risk, manning, and training in existing systems. Addressing high drivers in TDRA results in:

1. Avoiding deficiencies in existing systems;
2. Supporting the reengineering of the existing function allocations; and
3. Reducing the time and cost of the TDRA by focusing on the important missions, scenarios, and functions from the perspectives of system affordability, risk reduction, human performance, and safety.

## Conclusions

The primary conclusion in this paper is that the only effective technique for designing systems in terms of the requirements and considerations for the human in the system is the application of top down requirements analysis.

The payoffs expected from the application of TDRA in the early stages of military system design and development are:

- Workloads that are acceptable;
- Manning that is optimal;
- Personnel utilization that is efficient;
- Error and accident rates that are minimal;
- Human performance that is effective;
- Teams that are capable;
- Crew members that are productive;
- Environments that are safe;
- Facilities that are habitable;
- Information and knowledge that is readily understood;
- Communications that are meaningful;
- Human computer interfaces that are usable;
- Displays that are readable;
- Workstations that are integrated;
- Components to be maintained that are accessible;
- Training that is responsive to requirements and effective;
- Procedures that are consistent;
- Jobs that are enriching;
- Duty cycles that are satisfying;
- Systems that are affordable. ⚓

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