

# **INTEGRATING HUMAN ENGINEERING REQUIREMENTS INTO THE EARLY SYSTEMS ENGINEERING PROCESS**

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The authors present the proposed functionality of a Human Centered Design Advisor (currently under development) that will increase the extent to which human factors professionals are involved in the system design. The authors submit that the most effective way to convince systems engineers to include the Human Engineering Process in the Systems Engineering Process is to reference human factors issues contained in IEEE 1220-1998, because systems engineers consider this document a credible source. When systems engineers are developing specific requirements, the HCDA should recommend human factors oriented requirements from the systems engineering community as opposed to coming from the human factors community. Finally, as the design progresses, the HCDA will have sufficient knowledge of the design task at hand and can provide context-specific advice from the human factors community on how to fulfill the human factors requirements.

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## BACKGROUND AND OBJECTIVES

The push in the Navy to design and build new ships that can be effectively manned with dramatically fewer sailors raises key Human Factors (HF) issues that must be addressed in the system design process. Unfortunately, there is no guarantee that systems engineers will suddenly understand when and how to work with human factors engineers. The Naval Air Warfare Center Training Systems Division (NAWCTSD) has an effort currently underway to develop an intelligent software agent, the "Human Centered Design Advisor" (HCDA), which will alert and advise systems engineers regarding human factors issues and analyses appropriate to the current stage of the system design process. This paper will describe our efforts to document the systems engineering process and recommend a dialogue that will dovetail the HCDA smoothly into it.

There are many different types of support and interaction that this HCDA could provide to a systems engineer. The authors of this paper submit that the starting point must be in the early requirements analysis and that the dialogue between the agent and the systems engineer must be in a language that the systems engineer understands, as opposed to HF terminology. It should be noted that there are already reference documents for systems engineers that briefly address HF-related issues. Some of these documents give the systems engineers a list of HF questions to be asked at design reviews. These questions are stated in "systems engineeringese" as opposed to HF terms. To make certain the HF issues are addressed early in the requirements analysis, we are taking the design review questions and recasting them into recommended requirements as the systems engineer conducts the requirements analysis. The HCDA is being integrated with a systems engineering requirements analysis tool to make it easy to derive HF requirements that support higher level systems engineering requirements. Consequently, as design engineers conduct the design process, HF issues will be design requirements as opposed to "nice to have" features that are easily sacrificed when resources grow limited.

## STATEMENT OF THE PROBLEM

The primary goal is to develop a Human Centered Design Advisor that increases the extent to which human factors professionals are involved in the system design. In order to achieve this goal, the HCDA should:

1. Dovetail into the current systems engineering process and not require special effort on the part of the systems engineer.
2. Know what stage and subprocess of the systems design process the systems engineer is currently conducting (in order to provide context sensitive advice appropriate for that stage).
3. Improve awareness of HF issues on the part of systems engineers.
4. Help the systems engineers conduct functional analysis and synthesis trade studies involving human factors requirements
5. Help the systems engineers (at design reviews) to evaluate whether the detail design engineers have fulfilled the human factors requirements.

Each of these issues is discussed separately below.

## DOVETAIL INTO CURRENT SYSTEMS ENGINEERING PROCESSES

Figure 1 contains the typical system life cycle per IEEE 1220-1998 (IEEE Standard for Application and Management of the Systems Engineering Process), which begins with the System Definition Stage and ends in the Customer Support Stage. As the systems engineer proceeds from one stage of the life cycle to the next, the design becomes progressively more detailed (from System to Subsystem to Component Level). In each of these six stages, the systems engineer executes the Systems Engineering Process contained in Figure 2. Most large projects use software tools to assist the systems engineers in documenting the results of the assessments. It is critical that the HCDA support this flow and not require extra work on the part of the systems engineer. The HCDA is being designed to understand the systems engineering process and the software tool (e.g. TSI Interchange) used by the systems engineers to

document analyses and decisions. When a systems engineer agrees with HCDA advice, text or numbers will be transferred to the design tool as opposed to requiring the systems engineer to type it in.

