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Verification of the relevance and applicability of the proposed approach in industry

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Table of Contents

This project has received funding from the European Union's Horizon 2020- MSCA-ITN-2020 under grant agreement No. 955901

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Executive summary

This executive summary provides an overview of the key findings and insights gathered from interviews conducted as part of a project focused on collaborative systems between Human Factors and AI, with a particular emphasis on safety-critical applications. The purpose of the interviews was to gather feedback on the design of experiments and research hypotheses for each living lab, assessing their relevance to industry in various domains in the context of WP4 "Human factors & Neuroergonomics for collaborative Intelligence frameworks" The following subsections summarize the main points highlighted by the interviewed experts.

1.Collaborative Robotics and Naturalistic Interactions (LIVE LAB 1 Scenarios):

Teleoperations in cobots: The development of a Live Lab focusing on collaborative robots (cobots) proved valuable in investigating the impact of operator's loss of important sensing information and situational awareness on performance. Human-machine interfaces and modes of interaction were found to effectively address this issue, with potential applications in real-time monitoring of operator performance and incorporating intelligent features into systems.

Programming by demonstration in cobots: Experts highlighted the potential of programming by demonstration to leverage humans' cognitive skills and adaptability while combining them with robots' precision and repeatability. Challenges in transferring human task knowledge and improving robot-to-human communication were identified, suggesting improvements in smarter robots, enhanced communication methods, and better correction facilities.

Safety and Effectiveness for Human Robotic Collaborative Cells: Experts emphasized the need to enhance safety and risk assessment in human robotic collaborative (HRC) environments. They recommended the application of harmonized European norms, compliance with relevant safety standards, and the publication of specific harmonized European norms related to HRC. Clear safety life cycles, well-defined safety functions, and predictable performance requirements were identified as crucial in HRC applications.

Ergonomic Assessments and Real-time Monitoring in human robotic collaborative tasks: The use of EEG and EMG sensors to acquire physiological data during assembly tasks was considered innovative for assessing operator performance and providing feedback. The focus on ergonomics, human factors, and real-time monitoring of workers' physiological state demonstrated a proactive approach to improving safety and efficiency in collaborative workplaces.

2.Supporting Anomaly Detection in Manufacturing Environments(LIVE LAB 2 Scenarios):

Probabilistic Machine Learning for failure prediction: Timely and confident predictions of failures in machine operations were highlighted as valuable for enhancing industry floor safety. Proactive management of safety and maintenance can be achieved by employing ML models to predict failures.

Early signal warning for human errors and performance issues: Algorithms that consider all variables involved in optimizing operations were emphasized to prevent escalation of stressful conditions and optimize each line position.

Use of latent spaces in security risk detection: AI can model complex environments and provide security risk detection. However, AI itself presents security challenges, necessitating increased security measures for achieving concrete results.

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3. Decision Making and Alarm Management in Safety-Critical Control Room activities (LIVE LAB 3 Scenarios):

Experts stressed the importance of smarter human-machine interfaces (HMIs) to support human reliability in control rooms. Poor HMI design can lead to sub-optimal operator performance and potentially disastrous consequences. AI-enhanced decision support tools, troubleshooting procedural support, and efficient task allocation between human and automation tasks were identified as critical for improving operator performance, situational awareness, and reducing mental workload.

4 Cross sectional aspect: Neurofeedback and Physiological Signal Processing for Real-time Performance Assessment:

Objective measurement of mental workload in real-time was highlighted as a means to assess worker performance and prevent errors. By predicting the likelihood of errors and assessing worker distraction or fatigue, safety, production quality, and waste reduction can be improved.

5 Ethical Considerations in Collaborative Intelligence Workplaces:

It was emphasized that technological innovation should consider social norms and user comfort. Privacy protection, data quality, and responsibility were identified as important factors, and policies and regulations should support individual security and privacy without placing excessive burdens on individuals. Gaining insights into how technology and terminology impact human subjectivity, acknowledging biases in data-gathering devices, and valuing cultural diversity are essential for ethical analysis and the advancement of collaborative intelligence workstations.

The interview feedback collected provide valuable insights into the design and implementation of collaborative intelligent systems between Human and AI in the LIVE LAB application envisaged within the project.

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1. Introduction

The purpose of robustness tests is to validate assumptions, as empirical analysis requires clarity on these assumptions to confirm actual results. Despite the seemingly true nature of certain assumptions, it is impossible to avoid them. Given the preliminary stage of data collection, the robustness of the developed approaches cannot be verified at this time. However, it is possible to assess the relevance and applicability of the proposed approach in the industry.

This report presents a collection of testimonials from industry experts regarding the applications within the Live Labs that the ESR (Early Stage Researchers) in CISC (Collaborative Intelligence for Safety Critical systems) are currently working on. The focus is particularly on the Human Factors Engineering aspect. The report explores the importance of applying the methods developed by ESRs in the respective domain and why it is crucial to do so at this moment in time.

The report encompasses various areas, including:

1. Collaborative robotics and more naturalistic interactions.
2. Supporting decision making and alarm management in safety-critical control room scenarios.
3. Supporting anomaly detection with early warning signals in manufacturing environments.
4. EEG signal processing for real-time performance assessment.
5. Ethical considerations for collaborative intelligence settings: testimonials from experts connected to digital SMEs, discussing examples of ethical issues in academia and industry.

Furthermore, the report compares these testimonials with findings from the literature review, providing a comprehensive analysis.

2. LIVE LAB 1: Collaborative robotic and more naturalistic interactions.

Human-Robot collaboration has been shown to improve ergonomics on factory floors while allowing a higher level of flexibility in production. However, the current robot programming interfaces require domain expertise. Moreover, robots' response for every possible event needs to be configured in advance which makes them hard to reprogram. Therefore, more intuitive methods of programming are desirable for instance by demonstration. Such systems could allow a non-expert to intuitively program robots on-the-go, without explicitly coding each detail. This would in turn allows a user to guide the robot through a task which the robot can then repeat either through mimicry or, using more advanced algorithms to extract underlying task primitives.

Although much effort has been put towards demonstrating compelling results in the laboratory, such methods are still not widely used in industrial applications. The main challenges in this field are the automatic learning of task representations and adaptability of the learned tasks in an uncertain

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environment, where each task can be expressed as a series of primitive action components. Additionally, in order to facilitate the widespread use of such technologies, it is imperative to consider human factors including ergonomics, stress and comfort level but additionally legal and certification challenges. Within the Live Lab 1 environment there are two human robot collaboration stations. First a dual arm collaborative robot cell, shown in Figure 1 and secondly a teleoperation cell shown in Figure 2. Each scenario is equipped with a range of human factors sensors to evaluate the effects of the robot instruction on the human user. The objective of the Live Lab is thus two-fold, first explore innovative methods of robot programming and second ensure that the developed methods are human centred and there exists a mean towards certification of such methods in the future.

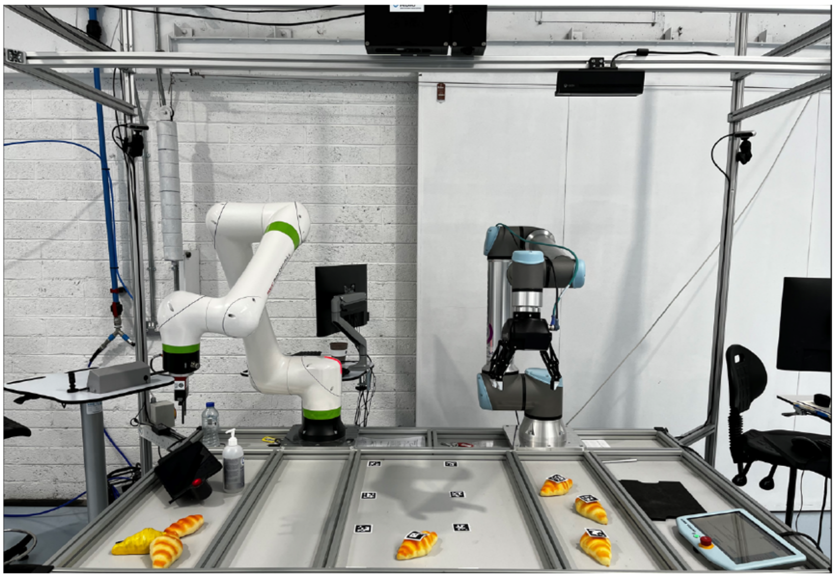

Figure 2.1. LiveLab1: Direct Human-Robot Collaboration cell, featuring two collaborative manipulators a FANUC CRx10 and UR10e each equipped with grippers, and a top down RGB-D camera.

2.1. The case study of teleoperations in cobots: testimonial gathered by ESR 8 Inês FERNANDES RAMOS (UMIL)

Herein the relevance and importance of the proposed approach in industry will be expanded based on the current literature landscape and on the valuable feedback obtained from the expert **Dr. Keerthi Sagar**, **a postdoctoral researcher of the Robotics and Automation team at the Irish Manufacturing Research (IMR) Centre**. As elaborated on deliverable D4.1, in the ESR 8 project human performance is the target collaborative intelligence metric to assess and predict. The project's goal is to perform human performance state prediction in complex human-computer interactions, based on explainable deep learning and multi-modal data fusion techniques. The collection of human data for training the model will be performed within Live Lab 1, using a specific use case of human-in-the-loop telerobotics for medical device manufacturing, as the industrial case study of collaborative human-machine/computer interactions. Live Lab 1.2 will follow the experimental hypothesis that human-machine interface and interaction factors can affect the cognitive/mental state of the operator and consequently the teleoperation task performance. Operator physiological signals will be monitored by mobile and wearable sensor devices, and their performance state will be validated with subjective

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measures collected through questionnaires, and objective indicators computed from the recorded physiological signals and task-related measures.

The Live Lab 1.2 is being conducted at the IMR's facilities in Mullingar in collaboration with another EU's Horizon 2020 project FineTETHER, Fine ManipulaTion in MEdical Device ManufacTuring witH TelERobotics, that studies the use of robotic teleoperation to perform complex tasks requiring fine manipulation, high performance, sterile environments and handling of miniature components, in medical device manufacturing applications. The project has one confirmed industry partner from the medical device manufacturing industry, Medtronic, that demonstrated their interest with a MOU. The partner is interested in improving a manufacturing process and potentially automating it, as a mean to increase yield rate of product and operator ergonomics. The use-case scenario and the proposed approach holds high relevance on both demographic and technological standpoint. At the demographic level, the use case is relevant for Ireland, which hosts 18 of the top 25 global medical device companies. With such a significant number of medical manufacturers, IMR recognises its demographic advantage and is willing to cater to this specialised market. CISC alongside FineTETHER directly targets one of biggest industries in Ireland (MedTech) and aims to solve the key-issue of robotic automation in a high labour cost market. The medical device manufacturing industry requires precise assembly tasks and the manipulation of complex objects. In particular, for the Medtronic's "Atherectomy Skive Process" use case (a subprocess of the manufacturing of a device used to perform atherectomies*), precise cutting involving skive and straight trim cuts on a small device are necessary (Figure 2.1.1 - A shows the two Hawkone models used and Figure x.1 - B shows the device tip and corresponding skiving tip work steps). Currently, these steps are performed manually, which requires skilled operators to perform difficult precise cuts with handheld razor blades (Figure 2.1.2-A). This operation not only presents a risk to the operator, but also leads to variable quality of the produced devices and the need to carry out visual inspections to monitor for acceptance, scrap, or rework. In addition, the process must be performed in a sterile environment, which requires the worker to wear personal protective equipment during the task.

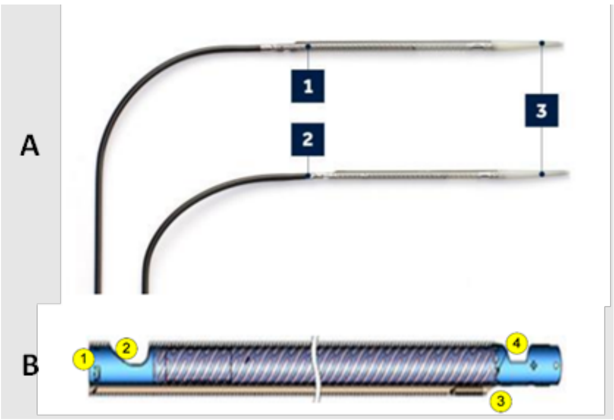

Figure 2.1.1- A: Two model's of the Hawkone directional device, B: Distal tip of the device, indicated on the top image as 3).

