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Workforce Readiness and Competency Development in Aviation Maintenance, Repair, and Overhaul: *An Integrative Review and Conceptual Framework*

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Abstract

Workforce readiness has become a strategic concern for aviation maintenance, repair, and overhaul (MRO) organizations, because digital and electric technologies, tighter certification requirements, and a retiring technician base are converging on the same skilled labor pool. This integrative review synthesizes peer-reviewed studies, regulatory documentation, and training-sector reports to map the competency domains, assessment approaches, and development pathways that shape technician readiness. The synthesis identifies three interdependent dimensions: technical and digital competence, transversal competence (communication, teamwork, and work management), and validated assessment. The evidence shows that transversal competencies are the least standardized and the hardest to assess, that competency taxonomies are fragmented across national contexts, and that workforce planners still rely on input indicators, such as certification counts and training hours, instead of outcome-oriented measures of performance. The review proposes a conceptual framework that links the three dimensions through a career-stage assessment model and a governance mechanism for a periodically reviewed competency baseline. Because the evidence base is small and heterogeneous, the framework is presented as a set of testable propositions and not as a validated model. The paper closes with a research agenda built around pilot, longitudinal, and multi-country validation.

Keywords: *Aviation Maintenance; Maintenance, Repair, And Overhaul (MRO); Workforce Readiness; Competency Development; Transversal Competencies; Competency-Based Assessment; Integrative Review*

1. Introduction

Workforce readiness has emerged as a strategic challenge for aviation maintenance, repair, and overhaul organizations, as technological change, regulatory expectations, and demographic pressures converge on the same skilled labor pool (Munteanu et al., 2025). The MRO sector must absorb new digital and electric technologies, meet tightening certification requirements, and replace a retiring technician base. The adequacy of current training pipelines is therefore a question of operational continuity and not an isolated human resources concern (Chavan et al., 2025; Munteanu et al., 2025).

Competency development refers to the deliberate process by which technicians acquire, validate, and maintain the technical knowledge, human factors skills, and safety orientation required to perform certifiable maintenance work. Current assessment and authorization practices in the sector still treat this process unevenly (Güneş et al., 2026). Certification standards define minimum competence levels, but the translation

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of those standards into structured training, skills verification, and continuing development differs considerably across training organizations, national authorities, and employers (Thulasy et al., 2022).

This review addresses that gap. It maps the competency domains, assessment approaches, and development pathways that recur in the literature on MRO workforce readiness, and it uses them to propose a conceptual framework for workforce planning. Section 2 reviews the literature. Section 3 describes the integrative review method. Section 4 presents the results of the synthesis, and Section 5 sets out the conceptual framework and its propositions. Section 6 discusses implications for workforce planning, limitations, and future research, and Section 7 concludes.

2. Literature Review

2.1. Technical and Digital Skill Demands

Research on MRO workforce skills has begun to document the competencies that modern aircraft maintenance demands, including the diagnostic and digital skills required by increasingly electrified and interconnected aircraft systems (Chavan, 2025). Training has not kept pace. Comparative analyses of curricula suggest that omissions are most visible in advanced technical areas, where programs often cover basic operation but leave limited room for practical training in complex or digitally integrated systems (Indrawan et al., 2026). The transition toward advanced aircraft requires technicians who can maintain both legacy and newer systems, a balance that current training approaches have not yet fully achieved (Mishra et al., 2022).

2.2. From time-based to competency-based training

The transition from time-based to competency-based training requires that transversal competencies such as communication, teamwork, and work management be defined through measurable standards that can support performance-based assessment (Kes et al., 2025). Existing curricula have only begun to operationalize these expectations. Studies of European aircraft maintenance training show that assessing transversal competencies is the most contested element of the shift. Surveyed aviation experts identify communication and teamwork as priorities while also reporting substantial obstacles to training and assessing them in practice (Kes et al., 2026). Delphi-based work points the same way: expert consensus on measurable criteria is a necessary precondition for valid performance-based assessment of these competencies in global vocational education and training (VET) settings (Kes et al., 2025).

