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Human Systems Integration

VOLUME ONE

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Human Systems Integration: A Primer

VOLUME ONE

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Editorial Comment:
The overall Human Systems Integration (HSI) Primer is the product of an extended effort of the INCOSE HSI Working Group (WG) that is targeted towards a broad range of readership audience and has been structured into 5 (five) articulated volumes:

Volume 1: HSI Fundamentals
- What is Human Systems Integration (HSI)
- Key HSI Perspectives
- References

Volume 2: HSI in Practice
- Principles, models and methods
- Maturity and readiness levels
- Contemporary challenges of HSI
- Further comments of the focus of HSI
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Volume 3: HSI and Related Fields
- HSI: a transdisciplinary discipline
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- HSI and systems of systems
- HSI and artificial intelligence
- HSI and knowledge management
- HSI and risk management

Volume 4: HSI in Various Domains
- HSI domain specific case studies and applications
- HSI in aeronautics systems
- HSI in astronautics systems
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- HSI in automotive systems
- HSI in oil-&-gas systems
- HSI in defense systems
- HSI in health care systems
- HSI in education systems

Volume 5: HSI Useful Materials
- HSI reference manuals
- HSI standards
- HSI acronyms and abbreviations
- HSI glossary of terms
- HSI references

Intended audience is anyone interested in knowing more on HSI from engineering systems designers, developers, human factors specialists, manufacturers, operations specialists, maintainers, dismantlers to top managers.

This document is Volume I of this Primer. It was written via a series of monthly teleconferences over approximately two years, which included frequent review by a large variety of teleconference participants. The HSI WG is grateful to these contributors and participants, who should collectively be considered the authors of this Primer: Jawahar (JB) Bhalla, Michael Boardman, Guy André Boy, Stélian Camara Dit Pinto, Ami Harel, Avi Harel, Grace Kennedy, Dimitri Masson, Peter Moertl, Cynthia H. Null, Edwige Quillerou, Alexander Rudolph, Yotam Sahar, Jackelynne Silva-Martinez, Jean-Jacques Speyer, Harald Molina-Tillmann, Andrew Wright, and Avigdor Zonnenshain. Drafts were offered for review to the full working group, and to individuals expressing interest at subsequent INCOSE workshops and conferences.

The other volumes are work in progress and planned to be delivered in 2023, and beyond if necessary.

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1. What is Human Systems Integration (HSI)?

Human Systems Integration (HSI) is a transdisciplinary sociotechnical and management approach of systems engineering (SE) used to ensure that system's technical, organizational, and human elements are appropriately addressed across the whole system lifecycle, service, or enterprise system. HSI considers systems in their operational context together with the necessary interactions between and among their human and technological elements to make them work in harmony and cost effectively, from the early design to disposal.

Human. The "human" in HSI includes all individuals and groups interacting within the System of Interest (SoI). Within HSI these are all typically referred to as 'users' or 'stakeholders.' Users and stakeholders can include system owners, operators, maintainers, trainers, customers, support personnel and the public. While most people who interact within the SoI will be cooperative or have a vested interest in its performance, consideration may also need to be given to people with malign intent such as criminals (physical and cyber), adversaries, and those seeking to use the system outside of its design intent. Life, human, and social sciences have different representations of the human element and can all bring different perspectives to HSI activities.

Systems. HSI adopts a sociotechnical system perspective that considers a system as a representation of natural and artificial elements, and organizations of humans and machines, where machines includes both hardware and software. Therefore, HSI considers that all systems include both humans and machines, operating within an environmental, organizational, and cultural context, and that to optimize the system all these elements must be considered within SE activities.

Integration. HSI considers integration from two keys viewpoints. The first is the effective integration of the human and technological components in a system, while the second is the efficient integration of the different perspectives of the human element within the system. An example of these different HSI perspectives can be seen in Figure 1. The specific perspectives relevant to a project will vary depending on the nature of the system and lifecycle organization's activities.

All systems involve or affect people and exist within a wider sociotechnical and organizational context. Therefore, HSI is an essential enabler to SE practice. The sociotechnical approach provided by HSI supports analysis, design, and evaluation activities in holistically understanding and effectively integrating the technological, organizational (including processes) and human elements of a system encompassing stakeholder needs and environmental constraints, to reduce risk and optimize effectiveness of the system. These four entities (i.e., Technology, Organization, People [TOP Model] within an Environment) are shown at the center of Figure 1 (first circle). It is particularly important that systems are designed to meet human capabilities, limitations, and goals.

HSI is interested in sociotechnical complex systems from several points of views, which include system of systems topology, activity, and emergent properties. Systems interact among each other through various kinds of organizations, communities, and informal groups. Several contributions can be references such (Blanchard & Fabrycky, 2013; Booher, 2003; Boy, 2020, 2023b; Chapanis, 1996; International Organization for Standardization, 2019a; Mayhew & Bias, 1994; Rouse, 1991) . A sociotechnical and human-centered system cannot be limited to its initial structural and deliberately designed form but should be incrementally extended to include emergent properties, functions and even forgotten sub-structures. As such HSI should be applied across the whole system lifecycle. This emergence is the result of human adaptation to meet the demands of a complex and dynamic work environment. Indeed, people have different behaviors in reaction to work requirements, especially interacting with and within dynamic socio-technical systems.

