Human-AI Teaming Platform for Maintaining and Evolving AI Systems in Manufacturing

D1.2 Catalogue of key performance indicators

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1 Abstract / Executive Summary

One of the main impacts of the TEAMING.AI project will be to create a new more effective way for human and machine to interact. We expect that the developed Artificial Intelligence within the TEAMING.AI project provides the human with a better control and understanding of the machining process in terms of characterization and visualisation of the whole operation such that the overall process performance can be improved. However, measuring successful teaming is a difficult task. The scope of the present document is to report about a catalogue of technical and organizational conditions, influencing factors and key performance indicators for successful human-AI teaming, considering:

- psychological, social and technology experience criteria.
- specification of how recording and evaluation should be carried out in upcoming validation studies.

In the reminder of this document we give a detailed analysis of the current state of the art and select a set of key performance indicators (KPI) for every use case that are suitable to measure teaming success. The following will be detailed:

1. provide an overview of the use case problem definitions, key actors, human and machines contributors in it.
2. clarify key goals, matching the requirements for the use case Key associated performance indicators OLE, OEE)
3. select KPI that can represent performance influencing factors to be mapped for each use case matching also the elements of the 4S framework for state (preconditions), structure (task mapping swim lane), skills (competence, capacities), strategies (goals).
4. provide an operationalization of the 4S model: observable-measurable variables or proxy for each necessary factor in each Use Case.
5. Customise the KPI and performance influencing factors identified to each use case and the specificity of their problem definitions.

For a detailed description of the use cases please see D1.1.

2 Introduction

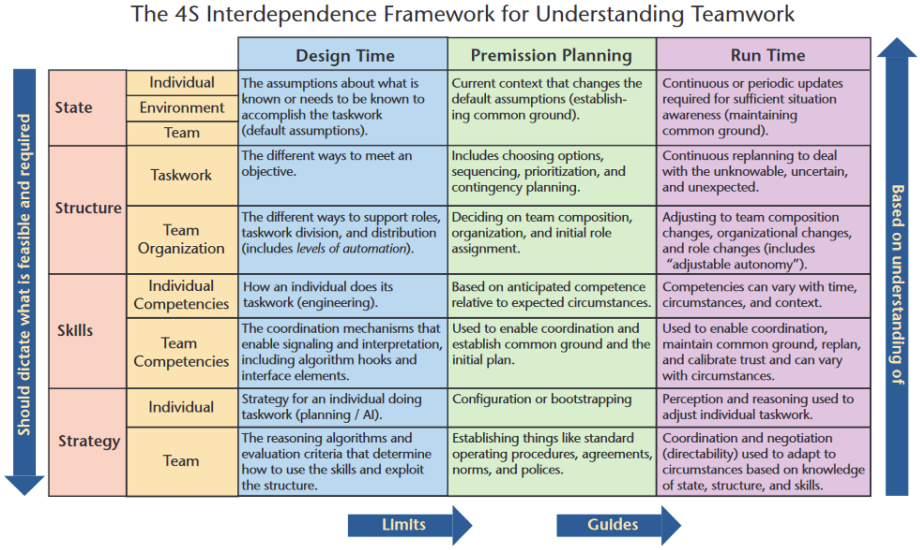
In this document we will provide a short summary of each use case and their problem definitions. We will then organise and summarise their information in relation to the 4S model to **give an indication of the necessary metrics/KPI to describe the as-is-process and the "to-be-process" and be able to measure/ assess key improvements to be targeted by the Teaming-AI solutions.**

The document will also offer a brief review about teaming intelligence and the literature referring to KPI and performance indicators that could be relevant in this context to assess the advantages offered by teaming intelligence approaches

2.1 Defining Teaming Intelligence and its relevant characteristics

The concept of teaming intelligence: properties and characteristics

Teamwork can be seen through many sophisticated models in the literature on the study of human teams. These models are generally made up of behaviours, properties and characteristics. For example, Baker, Day and Salas (2006) has a set of competencies that included communication, team leadership, backup behaviour, mutual performance monitoring, adaptability, shared mental modes, team orientation and mutual trust. From model-to-model teamwork categories, characteristics and properties vary but the one concept that is consistent throughout is the importance of interdependence. To better figure out the concept of interdependence, consider the example of playing the same sheet of music as a solo or as a duet. Although the music is the same, the processes involved are very different (Clark 1996). Playing music as a duet needs ways to support the interdependence and co-ordination between the players, therefore the process differs from when a player is playing solo. Utilising interdependency is what teaming intelligence is all about. For a duet to be successful there needs to be not only execution of the musical score (that is, individual competency), but also the ability to coordinating with someone else. This requires a knowledge of the coordination needs, possession of the mechanisms by which to achieve coordination and the reasoning to perform the necessary coordination. Teaming intelligence allows for the intelligent managing of interdependencies of work. The majority of human activities are more like a duet than a solo. For these activities to work all must be competent with the task because failure of either party in the duet will affect it's outcome.



The 4S Interdependence Framework for Understanding Teamwork

		Design Time	Premission Planning	Run Time
State	Individual / Environment / Team	The assumptions about what is known or needs to be known to accomplish the taskwork (default assumptions).	Current context that changes the default assumptions (establish-ing common ground).	Continuous or periodic updates required for sufficient situation awareness (maintaining common ground).
Structure	Taskwork	The different ways to meet an objective.	Includes choosing options, sequencing, prioritization, and contingency planning.	Continuous replanning to deal with the unknowable, uncertain, and unexpected.
	Team Organization	The different ways to support roles, taskwork division, and distribution (includes *levels of automation*).	Deciding on team composition, organization, and initial role assignment.	Adjusting to team composition changes, organizational changes, and role changes (includes "adjustable autonomy").
Skills	Individual Competencies	How an individual does its taskwork (engineering).	Based on anticipated competence relative to expected circumstances.	Competencies can vary with time, circumstances, and context.
	Team Competencies	The coordination mechanisms that enable signaling and interpretation, including algorithm hooks and interface elements.	Used to enable coordination and establish common ground and the initial plan.	Used to enable coordination, maintain common ground, replan, and calibrate trust and can vary with circumstances.
Strategy	Individual	Strategy for an individual doing taskwork (planning / AI).	Configuration or bootstrapping	Perception and reasoning used to adjust individual taskwork.
	Team	The reasoning algorithms and evaluation criteria that determine how to use the skills and exploit the structure.	Establishing things like standard operating procedures, agreements, norms, and polices.	Coordination and negotiation (directability) used to adapt to circumstances based on knowledge of state, structure, and skills.

Figure 1: 4S interdependence Framework proposed by Johnson and Vera (2019)

Often AI is believed to be replacing the human, the argument being that if people are the source of the problem, eliminating them is the solution. This however is a very narrow perspective that can lead to the dismissal of the potential benefits of teaming intelligence. A further problem with this replacement perspective is that replacement is rarely what actually happens. When replacement is seen as a problem it fosters “the idea that new technology can be introduced as a simple substitution of machines for people — preserving the basic system while improving it on some output measure (lower workload, better economy, fewer errors, higher accuracy)” (Dekker and Woods 2002). This is a naïve perspective and is one of many myths and misconceptions of autonomous systems (Bradshaw et al. 2013) and can lead consequences, including clumsy automation (Wiener 1989) and automation surprises (Sarter, Woods, and Billings 1997).

Additionally, humans are usually the enabling components of most technologies. It is people that are usually setting the goals and parameters, monitoring for anomalous situations, and acting as the de facto backup in case of automation failure, even for the most sophisticated technology.

2.2 Defining performance: KPIs in a Teaming AI framework

KPIs are usually a set of strategic and/or quantitative measures that show the success of an organization. They determine a company’s objectives and provide ways to measure and manage improvements for further development, allowing the company to assess operations that are performing well and those that may need to be improved upon. Their purpose is to enable measurement of a project and organisational performance. KPIs consist of a range of factors that could gain the objectives, such as modelling, measuring and analysis.

Having too many KPIs can sometimes be time and resource consuming, however KPIs are necessary for attaining operational excellence towards sustainability as they can specify decisive information that has the potential to lay the ground work for implementing development planning (Bag et al 2020), they also present an approach which allows for visualisation of whether strategic arrangements are working to reach the desired objectives and having KPIs can lead to improvements in the profitability and productivity of organizations (Horta et al 2010).

In the 1980s, the total productive maintenance (TPM) concept provided a quantitative metric called overall equipment effectiveness (OEE) that measured the productivity of a piece of equipment, i.e how well the equipment does what it should do (Nakajima,1988). Equipment is highlighted in the TPM concept due to its impact on productivity, cost, inventory, quality, safety and health and production output. This is especially important for automated processes (Muchiri and Pintelon, 2008). OEE identifies and measures losses of important factors of manufacturing namely availability, performance, and quality rate. By reducing any production machinery problems and making production improvement continuous, OEE performs corrective measures to decrease negative factors affecting production, and then extends corrective measures to other units of factory (Dadashnejad and Valmohammadi, 2019). OEE is an effective measure but is a stand-alone measure, leaving it with some shortcomings related to the interactions of labour with the equipment. For example, OEE doesn’t recognise the interdependency of the indirect and direct workforce, such as if a machine is regularly available but requires maintenance staff to spend a lot of time running it, this would mean maintenance staff aren’t available for other areas of the process if needed.

The original OEE expression was modified and overall labour effectiveness (OLE) was proposed as a specific KPI for labour effectiveness. In its original definition, the OLE, in parallel with the OEE, measures the cumulative effect and the interdependency of availability, performance and quality, both for individuals and for teams. OLE measures the performance, availability and the quality of the workforce and how this impacts productivity. The performance is measured as the amount of product delivered. Availability is measured as the percentage of time that employees spend adding effective contributions. While quality is a measure of the percentage of good or sellable product produced. OLE allows manufacturers to understand not only the effect the workforce has on the manufacturing procedure but also it provides a platform that helps to identify problems with and to predict the performance (Huber et al, 2010, Deepak et al, 2021).

2.2.1 Measuring availability

Many elements impact workforce availability and therefore the potential output of equipment and the manufacturing plant (Deepak et al, 2021). Availability seems like a basic criterion but the elements that impact it include:

- Absenteeism and utilization: labour utilization measures include approved or unapproved leaves, illness, meetings, times when people are unavailable due to training or other company-based activities.
- Scheduling: This is having the right skill set at the right time. Often it is not acceptable to have any old worker but a trained worker with the right qualifications is required, this work has to be available when needed and have a flexible work schedule.
- Indirect time: This is time needed but is not directly related to operating the machine, e.g. shift changeover, idle time, machine downtime or even material delays (Kronos, 2007)

OLE accounts for all these influential elements. Understanding these downtime losses and there impact can expose reasons as to why there might be delays in a line start up. By allowing managers to identify times were providing and scheduling the right type of employees, there is opportunity to see an increase or optimize production hours, as OLE helps managers to ensure they have the employee with the right skills set available at the right time (Braglia et al, 2020).

Calculation of Availability:

Availability= Time operators are working productively / Time scheduled

Example:

Two employees (workforce) are scheduled to work 9 hour (540 minutes) shifts

This shift includes a scheduled 45 minute break

The employees experience 60 minutes of scheduled downtime.

Therefore, Scheduled time for two employees= 1080 min – 90min = 990

Available time= 990min – 120min unscheduled downtime = 870

Availability= 870 Avail min/ 990 Scheduled min = 87.87% (Deepak et al, 2021)

2.2.2 Measuring performance

Performance can suffer when workers are unable to perform their work efficiently within standard times. Proper training can help to alleviate this and increase performance by improving the skills that directly impact the quality of output (Deepak et al, 2021). Training is not the only factor that impacts performance so can:

- Presence of instructions, tools and materials: shop floor issues such as material shortages, missing instructions, worn or misplaced tools, will slow production, limit output and likely have an impact on performance.
- Indirect support staff: A workforce that is not sufficiently trained or does not possess the right skill set will require additional support staff, such as maintenance technicians, IT experts or quality assurance personnel.
- Attitude and Motivation: An employee's attitude and motivation to carry out a task well will affect how well they carry out the task.
- Training and skills: As mentioned above training and skill level of employees directly effects performance. These aspects affect the ability to deliver the expected outcome throughout a shift or job run. A skilled employee knows how to measure work, stop production if the product is not up to standard and take corrective actions as well as knowing and understanding the impacts of variability (Kronos, 2007).

When this metric is measured accurately with OLE it gives the ability to pinpoint performance improvement conditions down to an individual reason, such as worn tools or unskilled worker (Kronos, 2007, Braglia et al, 2020).

Calculation of Performance:

Performance = Actual output of the operators / the expected output (or labour standard)

An example may help describe how those elements can be calculated: the example below is taken from Kronos (2007):

Two employees (workforce) are scheduled to work a 9-hour (540 minute) shift with a 45-minute scheduled break.

The employees experience 60 minutes of scheduled downtime.

Available Time = 1080 min − 90 min break − 120min Unscheduled Downtime = 870 min

The Standard Rate for the part being produced is 60 Units/Hour or 1 Minute/Unit

The Workforce produces 650 Total Units during the shift.
Time to Produce Parts = 650 Units * 1 Minutes/Unit = 650 Minutes

Therefore Performance can be evaluated as:
Performance = 650 minutes / 870 minutes = 74.71 %

2.2.3 Measuring quality

Many factors contribute to quality. Even in an effort to improve quality can result in a decrease in the labour performance. While quality is certainly a function of the materials used, it is impacted majorly by human factors including:

- Employee Knowledge: How well an employee understands the quality drivers of their specific operation. Knowledgeable workers know how to measure their work, how the process system operates, what adjustments can be made during process as they run and how variability effects quality. The ability to apply this type of knowledge reduces the amount of wasted work, cuts scrap and rework costs. Therefore, employee skills directly affect the quality of the product output.

- Proper use of instructions and tools: When the right tools are used this majorly impacts the quality of the product. For these tools to operate properly care must be taken when following instructions and carrying out their operating procedures (Kronos, 2007).

Factors such as skills of the employee, their understanding of how their role contributes to quality of a finished product and whether the necessary equipment is available should all be thought about when connecting the link between workforce and quality. OLE helps to analyse the productivity of each individual shift, determining which individual workers are most productive. Once this has been analysed manufacturers can also identify corrective actions to raise the operation standards to an optimum (Deepak et al, 2021).

Calculation of Quality

Quality= Saleable parts / Total parts produced

Example:

Two employees (workforce) produce 770 Good Units during a shift. 800 Units were started in order to produce the 670 Good Units.

Quality = 770 Good Units / 800 Units Started = 96.25% (Kronos, 2007)

2.2.4 Calculating Overall Labour Effectiveness (OLE)

When used effectively OLE exposes problem root-causes through data analysis and gives the corrective actions which need to be taken. OLE also reveals tendencies that can be used to diagnose problems that are slightly more subtle. Finally, it also shows whether corrective actions did work to solve problems and improve overall productivity (Deepak et al, 2021).

Calculation of OLE:

$$OLE = Avalability * Performance * Quality$$

Example (as above)

Availability= 87.87%

Performance=74.71%

Quality=96.25%

$OLE = 8.87\% * 74.71\% * 96.25\% = 63.18\%$ (Kronos, 2007)

2.2.5 Labor information tracked

The table below offers examples of the labour information tracked by overall labour effectiveness organized through its major categories. This labour information allows managers to make operational decisions that will improve the cumulative effect of labour availability, performance, and quality.

Table 1: Example of Losses for each OLE Category (adapted from Kronos, 2007)

OLE Category	Major Loss Category	Example of Loss

Availability Time operators are working productively / Time scheduled	Breakdown Changeover	Untrained or inexperienced Unplanned absenteeism Breaks and lunches that are poorly scheduled Material handlers starved the machine Mechanics maintenance delayed Set-up personnel shortages or delays Untrained or Inexperienced/Unskilled
Performance Actual output of the operators / the expected output (or labour standard)	Reduced Speed Small stops	Untrained or Inexperienced/Unskilled leading to operator inefficiency Untrained or Inexperienced/Unskilled leading to poor operator technique
Quality Saleable parts / Total parts produced	Scrap or rework Yield or start-up losses	Mechanic maintenance error Operator error Set-up team error Mechanic maintenance error Operator error Set-up team error

2.3 Accounting for important elements in Human Factors.

When evaluating impact of changes on the Human factors element the KPI that could be useful in that respects can be related to the assessment of different aspects of human performance:

1. Human Reliability Assessment: HEART (Human Error Assessment and Reduction Technique) (see section 2.4.1)
2. Workload Analysis: NASA TLX & other possible physiological measurements (see section 2.4.2)
3. Work Satisfaction: Hackman and Oldham's Motivating Potential Score (see section 2.4.3)
4. Physical Ergonomic Risk assessment methods: REBA, RULA, ART, MAC etc.. (see section 2.4.4)
5. Evaluation of Human Machine Interface (ISO 11064 part 5) (see section 2.4.5)

2.3.1 Human Reliability Assessment: HEART (Human Error Assessment and Reduction Technique

A human reliability assessment (HRA) can be taken to get the probability that a process will fail due to potential human error. It accounts for what type of human errors may occur, how likely such errors are to actually occur, what factors might influence this likelihood and how can the recognised human errors be prevented in the design (Kirwan, 1990). From this HRA method came HEART a method based on human error literature that is now one of the most commonly used methods for assessment of human error. It calculates human error probability (HEP) to prioritize errors related to human actions. It can be used to identify the quantity of human error probabilities by assessing the interactions between humans, their particular task and human factors/performance shaping or error producing conditions (EPCs). HEART allows for or gives a solution to prevent human related errors (HREs) and reduces the HREs impact by implementing additional controls (Can et al 2020).

In 1986, based on human error literature, Williams developed the HEART technique. To estimate the probability of failure for a specific task the human factors analyst must carry out the following steps:

1. Generic Task Unreliability: The task should be classified in terms of it's generic human unreliability, into one of eight generic HEART task types (These can be found in Generic Task Unreliability table of Annex I). This step gives the nominal human unreliability probability.

2. Error Producing Condition & Multiplier: For the task that is under analysis the relevant error producing conditions (EPCs) that could negatively influence performance should be identified and then the corresponding multiplier can be identified (these can be found in EPC Table of Annex I). This step gives the Multiplier or the maximum predicted nominal amount by which unreliability may increase.

3. Assessed Proportion of Effect: Judge the impact of each EPC on the task to get an estimate. This step should give the Proportion of effect, a value between 0 and 1.

4. Assessed Effect: for each EPC the 'assessed impact' should be calculated using the formula: (Multiplier-1*Assessed Proportion of Effect) + 1 = Assessed impact value

5. Human Error Probability: The overall probability of failure can be calculated based on the formula: nominal human unreliability*assessed impact 1*assed impact 2*…etc. = Overall probability of failure.