2.3. Fragmentation of competency models

Despite this consensus, the empirical literature on competency models for aircraft maintenance technicians remains dispersed across national contexts. Studies adopt different competency taxonomies, assessment instruments, and performance indicators, which limits direct comparison of findings and the cumulative development of a shared framework (Toth, 2016). The absence of a common vocabulary for technical, methodological, and interpersonal competencies also makes it difficult to determine which dimensions are consistently neglected across training programs (Vázquez-Villegas & Borrego, 2026).

A shared framework that links measurable transversal standards to the technical demands of electrified and digitally integrated aircraft would allow the sector to move beyond fragmented, country-specific taxonomies (Gauthama et al., 2024). Such a framework would need to reconcile a trade-off between standardized taxonomies, which support cross-context comparability, and more flexible, data-driven approaches that can capture emerging role profiles (Leogrande et al., 2026). Combining the two would give the sector

comparability together with the responsiveness needed to track rapidly changing technical roles, including those emerging from digital systems and new propulsion technologies.

2.4. Career-stage models of competence

Workforce planners and training providers must also agree on which competencies are assessed at entry level and which are expected of advanced technicians, since the level at which each competency is developed directly shapes how it can be measured (Jones et al., 2024). A career-stage model can operationalize this distinction by assigning assessment tools and responsibilities across technicians' development pathways (Güneş et al., 2026). Such a model specifies which transversal and technical competencies are verified at each stage. Entry-level technicians demonstrate foundational skills in communication and safety orientation, while advanced technicians are assessed against higher-order diagnostic and digital competencies. It also clarifies how employers, training organizations, and national authorities share responsibility for verification, so that assessment records remain comparable across stages and institutions.

2.5. Assessment evidence and outcome measures

Across the reviewed models, technical knowledge, safety, and human factors recur alongside communication and other transversal competencies, while assessment remains uneven, particularly for digital capability and observable interpersonal performance (Güneş et al., 2026; Kes et al., 2026; Thulasy et al., 2023). Closing this gap requires instruments that record how technicians apply digital and interpersonal skills under realistic operating conditions, and not only self-reported or knowledge-based indicators. Those instruments must also be validated against the performance outcomes that matter to operators, so that recorded competencies can be linked to differences in maintenance quality and safety. A validated link would show which transversal competencies justify dedicated training investment, because returns could be tracked against outcomes that regulators and operators already monitor (Pinzone & Taisch, 2023).

Without shared outcome measures, workforce planners rely on proxy indicators such as certification counts and training hours. These describe inputs to competency development and not the readiness of technicians to perform. They also leave the sector without a stable baseline against which to judge the effectiveness of workforce development programs over time, and findings from different studies cannot be placed on a common scale of technician performance. Establishing a small set of anchor measures, such as standardized competency assessments tied to observable task performance, is therefore a prerequisite for any longitudinal comparison of program effectiveness. Until such measures are adopted and validated, claims about the relative value of specific training interventions should be treated as hypotheses and not as established findings. Existing competency models also need further validation to show whether their tools capture digitally enabled performance consistently across varied MRO settings (Güneş et al., 2026; Thulasy et al., 2023).

3. Methodology

3.1. Review Design

This integrative review was designed to synthesize heterogeneous evidence on MRO workforce readiness. It draws on peer-reviewed studies, regulatory documentation, and training-sector reports to map the competencies, assessment approaches, and development pathways that recur across the literature. The integrative design allows studies with different methodological orientations, including quantitative, qualitative, and mixed-methods research, to be combined into a single account of how competencies are defined, assessed, and developed. It was selected because the conceptual boundaries of competence remain

contested in this field, and because it permits the formal structure of competence models to be examined alongside the practical training systems through which they are operationalized (Mikhridinova et al., 2024).

