Using Top Down Requirements Analysis To Maximize Small Unit Performance in DHS

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ABSTRACT

Small unit performance is an area of human systems integration that is often neglected, but includes requirements and constraints that are different from the concerns for individual human performance. The unique considerations associated with small unit performance extend to such topics as team building, maintaining team cohesion, team performance (e.g., collaboration, communication, coordination of tasks, situation awareness, and decision-making) and metrics, team training (e.g., applications of immersive training environments), team resilience and grit in extreme environments. The Department of Homeland Security (DHS) is collaborating with the US Joint Forces Command (USJFCOM) National Program for Small Unit Excellence to develop requirements, concepts, methods and metrics for enhancing the performance of incident First Responders, including police, firefighters, emergency medical technicians, and personnel involved in detecting and responding to the hazardous release of chemical, biological, and radioactive materials. Many products will result from this collaboration including techniques to enhance the communications, coordination and collaboration among First Responders, instruction delivery methods to ensure effective training for team performance, design requirements for protective equipment and clothing, wearable electronics to facilitate incident management, alarms and alerts, and outreach to public health organizations. The analytic method proposed to address these issues and produce these products is the Top Down Requirements Analysis (TDRA) process that is being developed and implemented by the DHS. This process begins with generation of scenarios that pose significant challenges to human performance, workload, health and safety, proceeds through function analysis and allocation of functions to task analysis, to establish the requirements associated with task performance under the conditions specified in the scenarios.

ABOUT THE AUTHORS

Darren P. Wilson currently serves as a Human Systems Research and Engineering Program Manager within the Department of Homeland Security (DHS) Science and Technology Directorate's Human Factors / Behavioral Sciences Division. The focus of the research and engineering efforts Mr. Wilson is currently managing are all aimed at ensuring human systems integration analysis, design and test activities are incorporated into DHS research, acquisitions and technology development. Mr. Wilson was previously employed as a Scientific and Technical Advisor for Human Factors with the Federal Aviation Administration (FAA) at their Headquarters in Washington, D.C. While at the FAA Mr. Wilson coordinated human factors research and engineering efforts within the Surveillance Systems Engineering Office. Before joining the Department of Homeland Security's Human Factors / Behavioral Sciences Division Mr. Wilson also served as a Lead Human Factors and Systems Engineer with Northrop Grumman Corporation working to establish Human Systems Integration policy and procedures as well as on design and development efforts on United States Air Force programs such as the E-10A and E-8C. He received both his B.S. and M.S. in Human Factors and Systems from Embry-Riddle Aeronautical University and is a Board Certified Human Factors Engineering Professional (CHFEP).

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USING TDRA TO MAXIMIZE SMALL UNIT PERFORMANCE

The final report of the Conference on Small Unit Excellence (2009), jointly sponsored by the U.S. JFCOM and the DHS, made the case for the consideration of issues related to and importance of small unit performance. Emphasis was placed on the number of individuals (operating in teams/units) that were killed in action. The report discussed the significant number of service members/infantry (80% or four out of five) that were killed during the American era of war (1950 to the present) and cited that in Iraq and Afghanistan 89 percent of all killed in action operated in small units. Add to these statistics the fatality numbers for America's first responders (i.e., over 2,340 law enforcement and firefighters have lost their lives in the line of duty since 9/11). These numbers make a compelling case for organizing an approach to small unit excellence. For the purpose of this paper, a small unit will be defined as the squad or team of soldiers or first responders operating in a collaborative, cooperative and interdependent manner to achieve a common goal, where the concern is for performance of the team itself rather than of individual members of the team.