2.3.2 Workload Analysis: NASA TLX & physiological measurements

Mental workload (MWL) is defined as a measure of human ability to retain focus and rational reasoning while processing multiple activities and facing distracting influences (Recarte & Nunes 2003). MWL is generally considered to be correlated with task demand and performance and studies showed that excessive, as well as low mental workload, can degrade task performance and cause errors (Gawron 2000). Therefore, there is an increasing need to quantify mental workload in real-time, in order to determine its optimal level and hence improve one's efficiency at work. Unfortunately, one of the main difficulties, when it comes to studying mental workload, is its measurement.

Conventionally, mental workload is evaluated through subjective and objective scores (yew and Wickens 1988). Subjective measures are obtained from individuals' subjective estimations of task difficulty and their overall perceived experience of the task (Reid & Nygren 1988). On the other hand, objective measures include metrics such as task score and accuracy. However, both subjective and objective workload measures have certain drawbacks, one of which is their inability to provide real-time and continuous information. Apart from that, subjective measures are derived from subject's self-report so this kind of data is gathered after the task is finished or the task must be paused for the report to be made. One of the most commonly used Method in this context in the NASA TLX (Hart, & Staveland, 1988).

The NASA Task Load Index (NASA TLX) is a multi-dimensional rating procedure to estimate a workload score based on six subdimensions that are weighted and averaged (Hart, & Staveland, 1988). From these subdimensions (also known as subscales) three are related to the demands imposed on the subject under study, which are Mental Demands, Physical Demands, and Temporal Demands. The other three subdimensions correspond to the interactions of a subject with the task, these are Own Performance, Effort, and Frustration.

The NASA TLX consists of a two-part evaluation procedure that consists of weights and ratings. The weights, or sources of load, allow the rather to evaluate the contribution of each factor to the workload of a specific task. This parameter accounts for differences in the workload definition between tasks, and differences in the sources of workload between such tasks. Then, the ratings, or magnitudes of load, correspond to a numerical value for every scale that reflects the size of that factor in each task. The subjects under study respond to a carefully designed rating sheet by marking each scale at the desired location. Often, the rate of each subscale is obtained after every task or task segment has been completed. A videotaped reply or computed recreation of the operator's activities, however, can be adopted as a mnemonic aid that offers the feature of being stopped after each task segment for retrospective analysis.

As perceptions and definitions of workload do indeed vary among individuals and workload ratings. The implementation of weighted ratings allows the workers to assigning a level of subjective importance of a specific task rather than an a-priori general workload definition. The weights not necessarily have to co-vary with the subscale rating. For example, Mental Demand may be the primary source of workload when performing a task, even though the score of subscale is rated low.

This approach has been tested in different simulations (e.g. helicopter simulation and supervisory control simulation) (Hart, Chesney, Ward & McElroy, 1986; Haworth, Bivens, & Shively, 1986). The results obtained "online" (i.e., operator rating tasks just after they were performed) were closely correlated to those obtained retrospectively with a visual recreation of the task. More generally, the NASA TLX approach has been successfully tested in a wide range of applications going from simulated flight to laboratory tasks. These studies involved assessing Sternberg memory task, critical instability tracking, choice reaction time, mental arithmetic, compensatory tracking, target acquisition, grammatical reasoning, among others which were published in (Hart & Staveland, 1988).

The standard procedure for collecting data with NASA TLX is as follows:

Instructions: The study subjects read the scale definitions and instructions. A set of generic instructions are defined in the original NASA TLX Paper and Pencil Package (Hart, & Staveland, 1988). However, modifications to this document must be done to adapt it to the specific situation.

Familiarization: Subjects make a practice rating using the rating scales after completing some test tasks. This action ensures that they have understood the standard rating process.

Ratings: Each subject is given a rating sheet. After subjects have completed the designated tasks, they rate the six subscales following all task conditions of interest.

Weights: A set of comparison cards containing the pairs of factors that are possible sources of workload. These cards must be prepared before the measuring procedure starts and distributed to each subject. The subject will randomly select a card and circle the Scale Title that represents the most important contribution to workload during the task.

The procedure to compute the weighted workload score consists of the following procedure:

Tally sheet: The scorer reviews the rating sheets and puts a mark on the appropriate row of the tally column of the "Sources-of-Workload Tally Sheet". For example, if the subject circled "Mental Demand" on a comparison card, then the scorer will place a mark in the row corresponding to "Mental Demand" in the tally column. After all the cards have been revised, the scorer adds up the tallies for each scale and writes the totals in the Weight column. The sum of weights must be 15 and each weight must not be higher than 5.

Worksheet: The results in the Weight column are transferred to the Weight column in the "Weighted Rating Worksheet". Then the subjects rating on each scale is placed in the Raw Rating column of the worksheet. Finally, an Adjusted Rating is computed by multiplying the Weight times the Raw Ratings columns. The adjusted ratings are added up and the result is divided by 15 to obtain the overall weighted workload score for the subject in those specific task conditions.

The results can be plotted in a graph as that shown in Figure below. The six scale ratings are represented on the bar graph on the left side. The bar width corresponds to each factor's weight, while the height reflects the rating of each factor in a specific task. The bar on the right represents the average area of the scale bars, i.e., the weighted workload score. A full account of the method is reported in Annex II.

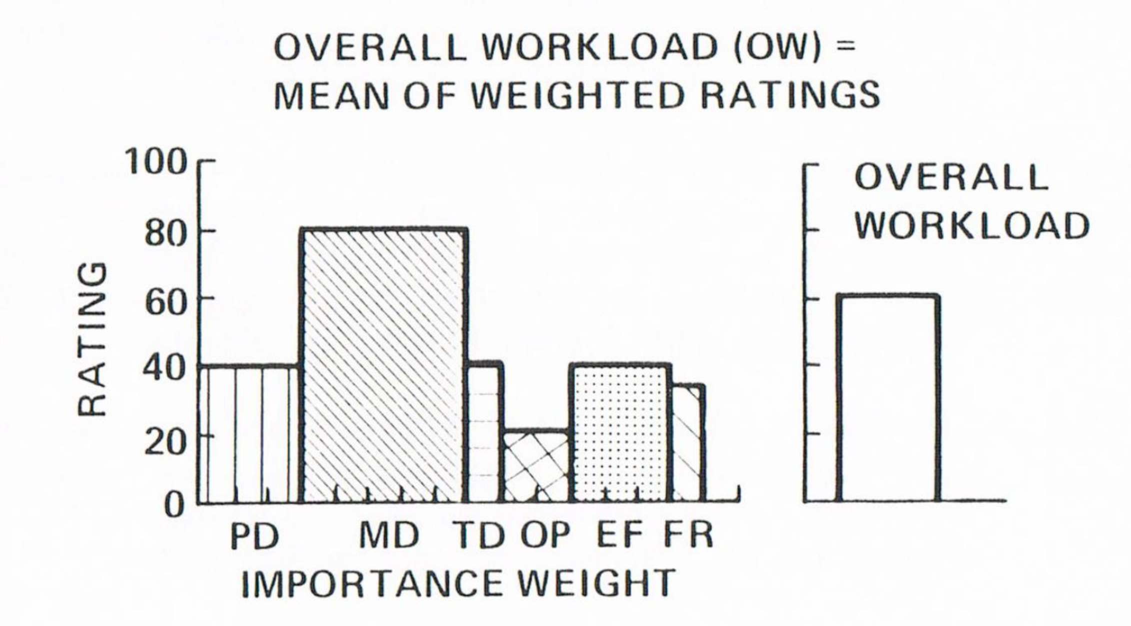


Figure 2: Weighted workload scores graph. Six scale's ratings (left), Overall workload (right)

2.3.2.1 Possible objective Measure for human workload in Teaming AI

When it comes to objective measures recent studies have been focused on validating the use of physiological responses for quantifying mental workload of individuals (Kapoor et al. 2007, Gevins et al. 2003).. It has been shown that neurophysiological measurements such as electroencephalography (EEG) signals are directly correlated with mental demand experienced during the task (Brookings et al. 1996) . Namely, certain EEG spectral components vary in a predictable way in response to the cognitive demands of the task (Missonnier et al . 2006. Stipacek et al.2003),. This means that correlation exists between EEG spectral power and task complexity. In fact, an increase in frontal midline theta band (4 – 7 Hz) and a decrease in parietal midline alpha band (8 – 12 Hz), have been observed when the task complexity increases. A ratio between these two power bands is proven to be a reliable estimate of mental workload (holm et al. 2009). Also, EEG measures of MWL correlate both with subjective and objective performance metrics (Berka et al. 2007). The need for a high temporal resolution, unobtrusive acquisition and obtaining reliable and accurate mental workload measures make EEG advantageous compared to other neurophysiological measurement techniques (Hogervorst et al. 20014). In Teaming AI we have considered deploying EEG measurement to support the assessment of the workload for the task before and after the intervention if informed consent is given by the operators involve din accordance with Teaming AI legal and ethical obligation as reported in Deliverable 1.3 and 10.1 on ethics requirements.

2.3.3 Assessing Work satisfaction and motivation in Teaming AI

The impact of AI on workforce can also have an effect on shaping and changing their work content. If employees are assigned to new positions that they perceive as not challenging, performance could then decline, and have a significant negative influence on productivity (Casey and Robbins 2009). Therefore in Teaming AI we want to ensure the effect of a teaming AI intervention will not impact negatively on the experience of work satisfaction and motivation for the workers as well.

The Hackman & Oldham Model was developed to specify how job characteristics and individual differences could affect the satisfaction, motivation and productivity of individuals at work. Even recent literature acknowledges, “the model is helpful in planning and carrying out changes in the design of jobs” (Casey and Robbins 2009).

In developing their model, Hackman & Oldham (1976) built upon Herzberg's two-factor theory (Herzberg, Mausner & Synderman, 1959) and elements of the expectancy theory (Evans, Kiggundu & House, 1979).

The first major section of the JCM is the core job characteristics. The core job dimensions are made up of skill variety, task identity, task significance, autonomy and feedback (Hackman & Oldham, 1975). Skill variety is the degree to which a job requires a variety of different activities that utilize the use of different skills and talents (Hackman & Oldham, 1975).

Task identity is the degree to which the job requires completion of a whole and identifiable piece of work--that is doing a job from beginning to end with a visible outcome (Hackman & Oldham, 1975). Task significance is the degree to which the job has a substantial impact on the lives or work of other people, whether in the immediate organization or in the external environment (Hackman & Oldham, 1975). Autonomy is the degree to which the job provides substantial freedom, independence, and discretion to the individual in scheduling the work and in determining the procedures to be used in carrying it out (Hackman & Oldham, 1975). Feedback from the job is the degree to which carrying out the work activities required by the job results in the individual's obtaining direct and clear information about the effectiveness of performance (Hackman & Oldham, 1975).

The next major section of the JCM is the Critical Psychological States. The Critical Psychological States include experienced meaningfulness of the work, experienced responsibility for outcomes of the work, and knowledge of the actual results of the work activities (Hackman & Oldham, 1975). Experienced meaningfulness of the work is how work can take on a personal meaning and how the work accomplishes something. The person must experience the work as generally important, valuable, and worthwhile. Three characteristics that affect this variable are skill variety, task identity and task significance (Hackman & Oldham, 1975). Journal of Diversity Management – Third Quarter 2009 Volume 4, Number 3 15

Experienced responsibility for outcomes of the work is the variable that promotes a feeling of personal responsibility for the work outcomes. The individual must personally be responsible and accountable for the results of the work performed. The primary factor that impacts this variable is autonomy, which can increase or decrease this variable (Hackman & Oldham, 1975).

Knowledge of the actual results of the actual work activities is the variable that deals with the results of one's work and the knowledge of the work. The individual must have an understanding, on a fairly regular basis, of how effectively he or she is performing the job. This variable is affected by the core job characteristic of feedback (Hackman & Oldham, 1975).

The third major section of the JCM is the outcomes. The outcomes include high internal motivation, high growth satisfaction, high general job satisfaction and high work effectiveness (Hackman & Oldham, 1975). High internal work motivation indicates the amount of motivation and satisfaction a worker will get from the job (Hackman & Oldham, 1975). High growth satisfaction is gained from self-direction and from learning, and from personal accomplishment at work (Hackman & Oldham, 1975). High general job satisfaction is the satisfaction or feeling of satisfaction with the overall job performance (Hackman & Oldham, 1975). High work effectiveness can be defined as to be successful in the job a person is doing to feel the job has made a difference (Hackman & Oldham, 1975).

The final section of the JCM is composed of the moderators. They are knowledge and skill, growth need strength, context satisfactions and relate to overall motivation (Hackman & Oldham, 1975). Knowledge and skills deal with a worker having adequate knowledge and skill to perform a job adequately (Hackman & Oldham, 1975). Growth-need strength is the need for considerable self-direction, learning, and personal accomplishment at work (Hackman & Oldham, 1975). Context satisfaction is a variable that looks at how a person feels about their surroundings at work. This deals with such things as pay, job security, supervision, co-workers and other relationships at work (Hackman & Oldham, 1975).

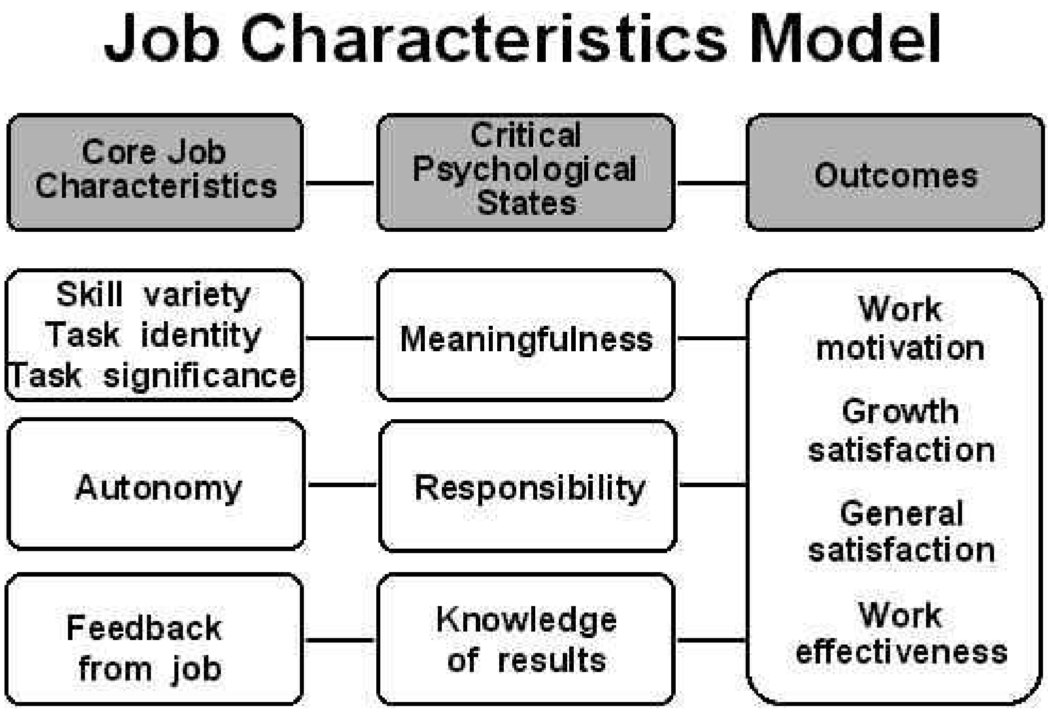


Figure 3: Hackman & Oldham (1976) key components for the Job satisfaction model

Motivating Potential Score (MPS) is the combination of the five dimensions above into a single index reflecting the overall potential of the job to prompt self-generated work motivation in job incumbents. MPS + (Skill Variety + Task Identity + Task Significance/3) X Autonomy X Job Feedback as reported in figure 3.

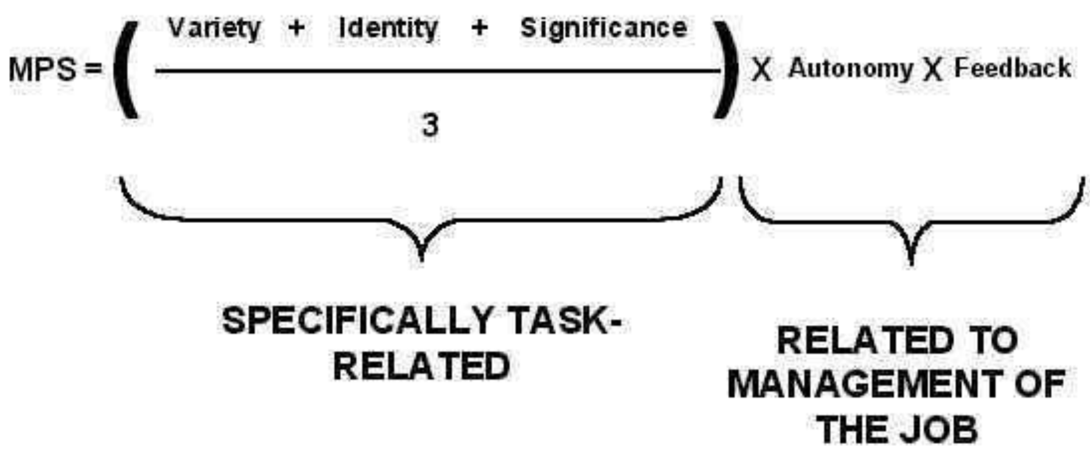


Figure 4: Hackman & Oldham (1976) key components for the motivating potential Score.

For teaming AI we will develop a survey based on the Hackman & Oldham (1976) model as *used in* George and Jones (2012) in their paper on understanding and Managing Organizational Behavior. and/or the one used in the paper by Hussein et al. (2016). Annex VIII reports a version of a survey we can modify and deploy in Teaming AI to evaluate job satisfaction before and after the changes.

2.3.4 Physical Ergonomic Risk assessment methods: REBA, RULA, ART, MAC.

Physical ergonomic risk assessment deals with the analysis and evaluation of musculoskeletal factors. These musculoskeletal factors may include measurement of work effort and fatigue, measurement of discomfort, observation of posture, assessing lower back disorder, analysis of workplace risks and predicting upper-extremity injury risks.

In Use case 3 for Teaming AI the manual handling and physical effort component related to the task performed is quite relevant, and the Teaming intervention may also affect it in a way that should hopefully improve it.

To assess how work is being performed the use of physical methods is essential. The physical methods used in this section can help to obtain essential surveillance data used to manage the risk of injury to the workforce. It has become commonly accepted that a lot of musculoskeletal injuries begin with the worker experiencing some sort of discomfort. This discomfort may turn to an increase in the severity of symptoms (aches or pains) if ignored. If in turn these aches and pains go unchecked they may eventually result in an actual musculoskeletal injury, for example tenosynovitis, or serious nerve-compression injury like carpal tunnel syndrome. These signals of discomfort are the body's early warning signs that some part of the worker's job needs to be changed. This discomfort will also affect the workers performance; this could be through decreasing the quality or quantity of work through increased error rates. By reducing the levels of discomfort the risk of injury is decreased. Changes in levels of discomfort can also be used to gauge the success of the implementation of an ergonomic program intervention or the design of an ergonomic program.

