

Moving Towards Industry 5.0: Competency-Based Training Assessment & Sector Unification

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ABSTRACT

This paper outlines a structured approach for transferring Competency-Based Training and Assessment (CBTA) frameworks from aviation into industrial production environments, in support of the broader Industry 5.0 transition. A five-phase implementation strategy was developed and applied in a Greek manufacturing facility, incorporating task decomposition, digital proficiency audits, and behaviorally anchored assessments across three domains: digital competence, intercultural intelligence, and role-specific technical proficiency. Observable behaviors were evaluated using structured rubrics, allowing for performance calibration beyond traditional skill verification. Initial findings revealed marked variation in digital readiness and resistance to automation across hierarchical levels, with trust emerging as a psychological rather than cognitive barrier. Intercultural training showed limited transferability unless explicitly role-adapted. Drawing on the aviation precedent, the model demonstrated efficacy in improving coordination, safety compliance, and behavioral clarity in supervisory roles. The concept of sector unification is advanced as a method for achieving methodological interoperability across industries by aligning competency taxonomies, enhancing workforce mobility, and promoting systemic learning without compromising role specificity or operational safety.

Keywords: Industry 5.0, Competency-based training and assessment, Human factors, Sector unification, Sectoral alignment

INTRODUCTION

Industry 5.0 denotes a marked departure from the automation-driven architecture of Industry 4.0. It introduces a reframed industrial paradigm centred on sustainability, resilience, and human-machine complementarity (Breque et al., 2021). This reorientation has implications for how workforce competencies are defined, assessed, and maintained - particularly in sectors with fragmented skills architectures or aging labor forces (EC, 2021a,b; Eurobarometer, 2023). The shift necessitates training systems that move beyond procedural compliance and instead emphasize demonstrable behavioural performance (EC, 2021a).

Competency-Based Training and Assessment (CBTA) has long been established in domains where failure tolerance is minimal. In aviation, for instance, regulatory frameworks mandate CBTA as the foundation for training, recurrent evaluation, and licensing (EASA ORO.FC.231; ICAO Doc 9868). This study explores the transfer of CBTA methodologies into a manufacturing context under transformation, focusing on how structured behaviourally anchored models can support the competency realignment required by Industry 5.0 principles.

FRAMEWORK DEVELOPMENT AND IMPLEMENTATION

Conceptual Underpinnings

Industry 5.0 represents a recalibration of industrial priorities. While the preceding paradigm emphasized sensor networks, cyber-physical architectures, and throughput optimization, the current trajectory places greater emphasis on worker adaptability, ethical technology integration, and the human-machine interface as a site of resilience rather than fragility. In this context, workforce development cannot rely on generic reskilling programs detached from job performance (Oeij et al., 2023). Instead, it must be anchored in observable behavioral patterns that align tightly with system-level reliability (Ziakkas et al., 2024).

CBTA addresses this misalignment by substituting nominal exposure with demonstrated capacity (EASA, 2022; Ziakkas et al., 2024). Rooted in safety-critical industries (e.g., aviation CBTA deconstructs roles into performance-critical behaviors and evaluates them using structured observation. It moves beyond indirect indicators such as qualifications, seniority, or subjective feedback, and instead captures competence through verifiable enactment in operational contexts. When properly implemented, this approach allows for both individualized development trajectories and system-level analysis of capability gaps.

The present study extends this logic to a manufacturing context transitioning into a post-automation operational model under industry 5.0 framework. The focus is on mapping, calibrating, and validating behavioral performance in ways that correspond to new industrial 5.0 demands - particularly in terms of digital interaction, multicultural coordination, and response agility under non-routine conditions.

Defining Competency Domains

The design of the CBTA framework was guided by a tripartite classification, derived from the intersection of human factors research, digital integration challenges, and observed workflow disruptions.

The first domain, digital competence, pertains to the operational use of digital interfaces, including production dashboards, real-time alerting systems, and collaborative incident documentation tools. Competence here is not merely defined by tool familiarity but by the worker's ability to extract relevant signals, identify anomalies, initiate escalation, and verify closure under time pressure.

The second domain, intercultural intelligence, reflects the growing operational salience of collaboration across language, cultural, and experiential boundaries. As manufacturing teams increasingly comprise diverse nationalities and educational backgrounds, breakdowns in delegation, conflict resolution, or information transfer cannot be dismissed as interpersonal idiosyncrasies. Instead, they constitute latent vulnerabilities with potential impact on safety, quality, and throughput. Observable behaviors in this domain include adaptive language use, culturally informed feedback provision, and inclusion strategies during shift transitions.

The third domain addresses role-specific operational behaviors, encompassing both routine and non-routine functions. These include compliance with safety protocols, handover documentation, predictive maintenance engagement, and error mitigation strategies. Crucially, this domain does not isolate task completion but incorporates the manner, consistency, and system effects of behavior.

Each domain was operationalized through sets of behaviorally anchored indicators, derived from structured job analysis, production audits, and direct observation. This allowed performance to be rated not in the abstract, but in relation to defined expectations, environmental pressures, and observed task outcomes.