The unique considerations associated with small unit performance extend to such topics as team building, maintaining team cohesion, team performance (e.g., collaboration, communication, coordination of tasks, situation awareness, and decision-making) and metrics, team training (e.g., applications of immersive training environments), team resilience and grit in extreme environments. The Department of Homeland Security (DHS) Human Factors/Behavioral Sciences Division's Human Systems Research and Engineering (HSR&E) Program has been developing HSI methods, techniques and data to enhance team performance (Wilson et al, 2009). HSR&E has been invited to participate in the USJFCOM National Program for Small Unit Excellence to develop requirements, concepts, methods and metrics for enhancing the performance of teams such as incident First Responders, including police, firefighters, emergency medical technicians, and personnel involved in detecting and responding to the hazardous release of chemical, biological, and radioactive materials. The analytic method proposed to address these issues and produce these products is the Top Down Requirements Analysis (TDRA) process that is being developed and implemented by the DHS. This process begins with generation of scenarios that pose significant challenges to human performance, workload, health and safety, proceeds through function analysis and allocation of functions to task analysis, to establish the requirements associated with task performance under the conditions specified in the scenarios (Malone and Carson, 2003). The DHS TDRA process tailored for deriving team performance requirements and concepts is depicted in this paper. The individual steps of the process are described in the following sections.

TDRA Step 1: Analyze Mission Requirements/Define Mission Scenarios

Mission scenarios are models of event sequences and conditions that are used to assess team performance in the context of the scenario. Mission scenarios define the activities and events associated with a mission, on a timeline, which are encountered between the initial conditions and the terminal conditions of the scenario period. The mission scenario also includes the top-level functions for achieving the mission as well as the measures of mission success. The top level functions are the mission-essential functions associated with the relevant mission area.

Mission scenarios are the drivers of HSI modeling and simulations that are used to define and assess team performance in the system.

For the purpose of assessing alternate system concepts, a mission scenario must be challenging so that team performance, individual and collective workload, situation awareness (SA), survivability, and safety may be assessed. To be challenging from an HSI perspective, the scenario should:

- Reflect a slice of the overall design reference mission and ensure a sufficient duration to include assessment of sustained performance.
- Include requirements at a level wherein all operational areas are simultaneously engaged on a continuing basis and each team member engaged.
- Include operations and conditions that challenge team as well as individual performance, workload, and safety in that they are complex, difficult to complete, labor intensive, or hazardous.
- Include operations that have a high degree of uncertainty as to outcome, decision making, and situation awareness.
- Include operations that require a high degree of precision in providing control.
- Enable threat characteristics (i.e., inclement weather, type of threat, threat hostility level, threat capabilities, etc.) be varied to support the determination of the impact of target loading on team performance and workload.
- Include operations known to be workload intensive in legacy systems (where they exist), as well as difficult to execute as a result of suboptimal interface design.
- Include requirements for operations that are time constrained and require coordinated interaction among team members, and that require sustained performance.
- Include evaluation of team performance in high workload situations (search and seizure, natural disaster, domestic IED event/bomb threat, nuclear/chemical/biological event arrests underway replenishment, help operations, and damage control).
- Include mission conditions that have high fidelity to those expected in the real world and which are demanding of team performance, workload and safety including natural environmental conditions and system level of readiness.

As described in Malone et al (2007), it is important that actual scenarios be used to drive the analysis and allocation of functions because they impose real world challenging requirements, include dependencies among functions and function sequences, and are based on a timeline that forces the pacing of functions and tasks. Relying on a generic mission that incorporates features from several different missions but omits the timeline will not result in realistic team performance drivers of function allocation strategies.

TDRA Step 2: Identify HSI High-Driver Functions

After completing the function analysis, HSI high-driver functions and sub functions will be identified. HSI high drivers include functions in legacy systems that are known to impose high demands on manpower (are labor intensive) and/or skills, or functions in new systems that are expected to impose high risks, workloads, and performance complexities. For each scenario, identification is made of high driver functions, tasks, and scenario conditions. High drivers are defined as functions which, in legacy systems:

- are prone to frequent occurrence of error
- are associated with situations where results of errors are critical for human safety and mission success
- produce error modes where it is difficult to detect the occurrence of the error
- produce error modes where it is difficult to correct the occurrence of the error
- are workload intensive
- are associated with hazardous conditions
- are difficult to complete successfully

There is a relationship between selecting mission conditions in a mission scenario (described in the next Process Step) and selecting HSI high-drivers as functions in legacy systems. Both should be challenging for human performance, workload and safety. More importantly, the selection of challenging mission conditions, events and functions should be based in part on the results of the HSI High-Driver analysis.

