1. Introduction

Human reliability involves analysing and assessing the factors that can influence human performance (HP). The fundamental goal of human reliability is to minimise the likelihood and consequences of human error, which can lead to accidents, injuries and fatalities. Many researchers have vouched for the human reliability analysis (HRA) as an essential technique to improve system safety and performance. However, there is a lack of adoptable HRA techniques for many industries that can predict the human performance of specific tasks and help management in optimising system safety and human productivity. So, this research aims to devise a methodology to predict human performance in the future task.

This chapter provides an introduction to the study by first discussing the background and context, followed by the research problem, the research aims, research objectives, research questions, the significance and the structure of the thesis.

1.1. Background

1.1.1. Human Performance (HP):

HP can be defined simply as a series of behaviours exhibited to accomplish specific task objectives (results) [1]. Behaviours are observable acts that can be seen and heard. The effectiveness and efficiency of these behaviours depend on the abilities and skills of individuals as they carry out tasks in their work environment. This includes both cognitive and physical abilities such as memory, attention, decision-making, reaction time and motor skills. It also encompasses the emotional and social aspects of human functioning such as motivation, communication and teamwork.

In any industry, the behaviours of operators, technicians, maintenance crew, engineers and a myriad of other professionals are aggregated into cumulative acts designed to achieve system objectives. The primary objective of the whole operation is the continuous, safe, reliable and efficient production of system-specific products. So, effective HP is critical for achieving desired outcomes in various domains such as safety, productivity and quality.

1.1.2. Human Reliability (HR):

HR is a term used to describe the extent to which HP can be relied upon in order to achieve a particular outcome, such as completing a task or operating a system without an error, omission or other undesired outcomes. It is defined as the likelihood of successful HP within specified timeframes and environmental conditions [2]. It is a measure of the effectiveness of HP in achieving desired outcomes and is often used as a metric of safety in safety-critical industries such as aviation, medicine, nuclear power and transportation, where the consequences of human error can be serious or even catastrophic. Overall, HR is a complex and multifaceted concept that requires a comprehensive approach to ensure that HP can be relied upon to achieve desired outcomes with a high degree of safety and efficiency.

1.1.3. Human Performance and Human Reliability:

HP and HR are two related concepts. One wants to improve HP and other wants to reduce the human error. Human error and performance are two sides of the same coin. "Human error" mechanisms are the same as "human performance" mechanisms. The performance later categorised as 'error' is done so in hindsight, therefore actions later termed as "human error" are actually part of the ordinary spectrum of human behaviour [3].

There are several factors that can influence HP and HR, including individual factors (e.g., motivation, skills, knowledge and experience) as well as environmental factors (e.g., physical conditions, time pressure and distractions). Organisational factors (e.g., job design,

training, workload and management practices) can also play a significant role in influencing HP and HR.

To optimise HP and HR, it is important to design work environments and systems by understanding the capabilities and limitations of individuals that support effective and error-free performance. Human factors engineering is a field that studies factors in designing work environments and systems to minimise the likelihood of errors besides making systems more error tolerant. Some of the strategies to mitigate human error and improve performance include providing clear procedures and checklists, optimising work schedules and workload, minimising distractions and interruptions, providing appropriate training and feedback and improving communication and teamwork within organisations. Overall, effective management of HP and HR is critical for ensuring safe, efficient and effective operation of complex systems and processes.

1.1.4. Safety-Critical Systems Scenario:

In safety-critical industries, HP plays a crucial role in ensuring the safety of operations. Safety critical systems can be categorised into two groups. The first group consists of systems with high severity but low likelihood of accidents, such as nuclear power plants, aerospace systems etc. The second group comprises systems with high likelihood but moderate severity, like transportation systems, construction industries etc.

Healthcare Industry: India faces a significant challenge in meeting the demand for healthcare services due to a shortage of doctors & staff, particularly in rural areas. High workload, time constraints, fatigue and burnout can impair cognitive abilities, decision-making and overall healthcare system performance, affecting patient safety and quality of care. The World Health Organisation (WHO) estimates that 1 out of 10 patients is harmed while receiving hospital care globally [4].

Road Safety and Driver Behaviour: Every county faces significant challenges in ensuring road safety due to various factors, including driver behaviour and road conditions. The HP aspects related to driver behaviour have a critical impact on road safety in the country. Aggressive driving, distracted driving, fatigue and long hours of driving can impair their alertness, attention and reaction times, increasing the risk of accidents. The World Health Organisation (WHO) highlighted that the number of annual road traffic deaths has reached 1.35 million and over 50 million people are non-fatally injured due to road crashes globally [5].

