A time-based approach for understanding human performance risks in sociotechnical systems: An integrative framework

Belinda Cham
Future of Work Institute, Curtin University
78 Murray Street, Perth, Western Australia, 6000
+61 8 9266 3792
Belinda.cham@curtin.edu.au

Alexandra Boeing
Future of Work Institute, Curtin University
78 Murray Street, Perth, Western Australia, 6000
+61 8 9266 3791
Alex.boeing@curtin.edu.au

Katrina Hosszu
Future of Work Institute, Curtin University
78 Murray Street, Perth, Western Australia, 6000
+61 8 9266 1274
Katrina.hosszu@curtin.edu.au

Mark Griffin
Future of Work Institute, Curtin University
78 Murray Street, Perth, Western Australia, 6000
+61 8 9266 2279
mark.griffin@curtin.edu.au

Karina Jorritsma
Future of Work Institute, Curtin University
78 Murray Street, Perth, Western Australia, 6000
+61 8 9266 4666
karina.jorritsma@curtin.edu.au

Abstract. To achieve system success, it is critical to design sociotechnical systems that optimize human performance. To do so, we need to define and characterize the various aspects of human performance that we aim to enhance. In this paper, we introduce a novel time-based approach for conceptualizing human performance in sociotechnical systems. This approach explores how human performance can be considered over short-, medium- and long-term timeframes. We incorporate this time-based perspective into a framework that organizes existing system design tools into different bundles, each focusing on specific aspects of human performance at various system levels. By integrating knowledge and methods from diverse system design perspectives, we emphasize the strategic application of human-centered design approaches. Our future work will refine this framework for practical implementation, collaborating with industry partners to ensure that human considerations are effectively integrated into systems design and acquisition processes

Introduction

The future of work is characterized by constant sociotechnical system evolution and change. This includes simpler changes such as technologies being inserted to refresh, replace, or improve existing functionalities of a system, to the acquisition and implementation of large-scale complex engineered systems that can transform an entire organization. Regardless of the scale, system changes disrupt and transform the environment and structures that shape human performance. Generating a comprehensive understanding of how system changes impacts on human performance is critical, as the human element will determine overall system performance and productivity (Booher, 2003).

Existing bodies of research have investigated the nature of human performance within sociotechnical systems. However, the way that human performance is interpreted, evaluated, and optimized varies greatly depending on what perspective is taken. Many of these perspectives and approaches to human performance have evolved independently of one another in research and in practice (Baxter & Sommerville, 2011). This lack of cross-disciplinary communication can result in siloed treatments of human performance, preventing a comprehensive understanding of the multifaceted impacts brought about by system changes. The aim of this presentation is to introduce a new and expanded approach to understanding human performance in a sociotechnical system that focuses on defining performance over different timeframes. We also present an integrative framework that organizes existing design tools and methods that exist across multiple research areas, into each of the human performance timeframes.

A time-based approach to human performance

The nature of human performance in sociotechnical systems has been investigated across many bodies of literature and from differing perspectives. We propose a time-based approach where different outcomes and processes of human performance are consolidated within three timeframes (i.e., short-term, medium-term, and long-term) and aligned with three broad design goals (i.e., designing for human limitations, designing for human productivity, and designing for human sustainability) (see Table 1).

Table 1: Human performance timeframes, design goals and examples.

Note: Examples provided below are not exhaustive. Some fields of study, methods and tools overlap across timeframes

Human performance timeframes ➔	**Short-term performance** (over a task to a workday)	**Medium-term performance** (over multiple days of a roster, operation, or mission)	**Long-term performance** (over multiple operations/missions to a whole career)
Human performance design goals ➔	**To limit human error at any given point in time**	**To support human productivity over a mission**	**To support human sustainability over a career.**
Example relevant human performance outcomes and processes ➔	Reaction time Errors Situational awareness Acute fatigue Attention/perception Decision-making Working memory	Cumulative psychological strain Cumulative physical strain Operational readiness and resilience Motivation	Mental and physical health Organizational commitment Job satisfaction Turnover intentions Adaptability Skill growth and development

Example relevant fields of study and scientific domains ➔	Cognitive psychology Human factors and ergonomics Human factors engineering Human-computer interaction	Organizational behavior Occupational psychology Industrial/organizational psychology Human factors and ergonomics Sleep science Occupational biomechanics	Strategic human resource management Management and organizational science Industrial/organizational psychology Occupational health psychology
Example relevant design methods and tools ➔	Function allocation Task analysis Workload analysis Usability testing	Work design Job analysis Ergonomic assessment Biomathematical modelling Usability testing	Workforce modelling Work design Change management Organizational design

This temporal categorization reflects inherent differences in the focus and methodologies of different fields of study and scientific domains. The first short-term timeframe includes the human performance outcomes that are important to address if the goal is to design for human limitations to mitigate immediate threats and failures (e.g., acute fatigue, reaction time). This timeframe captures fields of study such as cognitive psychology, human factors engineering and human-computer interaction. These fields of study tend to examine human performance outcomes and processes that change, manifest, or develop as humans interact with technologies over short periods, such as a task or a workday. Relevant outcomes and processes include reaction time, errors, and attentional processes. Relevant methods to evaluate these short-term performance outcomes and processes include task and workload analyses.