TDRA Step 3: Identify End-User Needs in a Team Context

In order to address end-user needs, human performance gaps must be considered. These gaps should address deficiencies in any one or more of the constituents of team. Within the DHS, capability gaps are addressed across the Doctrine, Organization, Training, Materiel, Leadership, Personnel, and Facilities, plus Regulations/ Grants/Standards (DOTMLPF+R/G/S) factor structure. From an HSI perspective, the assessment of gaps for these factors includes the following considerations:

- Doctrine – to what extent do team performance deficiencies result from in-place policies that impact required levels of manpower or otherwise constrain human capabilities?
- Organization – to what extent do team performance deficiencies result from organizational structure elements?
- Training – can team performance deficiencies be attributed to shortcomings in training?
- Materiel - do team performance deficiencies result from poorly designed user interfaces?
- Leadership - can team performance deficiencies be the result of inadequate leadership practices and guidelines?
- Personnel - do team performance deficiencies result from inadequate knowledge and skills on the part of systems personnel?
- Facilities - can team performance deficiencies be attributed to inadequacies in facility (workspace) arrangements or infrastructure design?
- Regulations/ grants/standards – to what extent do team performance deficiencies result from inadequate regulations, research or standards?

Gaps in capabilities will also be identified for end-user teams most appropriate for the mission. DHS end-user teams/units include:

- EMTs/EMS/Mobile Trauma Units
- Police and fire fighting first responders
- HAZMAT Teams
- Command and Control room operators
- Airport passenger and cargo screener teams
- Bomb Squads
- Secret Service details
- Border Patrol Agent teams
- USCG Port Security personnel
- USCG boarding parties
- Fire Investigation teams
- Local health official teams
- Explosive Ordinance Disposal (EOD) teams

TDRA Step 4: Conduct Mission/Function Analysis (MFA)

The mission/function analysis proceeds to a decomposition of top level functions to greater levels of detail based on requirements associated with each function in the context of mission scenarios. The functions are selected from appropriate functions as applicable to the specific scenario. Requirements used in the definition of the functions and decomposition of the functions to second, third, or even lower sub functions include: (1) information and knowledge requirements - what the team must know in order to complete the function, and characteristics of this information, such as source, accuracy, timeliness requirements, etc.; (2) performance requirements - performance capabilities which the team must possess in order to perform the function; (3) decision requirements - decisions to be made in the completion of a function, and decision options, and decision rules; and (4) support requirements - support needed by the team to enable successful completion of each function. In addition, in the Mission/Function Analysis (MFA) the time in the mission of function initiation and termination will be identified, and the frequency of occurrence of each function in the scenario will be identified.

The result of the MFA is a set of functions for each specified scenario, on a timeline, with associated information, performance, decision and support requirements for each function. The functions are decomposed on the basis of the requirements to a level of specificity where the next decomposition level would require identification of how the function is conducted. At this point the decomposition is terminated for that function.

TDRA Step 5: Allocate Functions and Define the Roles of the Human

Function allocation is the assignment of responsibilities for the conduct of system functions to human performance or to automation. Function allocation has been an important method used by HSI specialists in defining human performance requirements. Allocation of functions encompasses both a process and a product. As a process, function allocation refers to the sequence of steps involved in establishing the alternate roles, responsibilities, and requirements for humans in their team roles and machines in a complex human-machine system. As a product, function allocation refers to the end state of the application of the process, the optimal distribution of roles, responsibilities and tasks between humans within the teams and machines. In attempting to determine how humans as individual team members and the team itself should fit into complex systems, HFE practitioners assigned system functions to human or machine by differentiating the activities for which human performance is preferred against those for which the machine is preferred (Sheridan, 2002).