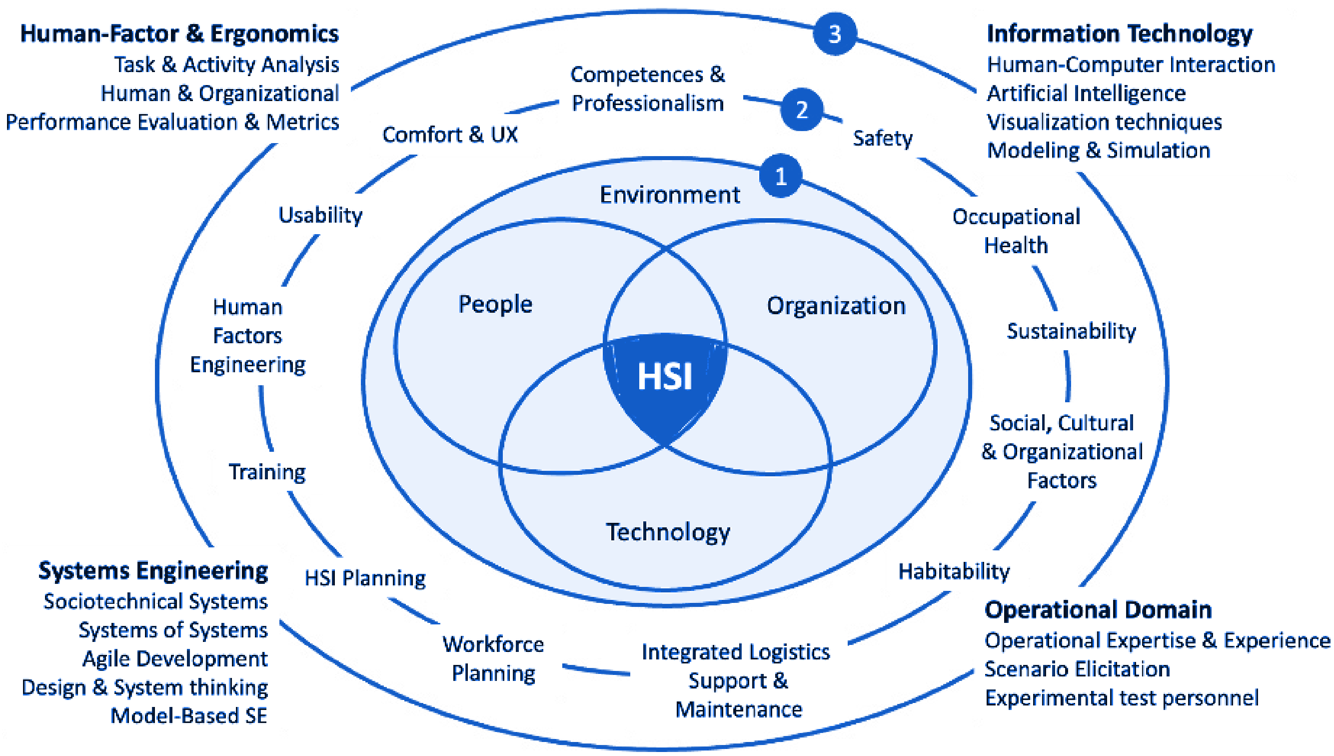

Figure 1. HSI emerges from the overlapping of three main circles: (1) technology, organization, and people within an environment at the heart; (2) examples of HSI perspectives; and (3) contributing disciplines and operational domain.

HSI was originally developed for large governmental acquisition programs, however the need for HSI also emerged within other product system industries, particularly within safety or performance critical industries and those where technology is used to undertake previously human tasks or where human and machine must work together to achieve the system purpose. Within commercial contexts, such as manufacturing, HSI is also an enabler of the development of efficient, cost effective systems that can dirtectly impact on productivity and profit, and must satisfy human benefits and well-being requirements. Human experience becomes significant when considering service system domains such as gaming, media, cinema, audio concerts, theater, sports, as well as advanced transportation, finance, education, and healthcare systems. Industrial HSI needs to not only consider a user's experience but the wider social, cultural, and societal factors.

HSI enables the discovery of emergent properties, behaviors and functions during the design and development processes using Human In The Loop (HITL) simulation. This enables engineering design teams to increase system knowledge earlier than before, keeps design flexibility, and better management of resources. HSI can be an excellent support for the development of new industrial endeavors, such as Industry 4.0 and Industry 5.0.

HSI can be applied to a wide range of ethical, philosophical, sociological, and psychological worldviews. HSI does not presuppose or promote any personal or cultural opinion. The only common denominator is the appreciation of each human as something unique by itself, beyond being a machine, a developed animal, a consumer, a troublesome entity, or a target group. The evolution of artificial intelligence and more generally information technology induces new issues in fields, such as law (e.g., legal responsibility of the various stakeholders during the life cycle of a system), ethics (e.g., societal responsibility sharing in systems engineering and operations), philosophy (e.g., introducing new ontologies and epistemological changes).

Whatever notions or methods are implemented in a specific project, the final objective of HSI is to design and to operate systems that allow humans to be humans. Every project (including the development of this primer) is to follow this ethical guiding principle. The final role of an HSI expert is to give value, space, and awareness to this idea.

1.1 What are the Purposes of HSI?

The purpose of HSI is to recognize the fundamental role of people in complex systems, resolutely taking them into account and integrating them during the whole life cycle.

The key aims are:

- To ensure the value of developed systems is optimized with respect to sustainability, which includes trading of economics (affordability, cost/benefit), environment (well-being, natural/artificial balance) and society (governance, organizations, societal issues),
- To ensure the efficient and effective integration of the human perspective into the engineering of systems from concept definition to realization, utilization, evolution, and eventual disposal. Human perspective encapsulates human-systems complexity, organization, criticality (safety, efficiency, and comfort), social and cultural aspects, human behaviors, health and well-being, regulations, and ethics,
- To enable integration of creative and innovative approaches, together with experience-based approaches, into the design and development of systems to complement technological and management, and organizational process considerations toward safe, acceptable, and effective systems.

Considerations for enacting HSI. Human activity and usage requirements should be defined; both longitudinally (e.g., along the lifecycle) and transversally (e.g., at various relevant levels of granularity from subsystem to system of systems) to enable and achieve HSI. HSI principles should be developed with respect to societal issues, organizational, governance, affordability (cost/benefit), safety, security, efficiency, comfort, and usability (not exhaustive list). HSI is holistic, model-based, supported by HITL simulations, and focuses on recursive adaptation of humans and machines, as systems, integration, and interaction. HSI considers systems complexity as a baseline, where emerging behaviors and properties are incrementally elicited (experience feedback) and integrated.

The Value of Human Systems Integration. HSI is an essential cross-cutting branch of Systems Engineering (SE), as well as a process for ensuring that the human component is adequately considered throughout the system lifecycle in terms of performance, risk, cost and time (Ministry of Defence, 2015). Investment into HSI activities must be made by businesses if they are to realize the following interrelated value propositions:

Performance. HSI activities support the development of systems to ensure that they not only meet the required capability, but also optimize the system's performance by considering both the human and the machine (hardware/software) within a given environment.

