*Proceedings of the 33rd European Safety and Reliability Conference (ESREL 2023)*
*Edited by* Mário P. Brito, Terje Aven, Piero Baraldi, Marko Čepin and Enrico Zio

doi: 10.3850/978-981-18-8071-1_P646-cd

# Revising the "Ability Corners" Approach: A New Strategy to Assessing Human Capabilities in Industrial Domains

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Human capabilities refer to an individual's innate and acquired abilities that enable them to complete a given task. These capabilities contain physical, mental, and cognitive skills. In an industrial environment, the complexity and nature of duties vary, and different jobs require different levels and types of human capabilities. For example, in an assembly line, a task that demands assembling small and fragile parts would require a high level of manual skill and precision. Understanding the human capabilities necessary for a job and matching them with the worker's capabilities is crucial for designing and implementing tasks in industrial settings. The term "ability corners" describes equipment (hardware and software) for evaluating and measuring human capabilities in industrial workplaces. The results of these tests are used to match workers with the specific abilities needed for a particular workstation.
This study proposes improving the "ability corners" by addressing some limitations, such as the insufficient number of tests to assess human capabilities and the lack of consideration for workers' motivation, personality traits, and other factors that might affect their performance on the task. Furthermore, the study in which they were adopted does not consider the dynamic nature of assembly line work or the possible changes in workers' capabilities over time due to factors such as experience, training, or fatigue. The present revision aims to enhance the accuracy and effectiveness of the "ability corners" approach by integrating new techniques, devices, and benchmarks into the current method to guarantee that the worker is well-suited for the job and can execute it safely.

This work is part of our Collaborative Intelligence for Safety-Critical Systems (CISC) project research activity. https://www.ciscproject.eu/

*Keywords*: Ability corners, human capabilities, human performance, safety-critical systems, task complexity.

## 1. Introduction

Human capabilities are crucial in determining the tasks an individual can efficiently perform across different industries (Comberti et al. (2020)). These capabilities contain physical, cognitive, and mental abilities (Longo and Leva (2017)). Physical abilities refer to an individual's physical skills and attributes that enable them to perform tasks that require physical effort (Murphy (2015)). Physical capabilities include strength, endurance, flexibility, coordination, and manual dexterity (Longo and Leva (2017)). In an industrial setting, manual labour jobs, such as lifting heavy objects, require high physical strength. In contrast, tasks that require fine motor skills and precision, such as assembling small parts, require a high level of manual dexterity. Cognitive abilities are the mental faculties or processes that enable individuals to think, reason, understand, learn, and remember information (Ispas and Borman (2015)). Cognitive skills include problem-solving, decision-making, critical thinking, and creativity (Mayfield (2011)). Machine breakdowns, quality issues, safety hazards, and supply chain disruptions can arise in an industrial setting. Workers need to have problem-solving skills to identify the root cause of the problem, analyze the situation, and develop effective solutions to prevent similar issues from recurring. On the other hand, mental abilities are the individual's emotional intelligence, social skills, and communication abilities (Srivastava (2009)). Therefore, mental capabilities are the psychological attributes and skills that allow individuals to understand their own and others' emotions, communicate effectively, build relationships, and manage their behaviours in various social and professional settings (Lappalainen (2015)).

Employers assess operators' capabilities for selecting and training the right workforce and matching them with the correct workstations and tasks within the organization. By understanding their employees' physical, cognitive, and mental capabilities, employers ensure that they assign them to the roles and workstations that best suit their skills (Comberti et al. (2018)). Several methods to assess human capabilities in the industrial context depend on the evaluation's purpose, the type of capabilities being evaluated, and the appraisal context. Comberti et al. (2019) presents the "ability corners" tests that offer a practical and thorough assessment of some crucial human capabilities. This paper aims to provide a comprehensive and functional approach to assessing human capabilities for assembly line work, building on the "ability corners" tests as a starting point for further study and improvement.

The following sections of the paper provide an exhaustive review of the "ability corners" tests in the first instance. We describe each of the four tests in detail and their limitations. Then, we propose revising the "ability corners" tests to address these limitations. Finally, we will explore the applications of these tests in various assembly line industries and discuss the potential for these tests to be used in the hiring process.

## 2. The previous "ability corners" tests

This previous framework is based on the idea that the concept of Human Performance (HP) is influenced by the interaction between the workload of a specific task workload and the worker's skills (Human Capability) (Leva et al. (2018); Comberti et al. (2018)). Workload includes the physical and mental demands of a given task. In contrast, Human Capability contains the worker's physical, mental, and cognitive resources under real working conditions. The sole focus of this work is to evaluate Human Capability by revising the "ability corners" tests. This study does not consider the task complexity factor.