The most well-known postural evaluation tools for physical ergonomic assessment include rapid upper-limb assessment RULA and REBA. The RULA method works well in measuring sedentary work such as computer work whereas the REBA method works well in measuring standing work (Hedge et al. 1995). Both of these methods have been used extensively throughout ergonomic research studies and in evaluating the effect of workplace design changes on body posture.

2.3.4.1 RULA for postural evaluation of upper limbs

RULA (McAtamney and Corlett, 1993) gives an easily calculated rating of musculoskeletal loads, especially in tasks where the worker has a risk of upper-limb and neck loading. A rating of the posture, force and movement required is provided as a score from the task. This score could be between 1 (low) to 7 (high) and are assigned into four action levels. These action levels give an indication of the time frame in which it is rational to expect risk control to begin. There are four main applications of RULA

1. Measure musculoskeletal risk, normally as part of an ergonomic investigation
2. Compare musculoskeletal loading of old and new workstation designs.
3. Evaluate outcomes
4. Educating workers about musculoskeletal risk that may occur due to various working postures

The RULA procedure is threefold:

1. A RULA assessment takes a close look at only a moment in a work cycle, it is important to observe all postures taken during a work cycle or a significant working period before selecting the postures that will be assessed. Depending on the aim the posture chosen could be the longest held position or the worst posture adopted. It is also helpful to estimate the amount of time spent in each position (McAtamney and Corlett, 1992).
2. Deciding whether the right, left, or both upper arms are at risk and need to be assessed is done by scoring and recording the posture. To score the posture for each body part, the loads and the muscle use required for the posture the RULA assessment diagrams (Annex III) is used.
3. Action level. The score that is obtained in step 2 can be compared with a list of actions (Annex III). Usually the actions lead to a more detailed investigation to ensure it's use as an aid in efficient and effective risk control.

2.3.4.2 REBA for postural evaluation of entire body

Rapid entire body assessment (REBA) (Hignett and McAtamney, 2000) was designed to assess the unpredictable working postures found in health-care as well as other service industries. Data such as the body posture, forces used, type of movement, type of action, repetition and coupling are all collected. REBA is used if an ergonomic workplace assessment results in a further postural analysis to be needed and if the whole body is being used, animate or inanimate loads are being handled either often or not often, posture is dynamic, static, rapidly changing, or unstable, modifications to training, equipment or workplace are being made (Janink et al., 2002)

The REBA procedure has is made up of six steps:

1. Observe the Task: A general ergonomic workplace assessment can be formulated by observing the task. Observations should include how equipment is used, impact of the work layout and environment and behaviour of worker with respect to risk taking. These observations should be recorded through imagery or video from multiple angles.
2. Select postures for Assessment: From the observations made in step one postures to analyse can be decided. The posture decided upon is often the longest held, most frequently repeated, posture known to cause discomfort or requires the most muscular activity or the greatest force. The reason for choosing this posture should be recorded.
3. Score the posture: The posture can be scored through the scoring sheet (Annex IV) and the body-part scores (Annex IV) The initial scoring is by group where Group A= neck, trunk and legs and group B= wrists, lower arms, upper arms. The load force score, activity score and coupling score can al be allocated at this time. This step can be repeated for each side of the body and for other postures.
4. Process the Scores: Table A can be used to get the score from the trunk, legs and neck which is then added to the load/force score to provide score A. Table B can be used to get the score from the upper arms, wrist and lower arm. This is repeated if the scores are different for each arm as it effects the musculoskeletal risk. This score is then added to the coupling score to give score B. These scores A and B are entered into table C to give a single score known as score C.
5. Calculating the REBA score: An activity score is given to the muscle activity and added to give the final REBA score.
6. Confirm the Action Level: The final REBA score can then be compared to an action level (Annex IV)

Apart from RULA and REBA, other physical ergonomic risk assessment methods include the assessment of repetitive tasks and the manual handling involved in it such as ART, MAC proposed by the Health and Safety Executive UK.

2.3.4.3 Brief intro to Assessment of repetitive tasks (the ART Tool)

The assessment of repetitive tasks (ART) tool helps to risk assess tasks that require repetitive movement of the upper limbs (arms and hands). It can be used to assess repetitive work for some of the common risk factors that contribute to the development of upper limb disorders (ULDs). It is aimed at those who are responsible for designing, managing, assessing and inspecting repetitive work. ART can highlight where to focus risk-reduction measures and tasks that involve significant risk. It works well for tasks that involve movement of the upper limbs that is repeated every few minutes and occurs for more than 1-2 hours per shift or day.

ART has three steps:

1. The Assessment guide: This provides information on how to use the tool, the risk factors and the assessment criteria
2. The Flow Chart: provides an overview of the assessment process.
3. Task Description form and score sheet: information about the task and findings is recorded here

The details of the ART Method is reported in ANNEX V

2.3.4.4 Brief intro to Assessment of Manual Handling tasks (the MAC Tool)

In relation to some possible aspects of Use case 3 manual handling activities may also require to be assessed.

The Manual Handling Assessment Charts – MAC, also know as the MAC tool provides a widely accepted reference standards for assessing the most common factors in lifting, carrying and team handling operations. It was developed pin-point high-risk manual handling.

The MAC procedure can be used to assess the followings:

- Lifting operations
- Carrying operations
- Team handling operations

For each there is an assessment guide and a flow chart, as well as the mac score sheet.

A full account of the tool and the scoring it provides in reported in Annex VI

2.3.5 Evaluation of Human Machine Interface (ISO 11064 part 5)

Maximizing the safe, reliable, efficient, and comfortable use of graphic screen displays and controls is the goal of the **human machine interface (HMI)`.**

ISO 11064 - Ergonomic Design of Control Centres (2006) provides nine principles for the ergonomic design of control centres and guidance on specific aspects of HMI design, including layout, workstation design, controls and displays, and environmental requirements.

The ISO 11064-5:2008 in particular presents principles and gives requirements and recommendations for displays, controls, and their interaction, in the design of control-centre hardware and software. It also provides a checklist to check compliance with the good practices distilled as part of the ISO 11064-5:2008 and for the purpose of Teaming AI that checklist has been adapted to take into account only relevant and applicable items in each of the nine principles to the use cases. Percentage of compliance with the capacity to satisfactory meeting those requirements provide an indication of the quality of the HMI designed for the applications envisaged in each use case.

Annex VII reports a version of a modified ISO 11064-5:2008 checklist to be used for HMI evaluation

2.4 Teaming AI approach for relevant KPIs selection in each use case

In summary the Table below reports the KPI that have can be proposed to evaluate the different 4S elements in each Teaming AI use case and the rationale of what they represent.

Table 2: summary overview of KPIs proposed in the Teaming AI evaluation for each Use case

4S element	**Contributing factor relevant for the Use case**	**Observable variable/ KPI metrics to compare the "as-is" and "to-be" process**
State	Preconditions necessary: 1. Resources: operators and their roles 2. Raw material: Availability and quality of the input material 3. Equipment: availability and reliability of hardware/ software for equipment used (moulding press)	Availability of resources (quality of material) Number of operators available vs number of operators required
Structure	Mapping of each phase of the task execution (for the "as is" and "to be" process). Different configurations in which the task objectives can be achieved.	• Level of automation for the task (before vs after) metrics such as the inputting rates of manual entry versus automated data entry can be used • Interim failure rates for each step (time and error detectable if any) • Task complexity (how can we measure what indicators can we use refer to NASA TLX) • Hackman and Oldham's Motivating Potential Score of Jobs
Skill	Automation function Operator function Man/machine communication/info exchange tasks (possible fault detection)	HRA (human error rate estimate for task as is and for task to be using HEART) Years of experience Ability testing? HMI evaluation for system as is, and to be (adapting of ISO 11064 part 5 checklist)

Strategy/ GOALS	Evaluation criteria for successful Human-system performance	Overall Labour Effectiveness= Availability*Performance* Quality for Teaming AI Availability= Time operators are working productively / Time scheduled… Uptime/Downtime of machinery and Equipment used (before vs after) Time to detect and recover errors (before vs after) Performance: Amount of parts successfully completed during expected mission time/ total number of parts produced during mission time (OEE) Percentage of errors successfully detected and corrected during production (Before vs After) Percentage of successful corrections executed during mission time (before vs After) Quality = Correct parts / Total parts produced (before vs after) Attitude and Motivation: An employee's attitude and motivation to carry out a task well will affect how well they carry out the task (use of Hackman and Oldham's Motivating Potential Score as a percentage on maximum possible score (before vs after) Ergonomic risk assessment scoring associated to the task (relevant for use case III (before vs after)

2.5 WP and Tasks related with the deliverable

This deliverable is going to provide relevant input for other tasks within the present WP (WP1) in relation to the use case requirement definition and data collection process and also impact WP 6 evaluation. Deliverable 1.2 also contains information coming from the description of the use cases presented in Deliverable 1.1 and also related to the data available for each use case as discussed in deliverable 1.4. Furthermore, the protocol envisaged for data collection all considered the ethical and legal aspects discussed in deliverable 1.3 and 10.1.

3 Overview of Use cases problem definitions and KPIs suggested for each

The following section will provide a quick overview of each use cases and contextualise the necessary KPI proposed to evaluate them. For more details we recommend to consult Deliverable 1.1.

3.1 Use Case 1

Use Case 1 had to do with injection moulding. Injection moulding is a process used during the manufacturing of parts. It works by injecting molten material into a mould. Farplas injecting machine is used in the production of polymer car parts. More detail about the Use case is available in Deliverables 1.1 and 1.4

The Injection Process

The injection process begins with the injection preparation carried out by a worker. A worker must then also set the injection parameters and perhaps set the robotic arm parameters. The injection machine can then be started up and the injecting can start. During this process quality control is important. To improve quality, the injecting parameters must be changed which often can only be done by process engineers. If a product is continuously defective the process engineer will need to adjust the injection parameters. A vision check can also be performed by an AI-based quality system, this can then be evaluated by an operator by giving feedback on the human interface with paint on the faulted areas. This is a clear process which requires the interaction of both the human worker and the automotive machine.

3.1.1 Problem definition for use case 1

To support the visual inspection for defect detection, AI visual recognition can be used. It supports the optimization of the injection process parameters and defects identification.

The AI algorithm allows for the identification of any process parameters that deviate the most from their expected values. This in turn supports the prediction of potential process deviations and the identification of their root causes.

<u>FARPLAS Problem Definition</u>

Automated Quality Control (AQC)

- The capacity of AQC based on ML will be enhanced and integrated to HITL the system.

Parameter Prediction for Injection Moulding Machine

- Available Data- The machine may have certain parameters during each of the production cycles, these parameters include voltage, pressure, time, count, temperature or an error code (inserted by staff) may also exist.
- Trial problems and solutions.
- There are 16 most common problems for which general guidelines for their solution can be set out.

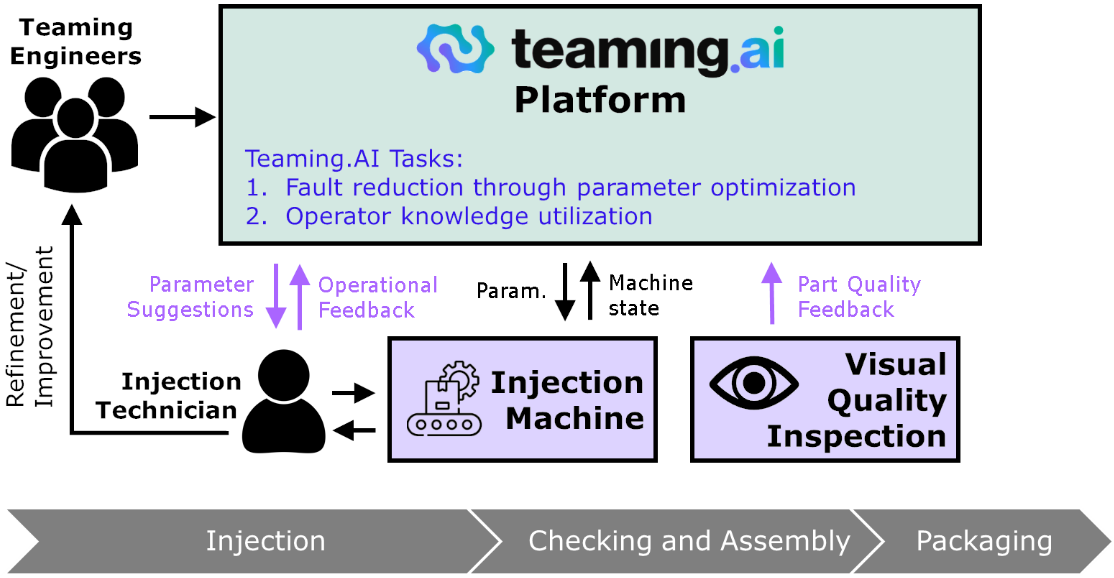


Figure 5: Overview of UC1 in Teaming.AI.

3.1.2 Overview of relevant KPIs selected for use case 1

The followings are the KPI that apply to the evaluation of Use case 1 considering its specific relevant items.

Table 3: summary overview of KPIs proposed in the Teaming AI evaluation for each Use case

4S element	Contributing factor relevant for the Use case	Observable variable/ KPI metrics to compare the "as-is" and "to-be" process
State	Preconditions necessary: 4. Resources: operators and their roles 5. Raw material: Availability and quality of the input material 6. Equipment: availability and reliability of hardware/ software for equipment used (moulding press)	Availability of resources (quality of material) Number of operators available vs number of operators required
Structure	Mapping of each phase of the task execution (for the "as is" and "to be" process). Different configurations in which the task objectives can be achieved.	• Level of automation for the task (before vs after) metrics such as the inputting rates of manual entry versus automated data entry can be used • Interim failure rates for each step (time and error detectable if any)

		• Task complexity (how can we measure what indicators can we use?) • Hackman and Oldham's Motivating Potential Score of Jobs
Skill	Automation function Operator function Man/machine communication/info exchange tasks (possible fault detection)	HRA (human error rate estimate for task as is and for task to be using HEART) Years of experience Ability testing? HMI evaluation for system as is, and to be (adapting of ISO 11064 part 5 checklist)
Strategy/ GOALS	Evaluation criteria for successful Human-system performance	Overall Labour Effectiveness= Availability*Performance* Quality for Teaming AI Availability= Time operators are working productively / Time scheduled… Uptime/Downtime of machinery and Equipment used (before vs after) Time to detect and recover errors (before vs after) Performance: Number of parts successfully completed during expected mission time/ total number of parts produced during mission time (OEE) Percentage of errors successfully detected and corrected during production (Before vs After) Percentage of successful corrections executed during mission time (before vs After) Quality = Correct parts / Total parts produced (before vs after) Attitude and Motivation: An employee's attitude and motivation to carry out a task well will affect how well they carry out the task (use of Hackman and Oldham's Motivating Potential Score as a percentage on maximum possible score (before vs after)

3.2 Use Case 2

3.2.1 Problem definition for use case 2

The AI algorithm allows for the identification of any process parameters that deviate the most from their expected values. This in turn supports the prediction of potential process deviations and the identification of their root causes. There are no optimal curves for the product injection currently but they could be derived (see figure XX).

Once an optimal curve has been derived if there are visual issues of the parts produced than an AI algorithm can detect or help to detect the process parameters causing the visual issue. These parameters can then be adjusted back to values along this optimal curve. The AI algorithm could even be designed to help identify the optimal curve by comparing the curves for the parts that are okay with the ones that are available for the defected parts.

1. Find the expected area that the curve describing the injection process should, this allows for a rough prediction of the optimal shape
2. This should allow for a prediction and to determine which parts are alright and which may not be alright (as the curve may be differing from the expected shape- or lie outside the expected area)
3. The AI algorithm can also detect which parameters are varying from the expected values and so are likely to be the parameter connected to the root causes
4. Dimensional and weight checking is already AI supported
5. Vision check performed by an operator
6. There is support in decisions to do with the root causes and the possible corrections that can be made to them. This support is based on the AI Algorithms ability to detect the expected optimal curve of the injection process, the deviations and it's ability to link deviations to the parameter values that are deviating too much from their expected values
7. If the parameters vary from their expected values this information may not always be enough to help operators gain situational awareness regarding the root causes of process deviations. In these situations it is possible to link the process parameters deviations to potential root causes using the information already captured in the FMEA study developed for the injection process failure modes identified.

To achieve the above and in order to assess the value of the before and after Teaming AI intervention, first gather a current estimate of the time and effort needed to diagnose and correct defects, as they happen. After the Teaming AI check the AI algorithm decision support is capable of correcting issues before they become a problem. This will decrease the number of defected parts produced as it allows the operator to correct the injection process early on, and/or allows for faster detection of root causes and therefore corrections.

In this sense a process map of both the process as it is and the to be process after Teaming AI should be provided. For this a map is needed of the process of detection, identification of root causes and possible solutions as it happens, for one of the specific parts selected for this concrete use case.

To facilitate the data collection the IALEGRE process engineers will help by mapping the data coming from the Management Information System and PLC for the troubleshooting of part defects correction already solved with the on formally described/reported in the Failure Mode and Effect Aanalysis (FMEA) available for the process.

Further details about Use case 2 are made available in Deliverable 1.1.

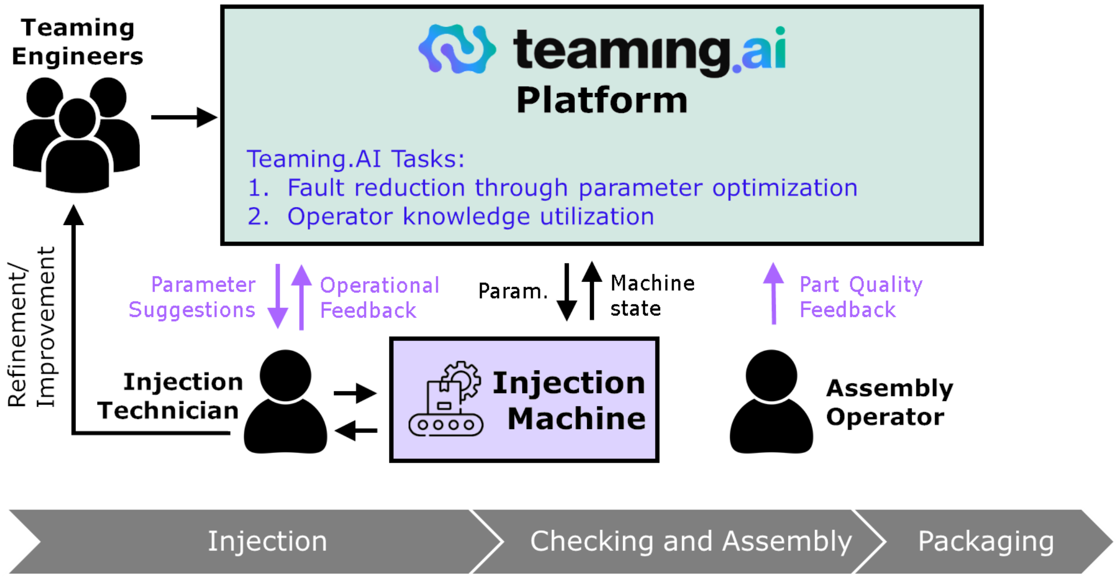


Figure 6: overview of UC2 in Teaming.AI.