Similarly, other current industrial manufacturing processes still employ manual teleoperation techniques with heavy reliance on the expertise of the operator. Although telesurgery has grown significantly in the medical domain, most of the techniques are not transferable to manufacturing scenarios, where task time and cycle time are of critical importance. To complete complex tasks successfully, the operator needs a high degree of sensor feedback, such as the vision system, force, and touch. This plethora of sensory feedback and their interactions gives rise to several technological

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challenges, which can affect human perception, compromising efficiency, decisions, and skill-based performance, resulting in naive one-to-one teleoperation cells for specialised applications (surgery) and not applicable to medical manufacturing.

An improved human-in-the-loop teleoperation system (Figure 2.1.2 - B shows a representational depiction of the telerobot Skive Cell setup) is proposed as the solution for these general industry and specific use case needs, combining the benefits of the robotic system (motion scaling for highly precise movements, speed, accuracy, repeatability, adaptable vision system) with the expertise of the operators, reducing automation costs, lowering safety requirements compared to the use of cobots or manual operations, and reducing the costs of maintaining a clean room. Within the FineTETHER project, teleoperation will be first explored as an assistive system to the worker in performing the skive process, and ultimately it will provide a demonstration of cobot capability and motivation towards full task robotization. In teleoperation of robots the operator loses important sensing information and situational awareness that is available otherwise in standard manual assembly. Therefore, this is an appropriate case study to assess states of degraded performance that can occur from poorly designed human-machine interfaces and modes of interaction.

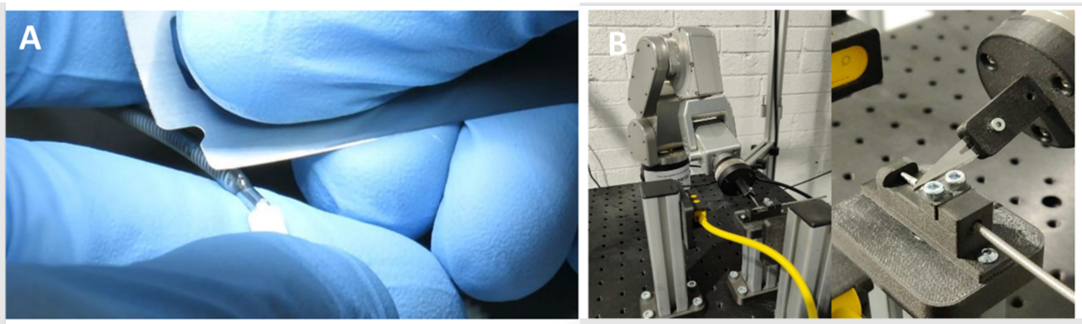

Figure 2.1.2- A: Operator holding product and blade during Skive process, using Personal Protective Equipment, B: Medtronic Skive Cell Setup (setup and scalpel trajectory are only representational and not functional cutting)

Human performance will be assessed in this specific context, but the developed framework, ideally, can be used in other human-machine/computer interaction contexts that require an evaluation framework to ensure the human-system interactions are designed with the human in mind. Beyond the development of a predictive model, the experiments conducted in Live Lab 1.2 aim to provide insight into the telerobotic factors and assistive tools that can improve or affect operator performance, and in particular what are the key features for more natural user-system interaction. According to robotics expert Dr. Keerthi Sagar, the current industrial manufacturing conditions can be significantly improved by applying state-of-the-art supervisory teleoperation in place of the traditional manual/semi-autonomous teleoperation alongside mixed reality user interface. This approach will add a new dimension to telepresence in all three domains of vision, haptics and control, and the human performance monitoring can help to synthesize the best combination of features to be implemented on the industrial use-case scenario. Features such as haptic force feedback combined with a mixed reality user interface will be tested in the telerobot, with the goal of improving the human-machine interface and reducing operator training time.

Due to recent advances in mobile, pervasive and wearable technology, it is now possible to monitor the operator's internal state (defined as a dynamic cognitive or affective condition that can affect the humans' behavior and performance during interaction with a system (Putze and Schultz 2014)), through changes in their physiological signals. Intelligence systems can then be informed of the

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operator's state, not only to avoid critical situations of degraded performance, but to act proactively and adapt the automation level, the interface or interaction mode to the operator's needs to achieve optimal system performance. The affective computing field has been the focus of many researchers for a while trying to achieve more intuitive and natural human-computer interactions. Most works have tried to recognise the emotions and stress of HCI users, using audio, video, text, or physiological data collected from users, and more recently the popularity of multimodal frameworks has increased to achieve better performance and robustness (Poria et al. 2017). In particular, physiological indicators of spontaneous state changes have gained popularity, since contrary to other modalities, these changes cannot be controlled or masked by humans. Most of the affective computing research is focused on commercial and health applications, such as consumer sentiment analysis using text or video reviews. With the recent concern about safe human-machine interaction and collaboration, in particular for safety-critical environments, a human-centric design of intelligent machines and systems became the goal. Performance-driven design has been previously researched using phsycho-physiological models of human performance in the fields of avionics (Lim et al. 2018) and nuclear industry, however for the now more mature telerobotics and virtual reality technologies, in which the human does not have direct access to part/all of the environment information and sensory modalities, further research into human factors is needed to achieve the same level of widespread use and dependability.

With this Live Lab, we can investigate the specific telerobot system factors that impact performance and collect relevant human performance data, specifically for HCIs, to train a deep learning model to predict performance degradation. Human performance will be modelled by the novel neuroergonomics framework developed by (Dehais et al. 2020), that maps human performance degraded states, such as mind wandering, effort withdrawal, perseveration, inattentional blindness and deafness to two dimensions, arousal, and task engagement. The framework proposes an alternative human performance analysis to the commonly used concept of mental workload, associated with limited information processing resources, that does not account for all of the identified performance degraded mental states. In this framework, the concept of task engagement captures the goal-oriented aspect of cognition and arousal captures levels of disengagement that happen in states of high arousal or low arousal. These two dimensions will be used to identify different internal states that are induced while performing a teleoperation task, by variations in the HMI's features. For monitoring of arousal and task engagement in HCIs, two types of physiological/bio sensors are commonly used, EEG and Eye-tracking. In Live Lab 1.2 we will use a mobile EEG cap from mBrainTrain (Smarting mobi, mBrainTrain, Serbia) and a Tobii Pro Nano eye tracker mounted on a monitor. The use of these consumer-grade sensor devices will also prove the practicality of the developed framework.

A potential application of such model, if demonstrated to have the required robustness, can be monitoring in real-time the internal performance state of an operator/user in safety-critical human-machine/computer interactions (e.g. using telerobotics for rescue missions, or other types of systems) and perform performance-driven interface adaptation actions to change this state to a more desirable one, or to simply inform the user and give them the decision-making control. For the medical device manufacturing use case, the developed model can also be used in the design stage of the HMI or for evaluation of added intelligent/autonomic features to the system. Continuous monitoring of physiological signals in real time and classification into the states of interest have proven to be an efficient framework for human-centred interface design in other fields (Lim et al. 2018), especially compared to traditional user studies that require explicit feedback and cannot access it in real time.

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The expert noted that, considering one of the project's industrial partners, KUKA with its significant market share in the global medical robotics industry and IMR's close connections to a well-established network of local device manufacturers, CISC alongside FineTETHER, in addition to exploring novel teleoperation techniques, will also create commercial impact.

*Minimal invasive procedure to remove plaque build-up from an artery.

2.2. The case of programming by demonstration: testimonial gathered by ESR 12. Aayush JAIN (IMR)

Currently, the process of programming a robot constitutes a significant portion of the cost of deployment in an industry which is often 4 to 5 times the cost of the robot itself (Statista Search Department, 2015). As the industrial environment evolves towards more complex and unstructured settings, the cost of programming will further rise. Additionally, it will be impossible to manually pre-program all the desired robot behaviours in the future. However, it's much easier and natural for a system integrator to demonstrate the desired behaviour similar to how we teach humans new tasks by showing. Therefore, programming by demonstration (PbD) is a promising approach to teaching robots on the go. Towards this end, we propose a PbD-based interactive learning task learning approach to aid the line workers in the fast deployment of the robots.

To gain insight into the feasibility of the proposed method in the manufacturing industry, we got the testimonial of an industrial expert and Dr. Philip Long. **Dr. Long is currently Lecturer at the Atlantic Technological University in Galway, Ireland**. When questioned about the current trends in the use of robots in the industry, Dr. Long highlighted- "While robotics and automation have been hugely successful in high-volume manufacturing, they struggle to manipulate complex objects and cope with unmodelled variations. As such, there is a strong reliance on manual labour for this type of manufacturing. Unfortunately, such roles tend to be dull, repetitive, and strenuous potentially leading to acquired disabilities in later life."

"Programming by demonstration can allow humans to once again be the centre of the industry by taking on a supervisory role of machines. Through the proposed approach, the cognitive skills and capacity to adapt, which humans excel at, can be coupled with a robot's precision and repeatability to achieve a high-volume flexible manufacturing system in which humans have an important high-value role", Dr. Long.

Additionally, Dr. Long expanded on the current state of the art in the industry, which is still "…pre-programmed robots executing repetitive tasks. However, there are now several smaller manufacturing companies that are using single robots for multiple applications. We believe this is an indication of the utility of retraining and repurposing robots for multiple tasks, an operation that would be greatly facilitated by the above approach. Secondly, due to the pandemic, many companies explored methods of reducing reliance on automation solution providers by training internal staff, the accessibility of the equipment can be reduced by the proposed method."

Dr. Long also expressed concern about the impact of low-cost economies on manufacturing workers and their well-being. "In an era of the aging population, it is imperative to find novel ways to achieve manufacturing without increasing ergonomic strains" Dr. Long.

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Dr. Long advocates for the implementation of PbD methods, like those suggested, within industrial settings, however, there are a variety of obstacles that must be addressed before this can happen. The primary challenge is effectively transferring human task knowledge to the robotic system in a way that is simple for the operator yet understandable for the robot. Stemming from this challenge, we also find a robot-to-human communication, such that the robot can deliver feedback about what it has learned, or anomalies encountered back to the human. Finally, many of the most effective teaching methods require shared workspace and physical human-robot interaction, this presents significant safety and certification risks based on current regulations.

In addition, when considering the current market of industrial automation, Dr. Long suggested three parallel improvements- "First, smarter robots to learn and interpret human actions and task requirements easier. Secondly, better communication means, humans communicate through multi-modal means as a single method normally does not have enough data to fully explain a task. Lastly, better correction facilities, like humans no automated system will likely be perfect for highly variable tasks first time with limited instruction, therefore we need to explore methods to judge and improve system performance over many iterations."

2.3. The case of addressing more safety and effectiveness for Human Robotic Collaborative cells in a more agile way: testimonials gathered by ESR 13. Shakra MEHAK (PILZ)

Human-Robot Interaction (HRI) is becoming a topic of increasing relevance in the industrial sector, as the integration of robots into industrial environments has the potential to improve efficiency, productivity, and safety. In manufacturing, for instance, robots can perform repetitive operations such as welding or painting, whereas humans can perform tasks that require dexterity or problem-solving abilities. This division of labour can help greatly and limit the possibility of human error. In addition, robots can be employed for inspection and maintenance, gaining access to inaccessible regions, or performing unsafe conditions. However, current human-robot collaboration (HRC) technologies are limited in terms of safety and reliability, which are crucial in risk-critical environments. Confusion about European safety regulations has led to situations where collaborative robots are used behind barriers, which negates their benefits and reduces overall productivity (Cuninka & Strémy, 2015).

Developing safe and effective HRC systems for complex industrial or daily tasks remains a challenge. Factors that should be considered in order to make HRC safe and reliable include the design and layout of the workspace (Michalos et al., 2015), the capabilities of the robot, the training and supervision of human workers(Matheson et al., 2019),the communication and coordination between humans and robots (Hiatt et al., 2017), and the development and implementation of safety standards and regulations. The current HRI framework has been mostly tested and validated on the robotics side, but the human element has yet to be explored, although humans play the key role. In addition, when designing HRI applications in the industry, much attention is paid to robot performance, but the human element does not get much consideration. This gap exists due to the need for more guidelines and recommendations in machinery industry standards considering human in the loop. In addition, another aspect of ESR 13's is establishing the relationship between artificial intelligence (AI) and human-robot interaction (HRI). One of the key challenges in HRI is to develop AI systems that can understand and respond to the subtle cues and signals inherent in human-human interaction. This approach involves recognizing and processing nonverbal communication, such as facial expressions,

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gestures, and body language, as well as verbal cues, such as speech, tone, and intonation (Li et al., 2022). The ability to interpret and respond to these cues is crucial for creating AI systems that can engage in meaningful interactions with humans. Another important aspect of HRI is to ensure that the AI systems are safe and reliable. It requires the development of algorithms and architectures that can guarantee predictable and safe behavior, even in complex and dynamic environments. It also requires rigorous testing and evaluation to ensure that the AI systems meet the highest human performance and safety standards. In order to enable the adoption of HRC technology with confidence in industry, there is a need for harmonized European norms related to HRC. Assessing the safety of human-robot collaboration is an ongoing process that involves a combination of risk assessment, testing, observation, training, and data analysis. Safety in human-robot collaboration refers to the measures and technologies that are used to ensure the safety of humans who are working with robots. This can include measures to prevent robots from causing physical or cognitive harm to humans, as well as technologies that allow robots to work alongside humans as team member.