3.2. Procedure

The procedure had five stages: (1) literature identification; (2) screening and selection against predefined inclusion criteria; (3) thematic coding of the selected sources; (4) qualitative analysis of recurring patterns; and (5) integrative synthesis, which informed the presentation of findings and discussion (Andrinos et al., 2026). The synthesis was iterative. Coded categories were refined against the full set of included sources so that each element of the framework is traceable to identifiable evidence and not to the reviewer's assumptions, and the reasoning behind each coded category was documented so that it can be audited against the source material. The synthesis moved from individual studies toward a set of cross-cutting competency domains, which then served as the empirical basis for the conceptual framework in Section 5.

3.3. Treatment of heterogeneity and status of the conclusions

The sources were not treated as interchangeable. The synthesis compared how each defined and assessed competence, used recurring patterns to organize the framework, and kept methodological differences as context for interpreting the evidence. Because the included studies varied in their operational definitions of readiness and in the outcome measures, they adopted, each study's framing of competence was treated as a claim to be weighed and not as a finding to be pooled directly. Where a definition of readiness was narrow, or an outcome measure was tied to a single training intervention, the limitation was noted explicitly so that conclusions were qualified by the scope of the evidence behind them.

The review's conclusions are conditional on the availability of standardized measures that do not yet exist. The framework is therefore a provisional synthesis, best understood as a set of testable propositions about technician competence and not as a settled account of MRO workforce readiness. Its credibility rests less on the completeness of any single competency model than on the transparency with which its evidential basis is documented and revised over time.

4. Results

4.1. Workforce readiness dimensions

The integrative synthesis yields a set of workforce readiness dimensions that organize competency needs in aviation MRO. They span technical and digital skills, transversal competencies, and the assessment mechanisms through which these are verified (Peña et al., 2025). Table 1 summarizes the three dimensions, the evidence on which each rests, and the gaps identified.

Table 1. Workforce readiness dimensions in aviation MRO identified by the synthesis

Dimension	What the Literature Shows	Gap Identified
Technical and Digital Competence	Diagnosis and maintenance of electrified and software-dependent systems, alongside legacy systems (Chavan, 2025; Mishra et al., 2022; Yu et al., 2025)	Limited practical training in complex or digitally integrated systems (Indrawan et al., 2026); indicator hierarchies developed mainly for the automotive domain (Yu et al., 2025)

Dimension	What the Literature Shows	Gap Identified
Transversal Competence	Communication, teamwork, and work management are priorities for aviation experts (Kes et al., 2026)	Least standardized element of the competency model; substantial obstacles to training and assessment (Kes et al., 2026; Lamri et al., 2026)
Validated Assessment	Competency-based training depends on defensible, performance-based assessment (Kes et al., 2025; Muzulon et al., 2025)	Uneven assessment of digital capability and observable interpersonal performance; no shared outcome measures (Güneş et al., 2026; Thulasy et al., 2023)

4.2. Technical and digital competence

The literature increasingly frames technical and digital competence as the capacity to diagnose and maintain electrified and software-dependent systems, and not only mechanical components. Competency frameworks for electric vehicle maintenance technicians identify a similar shift as central to their structured hierarchies of core dimensions, sub-dimensions, and specific indicators (Yu et al., 2025). These hierarchical structures have so far been developed mainly for the automotive domain. Transfer to aircraft maintenance requires that the indicators be re-specified against certification-driven task profiles and the safety-critical character of aviation work.

4.3. Transversal competence and its measurement

The re-specification would also need to address how communication and teamwork are made observable within these task profiles, since their measurement remains the least standardized element of the competency model (Lamri et al., 2026). Addressing this gap will likely require instruments that combine observable performance criteria with validated self-report measures. The Industrial Revolution 4.0 digital competency instrument developed for Royal Malaysian Air Force technicians shows one route. It translates competency dimensions such as problem-solving, communication, and analytical thinking into survey items validated by expert panels (Thulasy et al., 2023). Instruments of this kind are a useful template for MRO training programs, although their psychometric properties would need to be confirmed in aviation maintenance cohorts before they can support certification-level decisions.