Safety Hazards in Mining and Construction Sites: Mining and construction industries are crucial for infrastructure development and resource extraction. However, these industries face significant safety challenges due to physical demands and fatigue, lack of safety training and inadequate equipment maintenance [6].

In conclusion, the importance of HP is evident in various industries, including healthcare, road safety, mining and construction. Addressing these challenges requires collaborative efforts between industry stakeholders, policymakers and workers. In the healthcare sector, optimal HP among doctors is crucial for delivering quality patient care, accurate diagnoses, effective treatments and positive health outcomes. In road safety, responsible driver behaviour and strong HP play a vital role in preventing accidents, reducing fatalities and ensuring safe transportation. In the mining and construction industries, HP is essential for maintaining safety standards, preventing accidents and safeguarding the well-being of workers. Prioritising HP is paramount not only in these industries but also in Nuclear Power Plant and Chemical industry. By recognising the significance of HP and implementing strategies to enhance it, we can strive towards safer environments, improved outcomes and the well-being of individuals and communities.

1.1.5. Key Issues of Human Performance Research Domain:

The important research areas of safety critical systems are:

- **Human Factors and Performance Optimisation:** This research area focuses on understanding the human element in safety critical industries, including factors such as cognitive processes, decision-making, workload management and situational awareness. It aims to enhance human performance, minimise errors and improve safety outcomes.
- **Fatigue Management and Sleep Health:** Research in this area examines the impact of fatigue and sleep deprivation on performance and safety in safety critical industries. It explores strategies to manage fatigue, promote healthy sleep habits and design work schedules that optimise alertness and reduce the risk of accidents.
- **Safety Culture and Organisational Factors:** This research area investigates the role of safety culture, leadership, communication and organisational practices in creating a safe work environment. It explores how to foster a strong safety culture, improve safety-related behaviours and enhance safety management systems across industries.
- **Technology Integration and Automation:** Research in this area focuses on understanding the integration of technology and automation in safety critical industries. It examines human-machine interaction, usability, training needs and the impact of automation on performance and safety. The aim is to optimise the design and implementation of technology to enhance HP and mitigate risks.

These research areas address critical aspects of safety critical industries and encompass multidisciplinary approaches. By conducting research in these key areas, industries can gain

valuable insights, develop evidence-based practices and implement effective strategies to enhance safety, minimise accidents and optimise HP in demanding work environments.

1.2. Research Problem

The weakest link “human” is inherently prone to errors at any task or even in daily work. Most of the accidents analysed in different industries indicate that undesirable human behaviour (or human error) is crucial in causing system accidents and disasters. Although it is difficult to obtain valid values, the estimates agree that “undesirable human behaviour influences 60–80% of the accidents in every system and the rest is attributable to the technical deficiencies” [7].

Sundstrom-Frisk (1998) commented that human errors arise from the poor adaptation of the work task to human capacity [8]. It is imperative to assess the human ability to do a specific task without error. Although the workers are physically able to perform the task, their dynamic cognitive abilities may be inadequate for completing it correctly and amicably [9]. "Human cognitive ability" refers to a person's capacity to complete a task in the required time, accurately and with attention to detail using his/her innate knowledge. However, research into human cognitive ability to improve safety and productivity is still in its infancy. Therefore, developing an objective assessment tool for evaluating cognitive processes in work environments is one of the most promising areas for research. The researcher hopes to improve this situation by developing an objective assessment tool for evaluating cognitive processes in work environments. This research problem aims to create a reliable and valid tool that can assess and predict cognitive abilities relevant to performance in any task.

1.2.1. State of Art in the Human Cognition:

The current state of research in developing an objective assessment tool for evaluating cognitive processes is characterised by ongoing advancements in the technology,

methodologies and interdisciplinary collaborations. Researchers are actively exploring various approaches to create reliable and valid tools that can accurately assess cognitive processes in real-world contexts. Here are some key aspects of the current state of research in this area:

- **Cognitive Assessment Methods:** Researchers are utilising a combination of traditional and innovative methods to assess cognitive processes. Traditional measures, such as standardised cognitive tests, are still widely used to evaluate cognitive abilities. However, there is a growing emphasis on developing ecologically valid and context-specific assessments that capture the complexity of real-world cognitive demands. This includes the use of computer-based simulations, virtual reality environments, eye-tracking technologies, neuroimaging techniques and wearable devices to provide objective and detailed assessments.
- **Technological Advancements:** Advancements in technology have significantly influenced the development of objective assessment tools for evaluating cognitive processes. Researchers are leveraging sophisticated hardware and software systems to collect and analyse data with greater precision and accuracy. For example, portable EEG (electroencephalography) devices and functional near-infrared spectroscopy (fNIRS) are being used to measure brain activity and cognitive workload in real-time, allowing for objective assessment of cognitive processes.
- **Interdisciplinary Collaborations:** Given the multifaceted nature of cognitive processes, researchers from diverse disciplines, including psychology, neuroscience, computer science and human factors engineering, are collaborating to develop comprehensive assessment tools. These collaborations enable the integration of diverse expertise, leading to the development of more robust and comprehensive assessment frameworks.