The "ability corners" tests aim to assess the Human Capability of workers on an assembly line through the evaluation of manual skills, memory retention capacity, and physical dexterity. To achieve this, the researchers designed four empirical tests that simulate everyday tasks performed by workers in the assembly line:

- The first test is called the "Precision test", where workers move an iron stick along a nonlinear contour without touching the borders. This test evaluates the manual precision required in many assembly tasks where workers must assemble components without causing any impact. The duration taken to navigate the path and the tally of mistakes made by the operator when the rod touches the pathway are recorded during this test.
- The second test, the "Both-Hands test", assesses the worker's manual skills by measuring their ability to simultaneously perform simple actions using both hands. The time and the number of errors when completing the task were recorded.
- The third test is the "Methodology test", which requires workers to complete simple assembly steps with small parts based on provided instructions. Then, the researchers recorded the time to complete the task and the errors committed during the test.
- The fourth test, the "Memory test", evaluates workers' memory retention capacity by showing them sequences of geometric schemes for a few seconds and then asking them to replicate them on a desktop. The time taken to complete the task and its accuracy were recorded during this test.

Based on the results from these four tests, three indicators quantitatively were built on the specific Human Capability features assessed for each worker. These indicators are the Physical index (PSI), Memory index (MI), and Dexterity index (DI):

- The PSI is expressed on a scale of 1 to 10, representing consistency in good work performance. It was calculated by considering the variance in performance on the three manual tests; the more consistent the performance, the higher the value associated with the operator.
- The MI is expressed on a 1-10 Likert scale and is directly associated with a linearization of the results from the Memory test.
- The DI combines results from the Precision, Both-Hands, and Methodology tests, all representing a dexterity measure. The researchers used the linearized average of these results.

Figure 1 (see Fig.1) shows how the conceptual model variables and the operational model quantities are connected and how they lead to the three derived indicators. Each worker on the assembly line was assessed based on these three indicators, measured on a 1-10 scale. A training area was set up nearby with the four tests to minimize the impact on plant activity. Before the trials, operators received an explanation of the project and had the opportunity to try them. The tests took around 10-12 minutes. Workers were given a short break to perform them, and substitutes were used for temporary absences. The tests were repeated three times during the shift for all workers and showed good discrimination of workers' skills with a wide range of performance variations.

The "ability corners" tests have several advantages, such as they are designed to simulate frequent assembly line operations. They are performed by workers during their working activity, making them practical and efficient. In addition, the trials focus on crucial abilities for assembly line work and provide good discrimination of workers' skills with a wide range of performance variations. Finally, the tests can be repeated multiple times during a shift for a more accurate assessment.

Despite the benefits of the "ability corners", some drawbacks must be acknowledged.

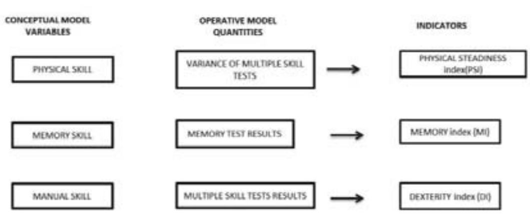


Fig. 1. Human Capability model Comberti et al. (2018)

### 2.1. *Drawbacks and shortcomings*

One limitation of the "ability corners" tests is that they only assess a limited range of human capabilities. While the tests primarily measure manual skills, memory retention, and dexterity, the study does not evaluate cognitive abilities such as problem-solving, decision-making, or attention. Additionally, the study does not consider the worker's motivation or mental capabilities, which are crucial factors influencing a worker's performance. Therefore, the "ability corners" test results should be viewed as a partial assessment of workers' capabilities.

Another drawback that should be considered is the "ability corners" tests are unsuitable for evaluating workers' performance in all types of assembly line work. The trials assessed workers' capabilities in performing manual dexterity and precision tasks, such as those in the automotive and electronic industries. However, the tests may not be suitable for workers in other sectors or those performing different functions on the assembly line.

The "ability corners" tests were conducted in a controlled environment, with workers aware that they were being evaluated. As a result, workers may have performed differently than they would in their typical work setting, and their effects may need to reflect their true capabilities in real-world situations. Additionally, in a real-life assembly line environment, many factors, such as noise levels, temperature, lighting, and other environmental factors, could have affected the worker's test performance.