3.2.2 Overview of relevant KPIs selected for use case 2

Taking into account the use case problem definition we have accommodate the KPI for it according to the table reported below. They match the same one selected for Use case I, although the data sources are going to be different.

Table 4: summary overview of KPIs proposed in the Teaming AI evaluation for each Use case

4S element	Contributing factor relevant for the Use case	Observable variable/ KPI metrics to compare the "as-is" and "to-be" process
State	Preconditions necessary: 7. Resources: operators and their roles 8. Raw material: Availability and quality of the input material 9. Equipment: availability and reliability of hardware/ software for equipment used (moulding press)	Availability of resources (quality of material) Number of operators available vs number of operators required
Structure	Mapping of each phase of the task execution (for the "as is" and "to be" process). Different configurations in which the task objectives can be achieved.	• Level of automation for the task (before vs after) metrics such as the inputting rates of manual entry versus automated data entry can be used • Interim failure rates for each step (time and error detectable if any) time and effort

		needed to diagnose and correct defects, as they happen • Task complexity (in NASA TLX) • Hackman and Oldham's Motivating Potential Score of Jobs
Skill	Automation function Operator function Man/machine communication/info exchange tasks (possible fault detection)	HRA (human error rate estimate for task as is and for task to be using HEART) Years of experience HMI evaluation for system as is, and to be (adapting of ISO 11064 part 5 checklist)
Strategy/ GOALS	Evaluation criteria for successful Human-system performance	Overall Labour Effectiveness= Availability*Performance* Quality for Teaming AI Availability= Time operators are working productively / Time scheduled… Uptime/Downtime of machinery and Equipment used (before vs after) Time to detect and recover errors (before vs after) Performance: Amount of parts successfully completed during expected mission time/ total number of parts produced during mission time (OEE) Percentage of errors successfully detected and corrected during production (Before vs After) Percentage of successful corrections executed during mission time (before vs After) Quality = Correct parts / Total parts produced (before vs after) Attitude and Motivation: An employee's attitude and motivation to carry out a task well will affect how well they carry out the task (use of Hackman and Oldham's Motivating Potential Score as a percentage on maximum possible score (before vs after)

3.3 Use Case 3

3.3.1 Problem definition for use case 3

The problem definition for this use case can be summarised as follow (for a more extensive description please refer to Deliverable 1.1):

1. Map out manual tasks associated to milling operations of large parts (Gearbox)
2. Collect information about estimated times for manual tasks
3. TASK MAPPING:
    a. Collect visual image info about the task (video recording-PROFACTOR) and perform risk assessment of the tasks (info about forces or EMG to be collected).
    b. Ask operators to describe the manual tasks they carry out and what happens in between milling steps, this will provide the missing information.
    c. The information may be collected also using the IDECO- GOIMEK software system used to log information about work orders on the Worker tablets (SUTAN software, “Bond” interface)
4. Improve the human to machine communication. Milling machine can inform operator of the approximate time between the milling automatic sub-steps, and therefore how much time they have to do something else before they need to attend to next manual task
5. Improve scheduling to allow for a combination of the automatic milling expected time and the manual tasks, this could let the operator attend to two simultaneous tasks (AI optimization problem)
6. Ergonomic risk assessment of the two simultaneous tasks in regards to Static loads and Repetitive strains.
7. Feasibility study on possible AI for visual recognition of possible real time Ergonomic risk assessment for MSD exposure and also idle time recognition (teaming with operators on reporting issues)

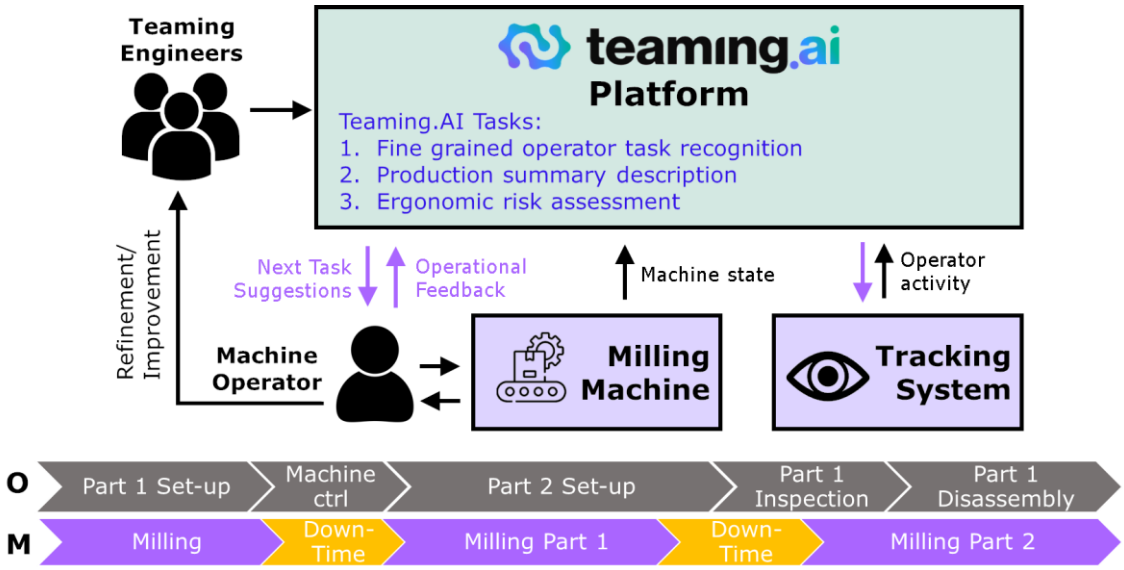


Figure 7: Overview of UC3 inTeaming.AI

The process selected for the case study so far is the Milling of Transition Housing Gearbox (e.g. GB0X4), defined in collaboration with IDECO

In some of the picture below it shows the HMI of the information system used by the company to organise and collect data about each working order and the usage of the equipment on the shop floor. IT is the ERP in use for IALEGRE and it’d called the SUTAN system.

The SUTAN system

The SUTAN system currently is used to link an operator to a work order and a phase of work (which can last many hours, e.g. 4-6 hours in average)

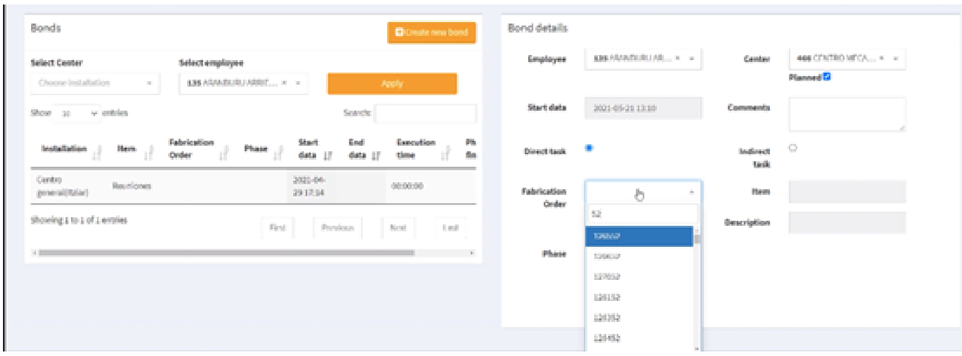


Figure 8: Overview of SUTAN system currently used to define working orders

When work is begun on a task in SUTAN the counter clock records the beginning time, and continues until the operator presses the stop button.

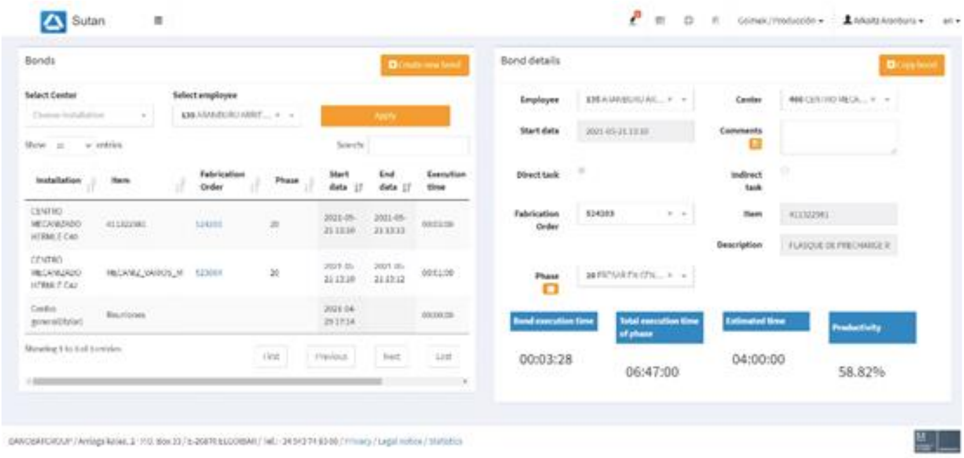


Figure 9: Overview of how the SUTAN system currently collects info on time spent on machining activities

The SUTAN System currently does not collect information about the operators actions during that period of time or if they encountered any operational issues. However quality technical issues related to the parts or equipment are logged into the Quality system part within SUTAN.

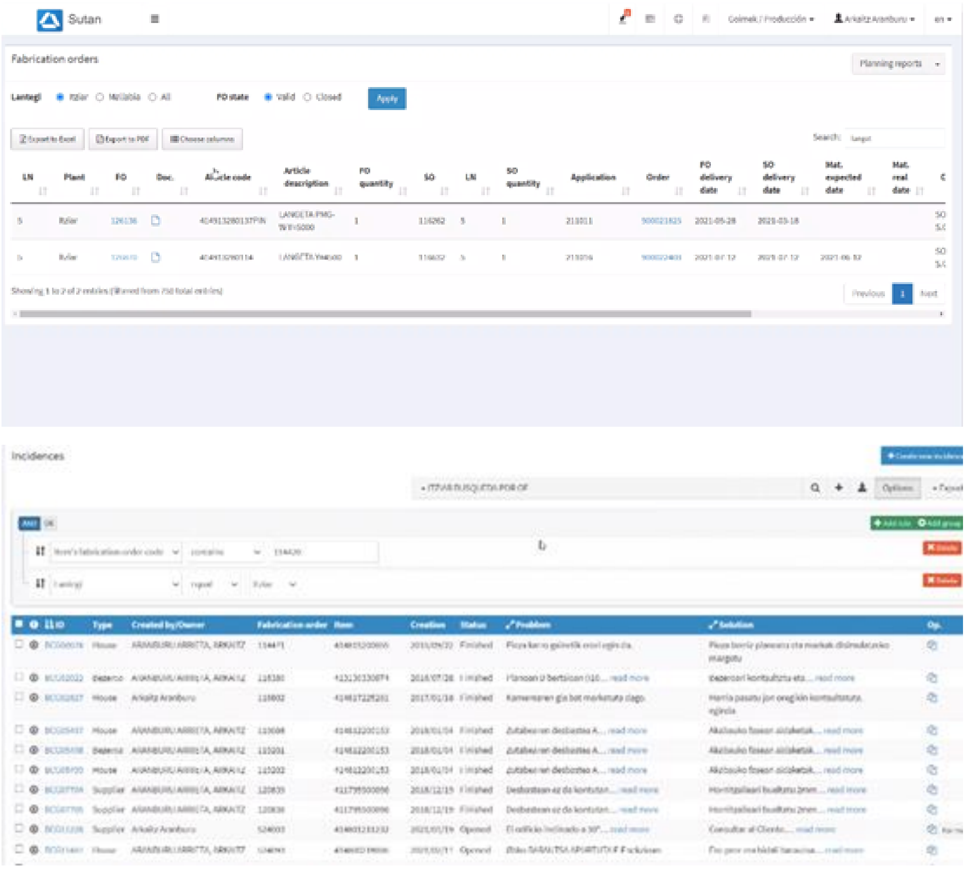


Figure 10: Overview of information available for each order on SUTAN

AI can potentially be used to file through the image recognition of what the operator was doing and then link this to the start and stop times of the machine, before asking the operator to confirm their activities and to add activities or issues connected to their work timeline if needed.

Each different colour in the “Programa” strip in figure below is where different CLC programs or working orders are taking place. The operator can comment on the different sections, activated, unscheduled stopping, etc. and provide information on whether the process can be improved or speed up.

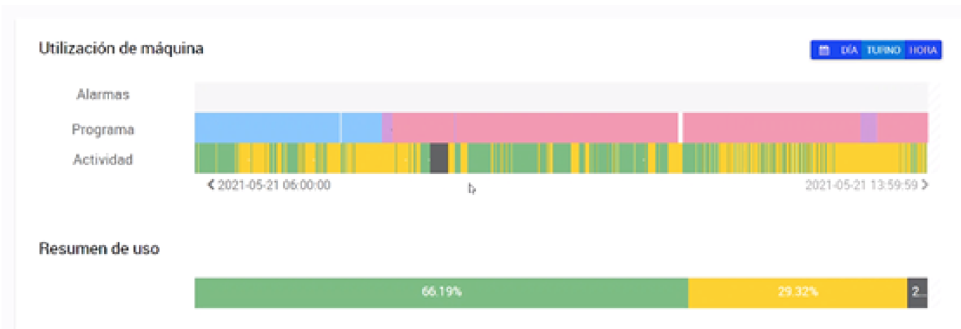


Figure 11: Overview of what info can be detailed from SUTAN system for different programs on the machine being monitored (Each colour is a different program)

The SUTAN platform is the ERP, and is not connected with the PLC for the machines providing information about stopping, downtime and quality usage/stopping for the equipment, therefore when this happens they are not associated with specific working order.

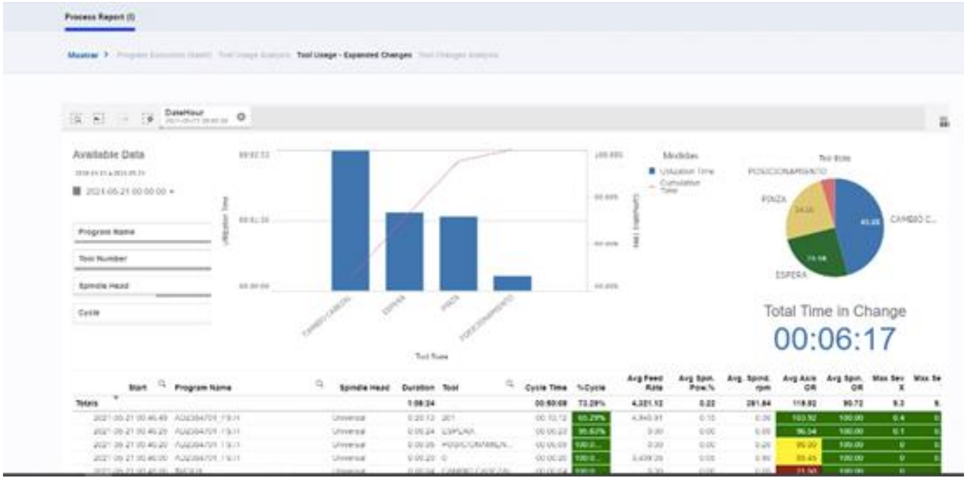


Figure 12: Overview of SUTAN system as ERP

3.3.2 Overview of relevant KPIs selected for use case 3

Considering the problem definition for this use case we will also include the ergonomic risk assessment to be part of the KPI that needs to be evaluated

Table 5: summary overview of KPIs proposed in the Teaming AI evaluation for each Use case

4S element	Contributing factor relevant for the Use case	Observable variable/ KPI metrics to compare the “as-is” and “to-be” process
State	Preconditions necessary: 10. Resources: operators and their roles 11. Raw material: Availability and quality of the input material 12. Equipment: availability and reliability of hardware/ software for equipment used (moulding press)	Availability of resources (quality of material) Number of operators available vs number of operators required
Structure	Mapping of each phase of the task execution (for the “as is” and “to be” process). Different configurations in which the task objectives can be achieved.	• Level of automation for the task (before vs after) metrics such as the inputting rates of manual entry versus automated data entry can be used • Interim failure rates for each step (time and error detectable if any) • Task complexity (as per NASA TLX)

		• Hackman and Oldham's Motivating Potential Score of Jobs
Skill	Automation function Operator function Man/machine communication/info exchange tasks (possible fault detection)	HRA (human error rate estimate for task as is and for task to be using HEART) Years of experience HMI evaluation for system as is, and to be (adapting of ISO 11064 part 5 checklist)
Strategy/ GOALS	Evaluation criteria for successful Human-system performance	Overall Labour Effectiveness= Availability*Performance* Quality for Teaming AI Availability= Time operators are working productively / Time scheduled… Uptime/Downtime of machinery and Equipment used (before vs after) Time to detect and recover errors (before vs after) Performance: Amount of parts successfully completed during expected mission time/ total number of parts produced during mission time (OEE) Percentage of errors successfully detected and corrected during production (Before vs After) Percentage of successful corrections executed during mission time (before vs After) Quality = Correct parts / Total parts produced (before vs after) Attitude and Motivation: An employee's attitude and motivation to carry out a task well will affect how well they carry out the task (use of Hackman and Oldham's Motivating Potential Score as a percentage on maximum possible score (before vs after) Ergonomic risk assessment scoring associated to the task(relevant for use case III (before vs after)

4 Conclusions

The present deliverable aimed at providing an overview of the KPI and assessment and evaluation methods that are going to be deployable in Teaming AI for the use cases selected within the project. IT also provides an overview of the rationale why those KPI have been selected and adapted to suit the needs of the uses cases and of the Human machine collaboration nature of the tasks and the related critical elements to be assessed.