- **Ecological Validity and Contextual Assessment:** There is a growing recognition of the importance of ecological validity in cognitive assessment. Researchers are designing assessment tools that closely resemble real-world environments and tasks, enabling a more accurate evaluation of cognitive processes in specific contexts. This includes the incorporation of dynamic and complex scenarios, time pressure, multitasking and decision-making components to create assessments that closely mirror the demands of high-pressure work environments.
- **Individual Differences and Personalised Assessments:** Researchers are exploring individual differences in cognitive processes and developing personalised assessment approaches. They are well aware that cognitive abilities can vary across individuals and customised assessments can provide a more accurate and reliable evaluation. This involves considering factors such as age, experience, expertise and cognitive styles in the assessment process.

Overall, the current state of research in developing objective assessment tools for evaluating cognitive processes is characterised by a focus on the technological advancements, interdisciplinary collaborations, ecological validity and individual differences. Continued efforts in this field hold promise for the development of reliable, valid and practical tools that can effectively evaluate cognitive processes in high-pressure work environments, leading to improved understanding of individual capabilities, targeted interventions and enhanced human performance.

1.2.2. Research Gap:

Reported studies have analysed HP related data that were collected when the subjects were performing tasks. The developed methodologies will be of use only for evaluating HP in parallel with the task activity. The practical adaptability of such technologies in industries is

questionable with respect to their compatibility with ergonomic standards. Even if they meet all the criteria of adaptability, with the present state-of-the-art technology, they are capital-intensive. Therefore, there is an urgent need to deal with the issue by progressing research toward devising a methodology for evaluating human cognitive capability prior to task allocation. There seems hardly any attempt to investigate and assess the cognitive capability as a predictor of HP in the upcoming task.

1.2.3. Problem Importance:

By addressing this research problem, researchers can contribute to the development of standardised and reliable assessment tools that accurately measure cognitive processes relevant to controlled work environments. The findings from such studies can advise on the design and implementation of objective evaluation protocols, allowing for targeted training interventions and identifying individuals who may benefit from additional cognitive support. Ultimately, the development of such assessment tools can help optimise human performance, enhance decision-making and improve safety outcomes in challenging work environments.

1.3. Research Aims, Objectives and Questions

1.3.1. Aim

The primary aim of this research is to improve safety and productivity in industry by devising a reliable and valid tool that can assess cognitive abilities necessary to perform the upcoming task reliably.

1.3.2. Research Objectives

- To find a way to accurately and objectively assess the cognitive processes, such as attention and working memory.

- To find the key performance indicators and metrics that can capture the effectiveness of cognitive processes in challenging tasks or situations.
- To find suitable advanced technologies to measure cognitive processes that can be implementable in industrial settings.
- To find or build computer-based programme to evaluate cognitive performance in upcoming task.

1.3.3. Research Questions

Potential research questions to meet the research objectives are:

- How can dynamic cognitive processes, such as attention and working memory, be accurately and objectively assessed?
- What are the key performance indicators and metrics that can capture the effectiveness of cognitive processes in challenging tasks or situations?
- How can advanced technologies, such as neuroimaging techniques or wearable devices, be utilised to measure cognitive processes. How can they be implementable in industrial settings?
- Can computer-based programmes be used as effective assessment tools to evaluate cognitive performance in the upcoming task?

Scope of Study:

This study aims to develop an objective assessment tool for evaluating and predicting state of cognitive processes, specifically focusing on assessing general cognitive abilities, such as attention and working memory. The study involves the design and implementation of innovative assessment methodologies, including computer-based modelling and physiological measures.

Inclusions:

- Development of Assessment Tools: The study will involve designing and developing innovative assessment tools, utilising techniques such as computer-based modelling and physiological measures.
- Validation of Assessment Tools: The developed assessment tools will be validated through rigorous testing, comparing the results with existing standardised measures and assessing their reliability and validity.
- Evaluation of Cognitive Processes: The study will assess cognitive processes related to attention and working memory in work environments.
- Interdisciplinary Approach: The study will incorporate interdisciplinary perspectives, drawn from fields such as psychology, neuroscience, computer science and human factors engineering, to develop comprehensive assessment tools.

Exclusions:

- Interventions and Training Programmes: The study will not focus on developing interventions or training programmes based on the assessment results. The emphasis will be solely on the development of the assessment tools themselves.
- Non-Cognitive Factors: While the study acknowledges the influence of non-cognitive factors (e.g., emotional state, motivation etc.), it will not extensively explore or include their assessment in the developed tools.