Risk. People assess risk and make trade-offs with respect to their background and environment. As with most Systems Engineering activities the management of HSI risk earlier in the lifecycle reduces the costs to rectify defects if they are discovered at later stages in the design and development of the system. HSI also reduces the risks throughout the lifecycle for example, safety incidents during operations and maintenance, long term damage to health or wellbeing, or possible loss of life.

Cost. HSI reduces and optimizes project costs over the whole system lifecycle.

Time. HSI reduces the risk of project-based time overruns, through improving the efficiency of effort, and reduction of rework during system development.

Organizational. An investment into HSI within the workforce develops the skill set within the organization and can be utilized across all project portfolios. Workplaces that are designed with HSI in mind show better employee performance.

The cost benefits from the proper application of HSI are difficult to quantify and often intangible. There are three levels of cost associated with HSI: 1) the cost of employing skilled HSI practitioners, 2) the costs to enact their recommendations for change during development, and 3) the costs during operations once the recommendations have been implemented (Rouse, 2011). HSI is commonly seen as an added (rather than essential) expense because cost benefit analyses often fall short in acquisition projects as the developer will not necessarily reap the benefits once a system is operational. Economic analyses have been undertaken in a variety of case studies in private and public enterprises (Hendrick, 2003; Rouse, 2011) to support decisions on appropriate scoping of activities and resourcing of HSI.

1.2 Scope and Breadth of HSI

HSI is based on the convergence of three key scientific communities of practice (third circle on Figure 1): I) human factors and ergonomics (HF/E) that provides human-centered and organization-centered evaluation techniques and tools (Boehm-Davis et al., 2015); II) information technology (IT) that includes artificial intelligence, human-computer interaction, visualization techniques, as well as operational modeling and simulation; III) SE that more specifically relates to systems of systems, design and system thinking, systems engineering for enterprises, agile development, socio-technical systems, SE-related modeling and simulation, resilience, survivability, system safety, and digital engineering across the lifecycle, and the operational domain at stake (e.g., oil & gas, aerospace, defense, transportation, healthcare).

These communities enable support of HSI through **Human-Centered Design (HCD)** as a major process (Boy, 2013; Boy, 2020) that involves development and use of domain ontology, prototypes and digital modelling, scenario-based design, modeling and HITL activities (simulations and physical tests), formative evaluations, agile design and development, as well as human and organizational metrics (e.g., maturity and flexibility). HCD processes are applicable across the SE lifecycle, from requirements definition, concept selection, to design and development process, more specifically enabling the discovery of emergent structural and functional properties that are incrementally integrated into the system being designed, developed, realized, and used. HCD validation both requires certification approval and contributes to certification rules evolution.

HSI considers systems **complexity analysis** as a baseline. It seeks for simplification where possible, and familiarity with complex systems where necessary. HITL activities enable discovery and elicitation of complex systems' emergent behaviors, properties, functions, and structures, which are incrementally integrated into the System of Interest (SoI) through its whole lifecycle. HITL activities provide SE and HCD teams with improved understanding of the SoI early in the lifecycle, contributing to design flexibility, and better resource management. HSI is a foundational enabler for industrial endeavors, such as Industry 4.0, where digital engineering, enabling virtual HCD, requires increased physical and cognitive tangibility testing across the lifecycle of a system.

HSI can be considered as both an enabling process associating HCD and SE during the whole lifecycle of a system, and a product resulting from this process. HSI is the result of this HCD-based convergence, which requires optimizing the TOP model. User eXperience (UX) and user interface (UI) development are integral parts of the HSI process, and not an "add-on" solution to help users adapt after the design is complete or nearly complete. HSI processes are iterative and supported by two main types of assets, methods, and tools: expertise elicitation and creativity. The former enables effective elicitation from subject matter experts through knowledge and know-how, supporting design teams during system formative evaluations, agile development, and certification. The latter enables out-of-the-box projections that are validated using prototyping and HITL activities.

1.3 Historical Background

We make a distinction between three approaches that focus on understanding and consideration of people in the development of machines, and more generally sociotechnical systems (Figure 2): human factors and ergonomics (HF/E); human-computer interaction (HCI); and human systems integration (HSI).

Figure 2. How people have been considered in three major sociotechnical approaches (Boy, 2020).

HFE effectively started after World War 2 to correct engineering production and generated the concepts of human-machine interfaces or user interfaces, and operational procedures. HF/E specialists made the point to distinguish task (i.e., what is prescribed to be performed) and activity (i.e., what is effectively performed). Activity-based evaluation could not be holistically performed before products were finished or almost finished, which enormously handicapped possibilities of re-design. When activity analyses were carried out prior to designing a new product, based on existing technology and practice, HF/E approaches tended to force continuity, reduced risk taking, and most of the time prevented disruptive innovation.

HCI started to be developed during the 1980s to better understand and master human interaction with computers. HCI contributed to the shift from corrective ergonomics to digital interaction design mainly based on task analysis. Activity-based design **(Norman, 2013)** started to be introduced within the HCI community by people who understood phenomenology **(Winograd et al., 1986),** distributed cognition **(Hutchins, 1995);** and activity theory **(Kaptelinin & Nardi, 2006)**. Based on cognitive engineering, Human-Centered Design (HCD) was born within the HCI community, and further considered in the HF/E and systems engineering (SE) communities, to handle growing automation issues **(Boy, 2013)**.

HCD considers the human as essential element of a system, which only the collective sum of the human and all other system elements can produce the desired result to satisfy the system requirements. HCD combines creativity, (from virtual to tangible) agile prototyping, formative evaluation, rigorous demonstration, and validation. It is based on design thinking, expertise, experience, organization design and management, advanced interaction media, and complexity analysis, and more specifically by considering Human Systems Integration (HSI) in the development of large systems (Pew & Mavor, 2007; Boy, 2013)) using modeling and human-in-the-loop simulation from the very beginning of the design process, as well as during the whole life cycle of a system (Boy, 2017). HCD enables design and development teams to put the human element at the center of systems engineering practices. More specifically, Virtual Human-Centered Design uses immersive HITL simulation to support discovery of emerging properties and functions. Such HITL simulation enables design and development teams to test tangibility of systems being designed and developed as early as possible. Sometimes a physical simulation may also be essential for simulating aspects that are not possible to virtually simulate, such as touch and feel.