The second medium-term timeframe includes the human performance outcomes that must be addressed if the goal is to design for human productivity. While the first short-term timeframe concentrates on accommodating human limitations so an overall system can function safely at any given point in time, the second medium-term timeframe is concerned with supporting humans to remain productive, effective, and efficient over time. The focus of this timeframe is on performance outcomes and processes that change, manifest, or develop over repeated periods of interaction, such as cumulative fatigue or strain over multiple days of a roster, operation, or mission. This timeframe is characterized by fields such as organizational behavior and occupational psychology which investigate cumulative strain using work design methods, as well as certain human factors and ergonomics perspectives that examine factors such as cumulative fatigue using biomathematical modelling techniques.

The third long-term timeframe includes the human performance outcomes that must be addressed if the goal is to design for human sustainability. The focus is on outcomes and processes that change, manifest, or develop over extended periods of interaction, such as over multiple operations to a whole career. Relevant fields of study include strategic human resource management and organization/management science that aim to shape organizational structures, systems, processes, and culture to sustain employee commitment, motivation, development, and retention in the long-term. Relevant methods and tools include workforce modelling, change management approaches and organizational design methods.

Overall, a time-based approach allows for an expanded and holistic consideration of the diverse human performance outcomes and processes relevant to sociotechnical systems. A unique advantage of this approach is the integration of different fields of study and existing design methods/tools that have historically developed and been used independently of one another. Although many performance taxonomies exist (e.g., Performance Shaping Factors [e.g., Boring et al., 2007, Kyriakidis et al., 2018]), there are few approaches which differentiate and integrate how diverse disciplines and methods address human performance and their links to specific design goals.

The integrative framework

Conceptualizing human performance across three timeframes allows for a widened breadth of tools and methods across many fields of study that can be used to inform human performance. To help navigate this breadth in methods and tools, we have developed a framework that cross-classifies the three human performance timeframes against several sociotechnical system levels. This classification produces clusters of design methods and tools that share a common focus. In the next section, we describe how we have conceptualized sociotechnical system levels for the purpose of this framework and provide illustrative examples of how the framework integrates across both human performance timeframes and sociotechnical system levels to offer a structured means to categorize design methods and tools.

An expanded hierarchy of sociotechnical system levels. To manage the complexity of sociotechnical systems and to emerge comprehensive and meaningful design considerations, systems are often decomposed into their hierarchical levels (Bartolomei et al., 2012). There are existing approaches to decomposing a system into smaller and more manageable parts. For example, systems engineering and sociotechnical systems theory propose two well-known approaches. Systems engineering approaches commonly focus on decomposing large-scale technical systems (e.g., aircraft, space systems) into smaller interacting sub-systems (e.g., engines, avionics), and then further into more simple functional components (e.g., data displays, gearboxes) (Kossiakoff et al., 2011). While different perspectives do exist within systems engineering with respect to whether human and/or social elements are considered part of a system or external entities, in most cases, human-users are considered as part of the environment external to the technical system (Kossiakoff et al., 2011). By contrast, sociotechnical systems theory proposes an approach to system decomposition that emphasizes interactions between human and technical aspects. These approaches tend to decompose a sociotechnical system into broad technical, human, and organizational parts (e.g., Trist, 1981; Davis et al., 2014). These two approaches can be seen as complementary – with the former emphasizing depth in system levels, while the latter emphasizes breadth in system levels. Despite calls to bring together systems engineering and sociotechnical systems approaches (e.g., Baxter & Sommerville, 2011), there has been limited cross-pollination of these two approaches to system decomposition to date.

We propose a hybrid of these two system decomposition approaches to provide an expanded hierarchy of sociotechnical system levels. This expanded hierarchy is comprised of five interconnected system levels that span simpler lower-level technical and human entities, to more complex higher-level organizational and social systems. Definitions and examples of each of the system levels of the expanded hierarchy are provided below:

- **Macrosocial System:** The highest-level system that encompasses whole communities, societal institutions, and entire industrial/business sectors. Examples include government safety regulations and requirements, cultural norms, and industry standards.
- **Organizational System:** A higher-level system that operates at the level of an entire enterprise, corporation or public agency and comprises the formal structures, processes, and strategies within a specific organization. Examples include safety systems, workforce recruitment strategies, career support systems, family support systems, acquisition strategies.