This methodology applies to the situation where the objective is to establish the optimal assignment of function performance responsibility to humans or machines.

In highly automated systems where both human and machine are equally competent to perform individual functions, the design issue is to determine the role of the human vs. automation in the performance of each function. The emphasis on the role of human in the system acknowledges the fact that the human has some role in every system function. In some cases that role may encompass actual performance of the function, while in others it may involve monitoring machine performance (Malone and Heasly, 2003) remembering to consider the optimum level of individual and shared workload and situational awareness.

Function allocation proceeds in three major steps. (1) Identifying areas where human performance is mandatory and/or where automation is proscribed. Alternative strategies are then identified for allocation of system functions and sub functions to human, machine or a combination of both. The requirement is to decide that a function (or sub function) should be completely performed by the human, being a team member, a combination of team members or the team as a whole (manual function), completely performed by machine (automated function), or performed by some combination of human and automated performance (semi-automated); (2) identifying the roles of the human in automated or semi-automated functions; (3) identifying requirements associated with human roles and responsibilities in all functions, including manual, semi-automated, and automated, and identify requirements for human-automation interaction. It is important to keep in mind that automating a function does not logically mean that the human does not have a role, that he or she has effectively been designed out of the system for that specific function. Rather, in an automated function or task, the role of the human is that of a manager, monitor, decision maker, system integrator, or backup performer.

The function allocation process begins with a review of functions and associated requirements which will be considered in the allocation of these functions. In addition, special consideration will be given to functions typified as high driver functions.
The steps in the function allocation decision process are as follows:

- Determine if the function can be fully automated. If it can, the roles of the human and automation are determined. If the decision is that the function in question cannot be performed totally by automation, continue the decision process:
- Determine if the function can be automated with human supervision. If yes, the roles of the human and automation are determined. If no, continue the decision process.
- Determine if the function can be performed by human/automation interaction. If yes, the roles of the human and automation are determined. In this allocation each element (human and machine) has some responsibility for some facet of function performance, and the allocation of these functions may vary in the operational setting due to workload, safety, or uncertainty considerations (dynamic function allocation). If this allocation is not viable, continue the decision process:
- Determine if the function can be performed by humans with machine aiding. If so, the roles of humans and automation are defined. If this allocation is not viable, the function will be performed manually.

In this step the allocation of functions is conducted not so much to achieve a design concept from an HSI perspective (which will occur in the later stages), but rather to provide guidelines for assessing the roles allocated to humans in individual alternative design approaches.

TDRA Step 6: Identify Concepts for Team Function Assignment and Performance Enhancement

In this step the roles assigned to humans in the allocation of functions are further assigned to individual team members along alternate assignment strategies. Associated with each function assignment strategy, an effort will be conducted to develop user technology applications and interface concepts that will reduce the impact of high drivers, address the needs of end user teams, and enhance team performance. Specific initiatives to be considered in enhancing the performance of small teams include, but are not limited to, the following:

- Techniques to enhance collaborative, shared situation awareness with individuals providing information to fill-in a fragmentary operating picture.

- Techniques to enhance synchronized task performance, based on development of tactics and procedures that emphasized cooperative action, and on training of teams as a unit.
- Techniques to enhance cooperative hypothesis testing and diagnosis of the situation based on shared feedback and varied individual experiences.
- Techniques to enhance experiences possessed by an individual, and a team, augmented beyond actual experiences to include those learned through simulation, resulting in development of intuition based on compressed experience, shaped and developed through simulation.
- Development of metrics for team performance (in most cases mission-dependent) and metrics for team cohesion.
- Techniques to enhance resilience and resourcefulness, defined as coherent adaptation to changing circumstances involving stress or the ability to continue to perform under stress.
- Techniques to improve team training with emphasis on resilience training, and training for in extremis situations, training individuals to conduct assigned roles within the unit, cross-training, and interaction with other team members.
- Techniques to foster success in team leadership and enhance morale.
- Techniques to enhance clear and concise communications, including use of chat and text messaging.
- Techniques to enhance unit identity, developed through the interactions of the roles of unit members.