**PROVIDE CONTEXT-SENSITIVE HELP**

The crux of the problem is what level of HF information the Systems Engineer needs for each stage of the design? One alternative is for the systems engineer to ask the HCDA questions and it will respond with recommended human factors principles for that question. This approach assumes that the systems engineer knows which human factors questions to ask. A more productive approach is to ask the systems engineer to indicate which Life Cycle Stage (Figure 1) and Systems Engineering Process subprocess (Figure 2) they are currently conducting. However, with thousands of human factors principles separated into only a few categories, the systems engineer would be inundated with principles and would ignore the advice. Consequently, a second level of detail is required in order to limit the advice to a manageable number of human factors principles that directly support the design effort at hand.

But this brings up another problem. The systems engineering process depicted in Figure 2 is well accepted and most organizations follow it. But at the next level of detail, there are wide variations in approaches across organizations. How do you clearly understand what the design stage is without a common reference process? Fortunately, IEEE has recently updated Standard 1220 (IEEE Standard for Application and Management of the Systems Engineering Process). The process described in this standard is commonly accepted across the engineering community. If the HCDA uses IEEE 1220-1998 terms for design activities and tasks, a systems engineer using a variation of this process will be able to identify the similar process in his/her design effort and use the advice properly.

**INCORPORATING HUMAN FACTORS ISSUES IN SYSTEM REQUIREMENTS**

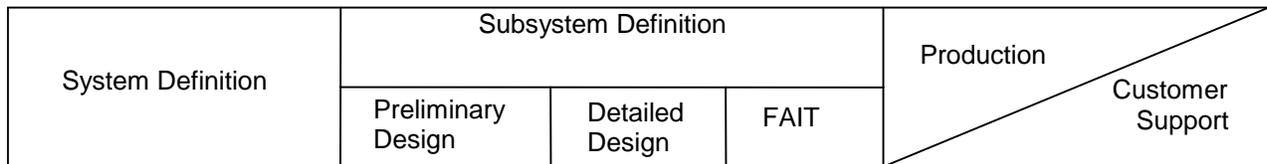
Systems Engineering is a requirements-based process. Once the requirements analysis has been completed by the systems engineer, it is difficult to go back and insert human factors needs that cannot be traced directly to documented requirements. Consequently, the most important step in putting the Human Engineering Process into the Systems Engineering Process is to aid the systems engineer in determining human factors requirements during the systems requirements subprocess. But the systems engineer will not put human factors into the requirements document unless they agree that they are critical requirements.

Table 1 contains the design tasks in the systems engineering requirements analysis process per IEEE 1220-1998. Note that all but five of the tasks specifically call out the need to consider human factors in the analysis.

The authors submit that the most effective way for the HCDA to convince the systems engineer to include human factors considerations in the system requirements baseline is to ask which of the requirements analysis tasks (Table 1) they are conducting and respond that IEEE 1220-1998 states that a given list of human factors issues should be addressed in the requirements analysis. Table 2 contains a sample dialogue between the systems engineer and the HCDA. Note that the HCDA never states that it is telling the systems engineer what to do, it states that a credible source (IEEE 1220) recommends that specific issues be addressed.