4.4. Validated assessment and the interdependence of dimensions

The transition to competency-based training depends on defensible assessment (Muzulon et al., 2025). The framework in Section 5 therefore treats the validation of assessment instruments as a prerequisite for linking transversal competencies to measurable outcomes in MRO training programs. It positions technical and digital competence, transversal competence, and validated assessment as interdependent constructs, with the strength of each proposed link to be tested in subsequent empirical work.

5. Conceptual Framework

5.1. Constructs and their links

The framework has three constructs. Technical and digital competence covers the diagnostic and maintenance skills required for electrified, software-dependent, and legacy systems. Transversal competence covers communication, teamwork, and work management, together with safety orientation and human factors skills. Validated assessment covers the instruments and criteria through which both are verified against observable task performance. The constructs are interdependent: technical competence cannot be certified defensibly without valid assessment, and transversal competence cannot be assessed without observable performance criteria.

5.2. Career-stage assessment

The framework assigns assessment responsibilities along the technician's development pathway, as summarized in Table 2. Specifying which competencies are verified at each stage, and by whom, keeps assessment records comparable across stages and institutions.

Table 2. Career-Stage Assessment Model

Career stage	Competencies verified	Shared responsibility
Entry Level	Foundational skills in communication and safety orientation (Güneş et al., 2026)	Employers, training organizations, and national authorities each hold defined verification roles, so that assessment records remain comparable across stages and institutions
Advanced Technician	Higher-order diagnostic and digital competencies (Güneş et al., 2026)	As above, with verification tied to observable task performance on digitally integrated systems

5.3. Propositions

Because the framework is a conceptual synthesis, its contribution at this stage is to make explicit the propositions that future validation must examine. Table 3 states each proposition with the test it requires.

Table 3. Propositions of the framework and the tests they require

No.	Proposition	Proposed test
P1	Technical and digital competence, transversal competence, and validated assessment are interdependent; readiness cannot be inferred from any one of them alone.	Operationalize each link as a measurable indicator and pilot it in a certified maintenance cohort.

No.	Proposition	Proposed test
P2	Assessments that record applied digital and interpersonal performance under realistic conditions can be linked to measurable differences in maintenance quality and safety.	Validate instruments against the performance outcomes that operators and regulators already monitor.
P3	A career-stage model yields assessment records that are comparable across stages and institutions.	Test whether assessors apply behavioral criteria consistently across career stages.
P4	Defining readiness by the competencies that certified task profiles demand, with completion records as one input among several, gives a sounder basis for workforce planning than completion rates alone.	Compare readiness judgments based on competency evidence with those based on completion records, against task-level performance.
P5	Competency descriptors and instruments remain valid across maintenance, repair, and overhaul roles only if they are sensitive to the distinct demands of each.	Test instrument sensitivity by role and map descriptors onto task-level activities.
P6	Some competency domains transfer across regulatory jurisdictions, while others depend on local licensing structures.	Run comparative pilot studies across national certification systems.

6. Discussion

6.1. Competency models as living instruments

For workforce planning, competency models in MRO cannot be treated as static documents. The same evidence that justifies role-based competency structures shows that their content must be revised as technologies such as artificial intelligence and electrified propulsion alter which tasks remain human-performed (Chaparro et al., 2025). Workforce planning therefore needs a periodic competency audit that compares current staff profiles against the task profiles expected under new certification and technology requirements, so that training investment follows demonstrated gaps and not historical curricula (Dahm & Kauffeld, 2026).