HSI technologies will also be applied to result in enhanced team performance capability, productivity, and safety. The attention to technology in the TDRA process is at the point of assessing feasible design approaches to reduce workload and number of personnel, while enabling the selected roles of the human. In identifying technology approaches to meet team performance requirements, the effort will addresses technologies to support (a) automation of system functions (mainly through software technologies, automated troubleshooting, robotics); (b) simplification of system functions (through decision aiding, advanced workstation concepts, intelligent tutoring, on-line help, operator's associate); (c) consolidation of system functions (cross training, data fusion, Intelligent Associate/expert system for decision aiding and procedural cueing); and (d) function elimination (tele-maintenance, tele-operations, collaboration tools to support dispersed team problem solving). The technology applications provide the means of achieving reduced workload, and reduced manpower. This is a coherent, integrated, systems engineering approach grounded in HSI principles.

The assessment of alternate concepts to enhance team performance will also address strategies to mitigate excessive workload identified in HSI high drivers. This step will also address the integration of the elements of HSI into the system acquisition process. Essentially this will involve assessing concepts for inserting technology, integrating humans and automation, and developing approaches for human-machine interfaces which will support and enhance the development of human capabilities, through training, and human utilization, through personnel management.

TDRA Step 7: Assess Affordability and Risk Potential of Team Concepts

The objective of this effort is to assess the impact of alternative concept design approaches on system affordability and risk. A major effort will be directed at assessing affordability and risk from an HSI perspective, especially as it applies to the alternate team performance optimization concepts. The objective of the HSI assessment is to determine the status and adequacy of HSI efforts in the R&D/materiel acquisition program and to present any unresolved HSI issues or concerns to decision makers at the appropriate decision points.

The analysis is focused on affordability and risk since these two characteristics embody the range of concerns to be addressed in selecting a preferred concept. To the extent that a concept is affordable, it is a feasible alternative for selection from a budgetary perspective. To the extent that a concept exhibits no serious risks, it is a feasible alternative from a performance perspective.

The assessment of affordability of alternate manpower optimization concepts will address the following questions:

- Does the concept result in reduced R&D/acquisition costs through integration of HSI domains?
- Does the concept result in reduced R&D/acquisition costs through reduced need to redesign systems and equipment to resolve unmet user needs?
- Does the concept result in reduced life cycle costs through reduced manning, reduced

training time and training pipelines, reduced accident rates, reduced human error rates, reduced time to repair, reduced supportability requirements, reduced system downtime, and reduced personnel non-availability?

The alternate concepts will also be evaluated to assess the risks associated with each concept. Questions for consideration in the assessment of concept risk include:

- Does the HSI risk analysis identify alternatives to the high risk technologies?
- Does the HSI risk analysis identify risks due to operational staffing levels, maintenance staffing levels, training costs, extended down time/system non-availability, excessive time to repair, excessive supportability requirements, excessive accident rates, non-availability of data or tools, or non-availability of technology?
- Does the HSI risk analysis integrate/assess cost risks and schedule risks?
- Does the HSI risk analysis identify if concepts provide safety-related equipment, safeguards, and possible alternate approaches such as interlocks, system redundancy, subsystem protection, fire suppression systems, personal protective equipment, industrial ventilation, and noise or radiation barriers?
- Does the HSI risk analysis identify risks due to expected accident rates?

TDRA Step 8: Analyze Team Tasks and Task Performance Requirements

This step is concerned with developing task requirements for the roles of humans in functions to support team performance. Task analysis is conducted to further the understanding of team task performance requirements and to establish task sequences and dependencies which result in task networks to be used in later task network simulations of human workload and performance.