Bibliography

1. Berka C., Levendowski D.J., Lumicao M.N., Yau A., Davis G., Zivkovic V.T., Olmstead R.E., Tremoulet P.D., Craven P.L.: EEG correlates of task engagement and mental workload in vigilance, learning, and memory tasks. Aviation, space, and environmental medicine. 78(5), B231-244 (2007)
2. Braglia, M., Castellano, D., Frosolini, M., Gallo, M., & Marrazzini, L. (2020). Revised overall labour effectiveness. International Journal of Productivity and Performance Management.
3. Can, G. F., & Delice, E. K. (2020). An advanced human error assessment approach: HEART and AV‐DEMATEL. *Human Factors and Ergonomics in Manufacturing & Service Industries*, *30*(1), 29-49.
4. Casey, R., & Robbins, J. (2009). A comparison of the elements of motivation in the hospital industry versus the retail and manufacturing sectors. Journal of Diversity Management (JDM), 4(3), 13-20.
5. Dadashnejad, A. A., & Valmohammadi, C. (2019). Investigating the effect of value stream mapping on overall equipment effectiveness: a case study. Total Quality Management & Business Excellence, 30(3-4), 466-482.
6. Deepak, V., Bhaskar, S., & Balaji, M. (2021). ENHANCING OVERALL LABOUR EFFECTIVENESS OF CSD WAREHOUSE BY ADOPTING LEAN TOOLS IN CONSTRUCTION EQUIPMENT MANUFACTURING PROCESS. Industrial Engineering Journal (ISSN-0970-2555), 14(1), 40-48.
7. Gawron V.J.(2000). Human performance measures handbook. Lawrence Erlbaum Associates Publishers, New Jersey.
8. George and Jones (2012).Understanding and Managing Organizational Behavior (2012, 189-191)
9. Gevins A., Smith M.E.(2003). Neurophysiological measures of cognitive workload during human-computer interaction. Theoretical Issues in Ergonomics Science. 4(1-2), 113-131.
10. Hart. S. G., Battiste, V., Chesney, M. A., Ward, M. M., and McElroy, M. (1986). Comparison of workload, performance, and cardiovascular measure: Type A personalities vs Type B. Working paper Moffett Field, CA: NASA Ames Research Center.
11. Haworth, L. A., Bivens, C. C., and Shively, R. J. (1986). An investigation of single-piloted advanced cockpit and control configurations for nap-of-the-earth helicopter combat mission tasks. Proceedings of the 1986 Meeting of the American Helicopter Society (pp. 657-672). Washington, D.C.
12. Hart, S. G. & Staveland, L. E. (1988) Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P. A. Hancock and N. Meshkati (Eds.) Human Mental Workload. Amsterdam: North Holland Press.
13. Hedge, A., McRobie, D., Land, B., Morimoto, S., and Rodriguez, S. (1995), Healthy keyboarding: effects of wrist rests, keyboard trays, and a preset tiltdown system on wrist posture, seated posture, and musculoskeletal discomfort for the global village, in Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting, Human Factors and Ergonomics Society, Santa Monica, CA, Vol. 1, pp. 630–634
14. Hignett, S. and McAtamney, L. (2000), Rapid entire body assessment (REBA), Appl. Ergonomics, 31, 201–205.
15. Hignett, S. (1998), Ergonomics, in Rehabilitation of Movement: Theoretical Basis of Clinical Practice, PittBrooke, Ed., W.B. Saunders, London, pp. 480–486
16. Hogervorst M.A., Brouwer A.M., Van Erp J.B. (2014) Combining and comparing EEG, peripheral physiology and eye-related measures for the assessment of mental workload. Frontiers in neuroscience. 8, 322
17. Holm A., Lukander K., Korpela J., Sallinen M., Müller K.M. (2009) Estimating brain load from the EEG. The Scientific World Journal. 9, 639-651.
18. HSE (2020) Assessment of Repetitive Tasks (ART) tool, Available: https://www.hse.gov.uk/msd/uld/art/index.htm Acsessed: 21/06/2021

19. Huber, N., Von Quast, M., Brosig, F., & Kounev, S. (2010, October). Analysis of the performance-influencing factors of virtualization platforms. In OTM Confederated International Conferences" On the Move to Meaningful Internet Systems" (pp. 811-828). Springer, Berlin, Heidelberg.
20. Hussein, B., Khachfe, H., Haj-Ali, A., & Aridi, M. (2016). Measuring the motivating potential score of academic staff at the Lebanese International University. *Athens Journal of Mediterranean Studies*, *2*(2), 161-174.
21. ISO 11064, 2006, Ergonomic design of control centres, The International Standards Organisation, Geneva, Switzerland.
22. Kapoor A., Burleson W., Picard R.W. (2007) Automatic prediction of frustration. International journal of human-computer studies. 65(8), 724-736
23. Kirwan, B. (1990), Human reliability assessment, in Evaluation of Human Work: A Practical Ergonomics Methodology, 2nd ed., Wilson, J.R. and Corlett, E.N., Eds., Taylor & Francis, London, pp. 921–968.
24. KRONOS, I. (2007). Overall Labor Effectiveness (OLE): Achieving a Highly Effective Workforce. Industry Week, 257(7), 53.
25. Janik, H., Münzbergen, E., and Schultz, K. (2002), REBA-verfahren (rapid entire body assessment) auf einem Pocket Computer, in Proceedings of 42, Jahrestagung der Deutschen Gesellschaf für Arbeitsmedizin un Umweltmedizin e. V. (DGAUM), April 2002, München, p. V25.
26. Johnson, M., & Vera, A. (2019). No AI is an island: the case for teaming intelligence. AI Magazine, 40(1), 16-28.
27. Lee, D., & Ferreira, J. J. (2003). *Reliability and usability evaluation of the Manual handling Assessment Charts (MAC) for use by non-regulatory professionals*. Health and Safety Laboratory.
28. McAtamney, L. and Corlett, E.N. (1993), RULA: a survey method for the investigation of work-related upper limb disorders, Appl. Ergonomics, 24, 91–99.
29. McAtamney, L. and Corlett, E.N. (1992), Reducing the Risks of Work Related Upper Limb Disorders: A Guide and Methods, Institute for Occupational Ergonomics, University of Nottingham, U.K
30. Missonnier P., Deiber M.P., Gold G., Millet P., Pun M.G., Fazio-Costa L., Giannakopoulos P., Ibáñez V. (2006) Frontal theta event-related synchronization: comparison of directed attention and working memory load effects. Journal of Neural Transmission. 113(10), 1477-1486
31. Muchiri, P., & Pintelon, L. (2008). Performance measurement using overall equipment effectiveness (OEE): literature review and practical application discussion. International journal of production research, 46(13), 3517-3535.
32. Nakajima, S. (1988). Introduction to TPM: total productive maintenance.(Translation). Productivity Press, Inc., 1988,, 129.
33. Recarte M.A., Nunes L.M. (2003) Mental workload while driving: effects on visual search, discrimination, and decision making. Journal of experimental psychology: Applied. 9(2), 119.
34. Reid G.B., Nygren T.E. (1988). The subjective workload assessment technique: A scaling procedure for measuring mental workload. Advances in psychology. 52, 185-218
35. Stipacek A., Grabner R.H., Neuper C., Fink A., Neubauer A.C. (2003) Sensitivity of human EEG alpha band desynchronization to different working memory components and increasing levels of memory load. Neuroscience letters. 353(3), 193-196

36. Stanton, N. A., Hedge, A., Brookhuis, K., Salas, E., & Hendrick, H. W. (Eds.). (2004). Handbook of human factors and ergonomics methods. CRC press.37.Yeh Y.Y., Wickens C.D. (1988) Dissociation of performance and subjective measures of workload. Human Factors. 30(1), 111-120

38. Williams, J.C., HEART – A Proposed Method for Assessing and Reducing Human Error, 1986

Annex I: Reference Material for HRA evaluation using HEART

Tables and values used for HEART evaluation from WILLIAMS, J.C. (1986)

Generic Task Unreliability

Generic task		*Proposed nominal human unreliability (5th–95th percentile boundaries)*
A	Totally unfamiliar, performed at speed with no real idea of likely consequences	0.55 (0.35–0.97)
B	Shift or restore system to a new or original state on a single attempt without supervision or procedures	0.26 (0.14–0.42)
C	Complex task requiring high level of comprehension and skill	0.16 (0.12–0.28)
D	Fairly simple task performed rapidly or given scant attention	0.09 (0.06–0.13)
E	Routine, highly practised, rapid task involving relatively low level of skill	0.02 (0.007–0.045)
F	Restore or shift a system to original or new state following procedures, with some checking	0.003 (0.0008–0.007)
G	Completely familiar, well-designed, highly practised, routine task occurring several times per hour, performed to highest possible standards by highly motivated, highly trained and experienced person, totally aware of implications of failure, with time to correct potential error, but without the benefit of significant job aids	0.0004 (0.00008–0.009)
H	Respond correctly to system command even when there is an augmented or automated supervisory system providing accurate interpretation of system stage	0.00002 (0.000006–0.00009)
M	Miscellaneous task for which no description can be found. (Nominal 5th to 95th percentile data spreads were chosen on the basis of experience suggesting log-normality)	0.03 (0.008–0.11)

Error-Producing Conditions (EPCs)

	Error-producing condition	*Maximum predicted nominal amount by which unreliability might change going from 'good' conditions to 'bad'*
1.	Unfamiliarity with a situation which is potentially important but which only occurs infrequently or which is novel	× 17
2.	A shortage of time available for error detection and correction	× 11
3.	A low signal-to-noise ratio	× 10
4.	A means of suppressing or overriding information or features which is too easily accessible	× 9
5.	No means of conveying spatial and functional information to operators in a form which they can readily assimilate	× 8
6.	A mismatch between an operator's model of the world and that imagined by the designer	× 8
7.	No obvious means of reversing an unintended action	× 8
8.	A channel capacity overload, particularly one caused by simultaneous presentation of non-redundant information	× 6
9.	A need to unlearn a technique and apply one which requires the application of an opposing philosophy	× 6
10.	The need to transfer specific knowledge from task to task without loss	× 5.5
11.	Ambiguity in the required performance standards	× 5
12.	A mismatch between perceived and real risk	× 4
13.	Poor, ambiguous or ill-matched system feedback	× 4
14.	No clear direct and timely confirmation of an intended action from the portion of the system over which control is to be exerted	× 3
15.	Operator inexperienced (e.g. a newly qualified tradesman, but not an 'expert')	× 3
16.	An impoverished quality of information conveyed by procedures and person–person interaction	× 3
17.	Little or no independent checking or testing of output	× 3
18.	A conflict between immediate and long-term objectives.	× 2.5
19.	No diversity of information input for veracity checks	× 2.5
20.	A mismatch between the educational achievement level of an individual and the requirements of the task	× 2
21.	An incentive to use other more dangerous procedures	× 2
22.	Little opportunity to exercise mind and body outside the immediate confines of the job	× 1.8
23.	Unreliable instrumentation (enough that it is noticed)	× 1.6
24.	A need for absolute judgements which are beyond the capabilities or experience of an operator	× 1.6
25.	Unclear allocation of function and responsibility	× 1.6
26.	No obvious way to keep track of progress during an activity	× 1.4
27.	A danger that finite physical capabilities will be exceeded	× 1.4
28.	Little or no intrinsic meaning in a task	× 1.4
29.	High-level emotional stress	× 1.3
30.	Evidence of ill-health amongst operatives, especially fever	× 1.2
31.	Low workforce morale	× 1.2
32.	Inconsistency of meaning of displays and procedures	× 1.2
33.	A poor or hostile environment (below 75% of health or life-threatening severity)	× 1.15
34.	Prolonged inactivity or highly repetitious cycling of low mental workload tasks	× 1.1 for first half-hour × 1.05 for each hour thereafter
35.	Disruption of normal work-sleep cycles	× 1.1
36.	Task pacing caused by the intervention of others	× 1.06
37.	Additional team members over and above those necessary to perform task normally and satisfactorily	× 1.03 per additional man
38.	Age of personnel performing perceptual tasks	× 1.02

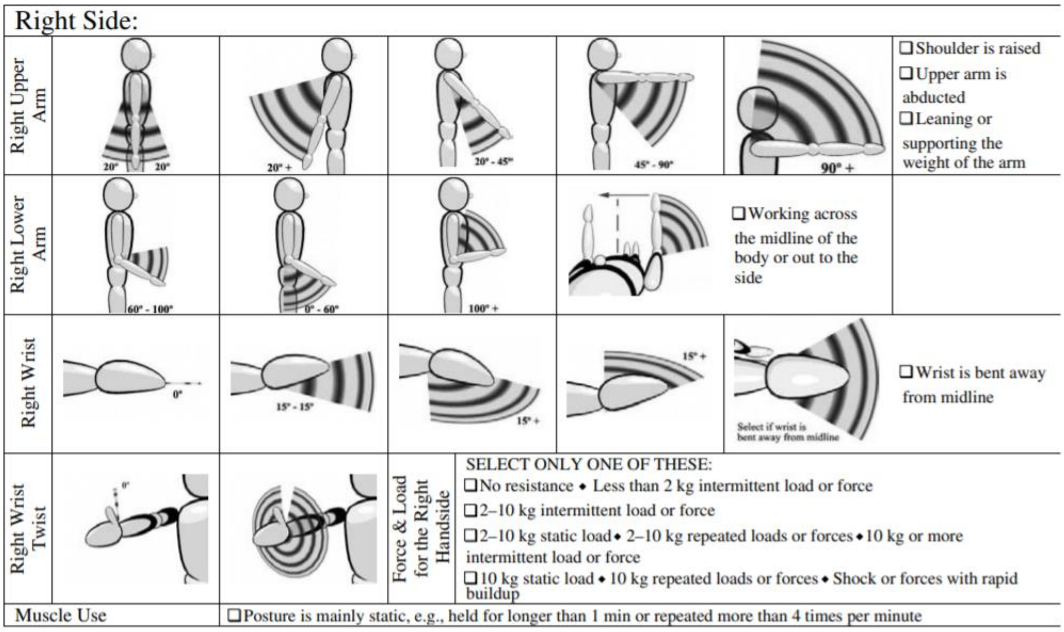
Annex II: NASA TLX reference material

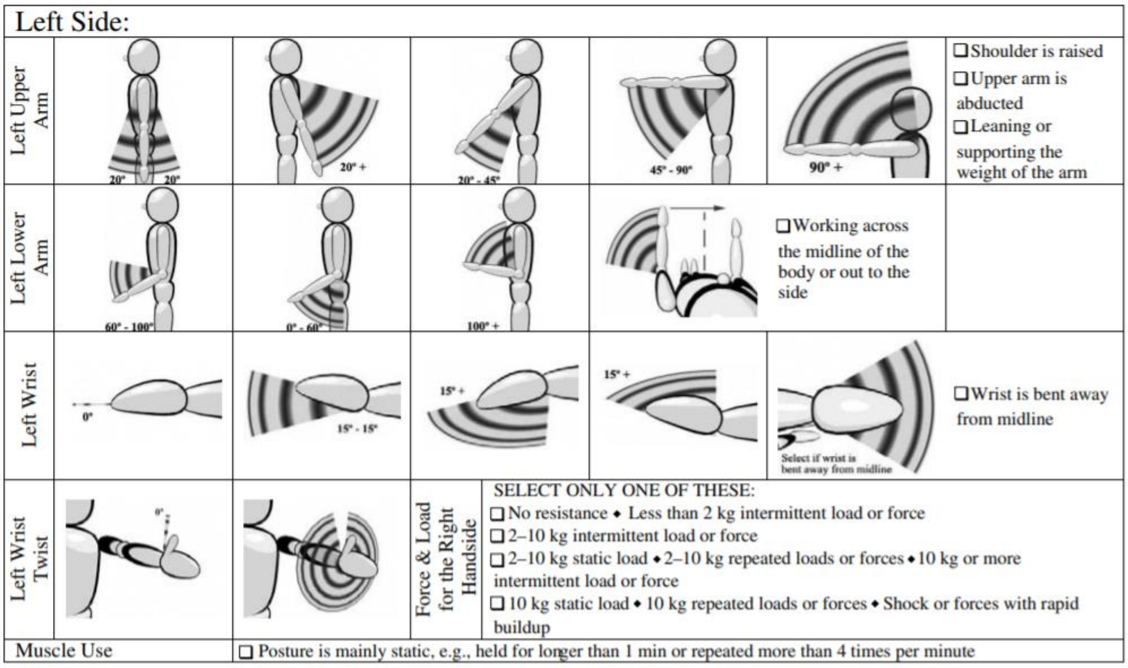
RATING SCALE DEFINITIONS		
Title	Endpoints	Descriptions
MENTAL DEMAND	Low/High	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	Low/High	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	Low/High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	Good/Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTATION LEVEL	Low/High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

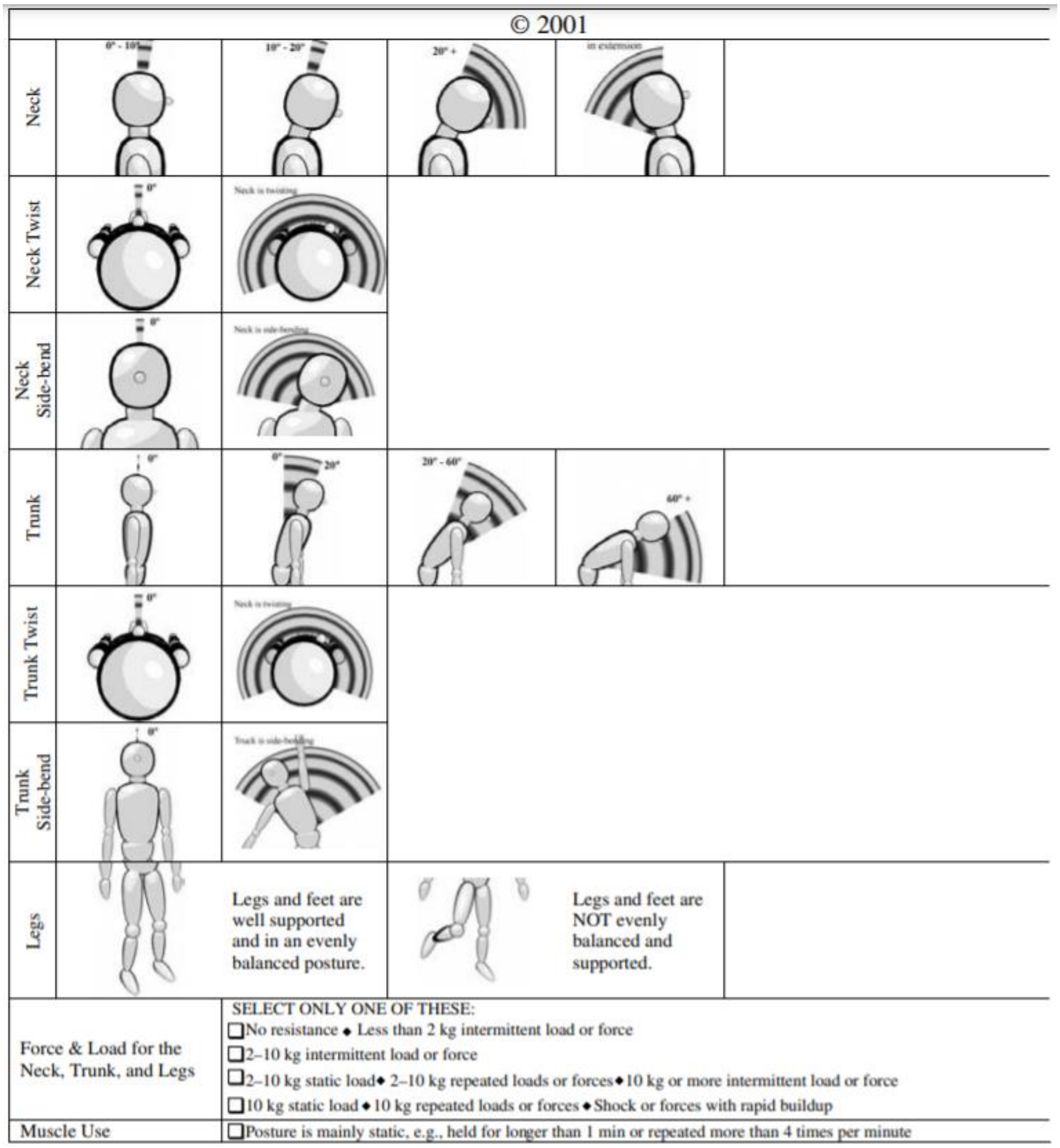
Annex III: Reference material for RULA in Ergonomic Risk Assessments