- **Primary Work System:** An intermediate-level system within an organization that consists of one or more functions carrying out sets of interrelated activities that contribute to the achievement of specific objectives within the broader organizational context. Primary work systems can be further distinguished into technical and human work systems. Technical examples include operational platforms such as ships and aircraft. Human examples include broad organizational departments such as a ship's crew or a human resources department.
- **Function-level System:** A lower-level system within a primary work system that carries out a set of interrelated activities, that together with other function-level systems, enable a primary work system to achieve its specific goals. Function-level systems can be further distinguished into technical and human functions. Examples of technical functions include propulsion systems and data management systems. Examples of human functions include the recruitment function within a human resource department, or a division within a crew such as engineering.
- **Unit-level System:** The lowest-level system that comprises of the specialized technological or human elements that carry out tasks, and when combined with other unit-level systems, contribute to a useful function. Examples of technical units include computers and control and monitoring consoles. Examples of human units include individual human job roles and positions.

Integrating the human performance timeframes and the expanded hierarchy of system levels. The framework integrates the three human performance timeframes and sociotechnical system levels to create a sorting structure for different design tools and methods (see Table 2 for an abridged illustration of the framework). The result is a cross-classification of tools and methods into bundles that have a shared focus in terms of the system level they can be applied at, and the types of human performance considerations they emerge. We note that the framework excludes methods and tools pertaining to the highest macrosocial system level because design considerations for entities at this level, such as cultural norms, industry standards, and government regulatory policies, are deemed out-of-scope for most instances of systems design and acquisition processes.

The integrative approach provides several benefits for systematic and strategic oversight. First, the framework enables cross-disciplinary awareness for decision makers during an acquisition and implementation process. This awareness is crucial for identifying opportunities for cross-disciplinary collaborations to address diverse aspects of human performance. For example, by considering the types of skillsets that may be required to successfully adopt the technology and inform which functions and departments may benefit from closer collaboration to ensure project success.

Second, the framework can help to navigate complementary approaches within and between bundles of methods and tools for a more comprehensive consideration of human performance. For example, we can consider the acquisition of an unmanned underwater vehicle (UUV) for a surface vessel. The introduction of UUV for a surface vessel is a function-level system change, with significant unit-level system implications. Accordingly, the framework distinguishes the methods and tools that can be used to inform human performance risks and considerations across all timeframes relevant to the unit-level. For instance, task workload analyses are popular tools applied to the unit-level, however they typically only inform short-term human performance (e.g., Hart, 2006; Cao et al, 2009). Medium-term and longer-term human performance considerations at the unit-level require application of other methods such as work design tools (e.g., Parker & Knight, 2023) and anthropometric/biomechanical modelling (e.g., Tripathi et al., 2014).

The integration of human performance considerations into systems design is a challenging endeavor that requires a deep understanding of the complexity of a system, as well as the humans who work within the system (Boy et al., 2024). The framework proposed herein is intended to create definition and clarity around how one chooses the activities and methods to conduct human-systems integration, thus aiding the systems engineering process. Human performance is a broad and diverse scientific area of inquiry and is a complex phenomenon, being shaped by many underlying interacting causal factors that unfold over time (Cham et al., 2021). Application of the framework does not require one to address all three timeframes of human performance (although it would be ideal, given unlimited time and resources). Rather, we argue that value of the framework lies in how it guides researchers and practitioners to make informed decisions about which human performance timeframes or design goals are a priority in a particular project (or during different phases of a project), then selecting the methods/tools that are appropriate for achieving that goal. By guiding prioritization of efforts, the framework helps to make explicit what aspects of human performance are/are not of focus.

Table 2: The integrative framework

Hierarchy of System Levels / Human Performance Timeframes	Unit level system	Function-level system	Primary work system	Organization system
Short-term human performance	• Manpower analysis (e.g., IMPRINT) • Task workload assessment (e.g., NASA-TLX) • Cognitive task analysis • Function allocation (e.g., KOMPASS) • Anthropometric & biomechanical analyses (e.g., biomechanical modelling) • Failure mode & effect analysis (FMEA) • Maintainability & supportability analysis (e.g., maintenance task analysis)	• Biomathematical modelling (e.g., SAFTE-FAST) • Manpower analysis (e.g., IMPRINT) • Function allocation (e.g., KOMPASS) • Failure Mode and Effect Analysis (FMEA) • Maintainability and supportability analysis (e.g., maintenance task analysis) • Social network analysis (e.g., EAST) •	• Biomathematical modelling (e.g., SAFTE-FAST) • Manpower analysis (e.g., IMPRINT) • Failure Mode & Effect Analysis (FMEA) • Damage control modelling & simulation (e.g., IPME) • Social network analysis (e.g., EAST)	• Scenarios tools (e.g., systems scenarios tools)
Medium-term human performance	• Manpower analysis (e.g., IMPRINT) • Function allocation (e.g., KOMPASS) • Anthropometric & biomechanical analyses (e.g., biomechanical modelling) • Macroergonomic methods (e.g., MEAD) • Scenarios tools (e.g., systems scenarios tools)	• Manpower analysis (e.g., IMPRINT) • Function allocation (e.g., KOMPASS) • Scenarios tools (e.g., systems scenarios tools)	• Manpower analysis (e.g., IMPRINT) • Macroergonomic methods (e.g., MEAD) • Scenarios tools (e.g., systems scenarios tools)	• Scenarios tools (e.g., systems scenarios tools) • Organizational design (e.g., strategic human resources frameworks)
Long-term human performance	• Scenarios tools (e.g., systems scenarios tools)	• Scenarios tools (e.g., systems scenarios tools)	• Scenarios tools (e.g., systems scenarios tools)	• Scenarios tools (e.g., systems scenarios tools) • Organizational design (e.g., strategic human resources frameworks)