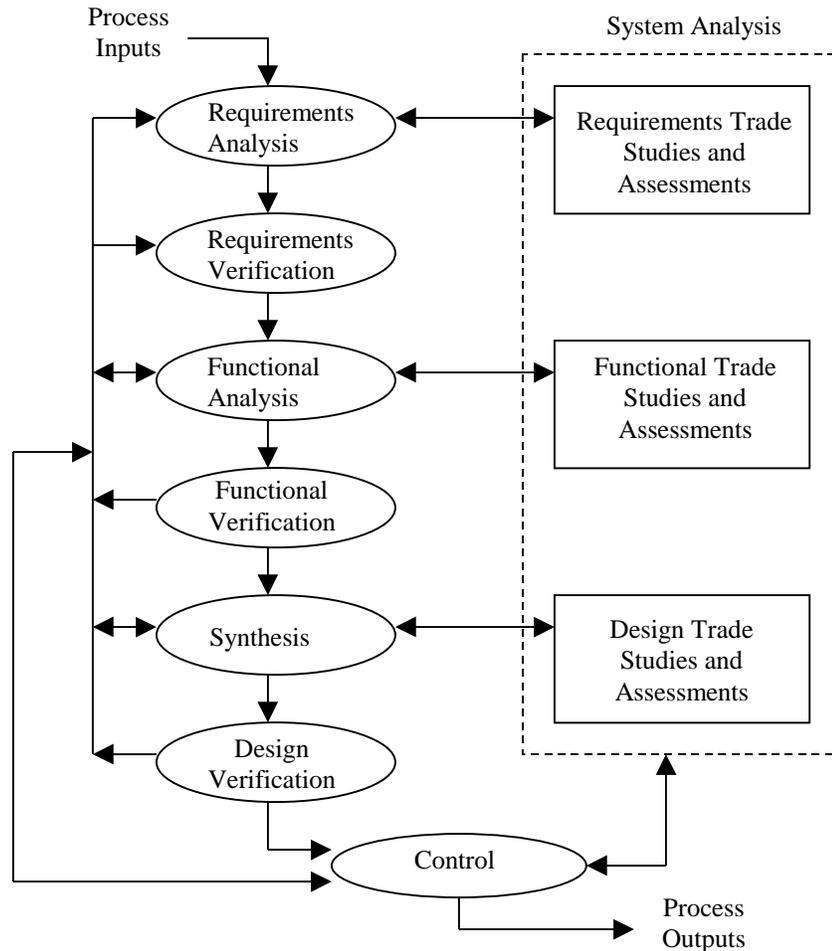
Once the systems engineer agrees that the requirements baseline should include MOEs for Human Performance Requirements, the question arises as to which principles should be recommended for inclusion in the requirements baseline. We could display appropriate human factors design principles, but most of them are used at a level of detail not normally addressed by systems engineers.

Figure 1. Typical System Life Cycle



Note: Per IEEE 1220-1998.

Figure 2. Simplified Systems Engineering Process (Sep)



Note: Adapted from IEEE 1220-1998.

The authors submit that in order to maintain credibility with the systems engineers, the next level of detail in the requirements analysis should be from a systems engineering source as opposed to being from a human factors source. *Systems Engineering and Analysis* by Blanchard and Fabrycky is a systems engineering textbook in wide use in the systems engineering community. In that book, they recommend a set of questions that systems engineers should ask detail design engineers during design reviews to determine whether they have properly fulfilled the human factors requirements baselined earlier. Table 3 contains this list of questions. However, you cannot review human factors into a design; it must be part of the requirements for the design. Consequently, we recommend that these questions be recast into requirements and displayed for the systems engineers to include in the requirements

baseline. For example, question 1 would be recast from Q1 to requirement R1 as below:

Q1. Have the qualitative and quantitative requirements for human factors in design been adequately defined and specified? Have they been allocated from the top down?

R1. The design shall define and specify qualitative and quantitative requirements for human factors and shall be allocated from the top down.

#### HCDA SUPPORT OF FUNCTIONAL ANALYSIS AND SYNTHESIS TRADE STUDIES

Once the systems engineers have inserted the desired human factors requirements into the requirements baseline, they will move on to subsequent design

Table 1. Tasks in the Requirements Analysis Process

Requirements Analysis Tasks		Human Factors Subtasks?	
		Yes	No
1.	Define customer expectations	X	
2.	Define project and enterprise constraints		X
3.	Define external constraints	X	
4.	Define operational scenarios	X	
5.	Define measures of effectiveness	X	
6.	Define system boundaries		X
7.	Define interfaces	X	
8.	Define utilization environments	X	
9.	Define life cycle process concepts	X	
10.	Define functional requirements		X
11.	Define performance requirements		X
12.	Define modes of operation	X	
13.	Define technical performance measures		X
14.	Define design characteristics	X	
15.	Define human factors	X	
16.	Establish requirements baseline.	X	

Note: Per IEEE 1220-1998.

subprocesses such as Functional Analysis or Synthesis (Figure 2). These stages provide increasing detail and specificity to the design. The high level analyses and decisions will be made by systems engineers but the more detailed trade studies will be done by detail design engineers. Table 4 lists the design tasks in the Synthesis Process per IEEE 1220-1998. Note that all but four of the tasks specifically call out human factors issues to be addressed in these tasks. In supporting the Synthesis process, the HCDA would have a dialogue with the engineer similar to the one shown in Table 2. The primary difference would be that the HCDA would provide advice on more detailed systems engineering tasks as well as highly detailed tasks of the detail design engineers. Since the HCDA knows the results of the earlier analyses, the engineer can select the design task and the requirement to be fulfilled and the HCDA should be able to provide very detailed advice on human factors principles that will assist in conducting trade studies. Whenever possible, the recommendations will be very context specific and limited to those that apply to the task at hand.

