Towards HSI Engineering

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Why HSI?

There is a large body of evidence showing that the critical system components are the human operators. Analysis of many case studies divulges that the system performance can be augmented by design, if the developers are aware of the special attributes of the operators. Special disciplines were developed to optimize the system performance according to the special features and limitations of the operators: human factors engineering (HFE), human-computer interaction (HCI) design, user-centered design (UCD), cognitive engineering, etc. All these disciplines contributed to enhancing the system performance (Norman & Draper, 1986), yet, the behavior of the human operators is often different from the expectations. It seems that the source for operational surprise is in the way the operators are integrated in the system design: in traditional systems integration (SI), we assume that the system modules interact with each other through communication channels, and that the processing in each module is independent of the other modules. This assumption is not valid for the operators: unlike machine modules, the operators are expected to master the system, especially in exceptional situation.

Human in system integration (HSI) is a new framework for optimizing the system operation by human factors. It is an extension of SI, considering the special requirements about the interaction with of the human operators. Unlike operator-centered disciplines, which focus on adapting the machine behavior to the operators' capabilities and limitations (e.g., Norman, 1988), HSI is transdisciplinary, implying that it deals also with the inter-dependencies between cognitive processes and machine processes (Sillitto, 2018).

The scope of HSI design

SEBoK adopts the definition of HSI by ISO/IEC/IEEE 2011, as "an interdisciplinary technical and management process for integrating human considerations with and across all system elements, an essential enabler to systems engineering practice" (BKCASE). The domain considerations include: "manpower, personnel, training, human factors engineering, occupational health, environment, safety, habitability, and human survivability". The 4th industrial revolution is about a shift in our view of the effect of technology on our experience of using systems. The potential impact applies to various kinds of resilience-critical systems:

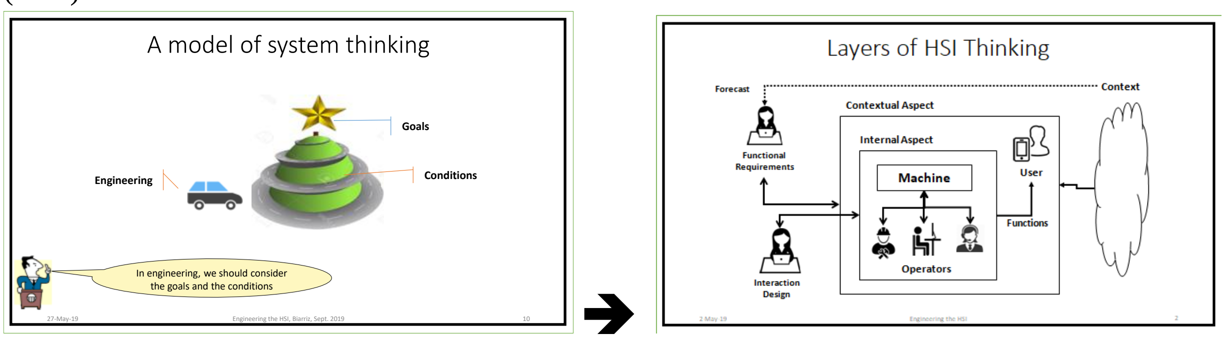
- Safety critical systems - where the impact could be injury, environmental impact etc,
- Performance critical systems where it might impact on profit, efficiency
- Consumer and entertainment products - frustration, loss of sales, negative brand image etc.

HSI thinking

The new framework may embrace a methodology of HSI thinking. HSI thinking is an extension of system thinking. According to the Systems Engineering Body of Knowledge (SEBoK) “system thinking is the application of system sciences to assist in solving real world problems”. The HSI approach to solving real world problems complies with the system approach defined by SEBoK as “a set of principles for applying systems thinking to engineered system contexts”. With system thinking a system engineer “can see both the forest and the trees; one eye on each” (Richmond, 1994). Accordingly, we may consider two aspects of HSI thinking:

- The ‘trees view’ is the internal aspect, about the functional units integrated with the operators, collaboration between components of the engineered system, and
- The ‘forest view’ is the contextual aspect, about the interaction of the engineered system with the real world, namely, the customers and stakeholders, as well as the operational constraints.

The following chart illustrates that the focus of HSI engineering should be the human-machine interaction (HMI):



The figure on the left demonstrates a model of basic system thinking, showing that engineering is goal driven and condition oriented. Engineering is required to repeat making the same design mistakes over and over again (Standish, 1995). Boy (2013) suggested that system design should be from purpose to means, from outside-in. According to this model, the contextual aspect is defined based on requirements specifications, with respect to the user’s tasks and capability, and considering forecast of the context. Also, the internal aspect is defined design considerations about the various roles of the operators, and their collaboration with the functional units. The figure on the right presents a two layers model of HSI thinking obtained from merging the basic model of system thinking with the Outside-In model.

Agile HSI Thinking

In the early days of systems engineering, system development followed the waterfall model. According to this model, the system design is based on the requirement specifications, which remained unchanged until the version release. This model did not work very well, because during the system development new requirements emerge. Therefore, the waterfall model was replaced by other models, such as iterative development or agile development, which facilitated changing the requirements during the system development. HSI thinking is a continuous process, integrated with agile development. The contextual aspect includes sensing the need to change the requirements and triggering the change. The internal aspect is the traditional response to changes, typical of agile development.