HSI emerged from the need to effectively consider human possibilities, limitations, and necessities as variables in SE; incrementally combined, SE and HCD led to HSI, to take care of complex systems during their whole life cycle (Boy & Narkevicius, 2013; NASA, 2021; Silva-Martinez, 2016). HSI involves more than human factors evaluations or task analyses. It involves activity analysis at design time using virtual prototyping and human-in-the-loop simulations (e.g., we can model and simulate an entire aircraft, fly it as a computing game, and observe pilot's activity). The resulting approach is often called virtual HCD (or VHCD). Resulting HSI involves various kinds of knowledge and skills, which include creativity, system thinking, risk taking, complexity analyses, organizational design, and management, as well as prototype development using agile approaches.

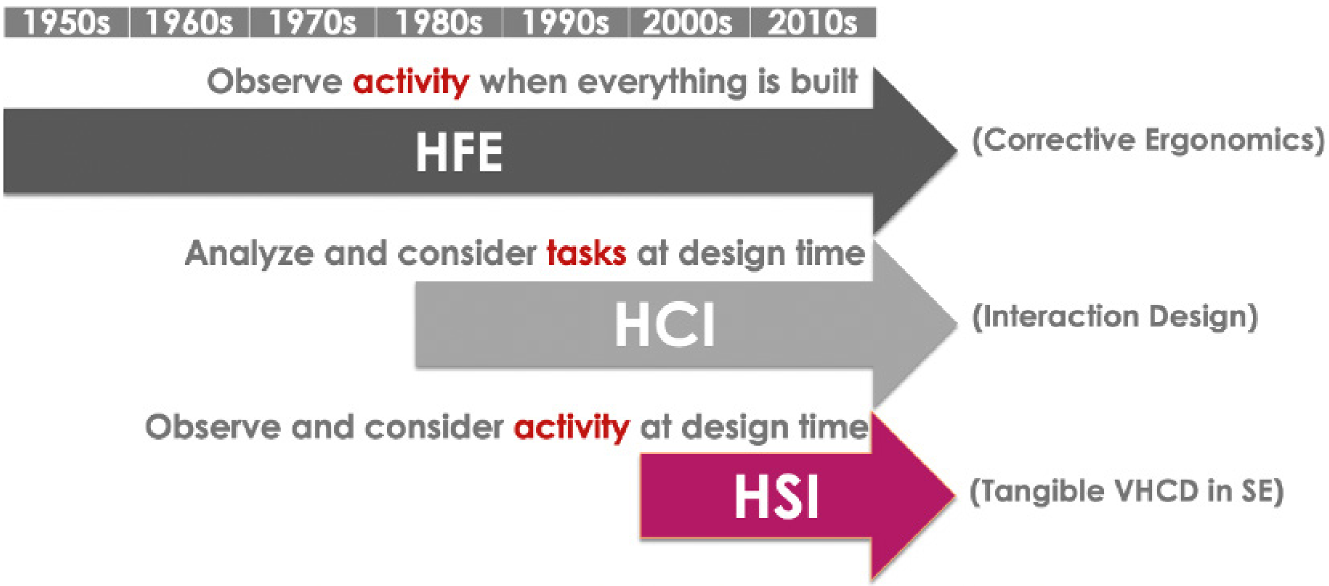

Figure 2. How people have been considered in three major sociotechnical approaches (Boy, 2020).

1.4 HSI Personnel & Career Development

The HSI personnel comprise of one or more individuals within an enterprise that bring skills, sufficient knowledge, and experience across the different perspectives of HSI. As both an essential quality SE process and an emerging transdisciplinary field, it is necessary to ensure that HSI personnel needs are considered at the outset of project management planning and through each organization's strategic skillset and career planning. This overlap of different disciplinary skills and lack of specialist HSI courses means that the current pool of HSI practitioners is formed in most cases either through training SE practitioners in human factors (HF) or by deploying HF practitioners into SE projects to gain SE skills.

Different enterprises will need different approaches to resourcing HSI personnel. Whilst large companies and projects may have a separate HSI team comprised of subject matter experts (SMEs) for each HSI perspective and integration managers, small and medium companies and projects will need to tailor the HSI personnel commensurately to their size and overall effort required for these organizations and projects. The role of the HSI personnel generally differs between private development organizations and large governmental acquisition programs. In private industry, there is generally less guidance and structure to regulate HSI activities, often requiring more informal channels and support by high-level management. It is important for management to be HSI aware or educated to ensure HSI is properly considered in high-level decisions, and to drive the support of an HSI aware culture throughout the organization. The establishment of proven practices and a culture of HSI within such private organizations is especially important to facilitate the cross-domain activities that are typical for HSI.

From a SE point of view, each project needs a HSI practitioner/SME who is working with other systems engineers on the coordination of the human engineering aspects. This coordinator is working with HSI engineers/specialists who can support or resolve the HF issues. These HSI engineers can be part of a HF department or could be consultants/sub-contracted organizations. HSI uses the same techniques and approaches as systems engineering with additional consideration for non-technical aspects of the system that include human and organizational factors. Therefore, the HSI practitioner/SME must be well-versed in the SE process and have a good working understanding of, without necessarily being an expert in, each of the HSI perspectives.

HSI practitioners need to be good communicators with sufficient knowledge of any parts of the SE activities to which their activities input or output to. Thus, all HSI practitioners must have a proficient level of integration skills. The HSI practitioner/SME will also need to liaise with the users (throughout the lifecycle) to ensure that the HSI needs are effectively elucidated, managed, and translated appropriately into the design.

1.5 Typical HSI Tasks and Activities

HSI activities are an integral part of the overall systems engineering effort (not only tests and evaluation) and the human systems Integrator participates in all relevant systems engineering activities during the whole life cycle of the system being considered.