The analysis identifies tasks for functions, based on the function allocation. The task analysis focuses on requirements associated with task conduct, including information requirements (information and knowledge needed to complete the task), performance requirements (special demands made on the performer), decision requirements (cognitive demands made on the performer), and communications requirements. The analysis also identifies the error potential associated with performance of the task, and identifies any risks associated with performing each task.

Team task analysis data are used in the later development of design concepts by serving as the basis for user interface design approaches, and for training solution development. Team task analysis data are derived from functional analysis, from systems requirement data in the requirements documents, and from the technology features of a specific design concept.
The outputs of task analysis serve a number of HSI objectives, including:

- A set of team tasks assigned to individual team members, decomposed from higher level functions, in the context of selected missions, associated performance requirements, based on roles and verbs derived from the function allocation approach;
- Identification of human performance metrics to be used in assessment of alternate design concepts, collection of lessons learned, and conduct of test and evaluation;
- Identification of risks associated with specific team tasks;
- Identification of the knowledge, skill and ability (KSA) requirements associated with team task performance;
- Estimates of workloads associated with the performance of team tasks and sequences of tasks in the context of the missions.

TDRA Step 9: Conduct Team Performance Enhancement through Modeling and Simulations

HSI modeling and simulation addresses the verification of function allocations and the development of design approaches. Simulations involve modeling of functional and task sequences for individual team members and for the team as a whole. The simulation receives input from the function allocation (roles of humans) and the task analysis.

HSI task network simulations identify the plausible outcomes of specific design assumptions and performance parameters (e.g., workload, high driver tasks). The simulation enables the analyst to assess alternate design approaches and workloads of individual team members conducting a sequence of team tasks 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 team member assignments to realistically model system operations. This simulation provides the analyst with a transcript of task completion status and team member availability for additional tasking 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: 1) manpower requirements; 2) training techniques and cross-training requirements; 3) critical task sequences; 4) critical nodes; 5) reiterative task sequences; 6) task completion times and performance accuracy; 7) redundant and/or unnecessary task sequences; 8) critical team members; 9) overextended resources/personnel; and, 10) underutilized members and member resources.

In addition, consideration will be given to the use of simulation, including Team-in-the-Loop simulation, to assess team performance under different function assignment strategies and user interface design alternatives. These assessments will include web-based, distributed, fully or partially immersive or desktop simulation to be used for (a) training of teams, (b) building of teams (cross training and role development), (c) measuring team performance, and (d) developing team performance tactics and procedures.

TDRA Step 10: Define Requirements and Metrics for Team Performance Enhancement

This step will produce requirements and metrics for measuring team performance based on design decisions made in the prior steps. Requirements will be developed specifically for collaboration techniques, leadership enhancement, user interface design, personnel management and team training, and team health, safety and survivability.

CONCLUSION

It is clear that the TDRA is an approach that lends itself to the design of effective team/unit performance. Implementation of this approach will support the generation of data, requirements, concepts, and metrics that will support the optimization of team performance. As demonstrated, the unique considerations associated with small unit performance (e.g., as team building, maintaining team cohesion, team performance, collaboration and coordination of tasks, and team training, communications and feedback, decision making under stress, in extremis leadership, and resilience and grit, etc.) can be easily addressed throughout the above-mentioned steps. Through a systematic, requirements-driven approach there is an assurance that end-user needs will be developed in accordance with human performance capabilities and limitations, as opposed to a technology-driven process. This process enables the identification of needs, requirements, data, metrics, performance specifications, and the development of workload appropriate design concepts that are critical in the development of human/team-centered systems. HSI is a Systems Engineering approach with an emphasis on the human component of the system. As we design for team (e.g., police, fire fighting first responders, HAZMAT Teams, Border Patrol Agent teams, USCG boarding parties, etc.) performance, safety, usability, and reliability, we must consider those capabilities, limitations, and characteristics unique to the human; unique to the team. This will ensure that we collectively and systematically work towards reducing the number of fatalities among our service men and women, as well as our first responders as they protect us from harms way.

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