Aligning training with operational needs also means tying the timing of competency development to certification milestones and fleet transitions, so that technicians acquire the digital and diagnostic skills required for new systems before those systems enter service and not after. This depends on partnerships

between operators, training organizations, and regulators, which together determine how quickly curricula are updated to reflect changes in certified task profiles. Where such partnerships are weak, curriculum revision lags behind certification changes and technicians are under-prepared for the systems they are expected to maintain. Partnership governance should therefore be treated as a planning variable in its own right, specifying how often curricula are reviewed against certification changes and who is responsible for triggering those reviews.

6.2. Governing the competency baseline

A shared, periodically revised baseline of required competencies, linked to certification timelines and reviewed on a fixed cycle, gives regulators and operators a common reference point for judging whether training capacity is keeping pace with the aircraft types entering service. It converts training lead times from an assumed constant into a measurable planning parameter, and it lets operators identify early which training providers can deliver the required competencies within certification lead times. Without it, the planning burden falls on individual organizations, which must reconstruct the baseline on an ad hoc basis at a cost that is high and uneven.

The framework also changes how readiness is defined. Existing curricula reflect historical training practice and not the competencies that certified task profiles will demand, so measuring readiness by completion rates alone risks certifying technicians who are formally qualified yet unprepared for the systems they will maintain. Readiness should instead be defined in terms of the competencies that certified task profiles demand, with completion records treated as one input among several. MRO organizations should document how competency evidence is weighed against completion records, so that certification criteria can be audited against the task profiles they are meant to represent.

Treated this way, the baseline becomes a documented feedback loop and not a static reference. Table 4 sets out the governance elements that make the loop auditable. The trajectory of the baseline over successive review cycles then becomes the principal indicator of whether workforce planning is responding to operational demand. Because each revision is tied to documented outcomes and not to fleet changes alone, governance failures can be distinguished from genuine shifts in fleet composition.

Table 4. Governance elements of the competency baseline

Element	What must be specified	Purpose
Review cycle and owner	A fixed review interval and a named owner responsible for initiating each review	Revisions follow a predictable schedule and not the visibility of an operational shortfall
Explicit thresholds	Auditable criteria showing whether certified competence has moved closer to, or further from, the demands of task profiles	Governance becomes diagnostic and not only descriptive
Data reconciliation	Training completion records, competency assessment outcomes, and operator-reported task deficiencies reconciled into a single auditable dataset before each review	A common evidence base for each review decision
Responsible body	A named body accountable for data quality, which publishes the resolution criteria it applies	Discrepancies are resolved transparently and not left to individual organizations
Traceability	Each threshold adjustment linked to the data discrepancies that prompted it	Review cycles can be compared over time and audited
Capacity planning	Review outcomes shared with training providers in time to plan course intake, instructor availability, and equipment access	Capacity adjustments precede certification gaps in service

6.3. Curriculum and Resource Response

Workforce planning should examine whether forecasts reflect anticipated fleet changes, task complexity, and maintenance demand, and whether training provision can respond in time through appropriate course capacity, instructor expertise, and access to relevant equipment. Evidence on aviation maintenance education points to persistent mismatches between existing curricula and emerging technology needs, alongside barriers such as limited access to modern equipment and insufficient collaboration between education providers and industry (Chavan, 2025; Chavan et al., 2025). Translating operational deficiencies and assessment results into targeted curriculum updates would help organizations direct resources toward demonstrated competency gaps and away from broad or reactive training revisions. Employers, regulators, and training organizations should use review findings to coordinate modular course updates and practical learning opportunities, then assess whether these interventions improve readiness for the tasks technicians are expected to perform.

Longer-term projections should also be connected to decisions about skill mix and training schedules, since expanding technician capability must be balanced against the cost and operational disruption of removing staff from active maintenance work (De Bruecker et al., 2017). This favors staged, task-specific development pathways that can be adjusted as demand changes, instead of assuming that a single curriculum or qualification will prepare every technician for every aircraft and maintenance context. Assessments should capture not only technical execution but also the communication, teamwork, and work-management behaviors needed to perform maintenance reliably in operational settings.