Table for the application of the RULA Method for Ergonomic risk assessment (Stanton et al., 2004)

RAPID UPPER LIMB ASSESSMENT		
Client:	Date/time:	Assessor:







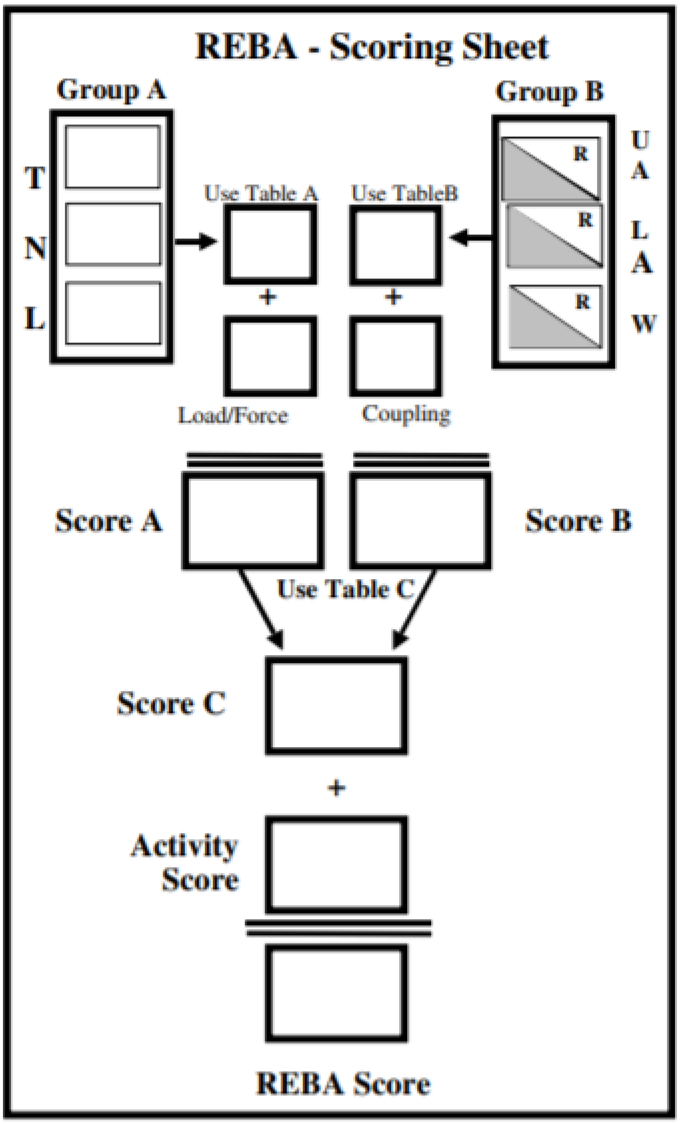
© 2001					
Neck	0° - 10°	10° - 20°	20° +	in extension	
Neck Twist	0°	Neck is twisting			
Neck Side-bend	0°	Neck is side-bending			
Trunk	0°	0° 20°	20° - 60°	60° +	
Trunk Twist	0°	Neck is twisting			
Trunk Side-bend	0°	Trunk is side-bending			
Legs		Legs and feet are well supported and in an evenly balanced posture.		Legs and feet are NOT evenly balanced and supported.	
Force & Load for the Neck, Trunk, and Legs	SELECT ONLY ONE OF THESE: ❑No resistance ◆ Less than 2 kg intermittent load or force ❑2–10 kg intermittent load or force ❑2–10 kg static load◆ 2–10 kg repeated loads or forces◆10 kg or more intermittent load or force ❑10 kg static load ◆10 kg repeated loads or forces ◆Shock or forces with rapid buildup				
Muscle Use	❑Posture is mainly static, e.g., held for longer than 1 min or repeated more than 4 times per minute				

RULA Action Levels

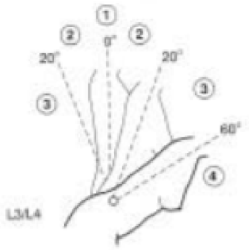
Action level 1	Score of 1 or 2 indicates that the posture is acceptable if it is not maintained or repeated for long periods
Action level 2	Score of 3 or 4 indicates that further investigation is needed, and changes may be required
Action level 3	Score of 5 or 6 indicates that investigation and changes are required soon
Action level 4	Score of 7 indicates that investigation and changes are required immediately

Annex IV: Reference material for REBA in Ergonomic Risk Assessments

Table for the application of the REBA Method for Ergonomic risk assessment (Stanton et al., 2004)

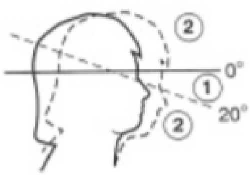


Group A scoring

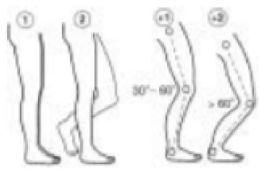


Trunk	Movement	Score	
	Upright	1	Change score: +1 if twisting or side flexed
	0°-20° flexion 0°-20° extension	2	
	20°-60° flexion > 20° extension	3	
	> 60° flexion	4	

Neck



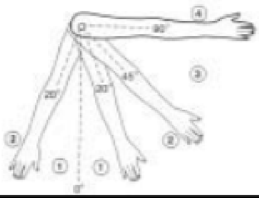
	Movement	Score	
	0°-20° flexion	1	Change score: +1 if twisting or side flexed
	> 20° flexion or extension	2	



Legs	Position	Score	Change score:
	Bilateral weight bearing, walking or sitting	1	+1 if knee(s) between 30° and 60° flexion
	Unilateral weight-bearing, feather weight-bearing, or an unstable posture	2	+2 if knee(s) >60° flexion (N.B. not for sitting)

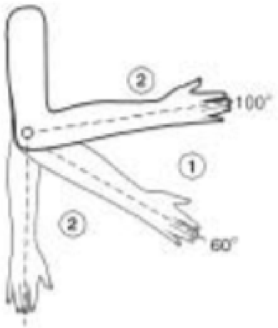
Group B Scoring

Upper arms



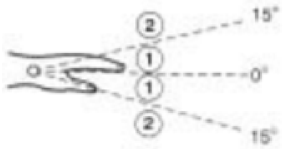
	Position	Score	Change score:
	20° extenion to 20° flexion	1	+1 if arm is: • abducted • rotated
	> 20° extension 20° - 45° flexion	2	
	45°-90° flexion	3	+1 if shoulder is raised
	> 90° flexion	4	-1 of leaning, supporting weight of arm or if posture is gravity assisted

Lower arms



	Movement	Score
	60°-100° flexion	1
	<60° flexion > 100° flexion	2

Wrists



	Movement	Score	Change score:
	0°-15° flexion/extension	1	+1 if wrist is deviated or twisted
	>15° flexion/extension	2	

Load/Force Score:

0	1	2	+1
<5 kg	5–10 kg	>10 kg	Shock or rapid buildup of force

Load Coupling Score

0 (Good)	1 (Fair)	2 (Poor)	3 (Unacceptable)
Well-fitting handle and a midrange power grip	Handhold acceptable but not ideal **or** Coupling is acceptable via another part of the body	Handhold not acceptable, although possible	Awkward, unsafe grip; no handles **or** Coupling is unacceptable using other parts of the body

Activity Score

Score	Description
+1	If one or more body parts are static, e.g., held for longer than 1 min
+1	If repeated small-range actions occur, e.g., repeated more than 4 times per minute (not including walking)
+1	If the action causes rapid large-range changes in postures or an unstable base

TABLE A

	Neck											
	1				2				3			
Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk												
1	1	2	3	4	1	2	3	4	3	3	5	6
2	2	3	4	5	3	4	5	6	4	5	6	7
3	2	4	5	6	4	5	6	7	5	6	7	8
4	3	5	6	7	5	6	7	8	6	7	8	9
5	4	6	7	8	6	7	8	9	7	8	9	9

TABLE B

	Lower Arm					
	1			2		
Wrist	1	2	3	1	2	3
Upper Arm						
1	1	2	2	1	2	3
2	1	2	3	2	3	4
3	3	4	5	4	5	5
4	4	5	5	5	6	7
5	6	7	8	7	8	8
6	7	8	8	8	9	9

TABLE C

		Group B Score											
		1	2	3	4	5	6	7	8	9	10	11	12
G	1	1	1	1	2	3	3	4	5	6	7	7	7
R	2	1	2	2	3	4	4	5	6	6	7	7	8
O	3	2	3	3	3	4	5	6	7	7	8	8	8
U	4	3	4	4	4	5	6	7	8	8	9	9	9
P	5	4	4	4	5	6	7	8	8	9	9	9	9
A	6	6	6	6	7	8	8	9	9	10	10	10	10
	7	7	7	7	8	9	9	9	10	10	11	11	11
S	8	8	8	8	9	10	10	10	10	10	11	11	11
C	9	9	9	9	10	10	10	11	11	11	12	12	12
O	10	10	10	10	11	11	11	11	12	12	12	12	12
R	11	11	11	11	11	12	12	12	12	12	12	12	12
E	12	12	12	12	12	12	12	12	12	12	12	12	12

REBA Action levels

REBA Score	Risk Level	Action Level	Action (including further assessment)
1	negligible	0	none necessary
2–3	low	1	may be necessary
4–7	medium	2	necessary
8–10	high	3	necessary soon
11–15	very high	4	necessary now

Annex V: Reference material for ART in Ergonomic Risk Assessments

Below are some references for how to apply ART for an Ergonomic Assessment of Repetitive Tasks (HSE 2020)

The Assessment

It is first decided which arm should be assessed. The assessment is split into four stages (Stage A: Frequency and repetition of movements; Stage B: Force; Stage C: Awkward postures; Stage D: Additional factors) and the level of risk is determined. The levels of risk are defined as G = GREEN Low level of risk, A = AMBER Medium level of risk – Examine task closely, R = RED High level of risk – Prompt action needed. Find the colour band and the corresponding numerical score on the flow chart and complete the score sheet to get the task and exposure score.

The four stages of assessment are:

Stage A: Frequency and repetition of movements

A1- Arm Movements

Through observing the movement of the arm choose the category that is most appropriate. It is possible that there may be a need to select an intermediate score.

		L	R
Arm movements are	Infrequent (eg some intermittent movement)	0	0
	Frequent (eg regular movement with some pauses)	3	3
	Very frequent (eg almost continuous movement)	6	6

Figure 13: arm movements evaluation in ART

A2 Repetition

This is repetition of the movement in the arm and hand but not the fingers. Through observation of this movement of the arm and hand, the number of times the same or similar motion is repeated over a certain period of time is counted.

		L	R
Similar motion pattern of the arm and hand is repeated	10 times per minute or less	0	0
	11–20 times per minute	3	3
	More than 20 times per minute	6	6

Figure 14: motion pattern repetition for arm and hand in ART

Stage B: Force

Determine the level of force exerted with the hand by first asking the workers to describe if there are any actions that require muscle effort of the fingers, hand or arm. If there is then ask the workers to describe the level of force involved and try to match it to a level in the following table:

Table 6: Force decription model in ART

Light force	There is no indication of any particular effort
Moderate force	Force needs to be exerted. For example: ■ Pinching or gripping objects with some effort ■ Moving levers or pushing buttons with some effort ■ Manipulating lids or components with some effort ■ Pushing or forcing items together with some effort ■ Using tools with some effort
Strong force	Force is obviously high, strong or heavy
Very strong force	Force is near to the maximum level that the worker can apply

Worker's description of the level of force exerted with the hand

	Light	Moderate	Strong	Very strong
Infrequent	G0	A1	R6	Changes required*
Part of the time (15–30%)	G0	A2	R9	Changes required*
About half the time (40–60%)	G0	A4	R12	Changes required*
Almost all the time (80% or more)	G0	R8	Changes required*	Changes required*

* Changes to the task are required due to unacceptable levels of force.

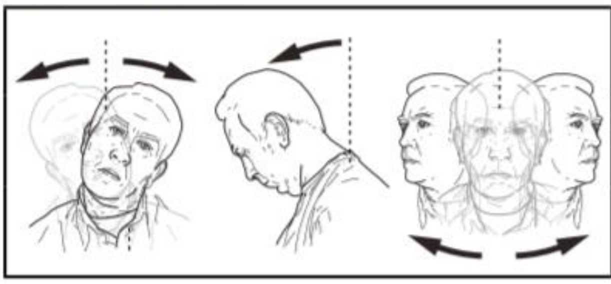
If more than one type of force is exerted, select the highest score obtained with the grid above.

Stage C: Awkward postures

The amount of time spent in the postures below should be determined, these postures include this includes time spent moving to a bent or twisted position repetitively as well as the time spent holding the position.

C1- Head and/or neck posture:

The head or neck is:



In an almost neutral posture	0
Bent or twisted part of the time (eg 15–30%)	1
Bent or twisted more than half of the time (more than 50%)	2

Figure 15: head and neck position valuation in ART tool

C2 Back Posture

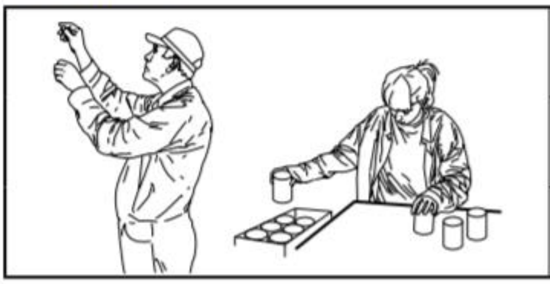
The back is:

In an almost neutral posture	0
Bent forward, sideways or twisted part of the time	1
Bent forward, sideways or twisted for more than half of the time	2

Figure 16: back position evaluation in ART tool

C3 Arm Posture

The elbow is:

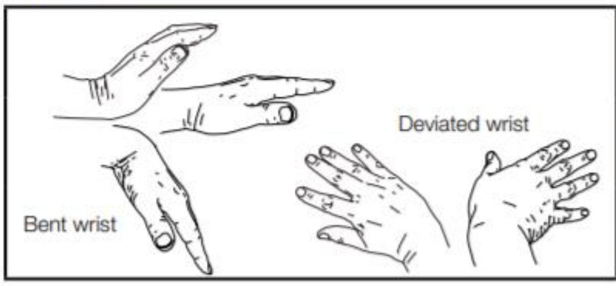


	L	R
Kept close to the body or supported	0	0
Raised away from the body part of the time	2	2
Raised away from the body more than half of the time	4	4

Figure 17: elbow position evaluation in ART

C4 Wrist Posture

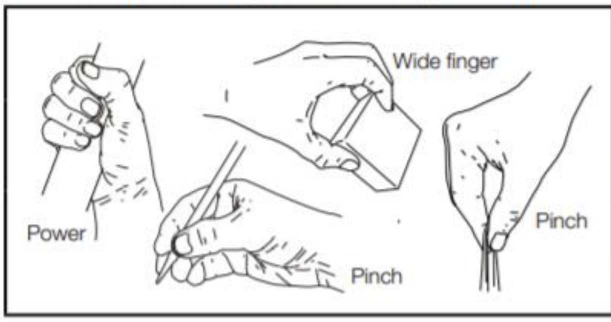
The wrist is:



	L	R
Almost straight/in a neutral position	0	0
Bent or deviated part of the time	1	1
Bent or deviated more than half of the time	2	2

C5 Hand/Finger Grip

The hands or fingers hold objects in a:



	L	R
Power grip or do not grip awkwardly	0	0
Pinch or wide finger grip for part of the time	1	1
Pinch or wide finger grip for more than half of the time	2	2

Stage D: Additional factors

D1 Breaks

Define the maximum amount of time that an individual must perform the repetitive task without a break, where a break constitutes as a pause or change in activity for at least 5-10 minutes.

The worker performs the task continuously, without a break, for:

Less than one hour, or there are frequent short breaks (eg of at least 10 seconds) every few minutes over the whole work period	0
1 hour to less than 2 hours	2
2 hours to less than 3 hours	4
3 hours to less than 4 hours	6
4 hours or more	8

D2 Work Pace

This is in regards to whether the workers find it easy to keep up with the pace the machines or the work is at.

Not difficult to keep up with the work	0
Sometimes difficult to keep up with the work	1
Often difficult to keep up with the work	2

D3 Other Factors

There may be other factors present in the particular task being assed. For example:

- Wearing gloves can effectgrip and make the taskmore difficult
- The workstation, equipment or tools may cause compression of the skin
- The tools may cause discomfort
- The hand is exposed to vibration

- Operators are exposed to draughts or grip cold tools
- Lighting levels efffect visibility

	L	R
No factors present	0	0
One factor is present	1	1
Two or more factors are present	2	2

D4 Duration

Define the length of time taken for a worker to perform the repetitive task over the course of a shift, not including breaks.