From a human-centered design point of view, a task is a prescription (i.e., something to be done) and an activity is an effective realization (i.e., something effectively done). Tasks are integrated in operational procedures. Even if SE personnel should follow procedures (i.e., documented prescribed tasks), it may happen that unexpected events requires appropriate knowledge and skills to solve induced problems. In these cases, the activity may differ from the planned associated task. HSI aims to ensure the capacity of the system to ensure the correct transformation of human tasks into corresponding activities using the designed system.

Functions enable to transform a task (what is prescribed) into activity (what is effectively performed). Therefore, **function allocation** is one of the main activities in HSI, where human systems integrators need to assign various tasks to systems, whether they are human or machine systems. After early function allocation based on appropriate doctrines, e.g., Fitts' list MABA-MABA (Fitts, 1951), functions must be reallocated incrementally based on the results of formative evaluations using human-in-the-loop simulations. Indeed, functions allocation should not be limited to the consideration of tasks but reflect people's activity involved in the system being designed, developed, assessed, operated, maintained, and eventually dismantled.

HSI is the combination of HCD and SE, where activity analysis drives the development of systems. This is impossible without using human-in-the-loop simulations during the design process. The use of virtual prototypes, formative evaluations and agile development are integrated to provide a framework for tangibility assessment. Tangibility is a mandatory goal to satisfy in our current digital world. Tangibility can be physical and/or figurative (cognitive) (Boy, 2016). The former induces physical assessments of technology being developed. The later induces intersubjectivity assessments of integration and interactions among people and machines, as well as within the organization being concurrently developed.

HSI is intrinsically model based. We talk about **model based HSI** or MBHSI (Boy, 2023a). For example, the digital twin paradigm typically supports the creation and maintenance of a digital image of the system at stake (i.e., a kind of vivid online system documentation). HSI starts during the early stages of the design process of a system with the development of a digital model of it, becoming an implemented prototype, that can be tested with humans in the loop (i.e., using HITL simulations). We are talking about Virtual Human-Centered Design (VHCD). Such prototypes can be incrementally maintained and become active digital documentation of the system being considered. Digital twins are very useful during the whole life cycle of a sociotechnical system for various kind of purposes, including operational support, maintenance, and incremental redesign.

HSI activities are performed at all stages of the SE lifecycle. Figure 3 depicts a set of typical SE activities as they are introduced and integrated throughout the wider lifecycle and SE activities. Broadly, the stages progress to being cyclical and iterative in nature as the design matures and progresses into operations and support. Note that HSI does not only occur during the system development and that each stage is not independent, i.e., planning, design and resourcing is required for future stages, and information from previous stages is considered live and updateable (e.g., operational issues should be recorded and reflected in design change decisions).

HSI is life cycled (Figure 3) following the evolution of the system being developed and operated. Therefore, HSI starts during the **concept phase** and extends beyond the design domain and continues during operations of the system including logistics and supportability. More specifically, HSI must directly influence the Concepts of Operations (CONOPS), which is a document describing the characteristics of a system from the viewpoint of a mix of stakeholders that includes engineers, human operators, and people in the organization who deal with the system one way of another, dealing with conceptual design from a large variety of viewpoints and contexts, supported by case-based scenarios. In this perspective, scenario-based design (and re-design) must be a constant focus and development support. CONOPS are widely used in the military, governmental services, and other fields.

Once the concept is defined, the **development phase** can start. During this phase HSI recommends iteratively extending modeling and HITL simulation for task analysis as well as complexity and activity analysis enabling function allocation. HITL simulation allows the observation of both human and machine activities that fosters the discovery of emerging behaviors and properties. More specifically, HITL simulation enables human- and machine-related risks identification and mitigation. Resulting human and organizational factors are analyzed and further considered in in the design process. This analysis will also enable the optimization of future working processes and practices. Note that progressive tangibilization is operated toward the manufacturing phase.

In the HSI perspective, **system manufacturing** comes after system development and focuses on the exploration of the human role in both manufacturing and subsequent operations processes. This implies conducting usability and acceptance testing during the manufacturing process, and therefore selecting and training appropriate manufacturing personnel. At this point, possible organizational changes must be prepared. If needed, some parts of the system may be reimplemented in the development phase.

During the **operations phase**, the system must be introduced to human operators. An experience feedback mechanism should be put in place to collect in-service experience that should be used to improve both the system itself and the way it is operated. Emergent properties are typically discovered and analysed for system optimization purposes.

The **support phase** consists in maintaining and upgrading the operability of the system. The system is updated based on identified emerging human operators' needs and requirements. These improvements are made possible through a continuous monitoring performed throughout the operations phase and analysed through HSI lenses.

In this **dismantling phase**, workforce retirement must be prepared, and sociotechnical changes managed. Replacement of the existing system should also be considered. Future systems must use lessons learned from the HSI experience captured during the previous phases.

A specific focus must be brought to **people and organizations** during the whole lifecycle of the system at stake, as well as on education and training of personnel, legal and ethical constraints, and cooperation organizational climate promotion.

When system engineering is performed by an organization that delegates SE work to a contractor to the benefit of a customer, it is recommended that this organization, contractor and customer should each have an HSI-Integrator and various domain experts; each role should collaborate with their counterparts to the appropriate extent.
HSI depends on sufficient scope of work and authorization from the project. Proper planning and leadership buy-in is a key enabler.