Experience and training are critical factors in an operator's performance on the assembly line, and the "ability corners" tests do not consider these factors. For example, an operator may have years of experience and extensive training in a specific task but still perform poorly in the test due to unfamiliarity with the testing environment or equipment. On the other hand, a new operator who performs well on the test may still make mistakes in their work due to a lack of experience and training. In general, both Human Capability and experience are critical factors for success and efficiency in assembly lines. While innate abilities, such as hand-eye coordination and spatial reasoning, are necessary for some tasks, experience with the specific assembly process and equipment is also crucial. Workers with experience are typically more efficient, make fewer errors, and can quickly identify and solve problems, increasing productivity and quality. However, workers with high innate abilities may soon adapt to new tasks and equipment.

Another factor influencing the results is that the results are the workers' state during the tests. For example, workers may have been tired, stressed, or fatigued, which could have affected their performance. Therefore, it would be beneficial to control for these variables in future studies to increase the validity and reliability of the results.

In the following section, we tackled these limitations by reviewing and revising the "ability corners" approach.

## 3. Revamping the "ability corners" tests

By improving the "ability corners" approach to overcome these limitations, we develop a more complete and precise assessment of Human Capability. This method could offer valuable information on workers' skills and areas for improvement, allowing companies to enhance efficiency, minimize mistakes, and ensure the safety of their workers. Additionally, a better understanding of workers' capabilities facilitates the optimal allocation of workers to specific workstations.

### 3.1. *Incorporating additional assessments*

The current "ability corners" tests focus mainly on evaluating manual skills, dexterity, and memory retention but fail to assess other critical cognitive abilities like attention, decision-making, and problem-solving. The revised approach incorporates additional diverse cognitive and mental capability tests, including:

- Memory test: estimates an individual's ability to retain and recall information (already included in the previous assessment).
- Verbal reasoning test: assesses an individual's ability to understand written information and draw logical conclusions.
- Numerical reasoning test: estimates an individual's ability to work with numerical information and solve problems.
- Spatial reasoning test: measures an individual's ability to visualize and manipulate objects in three-dimensional space.
- Critical thinking test: evaluates an individual's ability to analyze information and make sound decisions based on available evidence.
- Attention test: estimates an individual's ability to sustain focus and concentrate on a task.
- Inductive and deductive reasoning tests: evaluate cognitive abilities related to problem-solving and decision-making.
- Mechanical reasoning test: assess a person's ability to understand and apply concepts related to mechanical principles, such as how machines work, how they are designed, and how they are repaired.
- Situational judgment test: measures workers' behaviour and attitudes in work-related scenarios and can be valuable in assessing their mental capabilities. Such a test can provide insight into how workers would handle different situations in the workplace, their problem-solving skills, and their ability to work effectively in a team.

The trials in the previous approach are still relevant, but adding more cognitive and mental ability tests provides a complete picture of workers' strengths and weaknesses.

### 3.2. *Defining new indicators*

In assembly line settings, efficiency and quality are crucial. While workers need to perform tasks quickly and accurately, reducing errors is more critical than completing tasks rapidly in some in-

stances. Errors in critical components can lead to significant delays and additional costs. Therefore, the focus will be on test results rather than time to perform.
The definition of the new indicators remains consistent with the previous model (see Fig.1). The names of the new indicators for each of the cognitive and mental ability tests are:

- Verbal reasoning test: Verbal Reasoning Index (VRI)
- Numerical reasoning test: Numerical Reasoning Index (NRI)
- Spatial reasoning test: Spatial Reasoning Index (SRI)
- Critical thinking test: Critical Thinking Index (CTI)
- Attention test: Attention Index (AI)
- Inductive and deductive reasoning tests: Reasoning Index (RI)
- Mechanical reasoning test: Mechanical Reasoning Index (MRI)
- Cognitive Index (CI): A composite index of the above indexes provides an overall measure of cognitive ability.
- Situational Judgement Test: Situational Judgement Index (SJI)

Having separate indices for each cognitive test makes it easier to identify which areas an individual needs to improve and tailor training and development programs to their specific needs. Additionally, having separate indices would allow for a more targeted and accurate evaluation of an individual's cognitive abilities rather than relying on a single, aggregated score. These new indicators can be used alongside the previous PSI, DI and MI indexes.
To define the new indexes, we can first calculate the distribution of scores for each of the tests. We can then use this distribution to map the raw test scores to a 0-10 scale. For example, suppose that the distribution of scores for the verbal reasoning test is approximately normal, with a mean of 50 and a standard deviation of 10. We can then use the following formula to map raw scores to a 0-10 scale:

$$\text{index } = \frac{10}{\sigma\sqrt{2\pi}} \int_{-\infty}^{x} \exp\left(-\frac{(t-\mu)^2}{2\sigma^2}\right) dt \tag{1}$$

where $\mu$ is the mean of the distribution (in this case, 50), $\sigma$ is the standard deviation (in this case, 10), and $x$ is the raw score of the test. The above formula calculates the area under the normal distribution curve up to the raw score $x$, and scales this value to a 0-10 range. This ensures that the distribution of the index values will be similar across all the tests.
Finally, the updated method for determining the Physical Index (PSI) is as follows:

$$\text{PSI} = 10^{*}(1 - (\text{CV}/\text{ Mean })) \tag{2}$$

The formula considers the coefficient of variation (CV) and the mean score of the worker on the three manual tests. The coefficient of variation is calculated by dividing the standard deviation of the worker's scores by their mean score. The resulting value is subtracted from 1 and multiplied by 10 to obtain the PSI score. In other words, the higher the PSI, the more consistent the worker's performance on the three manual tests.

### 3.3. *Timing and frequency of tests*

Regular assessment of Human Capability is crucial in assembly line settings due to the dynamic nature of the work environment. The constant exposure to high workloads, repetitive tasks, and time pressures can lead to fatigue, stress, and mental workload, affecting workers' capabilities. By testing operators at different times during the work week, it is possible to detect changes in performance that may be due to these factors. For a preliminary study to generate reliable and accurate results, conducting three testing sessions, with one test administered at the start of the work shift and another at the end. This testing frequency generates enough data points for analysis, leading to more robust findings and conclusions. Hypothesis tests can be used to determine whether the differences observed between different testing sessions or groups are significant.

### 3.4. *Error rate performance indicator*

In many industries, the frequency and root cause of errors in each workstation are diligently documented and recorded. This information can be used to develop a new index that considers the errors committed by the operators. The indicator considers the operator's capabilities and their on-the-job experience, such as their learning curve and familiarity with the task. For example, an experienced operator performing a particular task for several years will likely have a lower error rate than a new operator who has just started. In addition, the trained operator may have developed shortcuts or techniques to avoid mistakes, while the new operator may still be learning the ropes. The equation to calculate the error rate performance indicator (ERI) is:

$$ERI = 10^* \frac{(E - E_{min})}{(E_{max} - E_{min})} \quad (3)$$

The index compares the number of errors committed by a worker during their shift ($E$) to the worker who executed the least number of errors ($E_{min}$) and the worker who committed the largest number of errors ($E_{max}$) at the same workstation. The resulting value measures the worker's error rate relative to their peers and is multiplied by 10 to obtain a value between 0 and 10. A lower value indicates better performance. The error rate indicator provides a reliable measure of the workers' performance and ability to perform tasks correctly because it directly counts the number of errors made by workers on the assembly line without their knowledge of being evaluated. Using the ERI in combination with the environmental conditions, we can evaluate whether the errors in error rates between workers are due to individual factors or external factors such as noise, temperature, lighting, etc.

### 3.5. *Incorporating subjective self-assessments*

The proposed method aims to enhance the reliability of cognitive assessment by administering two questionnaires, Numerical Analogue Scale (NAS) (Brunzini et al. (2021)) and NASA Task Load Index (NASA-TLX) (Hart and Staveland (1988)), to evaluate an individual's mental and emotional states subjectively. Additionally, the method includes aiding the Borg Test, also known as the Borg Rating of Perceived Exertion (RPE) scale Borg test (Borg (1982), to assess an individual's perceived physical exertion, thus increasing the reliability of the physical evaluation. NASA-TLX is a scale used to measure the overall workload of a task based on six factors: mental demand, physical demand, temporal demand, performance, effort, and frustration, while NAS measures stress levels based on five factors: workload, social isolation, danger, environment, and time pressure. The Borg Scale is a subjective scale used to measure physical exertion during exercise, ranging from 6 to 20. By running these three questionnaires before the "ability corners" tests, we can subjectively evaluate an individual's cognitive and physical conditions, which may impact their test results. If the ability corners test results change between the start and the end of the work shift, we can use the results of these questionnaires to determine why. For example, if their NAS scores show increased stress levels and their Borg Scale scores indicate increased physical exertion, we may conclude that these factors contribute to their decreased test performance.

The dynamic nature of assembly line work presents a challenge for manufacturers, as changes in worker capabilities over time due to factors such as experience, training, or fatigue can impact productivity and quality. However, with the proposed revamping of ability corners, we aim to address this issue and create a more adaptable and efficient manufacturing process.