Behavioral Framing through the SHELL Model

To contextualize these behaviors within systemic constraints, the SHELL model was employed as an interpretive and diagnostic scaffold. Originally developed for aviation human factors analysis, SHELL (Software, Hardware, Environment, Liveware, Liveware) interrogates the interface between human actors and their technical, procedural, and social environments.

Within this project, SHELL facilitated the identification of latent conditions influencing observed performance. For example, low digital tool engagement was not interpreted solely as resistance or deficiency. In many cases, it coincided with interface overload, undocumented tool updates, or inadequate signaling from upstream systems. Similarly, failures in intercultural coordination often traced back to task design that implicitly privileged monolingual communication or lacked escalation buffers.

This framing prevented over-attribution of performance gaps to individuals, and instead positioned behaviors as emergent outcomes shaped by interface conditions. As such, the model functioned both as a formative evaluation tool and as a justification structure for behavior-targeted intervention.

Phased Implementation Strategy

The implementation unfolded across five interlinked phases: diagnostic assessment, strategic alignment, pilot testing, system integration, and feedback-driven refinement. Each phase was designed not merely as a sequential step but as a stage of data consolidation, framework validation, and role recalibration.

The diagnostic phase began with detailed task decomposition for eight operational roles, encompassing both supervisory and non-supervisory functions. Observations were conducted during normal shifts without prior notification, to capture baseline behavior without intervention effects. Alongside this, archival analysis of incident reports, shift handovers, and digital tool usage logs provided secondary evidence of task engagement and failure points. Triangulating these data, the team identified behavior clusters strongly associated with task success, communication clarity, and operational continuity.

Behavioral descriptors were then formalized into “word picture” rubrics - rating scales with detailed descriptors across four levels of performance. Unlike typical Likert-type evaluations, these rubrics foregrounded not frequency alone but also interaction quality, accuracy, and follow-through. For instance, a behavior such as “digital coordination” was not credited merely for logging into a platform or opening a dashboard. To meet the “meets expectations” threshold, the operator needed to identify relevant alerts, initiate resolution protocols, and re-verify closure using real-time performance data.

The second phase involved strategic alignment. Cross-functional planning workshops were convened with department heads, HR coordinators, and digital systems engineers. These sessions aimed to calibrate behavioral definitions against operational standards and to identify evaluation risks (i.e., inter-rater inconsistency or ambiguity in task contexts). The group also identified integration levers (e.g., existing performance review structures) that could incorporate CBTA outcomes without duplicating effort. Resource allocations for evaluator training, scheduling buffers for observational activities, and evaluator - operator feedback loops were established to facilitate the pilot.

Pilot implementation was launched in two functions: Shift Leader (Production) and Shift Leader (Maintenance). These roles were selected based on their role as systemic nodes - connecting upstream planning with downstream execution - and their frequency of decision-making under pressure. Over a six-week cycle, structured observations were conducted during regular operations. Evaluators used the behavior rubrics to assess predefined indicators, supplemented by peer feedback and review of system logs. To mitigate observer bias, assessments were blind to prior performance data, and post-observation debriefs with a second evaluator were conducted for calibration. Notable behaviors assessed included real-time response to digital anomalies, multilingual handover facilitation, and conflict resolution in mixed teams. For each behavior, performance was contextualized using the SHELL model to assess potential environmental or system constraints.

The fourth phase saw gradual expansion. Based on pilot learnings, behavior definitions were refined for clarity and relevance. For instance, descriptors for “issue escalation” were adjusted to differentiate between escalation initiated due to uncertainty and that initiated proactively due to anticipated downstream impact. The CBTA system was embedded within the plant’s internal HRIS, with dashboards allowing department heads to visualize behavior-linked KPIs by shift, department, and role.

Finally, a feedback and refinement loop was formalized. Evaluators submitted not only ratings but commentary on observation conditions, deviations

from expected behaviors, and perceived causes. Quarterly meetings reviewed these data in aggregate, adjusting both behavioral definitions and training protocols accordingly.

The success of this approach did not rely solely on the granularity of behavior descriptors or the elegance of evaluation tools. Rather, it stemmed from the conceptual alignment between system-level performance concerns and individual-level behavioral accountability. Workers were not asked to adopt abstract principles or vague notions of “adaptability” or “digital readiness.” They were instead shown what observable behaviors matter, how these would be evaluated, and where the link lies between their actions and systemic reliability.

Moreover, integrating CBTA into the plant’s operational settings - rather than as an auxiliary HR initiative - allowed for sustained attention and legitimacy. Evaluations were not seen as surveillance but as structured interpretation of operational impact. In post-implementation surveys, a majority of supervisors reported that behavior rubrics improved the objectivity of discussions with staff and allowed more precise targeting of support interventions.

In sum, this phased, behaviorally anchored deployment demonstrates that CBTA is not confined to regulatory environments or high-consequence sectors. When adapted with local specificity, supported by systemic modeling, and delivered through credible observers, it can support the competency realignment required by Industry 5.0 transitions.