It should be noted, however, that we do not expect the HCDA to replace the Human Factors engineer on the design team. If anything, the result of using the HCDA should be just the opposite. By increasing the number of human factors issues that get incorporated into the

systems requirements, and by alerting systems engineers and design engineers to the role and importance of human factors issues, our goal is to increase their interactions with human factors engineers. This is crucial because, as with all aspects of system design, human ingenuity and creativity play an important role in resolving human factors issues.

#### **HCDA SUPPORT FOR DESIGN REVIEWS**

As the detail design engineers produce their recommended designs, the systems engineers review these decisions for compliance with the requirements. At this point, the HCDA would remind the systems engineers which topics in Table 3 were included in the requirements and suggest human factors oriented questions to be asked during the reviews.

#### **BUILDING THE HCDA**

Providing the HCDA with the knowledge and reasoning capability that it needs is not a trivial task. We have already described some of the key knowledge sources that will provide inputs to the HCDA. Knowledge of the systems engineering process will come from the recently updated IEEE Standard 1220 (IEEE Standard for Application and Management of the Systems Engineering Process.) Familiarity with the language and expectations of systems engineers will come, in part, from standard texts such as Blanchard & Fabrycky (1998).

Human factors guidelines will also come from accepted sources such as MIL STDs, NASA and the FAA. There are a wide variety of collections of case studies of designs that did not take into consideration key human factors issues (with negative consequences ranging from amusing to disastrous), which can be included in the software (see Table 2, WHY?).

An example of one HF oversight was an air defense system that had two consoles operated by one person. The two consoles were developed by two different subcontractors without coordination. During field trials of the prototype, it was discovered that the symbol for friendly aircraft on one console was identical to the symbol for threat aircraft on the adjacent console.

Table 2. Sample Dialogue Between Systems Engineer and HCDA

Systems Engineer	Human Centered Design Advisor
Activate HCDA	Displays the Typical System Life Cycle (Figure 1) and asks what stage of the design is currently being conducted.
Selects System Definition Stage	Displays the Human Factors goals (per IEEE 1220-1998) of this stage.
Selects HOW	Displays the systems engineering process (Figure 2) and asks what subprocess of the design is currently being conducted.
Selects the Requirements Analysis Option	Displays the Requirements Analysis Tasks (Table 1) and asks which task is currently being conducted
Selects Define Measures of Effectiveness	States that in IEEE 1220-1998, Key MOEs may include: Performance Safety Operability Usability Reliability Maintainability Time and Cost to Train Workload Human Performance Requirements Asks which MOE they are currently addressing.
Selects Human Performance Requirements	Lists recommended human performance requirements and asks which ones to add to the requirements baseline.
Selects menu item labeled WHY?	Displays case studies in which human performance requirements were and were not included in systems designs in the past and the consequences.
Selects the desired human factors performance requirements	Transfers the selected human performance requirements to the computer aided design tool being used by the systems engineer

A key source of knowledge and reasoning about the role of human factors engineering in the systems engineering process will be based on cognitive task analyses of experienced human factors engineers and systems engineers. We will rely heavily on their input for every stage of the design of this software. Initially, they will provide the knowledge of how, when and why human factors issues should be incorporated into each stage of the design process. Later on, they will provide validity checks to make sure that the dialogue with the HCDA is accurate and effective, that the HCDA does indeed speak the same language as systems engineers, and that it

increases the extent to which human factors is effectively incorporated into the system design process.

**SUMMARY AND CONCLUSIONS**

The authors present the proposed functionality of a Human Centered Design Advisor (currently under development) that will increase the extent to which human factors professionals are involved in the system design. In order to achieve its goal, the HCDA should:

- Dovetail into the current systems engineering process.