The Human Side of the Interaction

For the purposes of systems engineering, it is helpful to consider two aspects of the HSI:

- The task view, in which we examine the ways people interact with the system
- The capability view, in which we examine physical and mental capabilities, motivation and limitation of the human operators, and their effect on performance and successful operation of the system.

Accordingly, it is helpful to use two distinct views of the operator: as a system controller and as a system unit. As a system controller, we are interested in functions: production, performance, effect, etc. As a system unit, we are interested in the operator's ability to make the system work, and about safety. For example, we want to detect a situation of a pilot passed out due to G-LOC (g-force induced loss of consciousness) and activate an Auto-GCAS (Ground Collision Avoidance System) to stabilize the airplane and the pilot (Dockrill, 2016).

As a system controller, the operator can have various roles: a user, motivated by functions and performance, a supervisor, motivated by the need to make sure that the system operates as intended, and a controller, who needs to manually make the system work. As a system unit, we are concerned about the operator's ability to function as a system controller, which is determined by qualification, motivation, vigilance, etc.

The Engineering Chasm

Traditionally, the engineers who define the interaction with the operators are systems engineers or software engineers. Typically, they are technology-oriented, which means that they try their best to integrate state-of-the-art technological feature. Often, they are feature-oriented, which means that they include in the design as many features as the technology allows them to include, regardless of whether or how the operators will use them. Also, often, they are designer-centric, which means that optimize the interaction according to their knowledge about the operational procedures, and their own preferences. A primary challenge of system design in the 4th IR is about the people experience in going through this change. Recently, usability practitioners discuss challenges of incorporating human factors in system development. Unfortunately, systems engineers are not always aware of the benefits of considering human factors, and usability practitioners fail to explain their offer (e.g., Weinberg, 1971). There is a need to bridge this chasm from both sides. Systems engineers need to understand the benefits that they can get from incorporating human factors and usability practitioners need to demonstrate and explain to systems engineers how to integrate the theories of cognitive sciences in the system development.

Design Highlights

The discipline of HSI engineering may involve changes in the following aspects of the HMI design.

Timing: traditionally, human factors are added ad-hoc to the system design. This is too late. It is the responsibility of systems engineers to integrate human factors in the stage or system analysis and requirements specification.

Time span: traditionally, usability considerations focus on the stages of marketing and initial operation. It is essential to extend the scope of usability assurance to the whole life cycle.

Automation control: a main consideration in HMI design is the balance between automation and human control. The new discipline will propose guidelines for collaboration design, optimizes for maximal performance and minimal risks (e.g., Norman, 1990).

Failure analysis: Traditionally, failure prevention is based on root-cause analysis. Such analysis does not support coping with the unexpected and proposes developing rule-based protection. Rebounding from operator's slip should be integrated in the system design. The new discipline proposes that applying new methodologies for structured rebounding.

Error tolerance: a common practice in system design is to apply means for fault tolerance. Traditionally, systems engineers do not apply such means for protection from operator's errors. The new discipline proposes applying a model and means for preventing operator's errors (e.g., Zonnenshain & Harel, 2015).

Extended exception handling: traditionally, interaction design focuses on procedures of normal operation. However, system failure involves difficulties in operating in exceptional situations. Applying golden rules applicable to normal operation, such as those proposed by Shneiderman (1987), might hamper the interaction in exceptional situations. It is about time to expand the HMI design practices, such as of deciding on interaction styles, to also support exception detection, troubleshooting, recovery and emergency operation.

Modeling the HMI: a common practice for UI design is in terms of event-response. The new discipline considers typical sources of unexpected diversion, advocates scenario-based interaction styles and applies rule-based procedure-oriented definition (e.g., Leveson, 2004).

Human-machine collaboration: the new discipline proposes a new model of human-machine collaboration, enabling to cope with the exceptions. Also, it proposes that the implementation should be based on protocols describing proper interaction, which will enable diversion detection. Special safe-mode operational procedures are essential to deal with the unexpected in emergency.

Situation awareness: a primary source for system failure is the lack of information required for situation awareness. A key related problem is of attention distraction due information overload, and the role of nuisance alarms. The new discipline proposes to develop a means for assessing the effect of various S/N ratio of notifications and alerts.

Incidence investigation: traditionally, system failure is attributed to the operator (Dekker, 2007). The new discipline encourages radical changes in system thinking, to mitigate the risk of common biases in interaction design and to enable learning from mishaps. These changes should be accompanied by technological advances, including activity trackers and analyzers (e.g., Harel, 1999), based on data mining technology (e.g., Harel et al., 2008).

Glossary: various industry domains use specific terms for common attributes of HMI. The new discipline proposes a glossary that may enable engineers of the different domains speak using the same language.

CONCLUSIONS

HSI engineering is an extension of quality engineering. The engineering goals may be defined in terms of eliminating barriers to optimal performance. In order to ensure long-term high performance, the design should focus on enforcing operational reliability. Accordingly, it is primarily about HMI design and testing. A main conclusion from the complexity and variety of related considerations and methods is that in the 4th industrial revolution the theory of HSI engineering should evolve to a sub discipline of systems engineering. The 4th industrial revolution may involve various shifts towards HMI, associated with technology, methodology and HMI thinking and practices. These shifts may affect the people productivity, quality of life and safety. The new discipline may be based on scientific foundations, which may require studies for high degrees in universities. The discussion above suggests that the focus of these studies will be on HMI design, testing and optimization.

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