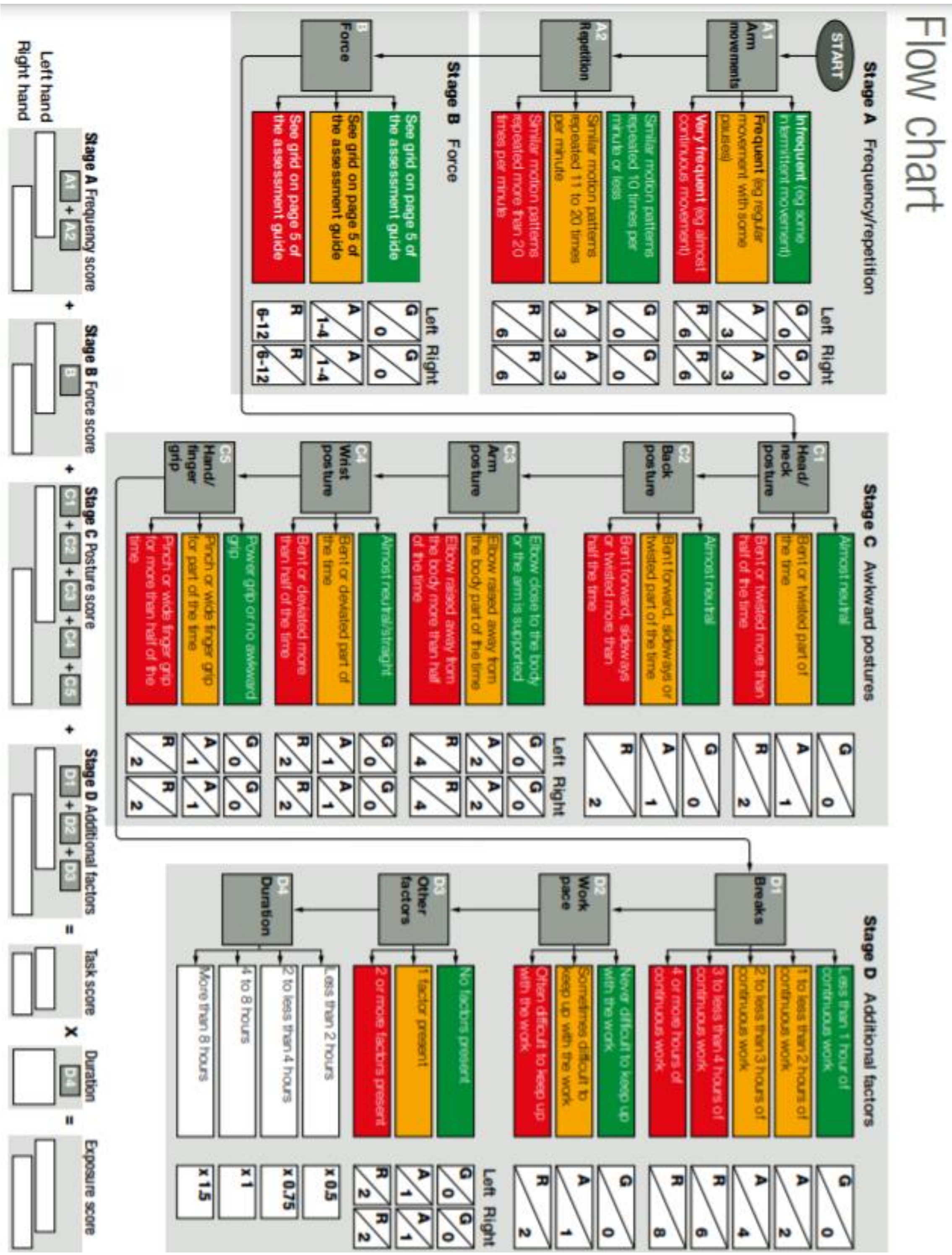
Duration of task by a worker	Duration multiplier
Less than 2 hours	X 0.5
2 hours to less than 4 hours	X 0.75
4 hours to 8 hours	X 1
More than 8 hours	X 1.5

D5 Psychosocial factors

The psychosocial factors are not given a score but should still be recorded on the score sheet if it is found they are presnt in the work place through talking to the workers. Psychosocial factors could include high levels of focus and attention required, monotonous work, frequent tight deadlines, skkipping breaks to finish earlier, insufficient training to do the job successfully and lack of support from supervisors or co-workers.

Getting a Score

The score sheet below should be filled out by entering the colour band and numerical score for each risk factor. Once these score have been filled in, the equation can be filled and calculated to get the exposure or final score.


Flow chart
Stage A Frequency/repetition
START
A1 Arm movements
Infrequent (eg some intermittent movement)
Frequent (eg regular movement with some pauses)
Very frequent (eg almost continuous movement)
A2 Repetition
Similar motion patterns repeated 10 times per minute or less
Similar motion patterns repeated 11 to 20 times per minute
Similar motion patterns repeated more than 20 times per minute
Left Right
G 0 G 0
A 3 A 3
R 6 R 6
Stage B Force
B Force
See grid on page 5 of the assessment guide
G 0 G 0
A 1-4 A 1-4
R 6-12 R 6-12
Stage C Awkward postures
C1 Head/neck posture
Almost neutral
Bent or twisted part of the time
Bent or twisted more than half of the time
C2 Back posture
Almost neutral
Bent forward, sideways or twisted part of the time
Bent forward, sideways or twisted more than half the time
G 0
A 1
R 2
C3 Arm posture
Elbow close to the body or the arm is supported
Elbow raised away from the body part of the time
Elbow raised away from the body more than half of the time
G 0 G 0
A 2 A 2
R 4 R 4
C4 Wrist posture
Almost neutral/straight
Bent or deviated part of the time
Bent or deviated more than half of the time
C5 Hand/finger grip
Power grip or no awkward grip
Pinch or wide finger grip for part of the time
Pinch or wide finger grip for more than half of the time
G 0 G 0
A 1 A 1
R 2 R 2
Stage D Additional factors
D1 Breaks
Less than 1 hour of continuous work
1 to less than 2 hours of continuous work
2 to less than 3 hours of continuous work
3 to less than 4 hours of continuous work
4 or more hours of continuous work
G 0
A 2
A 4
R 6
R 8
D2 Work pace
Never difficult to keep up with the work
Sometimes difficult to keep up with the work
Often difficult to keep up with the work
G 0
A 1
R 2
D3 Other factors
No factors present
1 factor present
2 or more factors present
G 0 G 0
A 1 A 1
R 2 R 2
D4 Duration
Less than 2 hours
2 to less than 4 hours
4 to 8 hours
More than 8 hours
x 0.5
x 0.75
x 1
x 1.5
Stage A Frequency score A1 + A2
Stage B Force score B
Stage C Posture score C1 + C2 + C3 + C4 + C5
Stage D Additional factors D1 + D2 + D3
Task score
Duration D4
Exposure score
Left hand
Right hand

Task description form

Assessor name:		Date:	
Company name:		Location:	
Name of task:			
Task description:			

What is the weight of any items handled?	

If items weigh more than 8 kg and the task involves manual handling consider using the MAC

Which side of the body is primarily involved?	Left		right		both	

What hand tools are used?	
Production rate (if available)	units per shift, hour or minute (circle as appropriate)
How often is the task repeated?	every seconds

Draw the breaks in the shift

First hour →

How long does a worker perform the task?	...without a break	hours
	...in a typical day or shift (excluding breaks)	hours
How often does an individual perform the task? (eg daily, weekly, etc)		
How often is the task carried out within the organisation? (eg daily, etc)		
Do workers rotate to other tasks? If so, what tasks?		

Annex VI: Reference material for MAC in Ergonomic Risk Assessments

The following elements provides a description of how to apply the Manual handling Assessment Charts (MAC) for use by non-regulatory professionals. (Lee & Ferreira 2003).

The MAC procedure is threefold:

- Lifting operations
- Carrying operations
- Team handling operations

For each there is an assessment guide and a flow chart, as well as the mac score sheet.

The detail of the tool is reported in Annex V

Lifting Operations

A Load weight and Frequency

The weight of the load should be recorded as well as the repetition rate of the lifting operation. Depending on these the task will be ranked into a colour band and numerical score which can be entered into the MAC: Score sheet, Annex X.

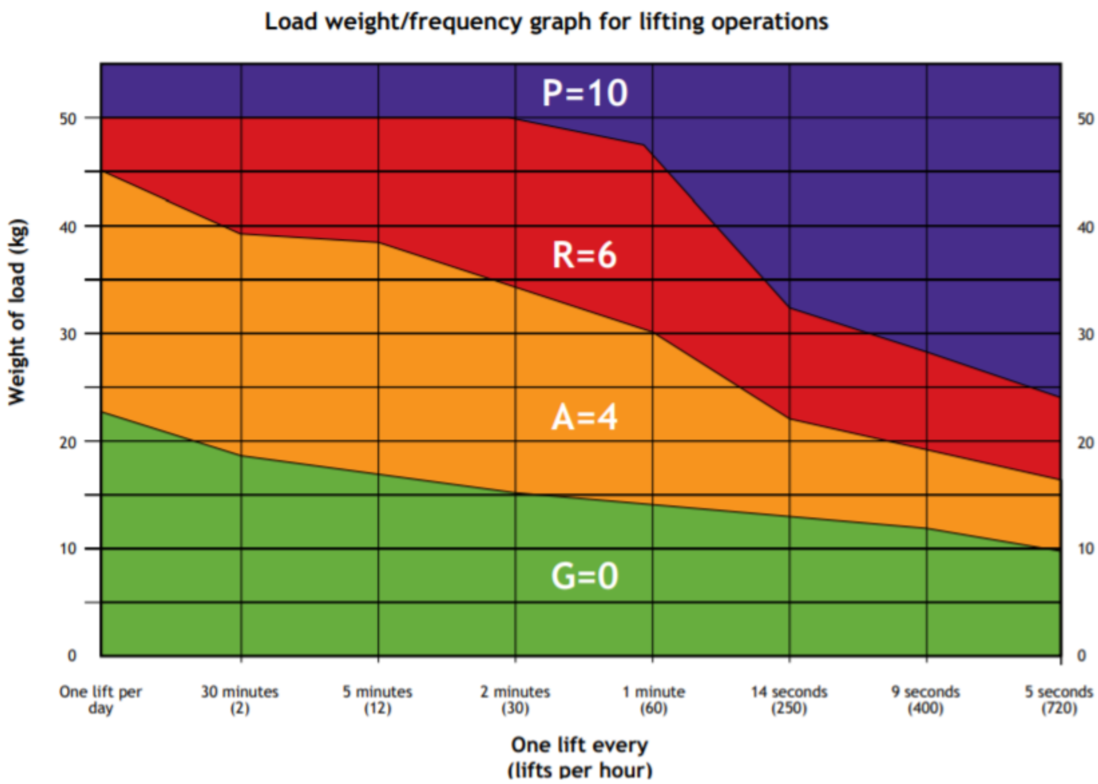
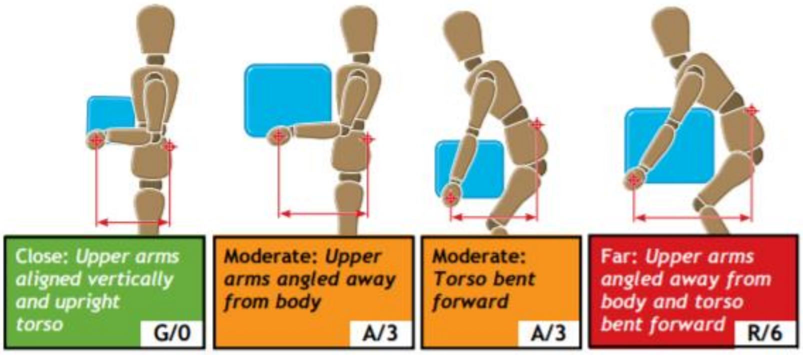


Figure 18: load weight/frequency for lifting operation in MAC

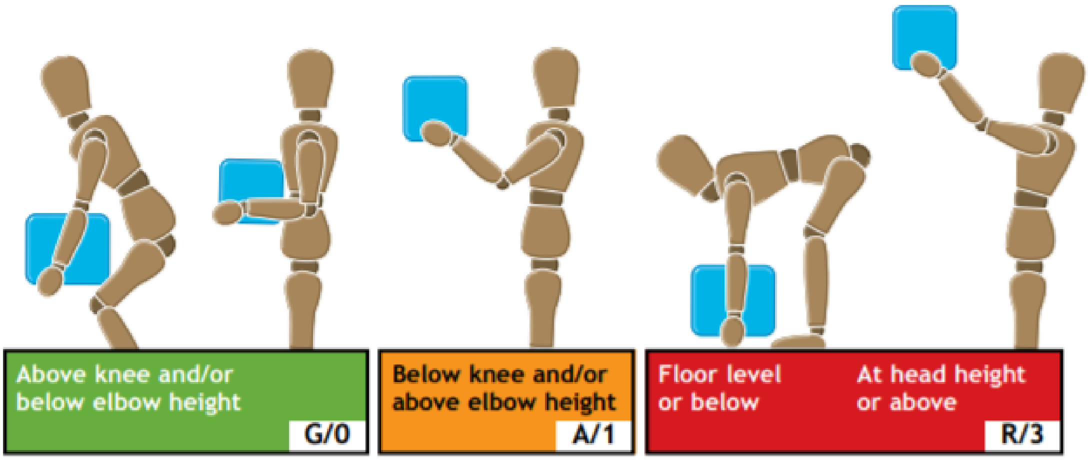
B Hand distance from the lower back

Observe and examine the horizontal distance between the workers hand and lower back, following the guide below:



C Vertical Lift

Observe the position of the workers hand before the task and as the task progresses. Assess this task using the guide below:



D Torso Twisting and Sideways Bending

Observe how the workers torso moves during the lifting task and assess following the guide below:

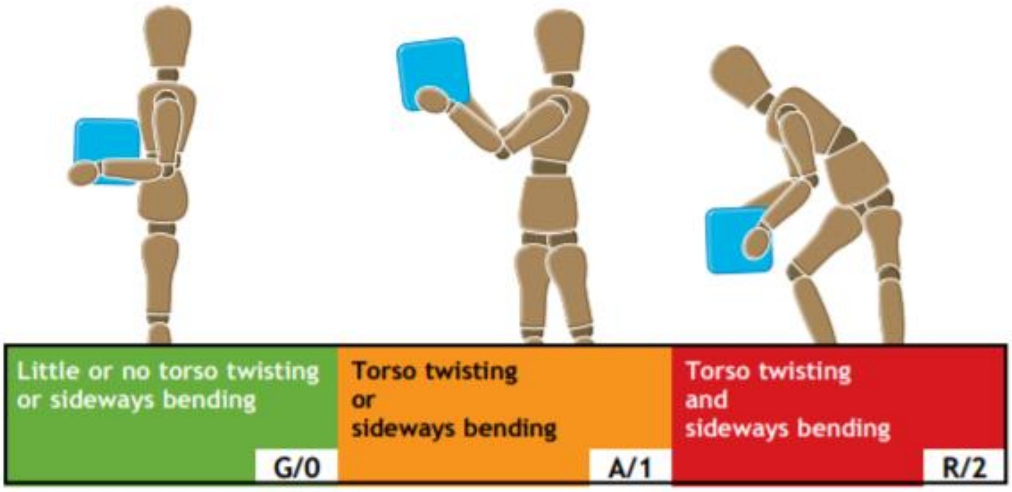


Figure 19: MAC tool evaluation steps

E Postural constraints

Observe the workers posture and of there are any constraints to it and asses following the table below:

No postural constraints G/0	Restricted posture A/1	Severely restricted posture R/3

Figure 20: worker posture observation in AMC tool

F Grip on the load

Good grip G/0	Reasonable grip A/1	Poor grip R/2
Containers with well-designed handles or handholds, fit for purpose	Containers with poor handles or handholds	Containers of poor design. Loose parts, irregular objects, bulky or difficult to handle
Loose parts enabling comfortable grip	Fingers to be clamped at 90 degrees under the container	Non-rigid sacks or unpredictable loads

Figure 21: consideration on the grip of the load in MAC tool

G Floor surface

Dry and clean floor in good condition G/0	Dry floor but in poor condition, worn or uneven A/1	Contaminated/wet or steep sloping floor or unstable surface or unsuitable footwear R/2

Figure 22: floor surface consideration in AMC tool

H Other environmental factors

No factors present G/0	One factor present A/1	Two or more factors present R/2

Figure 23: other environmental factors in MAC tool

Carrying Operations

For carrying operations A Load weight and frequency and B Hand distance from the lower back should be assessed in the same way as above for Lifting operations.

C Asymmetrical torso/load

The workers posture as well as the stability of the load are consider to be risk factors associated with musculoskeletal injury and so should be assessed as below:

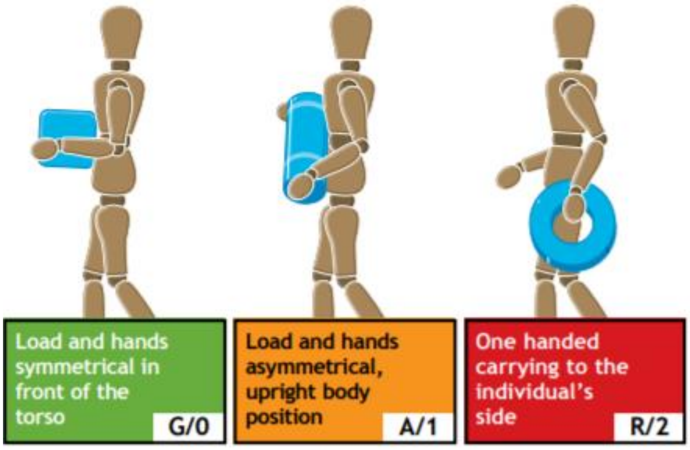


Figure 24: Asymetric torso/load

D Postural constraints

Observe the workers posture and of there are any constraints to it and asses following the table below:

No postural constraints G/0	Restricted posture A/1	Severely restricted posture R/3

Figure 25: Postural constraints

E Grip on load

Good grip G/0	Reasonable grip A/1	Poor grip R/2
Containers with well-designed handles or handholds, fit for purpose	Containers with poor handles or handholds	Containers of poor design. Loose parts, irregular objects, bulky or difficult to handle
Loose parts enabling comfortable grip	Fingers to be clamped at 90 degrees under the container	Non-rigid sacks or unpredictable loads

Figure 26: Grip on load

F Floor surface

Dry and clean floor in good condition G/0	Dry floor but in poor condition, worn or uneven A/1	Contaminated/wet or steep sloping floor or unstable surface or unsuitable footwear R/2

Figure 27: Floor surface

G Other environmental factors

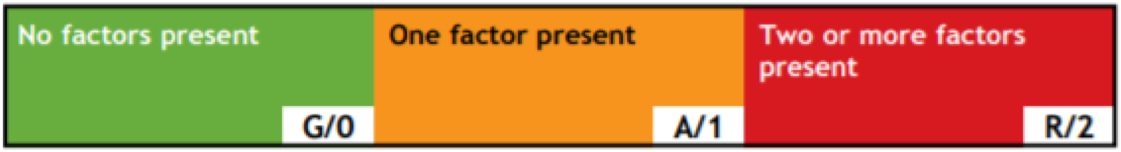


Figure 28: Other environmenral factors

H Carry distance

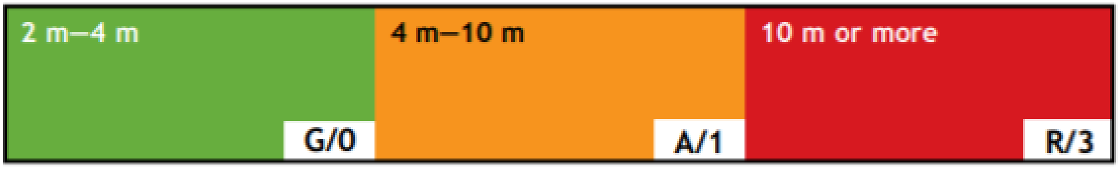
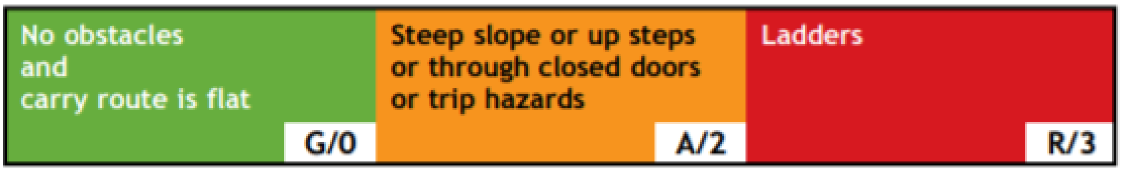


Figure 29: Carry distance

I Obstacles en route



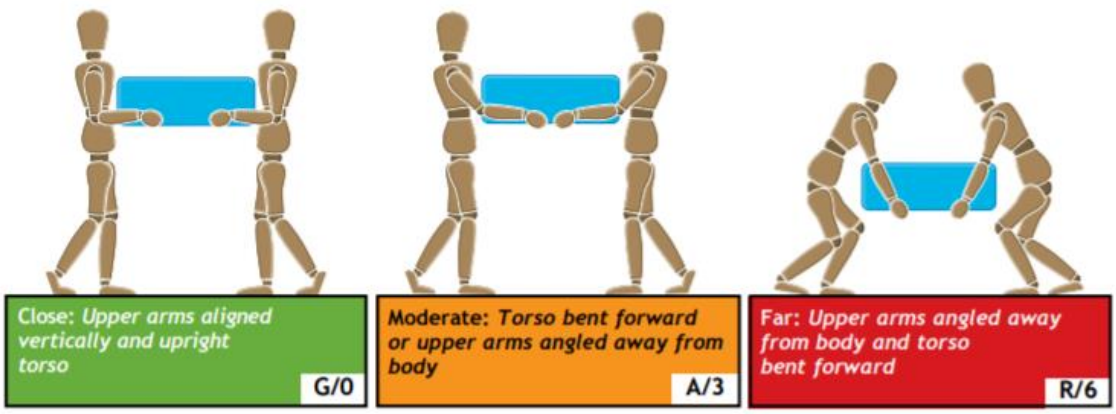
The operative's posture and the stability of the load are risk factors associated with musculoskeletal injury. The following illustrations should guide your assessment.