1.4. Significance

This research holds significant importance and contributes to both the academic and practical domains. The study's findings will fill the research gap by providing a novel and objective

assessment tool for evaluating and predicting cognitive processes in upcoming tasks. The significance of this study can be summarised as follows:

- **Advancement of Knowledge:** By developing an objective assessment tool, the study expands the existing body of knowledge in the field of cognitive assessment and HP optimisation. It contributes to the understanding of cognitive processes relevant to any task and provides insights into how these processes can be effectively evaluated.
- **Identification of Individual Capabilities:** The assessment tool will enable organisations to identify the strengths and weaknesses of individuals in relation to cognitive processes. It will also help in identifying high-performing individuals who possess strong cognitive abilities and those who may require additional support or training.
- **Targeted Training and Interventions:** The findings from this study can guide the development of targeted training programmes and interventions. Organisations can utilise the assessment tool to identify specific areas of improvement for individuals or groups, allowing for tailored interventions to enhance cognitive processes besides improving overall performance and safety outcomes.
- **Risk Mitigation and Safety Enhancement:** Accurate assessment and prediction of cognitive processes in work environments can significantly contribute to risk mitigation and safety enhancement. Organisations can proactively identify individuals who may be at a higher risk of errors or performance decline owing to cognitive limitations, leading to the implementation of appropriate strategies and countermeasures to reduce accidents and improve safety.
- **Selection and Recruitment Processes:** The assessment tool can also be utilised in the selection and recruitment processes of safety critical industries. Organisations

can use the tool to evaluate cognitive capabilities during the hiring process, ensuring that candidates possess the necessary cognitive abilities to perform effectively in work environments.

- **Practical Real-World Value:** The developed assessment tool has direct practical implications for organisations operating in safety critical industries. It provides a standardised and reliable method for assessing and predicting cognitive processes, offering actionable insights for human resource management, training and overall performance optimisation.

Overall, this study's significance lies in its contribution to the academic understanding of cognitive processes and the practical value it offers to organisations in terms of performance optimisation, safety enhancement, targeted interventions and improved decision-making. The findings have the potential to bridge the gap between research and practice, benefiting both the scientific community and organisations seeking to improve HP and safety outcomes.

1.5. Structure of the Thesis

Chapter 1: Introduction:

The introduction chapter provides an overview of the research topic and its significance. It outlines the research problem, research objectives and research questions. It introduces the context of the study, highlighting the importance of improving HP in safety critical industries. The chapter concludes by outlining the structure of the thesis and providing a roadmap for the subsequent chapters.

Chapter 2: Literature Review:

The literature review chapter presents a comprehensive review of existing research and scholarly work related to improving HP in safety critical industries. It explores key concepts such as cognitive processes, workload, fatigue, error reduction and safety enhancement. The

chapter critically examines the gaps and limitations in the literature, highlighting the need for further research in assessing and optimising human performance. It sets the foundation for the research by identifying the current state of knowledge and guiding the research hypotheses.

Chapter 3: Methodology:

The methodology chapter explains the research design, data collection methods and analysis techniques employed in the study. It outlines the chosen approach for developing an objective assessment tool for evaluating cognitive processes. The chapter discusses the sample selection process, ethical considerations and the procedures followed in data collection. It also addresses any limitations or potential biases that may arise from the chosen methodology.

Chapter 4: Results and Discussion:

The results and discussion chapter presents the findings obtained from the application of the developed assessment tool. It provides a comprehensive analysis and interpretation of the collected data. The chapter discusses the empirical evidence related to cognitive processes, workload, fatigue, error rates and safety outcomes. It examines the relationships and patterns identified in the data, addressing research questions and hypotheses. The chapter also compares the findings with previous research, highlighting areas of agreement or divergence.

Chapter 5: Research Application:

The research application chapter focuses on the practical implications and applications of the study's findings. It discusses how the assessment tool can be implemented in real-world settings to enhance human performance, reduce errors and improve safety. The chapter explores potential strategies for integrating the assessment tool into training programmes,

personnel selection processes and performance evaluations. It also addresses the challenges and considerations associated with the adoption and implementation of the tool.

Chapter 6: Conclusion:

The conclusion chapter provides a summary of the key findings, contributions and implications of the study. It restates the research objectives and highlights how the study addresses the research problem. The chapter discusses the significance of the findings in advancing the understanding of HP in safety critical industries. It reflects on the limitations of the study and provides recommendations for future research. The conclusion chapter concludes by emphasising the practical value of the research and its potential impact on improving safety and performance in various industries.