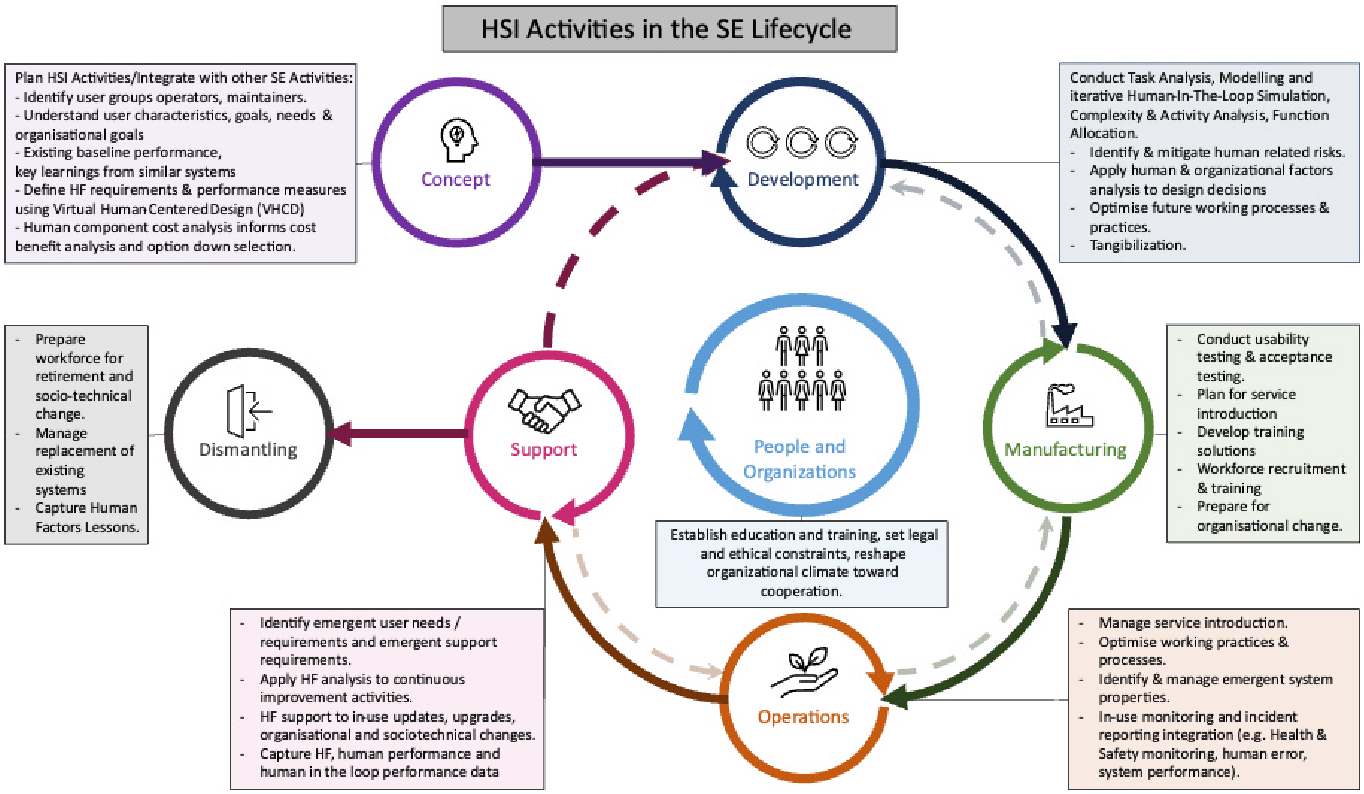

Figure 3. HSI Activities in the SE Lifecycle..

What makes an HSI approach effective? HSI activities should not be developed in isolation but performed in coordination with other SE activities. This is the topic of the next section.

HSI activities include both management and technical activities, specifically to:

- Plan HSI activities during the systems engineering lifecycle.
- Develop requirements and human in the loop measures of performance.
- Involve operational people in design processes and evaluations.
- Understand how human interactions (with technological aspects of the system and other humans in the system) affect whole system performance.
- Inform requirements and design trade-offs to ensure that human impacts are understood and considered within project decision-making.
- Identify risks to successful delivery of the system resulting from the human element of the system (human error, safety, health hazards, etc.).
- Test the system concerning human systems interactions and integration.
- Simulate the system to facilitate appropriate human systems interactions and integration.
- Understand costs associated with the human element of the system (training, manpower).
- Deliver products and solutions that meet the expectations, needs and desires of consumers and operational people.

1.6 Tailoring HSI Activities to Project Need

First, as a reminder, HSI must not be considered as an additional set of activities to be performed to compensate what engineering is supposed to do with respect to pure technological considerations. To the contrary, HSI must be considered as coordinating with other SE activities during the whole life cycle of a system. System concepts must then be tailored to HSI requirements at any time following up the discovery and validation of emergent properties.

It is strongly advised to tailor project requirements and developments together with HSI principles and perspectives in an agile manner (see the agile section). More specifically, scalability and flexibility should be considered at any time during the life cycle of a system.

Note. This HSI Primer was written in concert with HSI subject matter experts coming from various domains that include defense, civil aviation, space, oil and gas, telecommunications, medical, rail and automotive industries.

2 Tailoring HSI Activities to Project Need

Due to the breadth of human considerations and impacts that should be considered by a project - depending on its nature, complexity, and application area - HSI consists of several perspectives. Note that the term "Perspective" is also denoted as "Domain" in other SE/HSI literature. These are used to help ensure that no significant human considerations are missed within requirements analysis, design, evaluation and acceptance testing, and risk management (Hollnagel, 2008). These perspectives are not exhaustive and the degree to which they each apply will vary from project to project. The following provides an overview of the suggested HSI perspectives that should be used within most projects:

2.1 Human Factors Engineering (HFE)

Human Factors Engineering (HFE) — Involves an understanding of human capabilities (e.g., cognitive, physical, sensory, and team dynamics) to create effective, efficient, and safe human/hardware/software interfaces to achieve optimal total system performance.

Human factors engineering is currently integrated with HCD, often combined with human-computer interaction (HCI), involves an understanding of human cognitive and physical abilities to create effective, efficient, and safe human/hardware/software interfaces to achieve optimal total system performance. Human-machine interfaces include:

- Functional interfaces (functions and tasks, and allocation of functions to human performance or automation).
- Informational interfaces (information and characteristics of information that provide the human with the knowledge, understanding, and awareness of what is happening in the tactical environment and in the system).
- Environmental interfaces (the natural and artificial environments, environmental controls, and facility design).
- Operational interfaces (aspects of a system that support successful operation of the system such as procedures, documentation, workloads, and job aids).
- Cognitive interfaces (decision rules, decision support systems, provisions for maintaining situational awareness, mental models of the tactical environment, provisions for knowledge generation, cognitive skills and attitudes, and memory aids).
- Physical interfaces (hardware and software elements designed to enable and facilitate effective and safe human performance such as controls, displays, workstations, worksites, accesses, labels and markings, structures, steps and ladders, handholds, maintenance provisions, etc.) (DAU, 2020).
- Situation awareness aspects (in terms of perception, comprehension, and projection) (Endsley, 1995).