Table 3. Recommended Topics To Be Addressed By Systems Engineers In Design Reviews

1.	Have the qualitative and quantitative requirements for human factors in design been adequately defined and specified? Have they been allocated from the top down?
2.	Has a top-level system analysis been accomplished to identify those functions that are to be completed by the human? Have functions been broken down into job operations, duties, tasks, subtasks, and task elements to the extent practical?
3.	Have the appropriate interfaces been defined between the human and the other elements of the system (i.e., equipment, software, and facilities)?
4.	Does the system design adequately reflect the proper consideration of anthropometric, human sensory, physiological, and psychological factors?
5.	Does the design reflect consideration of the abilities and capacities of the human in dealing with information processing requirements?
6.	Have those tasks to be accomplished by the human been justified through the OTA? Can they be traced from the functional analysis?
7.	Have the personnel quantities and skill levels been defined for the system? Has the system been designed such that it can be successfully operated by an individual with <i>basic</i> skills? Have the number of operating personnel been optimized to the extent practicable?
8.	Have the interfaces between the human and other elements of the system been properly defined and justified through the development of OSDs? Are the OTA and OSDs compatible? Do they justify and lead into the development of training requirements?
9.	Has a system safety/hazard analysis been completed? Is it compatible with the FMECA?
10.	Has an error analysis been conducted? Do the results feed back to the FMECA and the safety/hazard analysis? Have the results been provided as an input in the development of personnel training requirements?
11.	Have the environments been adequately defined for each area where system functions/tasks are to be accomplished by the human? Are they optimal?
12.	In the design of control panels and displays, are the controls standardized? Are the controls sequentially positioned? Are they placed according to frequency or criticality of use? Is control spacing adequate? Is control labeling adequate? Has the overall design been justified through the OSDs?
13.	In the area of safety, have system/product hazards from heat, cold, thermal change, barometric change, humidity change, shock vibration, light, mold, bacteria, corrosion, rodents, fungi, odors, chemicals, oils, greases, handling and transportation, and so on been eliminated?
14.	Have fail-safe provisions been incorporated in the design?
15.	Have protruding devices been eliminated or are they suitably protected?
<p>Acronyms:</p> <p>OTA                      Operator Task Analysis</p> <p>OSDs                     Operational Sequence Diagrams</p> <p>FMECA                  Failure, Modes, Effects, and Criticality Analysis</p>	

Source: Blanchard & Fabricky, 1998.

Table 4. Tasks in the Synthesis Process

Synthesis Tasks		Human Factors Subtasks?	
		YES	NO
1.	Group and allocate functions	X	
2.	Identify design solution alternatives	X	
3.	Assess safety and environmental hazards	X	
4.	Assess life cycle quality factors	X	
5.	Assess technology requirements	X	
6.	Define design and performance characteristics	X	
7.	Define physical interfaces	X	
8.	Identify standardization opportunities		X
9.	Identify off-the-shelf availability	X	
10.	Identify make or buy alternatives		X
11.	Develop models and fabricate prototypes	X	X
12.	Assess failure modes, effects, and criticality	X	
13.	Assess testability needs	X	
14.	Assess design capacity to evolve	X	
15.	Final design		X
16.	Establish requirements baseline.	X	

Note: Per IEEE 1220-1998.

- Know what stage and subprocess of the systems design process the systems engineer is currently conducting.
- Improve awareness of HF issues for systems engineers.
- Help the systems engineers conduct systems analysis trade studies involving human factors requirements
- Help the systems engineers (at design reviews) to evaluate whether the detail design engineers have fulfilled the human factors requirements.

The authors submit that the most effective way to convince systems engineers to include the Human Engineering Process in the Systems Engineering Process is to reference human factors issues contained in IEEE 1220-1998, because systems engineers consider this document a credible source. When systems engineers are developing specific requirements, the HCDA should recommend human factors oriented requirements from the systems engineering community as opposed to coming from the human factors community. Finally, as the design progresses, the HCDA will have sufficient knowledge of the design task at hand and can provide context-specific advice from the human factors community on how to fulfill the human factors requirements. The next step in the HCDA process is to work with systems engineers to develop a dialogue that achieves the goals of both the systems engineer and the human factors engineer.

#### REFERENCES

- Blanchard, B. S., & Fabrycky, W. J. (1998). Systems engineering and analysis (3<sup>rd</sup> ed.). Upper Saddle River, NJ: Prentice Hall.
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