To assess the practicality and significance of our proposed HRI approaches, we asked for their opinion to three industrial experts from Pilz, Ireland, Dept: Industrial Automation. These experts, with extensive experience in the automation and safety industry, provided valuable insights into the applicability of our proposals. Their feedback was as follows:

***Michael Guilfoyle-* Services & Support Manager, Certified Machinery Safety Expert (TÜV Nord), Certified Expert in CE Marking, Pilz Ireland, Industrial Automation (PIIA):** I can confirm that your findings are in line with Pilz experience with HRC applications and feedback we get from our customers and industry partners. There is a lack of understanding as to when a HRC application is sufficiently safe in industry and what feeds this is a lack of clear guidance. In particular, the fact that there is no specific European Normative harmonised to the Machinery Directive 2006/42/EC feeds this lack of understanding and in turn confidence. The ISO 10218 standards are harmonised as EN norms to the Machinery Directive, but they do not delve into the detail for HRC, rather open the door for the option. The ISO/TS 15066 is an ISO normative document representing technical consensus but is not a European Normative directly harmonised to the Machinery Directive. There are links due to reference to harmonised EN norms, but it needs compliance expertise to explain this. Within Europe CE Marking is a legal requirement for machinery and industry achieves the CE Marking requirement by applying applicable ESRs from applicable regulations and directives. A means of doing this with confidence is identifying applicable harmonised European Normatives and applying them to the equipment and application. Harmonised European Normatives once published in the official journal of the EU have a legal standing abiding to the regulation or directive to which they are harmonised. As the is no specific Harmonised European Normatives related to HRC there is a lack of confidence in verifying compliance to the EHSRs of the Machinery Directive as is required for CE Marking. If I was to recommend any embellishment of your great work to date it would be to call out very clearly that for Europe, Harmonised European Normatives related to HRC need to be published in order for industry to adopt with confidence. Similarly, ANSI/RIA R15.06 standards are required for the USA. As Europe and the USA are leaders in how to give technical standards a legal basis other region will follow. There are many updates and new standards in development and of course this is easier said than done but the process is clear and proven. When industry has standards that provide legal protection, they are more willing to apply modern technology as there is a clear and compliant method to do so.

Also, as an industrial expert in the field of automation and safety, I can attest to the growing relevance and applicability of human-robot interaction (HRI) in industry. The integration of HRI into industrial

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processes has the potential to significantly enhance the efficiency, productivity, and safety of these processes. One of the key factors driving the growth of HRI in industry is the increasing importance of human factors. The ability of HRI systems to interact with humans in a natural and intuitive manner is crucial for creating safe and efficient work environments. This includes the ability to recognize and respond to human gestures, expressions, and body language, as well as the ability to understand and respond to verbal cues. Another important factor is the increasing complexity of industrial processes, which requires advanced HRI systems that can handle dynamic and unpredictable environments. These systems must be able to process vast amounts of data and make decisions in real-time, while also ensuring that the interactions with humans are safe and predictable.

Final thought, the integration of HRI into industrial processes has the potential to transform the way we work and interact with technology. By considering and focusing on human factors, HRI has the potential to create safer, more efficient, and more productive work environments. The potential applications of HRI in industry are numerous, and I believe that this technology will play a crucial role in shaping the future of work and industry.

Robynson Molinari- Machinery Safety Engineer, CECE - Certified Expert in CE Marking (TÜV Nord - Pilz). (PIIA)

Started in 2004 in Brazil performing compliance assessment in machinery to be delivered within Europe, following requirements for the Machinery directive and applicable harmonised standards, covering several industries segments for countless types of application. Since than it is possible to witness the increase of technologies employed in the industry to increase productivity, reduce operational costs, reducing the human use in repetitive tasks and gain safety on the interaction between human and machines. The application of robots working together with human is increasingly taking space in the industry and commonly possible to see a real application in the shop floor.

Perform a Risk Assessment on the application following requirements from EN ISO 12100 is fundamental during design and implementation of cobots solutions, additionally adding requirements from type C and B standards such as EN ISO 10218-2, ISO TR 15066, EN ISO 13855 and EN ISO 13849-1 are some examples. However, with the robots working together with humans, new challenges and hurdles are raised.

In particular those related with **human error** and **human behaviour** are the most relevance and in the focus.

Suggestions

Considering the human factor during the teaching task at the whole phase of the machine/solution life cycle, hazards can be listed as follow:

- Forget/not do a risk assessment regarding all activities to be performed during the teaching task, including risk assess the work area, the surrounding environment, the impact in other activities, the traffic of people/trucks/forklifts, if more than one person working together, any required work permit, the duration of the activities including start and stop times, the communication with relevant areas/departments/supervisors, and other identified hazards.
- Forget/not do the workspace limitation of the Cobot including end-effector and possible load, considering all sides, as well the service level (Installation level) and above area of it.
- Forget/not do the use of suitable PPE, if required.

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- Perform the activities with deviation from procedures.
- Perform tasks under stress, fatigue, physical stress.
- Perform incorrect tasks such as add incorrect input/output activation.
- Lack of well define tasks to be performed by the Cobot and teacher assume individually additional tasks without risk assess the results.

The application of technical standard is the state of the art when the subject is safety. In this regard I can notice in the industry that a huge lack of knowledge of how to identify the correct standards, how to read and link all applicable standards, and how to apply it for the indented application/solution generate the hazards and risks to the operator.

Islam Attia ||CMSE, CECE,CEFS ||Technical Lead | Process Functional Safety Engineering, (PIIA)

Over 12 years of experience assisting clients in the process industry sector through consultation services in managing functional safety, from Risk identification through Risk assessment to Safety requirements specification followed by SIS Design, verification, implementation to on-site Installation across Oil and Gas, F&B, Nuclear Power Plants and Pharmaceutical Industries. I see the applications of human robot collaboration as more applicable to the manufacturing processes in the different industry sectors, where processes like packing, assembly and precise manufacturing steps can make use of the enhancements offered by robotics in precision, automation, efficiency in repetition and various other aspects. Process industry applications in the oil & gas, petrochemicals, pharmaceuticals, and other comparable industries would involve chemicals processing as part of the production process through a fixed or modular plants layout with defined process boundaries where human contribution to the process is kept to the minimal and is mainly involved in operations supervision and keeping interventions within the scope of defined tasks of alarm or emergency response. The nature of these processes can be different from what have been known as man-controlled processes that have been developed to involve aiding machinery and continuously developed towards a heavy dependence on the various automation elements introduced by machinery in the manufacturing process, for example human robot interaction.

Suggestions: Functional safety in process industry sector shall seek performance compliance to IEC61511 specifically and in conjunction with the main functional safety standard IEC 61508 as applicable. Both standards are performance based and not prescriptive, with an ultimate target of providing the definition, tools, techniques, and methods to achieve clear safety through optimal design as long as the safety system integrator can prove functional safety is achieved throughout the lifecycle. Industrial applications that can involve risks to environment and personnel must have a framework that describes the methods and techniques to manage the identification, classification, control, and mitigation of these risks. IEC61511 clearly provide definitions of the functional safety management policies, provides clear definition to the safety life cycle activities that shall be performed when involved in functional safety from analysis to design & implementation up to Operation & maintenance. One main aspect of functional safety management is to be able to clearly define the risks, assess their severity and likelihood, be able to define how far is your process from the tolerable risk level, be able to define and allocate an effective design concept of a safety function that reduces the risks within the tolerable level, be able to clearly define safety requirements specification that the safety function should fulfil, this safety function design concept shall be verifiable and can undergo defined analysis to identify the level of probability of failure on demand, should also have the means to assess, control and eliminate as much as required any expected systematic failures that can be

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involved in the process of definition, design, implementation, operation of this safety functions. In summary, the safety functions required to reduce identified risks should have well defined predictable performance requirements that can be defined, assessed, verified, and validated through testing in applications like cobotics.

2.4. The case for ergonomic assessments and monitoring workers' physiological state in cobotic workstations: testimonial from Safety and Health Environment Officer by ESR 7. Carlo Caiazzo.

The Design of Experiment in the live lab 1 at the Faculty of Engineering, University of Kragujevac (RS) contributes to the design of an experiment aimed at verifying the architecture necessary to acquire physiological data in assembly tasks helpful to provide feedback on the operator performance. The tests are conducted in an innovative modular assembly workstation, the base of future experiments with the implementation of collaborative robots alongside with the human. The data are acquired using EEG sensors (cognitive workload) and EMG sensors (physical workload). The focus on Ergonomics is of pivotal importance in the collaborative workplaces to set the Safety and Human Factors principles and let the operator cowork with robots effectively. In this regard, a testimonial from an industrial company, highlighted the importance of an ergonomic assessment and its impact in the industrial assembly scenarios. According to the Safety and Health Environment officer (SHE) from Yangfeng company, https://www.yanfeng.com/en, stated:

"Workplaces that involve manual production of parts, manual positioning of materials, manual bending of material edges, manual finishing and packaging of parts are common in production companies in Serbia and as such need to be given greater focus. Such workplaces are covered by more frequent risk assessments, which define activities and measures to reduce identified risks. Greater focus is on ergonomic risks such as body position, body posture, number of repetitions, use of exertive force, etc. The situation on the shopfloor tells us that the workers do not work according to recommendations, but according to their feelings, or as they say, it is faster or easier this way. After speaking to them, some workers start working correctly, but during the day they leave the correct routine/procedure and take incorrect positions of the body, joints, etc. As they are exposed to the risks of non-physiological body position, long-term standing, constantly raised arms for a long period of time, long-term loading of parts of the hand, fingers, etc., it would be good to develop a method of monitoring workers when the first fatigue, drop in concentration occurs, and therefore when they deviate from the prescribed way of working".

Moreover, the necessity of monitoring in real-time the physiological state of the operator during the task is of paramount interest while operators work side by side with robots. According to the SHE, indeed:

"If we could monitor these loads or changes during work, we could define the correct choice of breaks, stretching programs, job rotation or possibly relieve the most critical loads by using cobots. We believe that the introduction of cobots and their proper use would lead to a reduction in injuries, i.e. a smaller number of health problems that later have a very large impact on future work ability and capacity. A methodology is needed to assess which work tasks the cobot would do, how much will be the reduction of ergo load for the worker, and how many benefits it would bring."

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Human Factors (HF) is a pivotal aspect to take into account in industrial manufacturing processes. **Another officer from the Health and Safety Environment department (SHE) from Adient company**, https://www.adient.com/, defined the most important goals that a company must pursuit:

- ***Workplace safety improvement*** *- Safety First approach, ergonomic, safety risk prevention & management;*
- ***Products & processes quality improvement*** *- scarp and reclamation reduction, first-time right approach (all activities are carried out in the right manner first time and every time);*
- ***Productivity & Production efficiency improvement*** *- maximizing results using available human and technical resources.*

Hence, the question asked is how Human Factors is relevant to achieve these goals?

The SHE states:

"In each of these goals & objectives, ***Human Factors*** *have a crucial role. Considering the technical and technological advancement in the industry, automation, robotics and artificial intelligence as well as the introduction of modern principles of organization and process management,* ***Human Factors*** *remain as a single most important factor that can be further improved, thus having significant impact on improvement of previously defined areas and objectives."*

Another relevant question is why HF is essential for the deplyment of collaborative robots in the workplace. According to the SHE:

"Looking for causes of problems encountered on daily basis in industrial practice, it is insisted on finding of real - root cause of problems. In most cases, the root cause of the problem is related to human factor, or behavior and actions of worker at workplace. Responses and measures taken to eliminate the negative elements of human factor on workplace are generally reduced to re-organization of the workplace, job rotation, intensification of training, raising of worker's motivation, penalty - reward mechanism etc. Why specific measures are taken, in what situations, and what are their actual effect on the root causes of the problem is, as a rule, not sufficiently researched or standardized."