6.4. Limitations

The framework is a conceptual synthesis and not a validated predictive model. Its indicators and proposed relationships require testing across organizations, aircraft types, and training contexts before they can support firm decisions about workforce sufficiency. The review draws on a relatively small and heterogeneous body of evidence, and some of the competency frameworks it draws on were developed in adjacent sectors, such as electric vehicle maintenance, automotive work, and advanced manufacturing, and are transferred to aviation by analogy (Dahm & Kauffeld, 2026; Jones et al., 2024; Yu et al., 2025).

Two further limitations concern context. First, licensing is administered by national authorities, and regulatory transitions can create distinct implementation challenges even where systems align with international standards (“Examining the Impact,” 2025; Güneş et al., 2020). The current evidence cannot say whether the framework’s domains hold across regulatory and training environments, so its applicability to workforce planning must remain provisional until comparative pilot studies show which domains transfer across jurisdictions and which depend on local licensing structures. Without that distinction, jurisdictional differences in licensing outcomes could be mistaken for differences in technician capability. Second, shift design, certification pathways, and the availability of supervised on-the-job experience differ between facilities. Without standardized measures of this variation, observed differences in readiness cannot yet be attributed to individual capability and not to the conditions under which that capability was developed.

6.5. Research Agenda

The proposed framework sets a structured agenda for empirical work. Six priorities follow from the propositions in Table 3.

- **Pilot Co-Designed Assessments.** Pilot competency assessments co-designed by technicians, supervisors, and training providers, using task scenarios that make both technical and transversal performance observable. The pilots should test whether assessors apply behavioral criteria

consistently across career stages, whether the resulting profiles can guide targeted development without obscuring differences among roles and workplaces, and whether the measures are usable in routine training and workforce decisions (Güneş et al., 2026; Kes et al., 2026).

- **Role Sensitivity.** Test whether assessment instruments remain sensitive to differences between maintenance, repair, and overhaul roles, and whether competency descriptors map onto task-level activities so that assessment outcomes can inform training design, sequencing, and deployment.
- **Longitudinal, multi-country Validation.** Test the competency models in longitudinal, multi-country samples, so that their validity across MRO organizations and regulatory regimes is established and not assumed, and so that the sector can converge on measurable workforce standards without losing the regulatory flexibility that national authorities require.
- **Reporting Discipline.** Require future studies and competency audits to report the workforce population studied, the assessment instruments applied, the validation evidence behind any revised competency link, and the conditions under which interventions were implemented, alongside changes in task-level performance. This would let improvements attributable to development initiatives be separated from changes in fleet or maintenance demand.
- **Transparent Revision.** Record each revision to the framework against the evidence that prompted it, using explicit criteria for when a proposition is retained, revised, or withdrawn, so that independent researchers and training providers can reproduce and test the competency domains in new settings.
- **Prioritization.** Establish which proposed links carry the most explanatory weight before resources are committed to full curriculum or certification redesign.

7. Conclusion

This review has mapped the competency domains, assessment approaches, and development pathways that shape aviation MRO workforce readiness. It proposes a framework in which technical and digital competence, transversal competence, and validated assessment are interdependent constructs, linked through career-stage assessment and a governed, periodically reviewed competency baseline.

Because the review draws on a small and heterogeneous body of evidence, the framework should be read as a hypothesis-generating structure that guides validation studies and not as a finished model of MRO workforce competence. Its immediate practical implication is a shift from input-based indicators, such as certification counts and training hours, toward validated, outcome-oriented measures of technician performance that can be compared across organizations and regulatory regimes.

The first step is an initial validation phase in which each proposed link between the technical, transversal, and assessment constructs is operationalized as a measurable indicator and piloted in a certified maintenance cohort. Its results should be reported as hypothesis-generating until they are compared against independent empirical evidence. Validating transversal competency assessment instruments in certified maintenance cohorts is the most immediate priority.

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