## 4. Potential applications

The previous approach focused mainly on manual dexterity and physical abilities. In contrast, the revised method considers a broader range of cognitive and mental skills necessary to successfully perform various assembly line tasks. Considering a more comprehensive range of mental indicators, the revised approach can provide a more thorough analysis of an individual's abilities and suitability for a particular assembly line job. Some examples of assembly lines in different sectors where Human Capability assessment can be applied include:

- Electronics Manufacturing: In manufacturing electronic components, Human Capability assessment can be employed to measure the accuracy in tasks such as soldering and assembly of circuit boards.
- Pharmaceutical Manufacturing: In manufacturing pharmaceuticals, Human Capability review can estimate workers' attention to detail and accuracy in tasks such as packaging and labelling.
- Textile Manufacturing: In the textile industry, Human Capability examination can evaluate the dexterity and hand-eye coordination of workers in tasks such as cutting, sewing, and finishing.
- Aerospace Manufacturing: In the aerospace industry, human capability checks can assess workers' problem-solving and critical thinking skills in tasks such as the assembly of aircraft parts and inspection.
- Automotive sector: In the automotive industry, assembly line jobs often require workers to perform repetitive tasks, such as attaching car parts or installing electrical systems.

Including error rate as a performance indicator in the Human Capability assessment model is essential because human errors can have significant consequences in many industries. Human errors can occur due to various factors, such as lack of attention, fatigue, stress, or lack of training, and can lead to adverse outcomes such as product defects, accidents, or even loss of life. By incorporating error rate as a performance indicator, the model can identify potential areas for improvement in industries.

Incorporating the human capability assessment into the hiring process benefit employers significantly. Employers can make informed decisions about selecting the best candidates by evaluating job applicants' cognitive, physical and mental abilities. This results in increased job performance, heightened productivity, and a more substantial alignment between the employee and the position. Furthermore, utilizing the Human Capability assessment in the hiring process help to reduce bias and foster diversity in the workplace. Instead of relying on subjective factors like resumes and interviews, which biases may influence, employers can use objective measures to evaluate job candidates' cognitive, mental and physical capabilities. This approach can create a more inclusive and diverse workforce.

## 5. Future work

Future works include revising the workload part of the Human Performance model (Comberti et al. (2018)). Modifying the workload assessment could involve incorporating new factors or variables necessary for assessing task complexity. It could also include refining existing aspects or developing more precise measuring methods.

In the future, the authors aim to implement a more advanced HP index that employs a weighted algorithm to enable a detailed assessment of the importance of each skill set required for every workstation. This method will increase the precision of the model by pinpointing which operator skills are more or less challenging in each workstation.

The proposed assessment method involves administering three questionnaires before conducting "ability corner" tests. Although subjective questionnaires can provide valuable insights, they may be prone to bias and inaccuracies. The approach could include collecting physiological parameters through non-invasive wearable devices like smartwatches to enhance accuracy and reliability. This objective data can supplement the subjective questionnaire responses. However, privacy concerns may hinder the implementation of physiological measures in manufacturing settings.

## 6. Conclusions

Incorporating these tests into existing workflows or training programs, optimizing test design for efficiency, scheduling tests during non-peak periods or shift rotations and prioritizing tests based on job roles are strategies to enhance the viability of the tests in an industrial setting. The revised human capability assessment approach has the potential to be applied to various assembly line sectors and provide a more accurate evaluation of cognitive and mental capabilities. Including error rate as a performance indicator can identify potential areas of improvement and help prevent human error in high-risk industries. The indicator now incorporates the operator's on-the-job experience and learning curve, which were previously not considered. Moreover, it effectively tackles the issue of workers being conscious of being evaluated by utilizing a direct measure from the assembly line under real environmental conditions. By including self-assessment questionnaires such as NASA-TLX, NAS, and the Borg Scale, we can overcome the limitations of the previous model, which did not fully consider the range of factors that can influence test outcomes, such as worker fatigue, stress, frustration, and other variables that can impact their mental, physical, and emotional state. Furthermore, using the Human Capability assessment in the hiring process can help reduce bias and promote diversity, leading to a more inclusive workforce. The Human Capability assessment approach ultimately leads to improved job performance, higher productivity, and a better fit between the employee and the job, benefiting both the employer and the employee. Therefore, the new approach covers all the limitations of the previous model.

Future research should focus on revising the task complexity component of the existing Human Performance model. In addition, there is a need to refine the definition of the HP index.

**Acknowledgement**

This work is funded by the CISC project, which is part of the grant H2020-MSCA-ITN-2020 grant agreement no. 955901.

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