Finally, the SHE concludes the interview proposing the advantages that the operator can benefit interacting with the robot:

"In that sense collaborative robots (cobots) are introduced to improve almost every aspect of the company business. It is not just related to the heavy lifting but working side-by-side producing more than either human or robot could ever do alone. Robots offer significant productivity gain with such precision (repetitive tasks, pick-an-place, gluing, etc.) which humans cannot offer. Considering the key critical elements of human behaviour in the workplace such as fatigue, concentration, focus, attention, stress level, mental load, overburden, etc., a solutions to the issues they pose can be offered by sharing work with coworkers such as cobots."

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3. LIVE LAB2: Supporting anomaly detection for human and technological tasks with early warning signals in manufacturing environment.

Live Lab 2 is focused on manufacturing operations in a large-scale automotive plant. The project will collect data during manufacturing and model the human operator's performance versus task complexity. The objective is to exploit this data to optimize human performance while simultaneously predicting anomalies and scheduling maintenance events. Despite increasing automation, the manufacturing sector is still widely based on human operations. Human operators still play a crucial role in many aspects of the industry. This is because manufacturing processes often require a high degree of flexibility and adaptability, which can be difficult for machines to replicate.

Additionally, human operators can make judgments and decisions based on their experience and expertise, which can be valuable in ensuring the quality and efficiency of manufacturing processes. As a result, the manufacturing sector will likely continue to rely on human operators for the foreseeable future. The automotive sector, for instance, is based on assembly lines, where the automation process is becoming increasingly complex. However, as automation technology has advanced, assembly lines have become much more complex, with robots and other automated systems performing various tasks. As a result, different operators contribute to assembly products requiring different operational capabilities and a multi-faceted approach for analysing critical-safety procedures and making technological decisions.

Figure 3.1. Manufacturing facility in IVECO.

3.1. Probabilistic Machine Learning (ML) models to predict failures/faults in machines/produced parts for automotive: Testimonial gathered by ESR 2. Devesh Jawla

The early-stage researcher will use a Probabilistic Machine Learning (ML) model to predict failures/faults in machines/produced parts at IVECO Suzzara during the secondment period. A Bayesian neural network will be used for the purposes of quality control and/or predictive maintenance. The software most importantly gives us estimates about how confident it is about the predictions and this will help decision making of the Human experts.

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The software will be further developed to incorporate human expertise in the form of active machine learning, wherein a human expert can teach a machine to observe and detect critical information so that we do not miss any faulty part and increase the efficiency of anomaly detection. This would be useful in the more efficient detection of faulty parts during the quality control step of production. Similarly, on the predictive maintenance side we can use the software to predict with a certain confidence about the lifecycle of working parts of machinery at the plant. Data collected at the plant will be analysed and pre-processed before being used by the ML model. The work aims to benefit the industry by making the manufacturing process more efficient and safer.

I asked for an opinion of an industry expert and leader in manufacturing, Stefano Desideri, Plant Quality Manager, IVECO S.p.A., Suzzara (MN) Plant – Italy. I had a nice conversation with him, and we discussed about the potential of active machine learning and its relevance in the industry. Below I enumerate the key questions:

1. How do you think this work will affect the safety on the industry floor? - "The usefulness of having timely and confident predictions of failures in the operation of machines will make the industry floor safer. Currently, we employ a planned maintenance of equipment but with correct predictions of failures before they occur, we can be proactive in managing the safety of the industry floor and the customers."
2. How do you think this work will impact the efficiency of the industry in general, and the production assembly line in specific? - "The efficiency of the industry is bound to improve if we can perform maintenance pro-actively. An intelligent and efficient prediction software will not only reduce the costs by preventing failures at critical times, but also reduce costs by preventing the replacement of good and healthy machine parts"
3. How imminent does the industry feel the need of this work in the present time? - "I think the industry is ready to adopt software which can predict failures. This will help to be proactive rather than planned"
4. How can the work promote growth in the industry, in areas such as employment (skill development and creation of jobs), public relations (effects of using machine learning in the industry)? - "I think that machine learning will generate employment of workers with new skills and help to develop new skills for the current employees. Innovation is a key factor which drives human growth and people appreciate a company which innovates"

3.2. Use of latent spaces for risk security detection: testimonial gathered by ESR 9. Doaa Almhaithawi (MATHEMA)

Testimonial was convened from **Dr. Alessandro Bellini, CEO - VICE President, Senior Research Engineer at Mathema SRL.** He provided his opinion about the project of ESR 9 with the title "**Empowering Human Computer Interaction: Artificial Intelligence methodologies and Security challenges**". In particular this ESR is focusing on the use of latent spaces for risk security detection using communication devices (e.g. WIFI, security cameras) or smartphone.

The application should be composed of two parts:

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1. Front-end: a user using a viewer (a cell phone or a VR/AR device) scans an environment and transmit to the back-end images with given frequency and resolution;

2. Back-end: it recognizes peculiar objects in the transmitted images (e.g. Wi-Fi d routers, cameras and the like) and, exploiting the service of an AI agent in the style of AutoGPT or BabyAGI makes aware the user of the security risks and the necessary actions to be undertaken to mitigate such risks.

Alessandro Bellini is one of the CEOs of Mathema and an independent researcher. He earned a Ph.D. in Computer Science from the University of Florence, and he has researched in AI from the early '90s. He is author of scientific papers and some best-seller books in Computer Science edited by McGraw-Hill. He is investigating security research, particularly related to securing Deep Learning and Reinforcement Learning using Multi-Party Computation and Homomorphic Encryption.

What is the relevance and applicability of methods developed compared to the state-of-the-art?

"The ESR's work is a blend of theory and practice so applicability is inherently guaranteed. For instance, to control a robotic arm theory is pursued to detect anomaly situations in the normal working in the arm due to an eventual physical obstacle between the robotic arm and its target (e.g., a weight to be lifted) but the theory is proved in practice. Is the obstacle correctly detected? Is the robotic arm able to lift the weight? "

Why does it matter to apply the methods developed by the ESR in the domain of reference?

"ESR's project is very relevant, due to the fact that it is impossible nowadays to pursue a concrete target without innovation and research. The classic industrial approach is no longer sufficient even to accomplish the more basic business."

Why is it important to do so at this moment in time?

"It is of paramount importance in this precise moment in history, as security challenges are relevant even in international conflicts. It was common practice to underestimate privacy and security, to be focused on achieving some technical or business goal but, in this historical context, even the most mundane goal could be hampered by the malicious and hidden attack of some enemy party.

How Artificial Intelligence is used in security challenges and what are the new contributions that it offers to the field?

"This is a remarkably interesting question. The relation between AI (Artificial Intelligence) and security challenges is twofold. AI may model complex environment that cannot be modelled with more traditional techniques (e.g., latent spaces can represent the essential and true relationships among entities in a certain domain) but, at the same time AI itself is a sort of security challenge, due to the fact, especially, Machine Learning is subject to the most insidious privacy and security attacks such as poisoning and evasion. So, AI systems must be made increasingly secure if any concrete result has to be achieved."

Can we still survive without Artificial Intelligence contributions in the industry or is it necessary to constantly keep up with the recent technologies?

"AI is a real game changer with the capacity of revolutionizing even the common conceptual workflow of design and producing products and services. However, AI is not the one that catches all technology.

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Another revolution is in view: the Metaverse, i.e., a completely unusual way to interact in the web including the ways in which business is made."

3.3. Early signal warning to prevent human errors and performance issues on the shop floor: Testimonial gathered by ESR 11. Carlos Albarrán Morillo

The Live Lab 2 project in IVECO can benefit the company's manufacturing operations in a large-scale automotive plant by detecting possible causes of human errors or performance issues at different workstations on the shop floor. Some of these benefits include:

1. Optimization of human performance: By collecting data during manufacturing and modelling the human operator's performance versus task complexity, the project can help identify areas where human performance can be improved and take steps to optimize it.
2. Prediction of anomalies and scheduling of maintenance events: By analysing the data collected, the project can help predict potential anomalies and schedule maintenance events to prevent them.
3. Improved product quality and efficiency: By reducing human errors, the project can help improve product quality and efficiency, leading to increased productivity and profitability for the company.
4. Safety improvement: By understanding and addressing human factors, such as fatigue, stress, and distractions, that can lead to workplace accidents and injuries, the project can help reduce the likelihood of these incidents and improve employee safety.
5. Better Human-in-the-loop-automation performance: By testing human-in-the-loop-automation performance in the context of different workstations, the project can help identify areas where the interaction between highly automated workstations and highly trained human resources can be improved.

These are potential benefits because the project in IVECO has not started yet, so it's not possible to know the real benefits until the research is conducted and analysed.

Francesca Murri is currently a Manufacturing Engineer at the Iveco Group. Before joining Iveco, she worked as a Plating Line supervisor for three years at Glenair Italia located in Granarolo dell'Emilia (BO).

Relevance and applicability of methods developed compared to the state-of-the-art

In a company like Iveco, which has almost three thousand people and with the evolution of the technological processes and the adaptations implemented along these lines, it is unthinkable to optimize the operations manually. So, it's fundamental to use algorithms that consider all the variables involved.

What is the significance of using the techniques developed by the Early-Stage Researchers in the specific area of study?

Regarding your project, we do not have a method or criteria to assign a person to a specific place; we only care about the medical state of people, not their particular skills. It will be important to optimize each line position.

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What's essential to do to implement these methods right now?

Understanding all the processes involved and mapping out a baseline can help you achieve your goals more effectively and efficiently.

What is the significance of using Iveco Group's ability corners in developing and implementing the evaluation methodology of workstations and related operations?

Using the ability corners also allows for a more comprehensive assessment of workers' capabilities, as it covers multiple dimensions of skills relevant to the assembly line work. This enables a better match between the task requirements and the workers' powers, leading to improved productivity, quality, and safety.

Why is it important to implement early warning signals for anomaly detection in the manufacturing environment?

Because our company believe in a proactive approach to all processes and because we are focused on improving every day improving.

4. LIVE LAB 3: Supporting Decision making and Alarm Management in Safety Critical control room scenarios.

The goal of Live Lab 3 is to demonstrate how data analysis and advanced control techniques can optimize the control for the process industry. This Live Lab is situated in Yokogawa's facility in the United Kingdom and additionally in POLITO's facility in Turin, Italy.

Safety is of paramount importance in critical industries like the process and energy industries, for example, in oil and gas facilities. Several error sources have been identified to impact safety in these domains of which human error has been most consequential. However, studies have shown that human error is also present as a result of their interaction with other systems and their environment. Indeed, while human operators are the key in a critical situation in the industry 80 % of accidents in the industry are caused by human. In a critical situation, humans tend to use intuition over systematic evaluation and trade-offs. Sensible to cognitive biases (like recency bias, confirmation bias,…) and overload.

The Live Lab focuses on control room operations and human situational awareness during stressful interventions i.e., alarms. Primarily this Live Lab will be based on Yokogawa's facility with a particular focus on risk monitoring in control runs. To facilitate the research, Yokogawa are providing a dataset with over 150,000 samples and 44 features, consisting of timestamps of alarm and alert events.

The Live Lab will also provide a simulated Distributed Control System (DCS) in a laboratory setting in POLITO in Turin. The system can accurately simulate a process plant and has the flexibility to allow different scenarios of normal operations, failures, and emergencies to be simulated through a scenario editor. The simulator is customizable to produce a range of scenarios and fit with different possible Human Machine Interface (HMI) and DCS environments. This empirical study aims to investigate the influence of both obvious and latent factors (human, organization, and technical) during man-machine interaction and the consequence on human performance and safety. A case study on the production

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of formaldehyde in a chemical plant has been selected and simulated for this purpose. The facility produces around 10000 kg/h of 30% formaldehyde solution, operating the partial oxidation of methanol with air. The human-in-the-loop configurations in the simulation are varied from monitoring to both monitoring and control. Both normal and abnormal situations have been considered as well.

The aforementioned aspects will link the control room operations simulations to the biometric data providing the opportunity to investigate adaptive "human in the loop" automation features, such as decision-making support and what real-time impact they have. These features will be defined in collaboration with a DCS equipment supplier (Yokogawa) who has a leading role in the committee for HMI for the International Society of Automation (ISA). By analysing the data from Yokogawa, the CISC project will:

- Help predict trips and critical scenarios using Bayesian Network (BN) to help decision making for a human operator (identify likely root causes for process deviations). Compare data-driven BN, expert knowledge and data, and purely expert knowledge BN for online prediction.
- Finding clusters of alarms to group them.
- Apply reinforcement learning to classify alarms and help identify nuisance alarms and reclassify them also in terms of priority in an online setting.
- Provide suggestions on response strategy (controllable variables) using reinforcement learning.