Team Handling Operations

A Load Weight

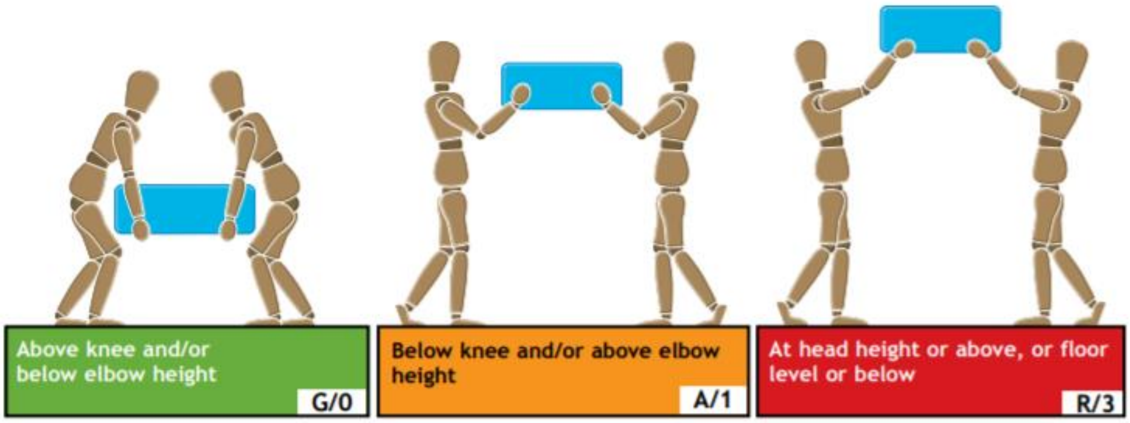
B Hand distance from the lower back

Observe and examine the horizontal distance between the workers hand and lower back, following the guide below:



C Vertical lift region

Observe the position of the operatives’ hands at the start of the lift and as the lift progresses.



D Torso twisting and sideways vending

Little or no torso twisting or sideways bending G/0	Torso twisting or sideways bending A/1	Torso twisting and sideways bending R/2

E Postural constraints

No postural constraints G/0	Restricted posture A/1	Severely restricted posture R/3

F Grip on load

Good grip G/0	Reasonable grip A/1	Poor grip R/2
Containers with well-designed handles or handholds, fit for purpose	Containers with poor handles or handholds	Containers of poor design. Loose parts, irregular objects, bulky or difficult to handle
Loose parts enabling comfortable grip	Fingers to be clamped at 90 degrees under the container	Non-rigid sacks or unpredictable loads

G Floor surface

Dry and clean floor in good condition G/0	Dry floor but in poor condition, worn or uneven A/1	Contaminated/wet or steep sloping floor or unstable surface or unsuitable footwear R/2

H Other environmental factors

No factors present G/0	One factor present A/1	Two or more factors present R/2

I Communication, co-ordination and control

Good G/0	Reasonable A/1	Poor R/3

Annex VII: Evaluation of Human Machine Interface (ISO 11064-5)

Principle		Questions to be used for verification	Notes
General Principles			
"1: System authority The human operator shall at all times be the highest authority in the human machine system"	1	Has the requirement to ensure that the operators are always within the control "loop" been fully addressed, except when functions are completely allocated to the machine?	
	2	Are all control functions required to cope with each situation available to the operator within a reasonable time?	
	3	Have all situation where system may fail been analysed? Does the system act without the operator's initiative, thus hampering him/her in finishing or continuing a task (e.g. pre-empting him/her by changing the display format automatically)?	
	4	Are inputs changed by the system without further inquiry?	
	5	Minimise the need for operators to manage 'windows' and menus on-screen	
"2: Information Requirements (includes SHELL requirement: support simultaneous awareness and shared awareness) **The operator at the human-system interface shall be provided with all the information needed to accomplish his/her tasks"**	6	Has appropriate information been provided for the operator to maintain situational awareness? Overview displays shall be visible at all times on one or more dedicated screens. This display shall show the key indicators spanning each panel operator's total area of responsibility. Overview displays may include a span-of-control overview display, dedicated trend displays, an alarm summary display, and potentially other support such as CCTV displays.	
	7	Does the operator have a permanent overview of the current status of the system he/she is responsible for? The console workstation shall have the minimum number of physical screens necessary to support the simultaneous viewing that the display hierarchy supports including the required overview screens. At a minimum, dedicated screen space shall normally be provided seperately for overview screens, process	

		control screens, trends and an alarm summary.	
	8	Are any elements of the overview display obscured by windows The panel operator shall not be required to remove a display intended as an overview display (schematic, alarm summary, dedicated trends, etc) in order to view a detailed display.	
	9	Is all the information presented relevant to the task? High priority information and controls shall be positioned within the operator's primary viewing angles while performing their core tasks. If this is not possible, significant changes in high priority information shall be supplement with other highly attention-catching mechanisms (such as audible signals or flashing visual signals).	
	10	Does the operator get sufficient and timely information to focus on any problem which may arise? Acoustic annunciations, including alarm tones, shall have sufficient intensity to be audible above ambient noise but not be startling or distracting. Care should be given to providing volume control to operators. If such volume control is provided it shall never be allowed to go below a low audible tone.	
	11	Are the different level of attention getting easily distinguishable?	
	12	Has all the information required to complete a particular task been presented on a minimum number of displays?	
	13	Cameras should provide live views of remote equipment and critical process areas, such as flare systems and hazardous units (e.g., HF alkylation unit). The operator should be able to pan, tilt, rotate and zoom on such cameras. Features to prevent burn in and or of the image on the monitor shall be utilized	
	14	Is the request exchange of information during shift changes minimized by the system? Communications that span shift handover - including daily shift handover and shift team meetings as well as extended operations (e.g., a plant startup procedure) - should be supported by a formal structure that ensures all safety or process critical information is exchanged and understood.	
	15	Each console position should have a dedicated radio channel for uninterrupted communications to their own field operations team. Maintenance personnel should use	

		radio channels separate from the operations team to minimize interruptions to operations communications during abnormal situations.	
	16	Have the requirements of all the potential users (e.g. maintenance engineers) been systematically evaluated? Consideration should be given to providing plant status information outside of the control room for use by personnel involved in Emergency Response or supporting plant upsets	
“3: Efficient human-system interface (includes SHELL requirement: LET OPERATORS CONCENTRATE ON PERFORMING OPERATIONAL TASKS) **The human-system interface shall support the user to complete her/his activities efficiently and effectively”**	17	Have tasks that can easily be automated been allocated to the technical system?	
	18	Are recurrent tasks executed by easily repeatable sequences?	
	19	Minimise the need for operators to manage ‘windows’ and menus on-screen	
	20	Navigation to any operating or information displays shall be possible with three key strokes or less and should not require the use of a drop-down menu or menu page.	
	21	The HMI shall support direct linking between an alarm and a display containing information about what is “in alarm”	
“4: Human-centered design The human's abilities, characteristics, limitations, skills and task needs shall be primary considerations when designing the human-system interface”	22	Over a short period of time (15 minutes) is the rate of message presentation to the operator restricted to a maximum of 15 per minute?	
	23	Over periods longer than 15 minutes, has the rate of message presentation to the operator taken account of all the other activities undertaken by the operator?	
	24	Are those displayed events that prompt the operator for a reaction (i.e. alarms) prioritized according to the urgency of his/her required response?	
"5: Application of Ergonomic principles The information presented to the operator should be based on known ergonomic principles	25	Are events that require the operator's quick response presented in an appropriate manner?	
	26	Are all events to which the operator has to respond easily perceptible and prioritized?	

to ensure that the information is conveyed quickly and accurately"			
"6: Mental Models (includes shell requirements for SUPPORT OPERATOR MENTAL MODELS) **The user shall at all times be provided with the necessary information such that they are able to maintain a comprehensive and robust mental model of the system and its associated sub-systems."**	27	Is the operator provided with an overview of the system at all times?	
	28	Has the operator been trained about the operating concepts?	
	29	Non-instrumented equipment should generally not be included in control system operating displays. There are however exceptions to this where it is important to allow the operator to maintain an accurate mental model of the process	
"7: Working ""Quality"" The task created should promote job satisfaction and provide both a satisfying and challenging work environment."	30	Have both operator underloading and overloading been analysed?	
Display related principles			
"12: Attention Getting (includes SHELL requirements for Use visual coding to support direction of visual attention) **The level of attention applied to a particular item of information should be matched to the importance of that information for the operator and the**	31	A visual coding hierarchy shall be used to ensure the most salient (i.e. attention catching) codes are used for the most important information. I.e., the salience of each visual code used should reflect the relative importance of the information type	
	32	The developer shall define the relative priority of all elements to be displayed using at least 2 and no more than 5 levels of priority. This prioritization shall be applied across the entire system, not only individual operator roles	
	33	In producing the information prioritization, the developer shall take account of an agreed set of critical operations (typically startup/ shutdown, pre-defined abnormalities or upsets).	

safety of the system."	34	High priority information coding shall be used for real-time data: i.e. key information (process values, alarm states, or equipment status) that can change in real-time	
	35	Are alarms presented in the same locations on screen formats or in relation to relevant icons?	
	36	Are overview alarm displays protected against being obscured by windows?	
	37	The ambient light level of the control room shall set to the recommended levels to maintain operator alertness. The display background colour shall be chosen to minimize the contrast with this recommended ambient light level. This reduces eye strain and fatigue while supporting appropriate alertness levels	
	38	Coding values for high priority information shall be unique. For example, if red is used to indicate an urgent priority alarm, it shall not also be used to indicate that a pump motor is turned off or a valve is closed	
	39	The visual coding scheme shall include elements that are redundant with colour coding, such as shape/pattern or text, to support individuals with colour vision deficiencies. ("Redundant" means using, for example, luminance as well as colour to code for priority	
	40	The colour scheme shall ensure that all probable combinations – including foreground combinations on the background and static object colours – are acceptable and provide sufficient contrast for legibility for all user populations, including users that are colour-deficient	
	41	Avoid clutter, particularly clutter created by the use of too many visual codes (e.g., too many colour codes or line types).	
"13: Consistency The same information presented on different displays should be consistent with respect to such features as location, coding (e.g. colour coding),	42	Is the system predictable and does it respond in accordance with the expectations of the operator?	

behaviour principles and access and navigation principles."			
"14: Information Coding Information coding shall be discriminable, legible, clear, concise, consistent, conspicuous and comprehensible."	43	Has the information been structured in accordance with the activity to be accomplished?	
	44	Does the presentation of the information on the human system interface allow for an intuitive understanding of its relationship with other information presented elsewhere?	
Control and interaction-related principles			
"17: Operator support **The system should aid the operator in inputting information efficiently and correctly as well as in minimizing the risk of errors.**	45	Interface content shall support not only monitoring and control activities, but all activities that fall within the panel operator's responsibility. These can include: startup, shutdown, upset response, troubleshooting, shift handover, start of shift orientation, proactive monitoring, responding to alarms, maintenance support, process optimization, batch operations and reporting	
	46	Wherever possible, show the operator information not just data. Consideration should be given to integrated schematic displays and task-based displays. In general, process data shall be presented in the context of the targets, limits, or calculations required to support decision making	
	47	Wherever possible if the process has gone above or below available instrumentation ranges the display design shall supplement the alarm system by making this obvious to the operator. The display should effectively tell the operator when it is not capable of providing situational awareness	

	48	Where severe consequences might result from an operator's action (e.g. where safety, or ible actions are involved), does the system request confirmation prior to execution? irreversible effects	
	49	Operator-centered safety-instrumented system information, such as first-out and interlock status, shall be in an easily accessible location	
	50	Integrated trending functions, such as x-y trend plots or other time-based indicators, shall be provided to support pattern recognition, detection of change in values over time and to support the operator in predicting potential future states and when process conditions may exceed a limit	
	51	The qualitative status of parameter values shall be shown with dynamic graphical objects that incorporate alarm or operating limits.	
	52	Deviation indicators shall be used to illustrate process value difference from target, SP, or time-marked value	
	53	If an input is obviously wrong, does the system generate an appropriate message?	
"18: Feedback Appropriate feedback shall be provided to the operator at all times."	54	Is there an indication whenever the control equipment is busy or out of order?	
	55	Does the system notify the operator of any failure to execute a control command?	
	56	Does the system provide self explanatory and unambiguous error messages?	
"20: Error Tolerance The system shall take account of the fact that the operator will make errors and minimize the effect of these."	57	Is the operator clearly informed of the consequences of an action before taking the action?	

Annex VIII: Survey to be adapted for Teaming AI job satisfaction evaluation in each use case)

The Survey below is a version of the Hackman and Oldham (Job Diagnostic Survey on Five Core Dimensions for apprising the before and after situation related tot he tasks involved in the Teaming AI uses cases as used by Hussein et al. (2016).

Skill Variety

1.How much variety is there in your job? That is, to what extent does the job require you to do many different things at work, using a variety of your skills and talents?

	Very little (The job requires me to do the same routine things over and over again.)			Moderate Variety			Very much (The job requires me to do different things, using a number of different skills and talents.)

2.The job requires me to use a number of complex or high-level skills. How accurate is the statement in describing your job?

	Very inaccurate	Mostly Inaccurate	Slightly inaccurate	Uncertain	Slightly accurate	Mostly accurate	Very accurate

3.The job is quite simple and repetitive. How accurate is the statement in describing your job?

	Very inaccurate	Mostly Inaccurate	Slightly inaccurate	Uncertain	Slightly accurate	Mostly accurate	Very accurate

Task identity

4.To what extent does your job involve doing a —whole and identifiable piece of work? That is, is the job a complete piece of work that has an obvious beginning and end? Or is it only a small part of the overall piece of work, which is finished by other people or by automatic machines?

	My job is only a tiny part of the overall piece of work: the			My job is a moderate sized —chunk of the overall piece of			My job involves doing the whole piece of work, from

	results of my activities cannot be seen in the final product or service.			work; my own contribution can be seen in the final outcome.			start to finish; the results of my activities are easily seen in the final product or service

5.The job provides me with the chance to completely finish the pieces of work I begin. How accurate is the statement in describing your job?

	Very inaccurate	Mostly Inaccurate	Slightly inaccurate	Uncertain	Slightly accurate	Mostly accurate	Very accurate

6.The job is arranged so that I do not have the chance to do an entire piece of work from beginning to end. How accurate is the statement in describing your job?

	Very inaccurate	Mostly Inaccurate	Slightly inaccurate	Uncertain	Slightly accurate	Mostly accurate	Very accurate

Task Significance

7.In general, how significant or important is your job? That is, are the results of your work likely to significantly affect the lives or well-being of other people?

	Not very significant; the outcomes of my work can affect other important effects on other people			Moderately Significant			Highly significant; the outcomes of my work are not likely to have people in very important ways

8.This job is one where a lot of people can be affected by how well the work gets done. How accurate is the statement in describing your job?

	Very inaccurate	Mostly Inaccurate	Slightly inaccurate	Uncertain	Slightly accurate	Mostly accurate	Very accurate

9.The job is quite simple and repetitive. How accurate is the statement in describing your job?

	Very inaccurate	Mostly Inaccurate	Slightly inaccurate	Uncertain	Slightly accurate	Mostly accurate	Very accurate

Autonomy

10.How much autonomy is there in your job? That is, to what extent does your job permit you to decide on your own how to go about doing your work?

	Very little; the job gives me almost no personal —say about how and when the work is done			Moderate autonomy; many things are standardized and not under my control, but I can make some decisions about the work			Very much; the jobs gives me almost complete responsibility for deciding how and when the work is done.

11.The job gives me considerable opportunity for independence and freedom in how I do the work. How accurate is the statement in describing your job?

	Very inaccurate	Mostly inaccurate	Slightly inaccurate	Uncertain	Slightly accurate	Mostly accurate	Very accurate

12.The job denies me any chance to use my personal initiative or judgment in carrying out the work. How accurate is the statement in describing your job?

	Very inaccurate	Mostly inaccurate	Slightly inaccurate	Uncertain	Slightly accurate	Mostly accurate	Very accurate

Feedback

13.To what extent does doing the job itself provide you with information about your work performance? That is, does the actual work itself provide clues about how well you are doing—aside from any —feedback co-workers or supervisors may provide?

	Very little; the job itself is set up so I could work forever without finding out how well I am doing			Moderately; sometimes doing the job provides —feedback to me; sometimes it does not			Very much; the job is set up so that I get almost constant —feedback as I work about how well I am doing

14.Just doing the work required by the job provides many chances for me to figure out how well I am doing. How accurate is the statement in describing your job?

	Very inaccurate	Mostly inaccurate	Slightly inaccurate	Uncertain	Slightly accurate	Mostly accurate	Very accurate

15.The job itself provides very few clues about whether or not I am performing well. How accurate is the statement in describing your job?

	Very inaccurate	Mostly inaccurate	Slightly inaccurate	Uncertain	Slightly accurate	Mostly accurate	Very accurate