2.2 Social, Cultural & Organizational Factors

Social, Cultural & Organizational Factors - Considers the organizational aspects of socio-technical systems and includes the organizations who will be using and supporting the operational system, as well as the organizations who are involved throughout the entire lifecycle of the system.

Organizational factors have an impact on systems design and vice-versa (whether the SoI is a product, service, or business). This perspective involves understanding formal and informal groupings of two or more individuals working towards common goals, through to teams and business divisions, up to organization and enterprise level. Organizational factors have several facets of concern for HSI, including strategy, governance, societal factors, team working, business processes, communication, knowledge management, organizational change, and culture.

Challenges for HSI practitioners considering the organizational factors include:

- co-operational interfaces (provisions for team performance, cohesion, collaboration, and communication among team members and with other personnel);
- organizational interfaces (job design, management structure, command authority, and policies and regulations that impact behavior);
- computer-supported cooperative work (CSCW) tools and methods;
- organizations are adaptive and show characteristics of self-organization, managing the complexity of change can be difficult; and
- management of intra and inter-organizational interactions and boundaries.

2.3 HSI Planning

HSI Planning - Addresses the planning and prioritizing of human-centered studies and design suggestions within a project. HSI priorities need to be set up-front upon mission definition and carried throughout the allocation of resources and project personnel.

This perspective addresses the planning and prioritizing of the roles of people within HSI projects. It also presents how HSI practitioners/experts interact with other stakeholders to accomplish the HSI activities and goals, which involves transdisciplinary work. In this perspective, HSI priorities need to be set up-front upon mission definition and carried throughout the allocation of resources and project personnel. Especially important is the formulation and consideration of human capabilities and limitations as part of the function allocation and alternatives analysis during the system development process. Studying HSI aspects on or outside the operating and maintenance envelope is of great importance as it provides insights into:

- systems robustness and resilience,
- adjustment of the optimal operation-point,
- re-definition of system requirements tolerance, and
- re-definition of envelope boundaries and recommendation of out-of-envelope use.

2.4 Integrated Logistics Support (ILS)/Maintenance

Integrated Logistics Support — Covers human performance during operations and support based on an HSI plan leading to an ILS plan.

HSI is a dominant aspect of ILS. ILS is designed to enable the product stakeholders to derive any benefit required from the outset, and to prevent an unexpected decrease in performance and termination. ILS covers all means and activities which support the systems during the entire life cycle of the system. It includes the following aspects for both operation and maintenance providers: updated knowhow, skill set definition, training, training aids and simulators, serviceable spare parts and materials, failures data collection, means such as tools, test and support equipment, packaging, handling, storage, and transportation.

ILS ensures human ability to perform effectively efficiently and safely:

- all operation stages in every mission profile defined, in all fully serviceable modes of operation and in degraded modes.
- all maintenance stages, such as fault identification and verification, fault documentation, disassembly, suitable and serviceable spares and materials allocation and installation, system serviceability verification, calibration and final documentation and certification as required.

2.5 Workforce Planning

Workforce Planning — Addresses the number and type of personnel and the various occupational specialties required and potentially available to, operate, maintain, and support the system.

Workforce Planning (also known as Manpower) describes the number, type (i.e., various occupational specialties), age, gender, and mix of personnel required to carry out a task, multiple tasks, or mission to operate, maintain, support, and provide training for a system. Workforce factors are those variables that define workforce requirements. These variables include job tasks, operation/maintenance rates, associated workload, and operational conditions (e.g., risk of operator injury) (DAU, 2020).

2.6 Competences / Professionalism

Competences / Professionalism – Considers the type of knowledge, skills, experience levels, and aptitudes (cognitive, physical, and sensory) required to operate, maintain, and support a system and the means to provide such people (through selection, recruitment, training, etc.).

Competences (also Personnel factors) are those human aptitudes (i.e., social, cognitive, physical, and sensory abilities), knowledge, skills, attitudes, culture, language, and experience levels that are needed to properly perform job tasks. Abilities can evolve, learned both individually and collectively. Competences are used to develop occupational specialties for system operators, maintainers, trainers, and support personnel (DAU, 2020). The selection, recruitment and assignment of personnel is critical to the success of a system, as determined by the needs set up by various work-related requirements.

2.7 Training

Training – Encompasses the instruction and resources required to provide personnel with requisite Knowledge Skills and Attitudes to properly operate, maintain, and support systems.

Training is the learning process by which personnel individually or collectively acquire or enhance pre-determined job-relevant knowledge, skills, and abilities (KSA) by developing their cognitive, physical, sensory, and team dynamic abilities to properly operate, maintain, and support systems. The "training/instructional system" integrates training concepts and strategies, as well as elements of logistic support to satisfy personnel performance levels required to operate, maintain, and support the systems. It includes methods, procedures and "tools" used to provide learning experiences, such as computer-based interactive courseware, simulators, actual equipment (including embedded training capabilities on actual equipment), job performance aids, and Interactive Electronic Technical Manuals (DAU, 2020).

2.8 Safety

Safety – Promotes system design characteristics and procedures to minimize the risk of accidents or mishaps that could cause death or injury to operators, maintenance, and support personnel; threaten the operation of the system; or cause cascading failures in other systems.

This perspective promotes system design characteristics and procedures to minimize the risk of accidents or mishaps that could cause death or injury to operators, maintenance, and support personnel; threaten the operation or functionality and serviceability of the system; or cause cascading failures in other systems. Specifically, the approaches promoted seek to minimize the potential for human or machine errors or failure that cause injurious accidents (DAU, 2020). Safety also encompasses administrative procedures and verifications associated with the operations, maintenance, and storage of a system.

2.9 Occupational Health

Occupational Health —Promotes system design features and procedures that serve to minimize health hazards which might cause risk of injury, acute or chronic illness, and disability; and to enhance job performance and wellbeing of personnel who operate, maintain, or support the system.