- Predict human performance and reliability of human response to critical scenarios.
- Help identify critical information and tasks to support situational awareness (trouble shooting strategy procedure and HMI support for them)

ESR 1, 3,4 and 5 will collaborate on Live Lab 3 as shown in Figure 4.1**.**

Figure 4.1. Breakdown of the roles of different researchers in Live Lab 3.

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4.1. Human reliability modelling to test features of good alarm management: Testimonial gathered by ESR 1. Houda BRIWA (TU Dublin).

Since the emergence of distributed control systems, various benchmark studies have been conducted on alarm evaluation criteria to validate the effectiveness of the current alarm management practices. However, only a few of them consider the perspective of the operators when evaluating the alarm system. Further, there is no unified standard for operator performance indicators when using an alarm system, and only few of the current standards discuss or mention the human performance for alarm management. *(Briwa, H., et al. (2022))*. Additionally, in human reliability, developing data-driven Performance Shaping Factors (PSFs) assessment models with enough transparency between models and source data, to deal with data scarcity and the uncertainty of expert judgments, is still yet to be investigated for oil & gas operations (Liu, J. et al (2021)). From the literature, there are many challenges to Human reliability for control operations in our current time. In our approach, we will be focusing on addressing the ones below:

Alarm flood is still a major issue for most process industries; A major refinery might average over 14,000 alarms every day on average *(O'Brien, L., & Woll, D. (2004)).*

Human performance is extremely situational. It is heavily influenced by the context as experienced and believed by the individuals involved at the time. Thus, it is important to understand the relationship between the different factors influencing the operator's performance.

Data scarcity (Objective & quantitative) has always been a big challenge for human reliability assessment methods as those methods have been initially developed to include qualitative evaluations of the different HRA elements and not objective measures. *(Laumann, K., et al. (2018)).*

Thus, the objective is to build a human performance assessment model for alarm handling for control room operations that tackles the challenges previously cited. The model will explicitly represent causal factors that impact the performance using Bayesian network (to combine both collected data and expert knowledge) and cognitive studies.

To validate our findings for the literature review and the validity of our approach to industry, we conducted interviews with relevant figures from industry to get their insights and feedback regarding our most recent findings.

In the first interview, we had a testimonial from Rob Turner [RTJ], a Consultant and Subject Matter Expert in alarm management good practice. His main areas of application are offshore oil & gas production, refineries, and thermal power generation. In the second one, Adrian Kelly [AK], a principal project manager with research focus on real time control centre operations for electricity networks, has answered our questions. His focus is on alarm management, display design and decision-making improvement efforts. Their answers are as follow:

What is the relevance of the method presented in your industry?

RJT: The subject area is highly relevant. Despite having guidance and standards in the area of alarm management good practice available since 1999 there is still a wide-spread problem in industry with making alarm systems fit for purpose. That is, designing alarm systems that recognise and address human needs.”

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AK: "Alarming in electrical control centres is a constant source of pain for operators and engineers. This issue is likely to be exacerbated by significant new energy resources and devices in future. Having a structured approach to alarm management and decision making will be very beneficial to system operators, to help them monitor assess and control the power system."

What is a potential application of this approach in industry?

RJT: "Part of the issue is recognising and addressing human cognitive limitations. This research has the potential to support an understanding of the many variables in human cognitive performance."

AK: "Most alarms have a standard structured response, a procedure or task to be carried out. Complexity arises where there is a flood of multiple alarms with different priorities and actions and when important alarms are masked by superfluous alarms. Applying a structured approach with analytical techniques to alarm response will help to identify important alarms, make linkages based on past patterns and to guide the operator to the right decision based on machine learning techniques."

Why is it important to do so at this moment in time?

RJT: "There is plenty of evidence that poor human-machine interface design is still a major factor in sub-optimum Operator performance, especially during periods of upset operation or other abnormal situations. These incidents can (and have) led to major equipment damage, environmental contamination, significant financial loss, and in some cases human injury or even fatalities. Consider for example the response during the Deepwater Horizon tragedy in the Gulf of Mexico in 2010. Even a small improvement in Operator performance has the potential for significant benefit."

AK: "Alarm systems are overwhelmed with data, there are multitudes of new resources on electricity systems and new control devices. Network issues are becoming difficult to solve in real time and climate related weather impacts are increasing. To prevent major electricity system catastrophes, the systems in control centres have to be made smarter, to guide the operator, rather than actively hinder them."

4.2. Decision support: Testimonial by ESR 3. Joseph MIETKIEWICZ (HUGIN EXPERT)

To support decision making in process control rooms and the ensure efficient and effective alarm management in process and energy infrastructure industries, ESRs 1, 3, 4, and 5 are working on several decision support systems for both control room operators and decision makers involved in management of change. These proposals include:

Modelling

- Human performance modelling in alarm management situation – ESR 1
- Bayesian network model for critical plant states– ESR 3
- Process safety data modelling for human-in-the-loop configuration in process control – ESR 4
- Human-in-the-loop reinforcement learning for process optimization - ESR 5

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Such models can be used to support operators and optimise the process control room interaction decision support elements being developed and investigated by the ESRs experimentally.

Support systems under development:

- Alarm rationalisation
- Human system interfaces and Procedures
- AI-based support
    - Reinforcement learning agent.
    - Bayesian network.

Verification of relevance and applicability

To verify the relevance of the proposals from the ESRs as detailed above, questions were asked to an **experienced consultant in Yokogawa UK**. Yokogawa is known for their expertise in the design of control rooms fand distributed control systems for various industries.

The discussion started with a presentation of current experiment proposals for different supports under development by the ESRs. The industry expert, together with other attendees gave feedback on the proposition related to:

- *Possible improvements*
- *How these can potentially address industry gaps, especially in process control rooms.*
- *Interests on what can be observed through an experimental study.*

The interview with The Yokogawa expert helped shape the experimental study plan to address the effect and impact of four support tools on control room operators' performance and behaviour in safety-critical scenarios. The decision support tools; alarm rationalisation, procedures/intervention strategy, and an AI-based support system will be varied in four levels with a study group representing each level. The groups are described as follows:

Group 1 – level 1: No decision support

Group 2 – level 2: Alarm rationalisation with procedural guidance

Group 3 – level 3: AI-based support (RLA and BN)

Group 1 – level 4: Alarm rationalisation, AI-based decision support combined with procedural guidance

Each group would test progressively three defined process safety related scenarios (with increasing task complexity and stressors like alarms) for this experimental study.

Potential observation and industry interest from the experimental study

- *Situational awareness improvement in each group using the specific support type vs. combined supports.*
- *Mental workload in each group using the specific support type vs. combined supports.*
- *Mental Fatigue in each group using the specific support type vs. combined supports.*
- *Performance in terms of time etc given the different supports.*

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4.3. Troubleshooting procedural support for human-in-the-loop configurations in process control: testimonial gathered by ESR 4. Chidera Winifred AMAZU (POLITO)

Control rooms operators oversee monitoring, alarm handling, fault detection and handling, of communication with the field operators, etc. in many process plants and or grid facilities (Naito, T, et al. 2011). Their performance is critical to ensure performance of safety-critical industries, as process and energy facilities. However, also their tasks and the systems they are interfacing are changing and they are faced with increased cognitive loads and task complexity. This changing role and its associated issues have been discussed in the literature (*Li, X., et al. 2011)*. ESR 4, through her thesis and together with researchers in Live Lab 3 is focusing on focused on addressing some of those issues in particular troubleshooting procedures.

A human-in-the-loop approach that takes into account the operators' dynamics (cognitive, behavioural and physiological) and system behaviour for process safety data modelling is proposed by ESR4. This probabilistic integrated approach known as the human-in-the-loop cognitive process control and safety model (HITL-CPCS) combines, for the task modelling, the cognitive process concepts (Chang Y.H.J., Mosleh A, 2007), and a process control task framework into SHERPA (for its systematic approach to task analysis of selected safety-critical scenarios and error mode identification). It further proposes operator and system monitoring and data collection on the cognitive states of operators for human and system behaviour in safety-critical tasks such as troubleshooting (see Figure 4.3.1).

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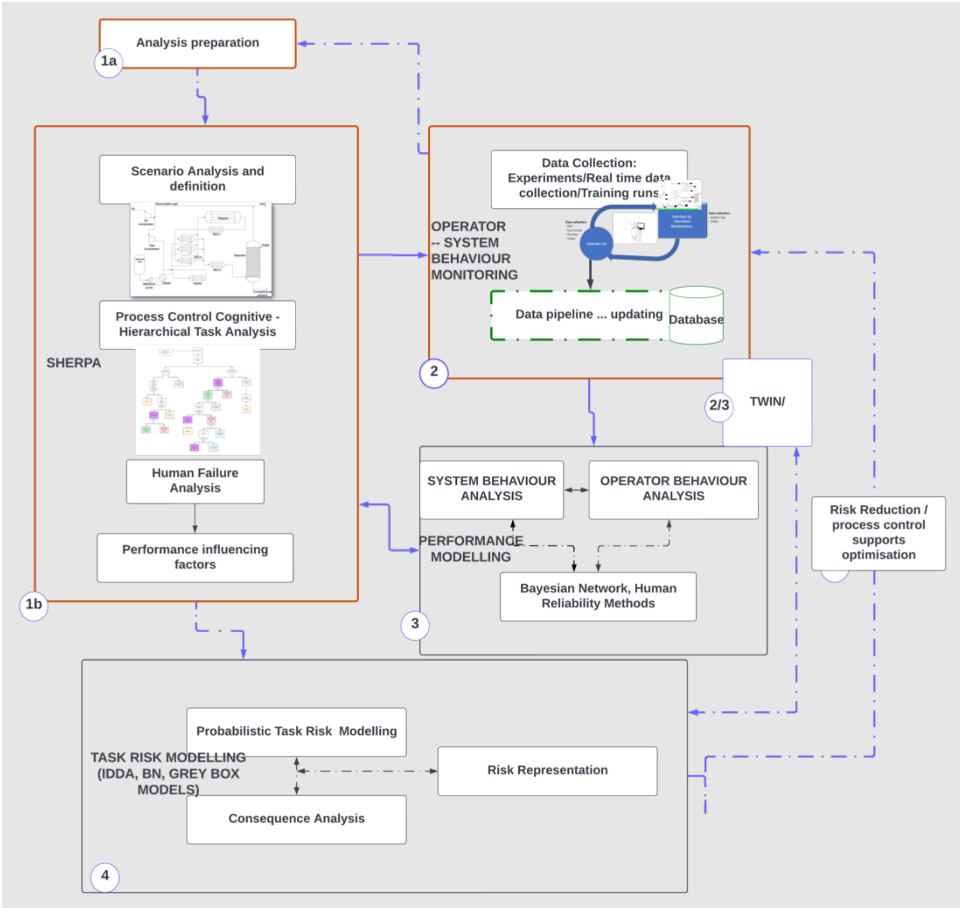

Figure 4.3.1: proposed HITL-CPCS Model/framework

ESR 4 through her thesis investigates the use of procedures and human machine interfaces (HMIs) by operators and how these impact their cognitive states (situational awareness, decision making etc). An experimental approach to studying this proposal is explored in Live Lab 3 using a case study of a simulated formaldehyde production plant with three selected process safety scenarios:

1. Failure of a pressure control indicator of a methanol storage tank.
2. Failure of a control valve of a methanol storage tank.
3. Failure of a temperature control logic of recovery system 3 controlling inlet water temperature to the absorber in the plant.

The potentials of the process safety modelling approach for safety analysis and the optimisation of process control rooms elements such as the procedures/ intervention strategies, human system interfaces have been identified previously in the litterature (*Cacciabue, P.C., 1998)*. However, there are still not many best practices showcasing the achievement of these goals in the process industry. Some interviews were conducted with industry experts to further investigate the relevance of the problem. The experts involved have experienced on operations and design of control rooms for process and energy domains and the use of standards for ergonomic design of control centres (*Cacciabue, P.C., 1998)*. The expert highlighted that it would be interesting to verify the most effective way to offer the use of trouble shooting procedures, alarm rationalisation, to offer better support on the HMI for control room operators. Procedures, depending on the industry, can be computer based, paper based, etc. Further email conversation with an expert in the Human Reliability company in UK

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confirmed the importance of this study and especially the possibility to offer optimisation and visualisation approaches for procedures/intervention strategies in control rooms.