DISCUSSION

The integration of CBTA in manufacturing settings highlights both opportunity and constraint. The industrial CBTA deployment with aviation-derived taxonomies allows the implementation leveraged mature behaviour calibration practices while avoiding the pitfalls of context-blind replication. Sector unification in this context therefore refers to methodological interoperability: the application of behaviour-based evaluation structures that retain sector-specific validity while drawing on translatable principles of observable competence, behavioural anchoring, and system-integrated training logic.

On one hand, the adaptation of aviation-derived frameworks allows for systematic behavior tracking that moves beyond compliance documentation. On the other, CBTA success depends heavily on the fidelity of behavioral descriptors, observer calibration, and contextual sensitivity to role variance.

Notably, the inclusion of intercultural intelligence as a core evaluative domain addresses a critical gap in existing industrial competency frameworks. The misalignment between assumed language fluency and communicative effectiveness is frequently underestimated in mixed-labor settings. Embedding such factors within CBTA allows them to be addressed through performance-driven training rather than remedial workshops disconnected from operational contexts. This effort also revealed that behavioral reinforcement - especially in digital competence - requires more than instruction. It necessitates structured observation, feedback, and visible relevance to daily tasks. Performance change was more durable when staff could link new behaviors to operational results.

CONCLUSION AND FUTURE RESEARCH

This study conceptualized sector unification not as administrative convergence but as a deliberate cross-pollination of training architectures - specifically, the CBTA framework transfer from safety-critical aviation environments into industrial production settings. The rationale behind this approach lies in the shared operational demands both domains exhibit: time-constrained decision-making, systems monitoring under uncertainty, and inter-role interdependence. This research documents the development, application, and early impact of a structured CBTA model in an industrial context navigating the transition to Industry 5.0. The results suggest that behavior-anchored competency systems, when locally adapted and implemented with evaluator alignment, can meaningfully improve coordination, reporting, and task execution under digital and intercultural pressures.

Several implications arise:

- CBTA supports not only skill development but also system-level visibility of performance variance, allowing targeted intervention before procedural degradation occurs.
- The use of behavior-based evaluation mitigates reliance on subjective assessments, particularly in areas traditionally seen as “soft” (e.g., communication or adaptability).
- Sector-wide competency harmonization supports labor mobility and facilitates coordinated training delivery without sacrificing domain specificity.

Future work will examine the feasibility of integrating machine-logged behavioral data (e.g., digital task timestamps, error rates) with human observation to generate composite competency profiles. Additionally, cross-site comparison with other plants undergoing similar transitions may reveal generalizable patterns in CBTA calibration, resistance dynamics, and post-implementation sustainment strategies.

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REFERENCES

- Breque, M., De Nul, L. and Petridis, A., 2021. Industry 5.0: Towards a sustainable, human-centric and resilient European industry. Brussels: European Commission Directorate-General for Research and Innovation.

- Edwards, E., 1972. Man and machine: Systems for safety. In: Proceedings of the British Airline Pilots Association Technical Symposium. London: BALPA, pp. 21–36.
- European Commission, 2021. Industry 5.0: Towards a sustainable, human-centric and resilient European industry. Brussels: Directorate-General for Research and Innovation. Available at: <https://www.horizon-europe.gouv.fr/sites/default/files/2022-01/industry-5-0-pdf-5324.pdf> [Accessed 27 July 2025].
- European Commission, 2021. The 2021 Ageing Report: Economic and Budgetary Projection for the EU Member States (2019-2070).
- European Union Aviation Safety Agency (EASA), 2022. Easy Access Rules for Air Operations (Regulation (EU) No 965/2012). [online] Cologne: EASA. Available at: <https://www.easa.europa.eu> [Accessed 15 July 2025].
- Flash Eurobarometer 529 (2023). European Year of Skills: Skills shortages, recruitment, and retention strategies.
- Hawkins, F.H., 1987. Human Factors in Flight. 2nd ed. Aldershot: Gower Technical Press.
- International Civil Aviation Organization (ICAO), 2013. Manual of Evidence-Based Training (Doc 9995). 1st ed. Montreal: ICAO.
- International Civil Aviation Organization (ICAO), 2018. Manual of Criteria for the Qualification of Flight Simulation Training Devices (Doc 9625). 4th ed. Montreal: ICAO.
- Mulder, M., 2017. Competence-based education and training. In: M. Mulder, ed. Competence-Based Vocational and Professional Education. Cham: Springer, pp. 1071–1090.
- Oeij, P.R.A., Vaas, F. and Dhondt, S., 2023. Conceptual framework of Industry 5.0 to study workforce skills. BRIDGES 5.0 Deliverable D1.1, Version 2. Leiden: BRIDGES 5.0 Consortium. Available at: <https://bridges5-0.eu/publications/> [Accessed 15 July 2025].
- Ziakkas, D., Plioutsias, A. and Pechlivanis, K., eds., 2024. Aviation Workforce Planning: The Artificial Intelligence and Competency-Based Era. Human Factors Horizons Series. ISBN: 979-8325038396.