Note: The table presented above is not fully populated, as brevity is prioritized for the purpose of this submission. Our focus is on commonly used, well-established methods and tools to demonstrate the sorting structure of the integrative framework. Additionally, the table excludes methods and tools pertaining to the highest level of the expanded hierarchy of system levels (i.e., the macrosocial level). Design considerations for entities at this level, such as cultural norms, industry standards, and government regulatory policies, are deemed out-of-scope for most instances of systems design and acquisition processes.

Summary and Future Directions

In this paper we have introduced a novel time-based approach to considering human performance in sociotechnical systems, emphasizing short-term, medium-term, and long-term human performance outcomes that are aligned with distinct design goals. This approach broadens the view of human performance for sociotechnical systems and draws links between traditionally disconnected fields of study such as human factors engineering and organizational behavior. Building on these human performance timeframes, we also proposed a framework that integrates human performance timeframes with sociotechnical system levels to identify structured bundles of design tools and methods. This approach helps to navigate cross-disciplinary design perspectives and associated methods and tools. However, we note that the framework also highlights gaps in existing design methods and tools. Specifically, design methods and tools for informing the long-term human performance timeframe and the organizational system level were relatively limited. This disparity echoes previous scholarly calls that broader and more holistic consideration of human and social elements is critical for effective sociotechnical system design (Norman, 1993; Baxter & Sommerville, 2011).

Current and future research efforts involve working with an industry partner to utilize the framework as a decision-support and strategic oversight tool for different stakeholders (e.g., system designers, procurement personnel, research and development personnel, and human resources professionals) involved in technology change and/or acquisition processes. As part of this work, we have also been developing an evaluation tool that analyses medium- and long-term human performance, across various sociotechnical system levels. In developing this evaluation tool, we aim to test the utility of the concepts put forward by the integrative framework – namely, the benefits and usefulness of examining human performance across different timeframes and system levels. We are currently applying this tool with an industry partner to evaluate the human performance implications of introducing a new maritime platform. This involves analyzing human performance risks on both the existing platform and the new future platform.

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Biography

Belinda Cham. Dr. Cham is a research fellow at the Future of Work Institute at Curtin University. She has a background in Organisational Psychology and a PhD in Management. Belinda has worked together with the Defence Science Technology Group for the last 7 years to optimize human performance for various Australian maritime platforms.
Belinda's applied research focuses on how to design work systems to support sustained worker performance and wellbeing in extreme or high-risk work environments such as defence and emergency services.

Alexandra Boeing. Alexandra Boeing is an Applied Organizational Research Leader at the Future of Work Institute, Curtin University. She undertakes applied research, engaging with industry and government to concurrently improve workplace practices and scientific knowledge. Her research focuses on developing novel methodologies for evaluating human, social, and organizational elements in complex large-scale engineering systems.

Katrina Hosszu. Katrina Hosszu is an Applied Organizational Research Specialist at the Future of Work Institute, Curtin University. She conducts applied research, working at the intersection between human-systems integration and organizational psychology. She collaborates closely with industry and government organizations to inform the design of work systems that support the performance and well-being of employees working in complex human-machine systems.

Mark Griffin. John Curtin Distinguished Professor Griffin is the Director of the Future of Work Institute at Curtin University. He is a global leader in health and safety research, an expert in modelling multilevel and longitudinal data, and a Fellow of the US Society for Industrial/Organizational Psychology. In 2019 he received the Society's Presidential recognition as a leading scientist-practitioner in the field.

Karina Jorritsma. Professor Jorritsma is an applied organizational psychology researcher who holds over 15 years' experience in successfully bringing together academic thinking across disciplines and working with industry stakeholders to address critical workplace challenges. She has worked across a wide range of industries including health care, mining, aviation, fire and emergency services, law enforcement and the Royal Australian Navy. She has special interests in the design and evaluation of interventions for employee performance and wellbeing.