ESR4 has developed together with colleagues a human system interface and procedures which are to be tested experimentally. The procedures are split into paper based (which simulated status-quo in most process plants) and screen-based. These intervention procedures further guide the breakdown of tasks for cognitive based safety-critical task analysis as earlier discussed under 'literature'. Hence, the need to verify the design and proposed experimental study approach to test it. These were presented to the decision makers being interviewed.

Summary of feedback received from Interview with Rob Turner (Control Systems Engineer in Yokogawa) and Adrian Kelly (EPRI)

Feedback on procedures: the procedural design and representation formats are worth testing as proposed by ESR4. Both procedures and HMI are very critical for control room operations. From the proposed study, the screen-based procedures have the potential to reduce response time compared to the paper procedures. Also, it would be worth testing in future studies procedures represented as flow charts.

The procedural designs in use by industry have not been tested experimentally on how they impact operators' performance. Therefore, this study is very important.

Summary of feedback received from Interview with Dr Ferdinand Coster (Strategic Ideation Consultant & Internal Innovation in Alliander NL)

This is a very interesting work. It is important that the screen-based procedures are digitalised and what effects this can have on the operator performance. I hope the study provided empirical evidence in this respect.

A survey was further distributed to other decision makers in process industries and the result is published in a paper titled "Decision Making for Process Control Management in Control Rooms: A Survey Methodology and Initial Findings" under the Chemical Engineering Transactions (Amzu et al. 2023)

4.4. Human-in-the-loop reinforcement learning configuration in process optimization: testimonial gathered by ESR 5. Ammar ABBAS (SCCH)

Based on the interview conducted from the industry experts in the area of process optimization such as Rob Turner, Adrian Kelly and Ferdinand Coster, a key aspect was identified that human-in-the-loop configuration is highly desirable in safety-critical process industries. For this reason, a general hierarchical framework with human-in-the-loop architecture is proposed having a probabilistic model as the top hierarchy defining the system states distribution and reinforcement learning acts as a low-level controller to optimize the process in required states as identified by the probabilistic model. Human interprets the data and acts as a feedback model to fine-tune the model for better suggestions.

General Framework: a general framework is illustrated in Figure 4.4.1 for a specialized RL agent which provides interpretations for humans along with the RL actions through a probabilistic model-based RL. The RL agent specializes in a specific situation and provides a hierarchical architecture (Abbas, A. N., et al, 2022).

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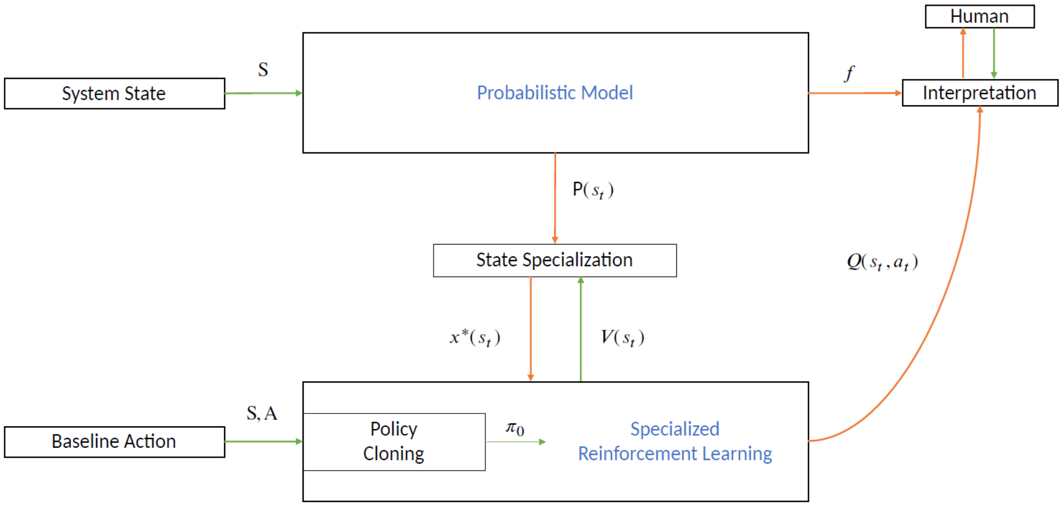

Figure 4.4.1: Specialized Reinforcement Learning Agent (SRLA) from Abbas, A. N., et al, 2022.

The important objectives to fill the gap in the industry related to the use of RL technology in process industry involves:

Objectives

1. Reduce the number of alarms by optimizing the process control through deep reinforcement learning Alarm suppression and prioritization using deep reinforcement learning.
2. Suggest control actions and/or setpoint to the operator.
3. Explainability for the proposed actions/ suggestions.
4. Root cause failure analysis using Bayesian-based methods (such as the hidden Markov model)
5. Disturbance rejection and setpoint tracking using deep reinforcement learning.
6. Residual Policy Learning (RPL) to add a correction factor to the output of the controller response and then feed it to the plant for minimizing alarm flood.
7. To be able to incorporate human ergonomics as the decision-making factor (input) for reinforcement learning.

4.5. Development of advanced methodology for efficient task allocation between human and automation collaborative tasks: Testimonial gathered by ESR.14 Andrés Alonso Pérez (TU Dublin)

For the last few decades, there has been an increasing trend to attempt to automate as many processes as possible in industry, due to the increases that automation brings to efficiency in the processes. That has created many environments in which operators actively collaborate with machines in industrial workshops.

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With automation comes a need to properly define the information that the machine provides to the worker. As was shared in Coster, F. et al., (2017), the problem with excessive automation is that the operator becomes detached from the process, and can lose plenty of useful information, relevant for the performance of tasks. Additionally, automation could not work properly during abnormal situations, like the case of an alarm flood in a control room because of the malfunction of several components from the system.

The solution proposed by (Coster, F. et al., 2017) is Intelligent Adaptive Automation, in which the different tasks of an industrial process should be distributed between the operator and the automated system, in a way that the operator has some relief in the workload assign but doesn't lose important information about the process.

The two main psychological concepts for being able to perform his task allocation are Mental Workload and Situation Awareness. Both have three general ways to assess them: with subjective evaluation from the operator, with psychophysiological measures and with task analysis and performance-related data.

ESR14 has been focusing so far on developing a Deep Learning Feature Extraction Model, that could be used for the assessment of Mental Workload and, ultimately, contribute to the Intelligent Adaptive Automation. This would be part of his contribution to the Live Lab 3, the experiment that simulates a control room.

To determine to what extent Intelligent Adaptive Automation is applicable to a real industrial environment, and what could be the main challenges, Ferdinand Coster, consultant in Alliander and former consultant in Yokowaga, and main author of the referenced paper, has participated in a conversation with ESR14 and the rest of the members of Live Lab 3.

He states that knowing which tasks should be automated is "the million dollar question". Intelligent Adaptive Automation is incredibly complex and depends on many factors, including the environment and the systems, but also the experience from the worker. Assessing the Mental Workload and Situational Awareness is the most challenging part because the mental model of the workers is difficult to define. For example, an operator can be performing the right actions for the wrong reasons. It might not be possible to know what information and knowledge the operator has from the system.

He stated that he is not sure if "it is possible to completely "solve" IAA, but if we can take the concepts to come up with practical solutions that improve the safety and quality of plant operation that's already a big win in my book It might not be possible to precisely quantify workload nor situation awareness, but for a practical application this might also not be required. We do know there are (measurable) factors that influence subjective cognitive workload positively or negatively. If it is possible to use some fuzzy logic to at least come up with something like a High/Medium/Low categorization. I think that's good enough for practical application."

He gives an example from his current industry, which works on the distribution of electricity. Traditionally, it doesn't involve much automation, with the workers mainly focusing on maintenance tasks. However, as they develop a "smart" way to control the network, the operators see their number of tasks increased, and they need to have more information.

Further, he declares that "a practical application also means that implementation must be possible at an affordable cost. For the research you can afford to really dig deep into a couple of procedures /

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abnormal situations with an operator (read: knowledgeable person), but in an actual plant with 100's of procedures that kind of exploration becomes too expensive very quickly and nobody will apply it."

"The idea that's been on my mind was to define for each procedure a set of key performance variables based on the purpose of the procedure and pass/fail criteria. Then with a relatively simple model of the process (e.g. something like Multilevel Flow Modeling) to provide structure of how a neighborhood of variables is related, score each variable based on how much it can influence the key performance variables. Score each step of the procedure on how many variables it touches that have a high level of influence. Steps with a high score are prime candidates for manual execution, steps with a low score for automated execution."

"Again, some high/medium/low score might be good enough. The experimental validation required here is whether such a method is indeed able to pinpoint the variables that an experienced operator would indicate as important, and whether manual execution of task steps with high scores indeed improves SA related to the performance of the task (more so than manually executing steps with low scores)."

5. CROSS SECTIONAL ASPECTS: EEG signal processing for real time performance assessment.

5.1. Use of neurofeedback for real time performance monitoring: Testimonial gathered by ESR 6. Miloš Pušica (MBRAINTRAIN)

Automotive industry is one of the industries where manufacturing operations performed by both robots and humans are an integral part of the process. Even though the manufacturing sector is highly automated, it still depends on human operators to a high degree in various stages. Predictions are that humans will play a key role in the sector in the future, too. Since the focus of the CISC project is on the safety and performance boost in these systems where we have human-in-the-loop, ESR 6 project targets that same goal. Having human-in-the-loop as a key factor, aspects such as operator's mental state, fatigue, attention, and vigilance are something that we must consider. The ESR 6 project is focused on the mental state of human operators in the process, more precisely on near real-time mental workload estimation. There are various physiological indicators of mental workload, but if we need to estimate mental workload in real time, with high temporal resolution, research has shown that the best source of information is EEG. With the advancements of EEG technology, making it more robust, portable, and convenient to use, it is indeed the technology that can be easily incorporated in the manufacturing process in different settings.

To get a better insight in the current state of the industry, EEG technology and mental workload estimation relevance, two interviews were conducted with experts in the field, Dr Ivan Gligorijević, CEO and co-founder of mBrainTrain in Belgrade, Serbia, and Aleksandar Stanković, sales manager at Mitsubishi Electric Europe. Questions asked to Dr Gligorijević and Aleksandar Stanković and their answers are reported below:

How important is the aspect of mental workload of human operators in the manufacturing sector in modern industry?

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Dr Gligorijević: There are a not-so-small number of safety-critical work posts, where the mental workload may play a decisive role. If a worker is under distraction, is tired, or otherwise mentally unable to perform the task at hand - this may cause even a life critical situation. In many more cases this results in creation of faulty components or conducting suboptimal operation and causing damage to the equipment or products. Currently, there is no way to assess the varying mental state of a worker beyond general capabilities. This means we are not able to account for, predict or measure, the objective ability to perform a task. We know only if someone is in general, or, as we say "on a good day" capable of doing a dedicated job. But we know from personal experience that our mental abilities can vary in dependence on previous work, sleep, stress and other conditions.

What benefits could real-time information about mental workload bring to the safety and performance of the manufacturing process?

Dr Gligorijević: If we could objectively measure the mental workload in real-time, we would be able to assess if the worker is likely to perform a task as planned - or not. If there was a model, based on previous experiences, that would predict the likelihood of error is high, we could interfere with the task, stop it completely or simply postpone it. At the same time, we could let the worker, or an operator know that they are distracted or tired. This would benefit everyone and dramatically increase safety, quality of production, and reduce waste. This would be beneficial in general, but especially on workplaces that have safety-critical elements, like railway, flight-control, heavy/production industries. On the other hand, observing mental workload in real-time is not a safety-only issue. By real-time monitoring of mental workload, we could design better workplaces and increase productivity. This is also tightly related to the workers mental well-being. We observe a large number of sick days and stress-related illnesses. If we could pinpoint what causes this mental exhaustion and stress, we could address it in the work process design and save billions of dollars annually.

How relevant is EEG as a source of information about human mental workload?

Dr Gligorijević: Brain is the only source of relevant and real-time information on the mental workload. We still don't know what leads to mental states of stress, increased workload, anxiety - but we can sometimes observe these states by directly measuring brain activity. There is no substitute to this direct observation if we want to assess mental workload in real-time. If we are talking about methods that can be practically employed, EEG comes on top for the simple reason of technology - it can be made small and mobile enough and fit into daily routine. There are other methods, like video systems trained to recognize these differences in mental states - but this hasn't proved sufficient and is an indirect way of quantifying what may be happening in our brains. EEG comes as an intersection of the need to observe the brain in real-time, directly and in a way that could be merged with the existing work routines.

How suitable is modern EEG recording technology for every-day usage in today's manufacturing workplaces?