Occupational health promotes system design features and procedures that serve to minimize health hazards which might cause risk of injury, acute or chronic illness, and disability; and to enhance job performance and wellbeing of personnel who operate, maintain, or support the system. Prevalent issues include noise, lighting, chemical safety, atmospheric hazards (including those associated with confined space entry and oxygen deficiency), vibration, ionizing and non-ionizing radiation, biological threats, and human factors issues that can create fatality, chronic disease, and discomfort such as repetitive motion diseases. Many occupational health problems, particularly noise and chemical management, overlap with environmental impacts. Human factors stress that creating a risk of chronic disease and discomfort overlaps with occupational health considerations (DAU, 2020).

To be able to simultaneously anticipate or prevent health and safety risks through an integrated approach, the techniques and methods used so far that dichotomize actions, decisions and interactions must be reviewed.
The important thing is to perceive the "here and now" of human interactions with an existing technical system to understand the potential for overall safety and health (physical, social, mental - including the affective and cognitive dimensions). A project that wishes to integrate a HSI vision must take a creative and singular stance when analysing human-human and human-technical interactions to allow optimal and developmental integration for humans (i.e., with flexibility as part of the technique or technology to allow efficient action).

Numerous studies in technical engineering and human factors have made an integrated approach to either safety (Vincent & Amalberti, 2016; Hollnagel, et al., 2006) or health possible as global managing risks, but there remain few global approaches to the human being that defend a holistic point of view (Carayon et al., 2020). Human-factors approaches, which start from a health approach, derived from human and social sciences, but also consider safety dimensions provide an additional basis to support this holistic view. Occupational, or educational psychology can also provide lessons through its defence of a vision of the dynamics and developmental perspectives of human activity, which can be used to transform technical possibilities (Engeström, 1999 & al etc.).

2.10 Sustainability

Sustainability – Covers the environmental considerations that can affect operations and particularly human performance.

This perspective covers the environmental considerations that can affect operations and particularly human-system performance. Environment includes the physical conditions in and around the system, as well as the operational context within which the system will be operated and supported. Environmental attributes include temperature, humidity, noise, lighting, vibration, radiation, shock, air quality, among many others. This "environment" affects the human's ability to function and experience as a part of the system (DAU, 2020).

Environment is part of a bigger concern regarding sustainability of technology, organizations and people's jobs being progressively developed, where at the same time society and economy play crucial roles. Without appropriate regulatory programs, sustainability that associates environment, society, and economy, cannot be considered seriously. This is the reason why human systems integration should be better explored as a discipline and include sustainability issues.

2.11 Habitability of the Designed Environment

Habitability – Involves characteristics of systems living and working conditions.

Habitability factors are those living and working conditions that are necessary to sustain the morale, safety, health, and comfort of the operational people. We include workspace, workplace, life-space whether in industry, in public areas or at home, and more generally personalized work environments. They directly contribute to personnel effectiveness and mission accomplishment and often preclude recruitment and retention problems. Examples include lighting, space, ventilation, and sanitation; noise and temperature control (i.e., heating and air conditioning); religious, medical, and food services availability; and berthing, bathing, and personal hygiene. Habitability consists of those characteristics of systems, facilities (temporary and permanent), and services necessary to satisfy personnel needs. Habitability factors are those living and working conditions that result in levels of personnel morale, safety, health, and comfort adequate to sustain maximum personnel effectiveness and efficiency, support mission performance, and avoid personnel retention problems (DAU, 2020).

2.12 Usability

Usability — Uses objective evaluation methods to address aspects such as efficiency, conformity to human expectation, and tolerance towards human errors to improve the degree to which involved humans can reach their objectives when interacting with a system.

Usability engineering enhances the degree to which involved humans can reach their objectives when interacting with a system. Fundamental criteria of good usability are effectiveness, efficiency, self-description, conformity to human expectation, tolerance towards human errors, self-description, ease of individualization, and learning suitability. Usability engineering provides a wide range of measurable objective evaluation methods. While classic usability focuses on user interfaces, HSI is interested in considering the role of people (e.g., maintainers, cleaning personnel, people working on the selling floor, safety engineers, or safety personnel) in complex sociotechnical systems during their whole life cycle.

2.13 Comfort/UX

Comfort aspects — Are personal internal human aspects such as joy, guilt, opinions, and unconscious aspects which are to be considered not only regarding the primary users of the final product but regarding all humans involved in the systems engineering process.

HSI should not exclusively manage general external human aspects such as safety, health, functional needs, general aesthetics, or usability. Personal internal aspects such as joy, fear, guilt, personal likes/dislikes, and subjective opinions should be considered at the same level. HSI might also consider and integrate intrapsychic comfort aspects of which the involved humans may not be fully aware of e.g., projections, identifications or suppressed desires. Comfort aspects strongly influence both the human experience of the provided product/service and the quality of the SE processes themselves.

3 Conclusion

This HSI Primer Volume 1 is the result of a two-year international collaboration within the INCOSE HSI Working Group. It provides the state of the art of Human Systems Integration with current definitions and perspectives.
It is essential that systems engineering, and technical design teams be human centered in their management, composition, project analysis, diversity and articulation of skills, i.e., that they be an "orchestrated and orchestrating team." (Boy, 2013)

The dynamics and coordination of both engineering and operations teams are crucial to really have the means and the mindset to build an HSI project. A good mix of expertise/experience in the domain being concerned and creativity are essential. Specifically, we must be open-minded to other areas of expertise to better observe, analyze, and understand human interactions and evolving needs to find the best technological solutions.

In the next volumes of the HSI Primer, HSI fundamentals will be developed such as principles, models, and methods, as well as maturity and HSI readiness levels, and contemporary challenges of HSI. Transdisciplinary relationships with other fields such as systems science, systems of systems, sociotechnical systems, artificial intelligence, certification, knowledge management, risk management, agile development, and safety. Case studies and domain specific applications will be described in terms of HSI. Finally, reference materials will be provided, including relevant standards, appropriate references, acronyms and abbreviations, and a glossary of terms.

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