Dr Gligorijević: EEG technology has come a long way in a very short time. For one, professional mobile EEG systems have been on the market for less than 10 years. And these systems are research devices, not directly applicable in real-life settings where untrained personnel would use them. So far, there have been proof of concepts studies - what EEG could do for us - that disregard the current limitations. And, in my opinion, this proof-of-concept work is very important. If EEG lives up to its promises - there

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will certainly be an investment from various parties to make it usable and advance the technology, design and UX to the point where they could be used similar as helmets or goggles. What we have now is pieces of technology that develop at their own pace: self-applicable dry electrodes, algorithms for data processing, cloud-technology, safe data transfer, etc. Again, in my opinion, what we should do now is not fine tune each of these elements hoping they miraculously come together - but rather focus on the value we could get from EEG even with today's imperfections. If we observe the value that offers roughly 10 times less waste, more safety or similar - we could interest all the parties to solve the remaining issues and come up with a solution fully usable by factories.

Where do you see the role of EEG technologies in integration of human operators in Industry 5.0?

A. Stanković: In the automotive industry, the trend is maximum efficiency and efficiency of the production process. Bearing in mind the electrification of vehicles as an increasingly rapid implementation of new technologies, the key question is how to integrate modern human operators into the production process.

New production lines are increasingly complex, robotic, and very expensive.

It is the task of Industry 5.0 to connect human operators and technology. EEG is the bridge that provides Industry 5.0 with the right information at the right time.

The information that makes up the future of the workplace and that EEG technology enables us to:

- safety and security of human operators and processes

- immediate response based on process monitoring

- Real-time modelling of the workspace. Not all workers have the same skills and behaviours.

- EEG provides data for AI and data analysis, all for modelling and creating the most efficient working place possible in the future.

Where do you see the advancements in EEG processing methods in the future?

A. Stanković: The solutions that have been used so far have mostly looked at the process from the outside in. EEG technology allows us to observe the process from the inside to the outside. In this way, shortly, the human operators as the center of Industry 5.0 will gain importance and production will be more efficient, effective, flexible, and adaptive to changes.

What benefits would advanced processing methods bring to the application of EEG in modern manufacturing workplaces?

A. Stanković: EEG provides an answer to the key question in modern times, why this happens in the process of human operators and machines? When we have the answer to the WHY, WHAT, and HOW come as a logical next event.

EEG is the future of the Smart Factory

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6. Ethical consideration for collaborative intelligence setting.

6.1. Ethical and legal considerations for collaborative intelligence workplaces: Testimonial gathered by ESR 10. Naira López Cañellas (DIGITALSME)

The methods developed for the research aim at providing a multifaceted view of the ethical and legal considerations to bear in mind when setting up collaborative intelligence workstations. All too often, a very narrow set of views is represented when drafting novel codes of ethics and pieces of legislation. Thus, the four research methods chosen for the occasion offer complementarity in several aspects, as they seek to represent a diversity of national contexts; sectors (from representatives of trade unions and EU institutions to the professionals from the private sector and academia); roles in the workplace (such as employees, employers and external partners, e.g. advisors and consultants) and stages in the AI lifecycle (from researchers to consumer association representatives).

To best capture their point of view, the research will combine inputs from:

a) **Document Analysis.** This includes gathering inputs from a wide range of frameworks crafted with the intention of governing AI research and development. Some of those have already been implemented, while others remain on their first stages of development, or contribute to more of a theoretical discussion. Examples include the Montreal Declaration for a Responsible Development of Artificial Intelligence (2018), UNESCO's Recommendation on the Ethics of Artificial Intelligence (2021), the extensive work done by the Council of Europe (CoE) Ad hoc Committee on Artificial Intelligence (CAHAI, 2021), the Ethics Guidelines for Trustworthy AI by the EU High-Level Expert Group on Artificial Intelligence (HLEG AI, 2020), or the Data Ethics Decision Aid (DEDA) by the Utrecht Data School (2021) (Franzke et al. 2021).

b) **Focus Groups**. Composed by representatives of European small and medium enterprises (SMEs) working in the ICT sector, they have been devised to help understand the concerns, challenges, capabilities, unmet needs and views held by SMEs in Europe of emerging ethics codes and regulation.

c) **Semi-structured Interviews** from a more policy-oriented perspective, including professionals whose tasks include reflecting on the regulatory and ethical implications of emerging technologies.

d) **Ethnographic Research.** This kind of research can often provide unique insights that escape more traditional research methods. Hence, conducting observations and taking detailed fieldnotes during on-site visits to partner organisations offers an entry point to the real-life or simulated environments where data-gathering equipment is tested and deployed. The idea is to understand their current use to provide more tailored insights on how to improve the EU's Ethics and legislative framework on matters related to data, AI and privacy.

In order to validate the insights of the research conducted until now (outlined in Deliverable 3.2.), testimonies from professionals in the field were sought out. What follows now are the interventions of Assistant Prof. Stuart Murray and Prof. Adrian Chan, which seem to identify similar issues to the ones that arose during the first round of data-gathering.

<u>Associate Professor Stuart Murray, Canada Research Chair of Rhetoric and Ethics</u>

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The first aspect to point out, according to Prof. Murray, regards the profound effects that a change in terminology has on how humans perceive themselves, their job and the world around them. The coinage of the concept of *the quantified self* (commonly attributed to Gary Wolf and Kevin Kelly) reflects on this reality and will feature heavily in the theoretical foundations of the ethical analysis of collaborative intelligence workstations.

"When technologies intervene and you have a whole set of terms, say biomedical terms, instrumental terms, these are terms that regulate – even when we think we're being autonomous, they regulate the ways that we relate to ourselves. Our wearable biotechnology, is it helpful for an agent population? That question already has a set of presumptions behind it; it presumes that we are autonomous subjects, that we are going to use tools as instruments, but what I would want to question is 'what are the effects of this, what are the effects on human and ethical subjectivity? How do we relate to ourselves and to our bodies?'."

Similarly, Murray is concerned with the assumption of an 'average' patient as a baseline for the aforementioned calculations. Taking such a starting point often leads to the controversial biases and discrimination that greatly undermine public trust in today's data-gathering devices.

"Technologies (...) are programmed often for an average "patient" that may or may not even exist in the world – they are programmed with terms that are ethically normalizing, so if I'm going to begin to relate to my body in the terms that certain biotechnologies give me (blood pressure, cholesterol counts...), that's one way to relate to my body, but it's a very instrumental way that comes with norms and presumptions attached to it: 'Oh, healthy blood pressure is...'. And these are changing all the time, based on so-called best practices, evidence and so forth."

Professor Murray encourages the adoption of a less Western-centric point of view, too. The author remarks that the vision of autonomy, like many other values, is culturally dependent, and newly emerging technologies need to develop greater sensitivity towards that too.

"Some would have a presumption of a very strong view of autonomy, and some people might prefer to take the risks of falling or forgetting their medication rather than to be tracked and watched, while others might be perfectly happy being watched (...) We're talking about a multi-ethnic and multi-space population, so not everybody is going to come with a presumption of autonomy... There's certain cultures where the expectation is absolutely not of autonomy, but more community or family stepping in together not only to raise kids, but to take care of the sick and the elderly. So the principle of autonomy is pretty much a Western Enlightenment principle, and there's a long history of it. It's this notion of autonomy the effect of a certain kind of discourse that we've grown up with and has become embedded in our culture, but it doesn't belong to all cultures."

Professor Adrian Chan, Department of Computer Systems and Engineering (Carleton University)

Professor Chan shares that it is important to remember that technological innovation is driven by social acceptability, not ethics, hence we need to look at the former in order to anticipate the evolution of new technologies in the near future.

"As technology evolves what we're going to see is not necessarily a clean solution of what is ethical and what is not, but what is acceptable from a social norm point of view, for example tracking someone through their cell phone"

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Aside from the aforementioned diversity stemming from different cultural backgrounds, Prof. Chan discusses the need to bear in mind that the acceptability of new technologies also depends on age and needs to evolve in a way that is welcoming to all age groups.

“Different demographics of users will have different affinities towards technology. With the younger demographic, they're used to technology, they’ve grown up as digital natives, and are used to being connected all the time. Some older adults might be less comfortable with them (…) not understanding how they're used, how to configure them, set up the system, set up the user account, they might not be as comfortable (…) [We need to] develop systems that are transparent and seamless, so that they are non-obtrusive (...) You want the user experience to mimic a regular shirt, except that it has smart sensors built into it.”

When asked to enumerate some of his greatest concerns regarding data-gathering devices, Prof. Chan emphasises the importance of fighting against fatigue, and remaining attentive to privacy, given that the mode of transportation of most data is commercial, hence centred around profit-making.

“... False alarms [are] one of the top health hazards for the past 4 years, so if we get a lot of false alarms, this causes alarm fatigue, where we start missing true alarms, and the actual setup and sensors and monitoring becomes less useful. The other problem is, of course, privacy. We're collecting information about a patient that is less secure, because oftentimes when we transmit it over to communication channels, if it’s a wearable device outside of a well-controlled environmental, we’re typically using commercial communication channels, whether that be the Internet, and whenever there’s patient data in it there are issues of privacy that we concern ourselves with.”

Regarding privacy, the Carleton University professor echoes the view previously voiced by many civil society organisations, i.e. the need for both an individual and a collective vision of the protection of privacy.

“I think the role of the individual in terms of security and privacy is kind of ill-defined. We see it today as we’re interacting with different applications on the internet. We get these long forms and we’re consenting to things that no one actually reads. Certainly, the individual has an ultimate responsibility to it, but I don't think it’s right or fair to put all the onus on the individuals themselves. Individuals should make some attempt to be informed, but it’s important that we have policies, regulations in place, that doesn't put the burden solely on the individual themselves.”

All in all, his greatest concern remains clear, and offers a not-so-often discussed perspective of data collection. Prof. Chan believes that, nowadays, we are too focused on mass data collection that we are at risk of judging its usefulness clearly. According to him, this puts us at risk of both dangerous practices and of abandoning our research quests too quickly and unsuccessfully.

“There are two things in terms of collecting patient data: the first is to look at the data quality, whether it’s useful or not... Just cause we’re collecting data doesn't mean that it’s useful. Sometimes, too much information is not good. When we have the availability of more information without the wisdom to go along with it, we end up with these kind of danger zones where we could suppose the worse out of things, without the right type of knowledge, caution and understanding that comes with the information that we’re presented.

The wearable technology is now commercialized (…) But we need to get more user acceptance to provide that infrastructure that we can actually take the data that we’re actually collecting and

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transform that into something that's useful. And we haven't really moved from that stage where we got the ability to not only collect data but transform it into something that's useful. So you look at Fitbit for example... They go with good intentions thinking that it'll provide a motivation, a way of tracking that their activity level, but oftentimes after a honeymoon phase with the Fitbit, ends up being in a drawer or in a shelf, forgotten. So we have to find those places where it becomes a usable and useful system, and we need to figure out how that's designed and the infrastructure can be improved (…) technology has advanced quite rapidly, but the social utility of it hasn't advanced along with it.

Some of the benefits of wearable technology is that we are actually collecting data in a more continuous manner. Currently the regular practice is that we go to a hospital and collect data in a short period of time, it provides us a snapshot of how the person is doing. This doesn't necessarily reflect a person's daily life, especially when you consider e.g., the white coat effect (you're more intimidated), so it's not a representative dataset when you're trying to make decisions on how a person is doing".

These testimonies have been gathered from an insightful article *The New Normal,* by the Wearable Technology and Senior Care in Canada. For more information: https://cusjc.ca/agingtech/chapter-three/

7. Conclusions

At this stage of the project, we decided to gather feedback on the actual details of the design of experiments designed for each living labs and the research hypothesis that were going to be addressed focusing on the relevance they may have for industry in each domain of reference. The testimonials gathered served the purpose of verifying how the work and the data about to be gathered could be useful or not in addressing the challenges faced in designing systems that are collaborative in nature between the Human Factors and AI and what benefits or need there is in addressing the challenges that they pose focusing on safety critical applications.

The key points highlighted in each interviewed are summarised here in the following subsections.

7.1. Collaborative robotics and more naturalistic interactions:

7.1.1. The case study of teleoperations in cobots.

The interviews with Dr. Keerthi Sagar, a postdoctoral researcher of the Robotics and Automation team at the Irish Manufacturing Research (IMR) Centre highlighted how there is a growing market interest for in human-in-the-loop telerobotics to perform complex tasks requiring fine manipulation, high performance, sterile environments and handling of miniature components, in medical device manufacturing applications. However, although telesurgery has grown significantly in the medical domain, most of the techniques are not transferable to manufacturing scenarios, where task time and cycle time are of critical importance. The development of the Live Lab, aimed at demonstrating the capabilities of collaborative robots (cobots), has proven to be highly valuable for investigating the impact of operator's loss of important sensing information and situational awareness on performance.

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It highlights how the design of human-machine interfaces and modes of interaction can effectively address this issue. If the model's robustness is established, a potential application could be real-time monitoring of the internal performance state of an operator in safety-critical human-machine/computer interactions. This can be particularly useful in scenarios like telerobotic rescue missions, where performance-driven interface adaptations can be made to improve the operator's state or provide them with decision-making control. In the context of medical device manufacturing, the developed model can also be utilized during the design stage of the human-machine interface or to evaluate the incorporation of intelligent or autonomic features into the system.

7.1.2. The case of programming by demonstration in cobots

The interview with Dr Philip Long expert in robotics form the Atlantic Technological University stated that "Programming by demonstration can allow humans to once again be the centre of the industry by taking on a supervisory role of machines. Through the proposed approach, the cognitive skills and capacity to adapt, which humans excel at, can be coupled with a robot's precision and repeatability to achieve a high-volume flexible manufacturing system in which humans have an important high-value role". Dr. Long highlights the trend of using single robots for multiple applications, indicating the potential of retraining and repurposing robots. The case study devised for the living lab in this sense on programming by demonstration is useful as challenges remain in transferring human task knowledge and ensuring effective robot-to-human communication. Improvements in smarter robots, enhanced communication methods, and better correction facilities are suggested for the industrial automation market.

7.1.3. The case of addressing more safety and effectiveness for Human Robotic Collaborative cells in a more agile way.

Three experts were interviewed and their opinions were converging in similar direction regarding the need to enhance the way safety and risk assessment of HRC environments needs to improve:

Expert 1: Michael Guilfoyle - Services & Support Manager, Certified Machinery Safety Expert (TÜV Nord), Certified Expert in CE Marking, Pilz Ireland, Industrial Automation (PIIA)

Confirmed that the findings align with Pilz's experience and feedback from customers and industry partners.
Mentioned the lack of understanding and clear guidance regarding the safety of HRC applications in the industry, particularly due to the absence of specific European Harmonised norms related to HRC.
Highlighted the importance of applying applicable harmonized European Normatives for compliance and CE Marking in Europe.
Recommended the publication of Harmonised European Norms related to HRC to provide industry confidence in adopting HRC technology.

Expert 2: Robynson Molinari - Machinery Safety Engineer, CECE - Certified Expert in CE Marking (TÜV Nord - Pilz). (PIIA)

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Noted the increasing use of technologies, including robots, in the industry to enhance productivity, reduce costs, and improve safety.
Stressed the need for conducting risk assessments and following relevant standards during the design and implementation of collaborative robot (cobot) solutions.
Highlighted the significance of considering human factors, human error, and human behaviour in the application of HRI.
Emphasized the importance of industry knowledge in correctly identifying and applying applicable standards for safety.

Expert 3: Islam Attia ||CMSE, CECE, CEFS || Technical Lead | Process Functional Safety Engineering, (PIIA)
Provided over 12 years of experience in assisting clients in managing functional safety in the process industry sector.
Mentioned the applicability of HRI in manufacturing processes, such as packing, assembly, and precise manufacturing, for improving precision, automation, and efficiency.
Discussed the distinction between man-controlled processes and those involving HRI, particularly in process industries like oil & gas, petrochemicals, and pharmaceuticals.
Advocated for compliance with IEC 61511 and IEC 61508 for functional safety in the process industry sector and emphasized the importance of risk identification, classification, control, and mitigation.
Stressed the need for a clear safety life cycle, well-defined safety functions, and predictable performance requirements in HRI applications.

7.1.4. The case for ergonomic assessments and monitoring workers' physiological state in real-time

The interview with the Safety and Health Environment officer (SHE) from Yangfeng company highlighted the following key innovative aspects regarding the design of experiment of the Live lab in Serbia.

- The use of EEG and EMG sensors to acquire physiological data during assembly tasks is an innovative approach to assess operator performance and provide feedback.
- The focus on ergonomics and human factors in the design of the modular assembly workstation and the implementation of collaborative robots reflects a forward-thinking approach to enhance safety and efficiency in collaborative workplaces.
- The emphasis on real-time monitoring of workers' physiological state and the proposal to use cobots to address ergonomic loads demonstrate a proactive approach to improving worker well-being and reducing health issues.
- Recognizing the pivotal role of Human Factors in workplace improvement, quality enhancement, and productivity, and highlighting its relevance even in the face of technological advancements showcases a comprehensive understanding of the importance of human-centered design. This in turn can help realise the benefits of collaborative robots in terms of productivity, precision, and the ability to work alongside humans. However, as stated by the expert interviewed "*a methodology is needed to assess which work tasks the cobot would do, how much will be the reduction of ergo load for the worker, and how many benefits it would bring*".

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7.2. Supporting anomaly detection with early warning signals in manufacturing environments.

The three areas of relevance in this Living Lab are summarised below.

7.2.1. The case for Probabilistic Machine Learning (ML) models to predict failures/faults in machines/produced parts for automotive.

Stefano Desideri, Plant Quality Manager, IVECO S.p.A., Suzzara (MN) Plant highlighted how "The usefulness of having timely and confident predictions of failures in the operation of machines will make the industry floor safer. Currently, we employ a planned maintenance of equipment but with correct predictions of failures before they occur, we can be proactive in managing the safety of the industry floor and the customers."

7.2.2. The case for early signal warning to prevent human errors and performance issues on the shop floor.

Francesca Murri is currently a Manufacturing Engineer at the Iveco Group stated how "In a company like Iveco, which has almost three thousand people and with the evolution of the technological processes and the adaptations implemented along these lines, it is unthinkable to optimize the operations manually. So, it's fundamental to use algorithms that consider all the variables involved" therefore the approach will help identify mismatching of operators and required tasks and prevent escalation of repeated stressful conditions leading to deteriorated performance. As currently the industry does not have a method or criteria to assign a worker to a specific task or workstation; only the general medical state of people is considered, not their particular skills; while it would be important to be able to optimize each line position.

7.2.3. The case for Use of latent spaces in security risk detection

The interview with Dr. Alessandro Bellini, CEO - VICE President, Senior Research Engineer at Mathema SRL. Highlighted how the relation between AI (Artificial Intelligence) and security challenges is very important and therefore worth investigating further : "AI may model complex environment that cannot be modelled with more traditional techniques (e.g., latent spaces can represent the essential and true relationships among entities in a certain domain) but, at the same time AI itself is a sort of security challenge, due to the fact that Machine Learning is subject to the most insidious privacy and security attacks such as poisoning and evasion. So, AI systems must be made increasingly secure if any concrete result has to be achieved." Thus confirming the relevance of looking into this aspects in terms of anomaly detection to highlight possible security risks.

7.3. Supporting decision making and alarm management in safety-critical control room scenarios.

Three experts were interviewed for this LIVE Lab: Rob Turner (Control Systems Engineer in Yokogawa), Adrian Kelly (Principal at EPRI Europe), and Dr Ferdinand Coster (Strategic Ideation Consultant & Internal Innovation in Alliander NL).

The feedback collected on the various aspects tackled in this LIVE Lab are summarised in the following sections.

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7.3.1. The case for smarter HMI features to support human reliability in control rooms.

The opinions of the three expert interviewed regarding this LIVE lab converged on the following points:

1. Poor human-machine interface design is a significant factor in sub-optimal operator performance, particularly during abnormal situations. This can lead to equipment damage, environmental contamination, financial loss, and even human injury or fatalities.
2. The Deepwater Horizon tragedy in 2010 serves as an example of the consequences that can arise from subpar operator performance.
3. Improving operator performance, even by a small margin, can yield significant benefits.
4. Alarm systems are inundated with data, and there is a growing complexity in electricity systems and control devices. Real-time resolution of network issues and the impact of weather on the power grid are becoming more challenging.
5. To prevent major catastrophes for control rooms operations in process industry or in critical infrastructures such as grids, control centre systems need to be smarter and assist operators rather than hinder them.

7.3.2. The case for AI enhanced decision support tools in control rooms.

The interview with The Yokogawa expert helped shape the experimental study plan to address the effect and impact of four support tools on control room operators' performance and behaviour in safety-critical scenarios. The decision support tools, alarm rationalisation, procedures/intervention strategy, and an AI-based support system will be varied in four levels with a study group representing each level.

In this was the potential observation and industry interest from the experimental study are to find out:

- Situational awareness improvement using specific support type vs. combined supports.
- Mental workload using each specific support type vs. combined supports.
- Mental Fatigue using specific support types vs. combined supports.
- Performance in terms of time and error rates given the different supports.

7.3.3. The case for Troubleshooting procedural support in process control.

As gathered by the expert interviewed and from the literature both procedural support and HMI features are very critical for control room operations. From the proposed study, the screen-based procedures have the potential to reduce response time compared to the paper procedures. Also, it would be worth testing in future studies procedures represented as flow charts and how effective their navigation on the HMI actually is during troubleshooting.

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7.3.4. The case for Human-in-the-loop reinforcement learning configuration in process optimization.

The use of deep reinforcement learning can help optimize process control and reduce the number of alarms. In particular:

a) Deep reinforcement learning algorithms can suggest control actions or setpoints to the operator.
b) The proposed actions or suggestions should be explainable to ensure transparency and understanding.
c) Bayesian-based methods, such as the hidden Markov model, can be employed for root cause failure analysis.
d) Deep reinforcement learning techniques can be utilized for disturbance rejection and setpoint tracking.
e) Residual Policy Learning (RPL) can be implemented to minimize alarm floods by incorporating a correction factor into the controller response.
f) Human ergonomics should be considered as an input for reinforcement learning to incorporate decision-making factors.

7.3.5. The case for efficient task allocation between human and automation collaborative tasks.

The increasing trend of automation in industry has highlighted the need to find a balance between operator involvement and automation. Excessive automation can cause operators to lose important information and lead to inefficiencies during abnormal situations. Intelligent Adaptive Automation proposes a distribution of tasks between operators and automated systems to alleviate workload while ensuring operators maintain critical process information. Assessing Mental Workload and Situation Awareness is a challenging aspect of this approach. The development of a Deep Learning Feature Extraction Model aims to contribute to the assessment. Practical implementation and cost-effectiveness are important considerations, and finding key performance variables and steps for manual or automated execution can be achieved through methods like Multilevel Flow Modelling. Experimental validation is necessary to determine the effectiveness of these approaches in improving operator performance and situational awareness.

7.4. The case for neurofeedback and physiological signal processing for real-time performance assessment.

Dr Ivan Gligorijević, CEO and co-founder of mBrainTrain in Belgrade, Serbia, and Aleksandar Stanković, sales manager at Mitsubishi Electric Europe.

Both expert concurred that If we could objectively measure the mental workload in real-time, we would be able to assess if the worker is likely to perform a task as planned - or not. If there was a model, based on previous experiences, that would predict the likelihood of error is high, we could interfere with the task, stop it completely or simply postpone it. At the same time, we could let the worker, or an operator know that they are distracted or tired. This would benefit everyone and dramatically increase safety, quality of production, and reduce waste.

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7.5. The case for ethical considerations in collaborative intelligence workplaces

The key points highlighted by the article of Professor Adrian Chan, Department of Computer Systems and Engineering (Carleton University) regarding the relevance of considering always Ethical and legal aspects in shaping collaborative intelligence scenario in the workplace are:

- Technological innovation is driven by social acceptability rather than ethics, and understanding social norms is crucial to anticipate the future of new technologies.
- Acceptance of new technologies varies based on cultural backgrounds, age groups, and user demographics. Efforts should be made to develop transparent and seamless systems that cater to different user affinities and ensure comfort and ease of use.
- Concerns regarding data-gathering devices include combating fatigue, protecting privacy, and addressing issues related to transmitting patient data over commercial communication channels.
- Individual responsibility for security and privacy should be supported by policies and regulations that don't place the entire burden on individuals.
- The focus on mass data collection without sufficient consideration of data quality and usefulness poses risks and may lead to dangerous practices or premature abandonment of research endeavours. The social utility of wearable technology needs to catch up with technological advancements to ensure its usability and usefulness in transforming collected data into actionable insights.
- Finally understanding the effects of technology and terminology on human subjectivity, recognizing biases in data-gathering devices, and embracing cultural diversity are crucial for ethical analysis and the development of collaborative intelligence workstations.

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