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A Conceptual Research Framework for Workforce 5.0 Skills Development in Industry 5.0 Transformation

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Abstract

The evolution from Industry 4.0 to Industry 5.0 signifies a paradigm shift from technology-driven automation towards human-centric, sustainable, and resilient manufacturing systems. While advanced technologies remain critical enablers, workforce readiness has emerged as the decisive success factor in this transition. This study proposes a conceptual research framework for Workforce 5.0 skill development, integrating theoretical foundations with empirical industrial contexts across multiple sectors. The framework systematically contrasts Industry 4.0 and Industry 5.0, as well as Operator 4.0 and Operator 5.0, highlighting the shift from efficiency-focused automation toward human–machine collaboration, adaptability, creativity, and sustainability. Key challenges include skill mismatches, the absence of comprehensive human-centric competency models, limited readiness assessment tools, and the heterogeneity of industries, particularly within S-curve sectors. The proposed multi-phase methodology comprises:

(1) a PRISMA-based systematic literature review and bibliometric analysis to construct a Workforce 5.0 competency taxonomy across three foundational pillars and to identify relevant competencies for Thailand's S-curve industries; (2) Multi-Criteria Decision-Making (MCDM) techniques with expert validation to prioritize core competencies and sub-skills; and (3) an empirical skill gap analysis across S-curve industries using structured surveys, competency evaluation models, and statistical validation. This framework strengthens the theoretical and empirical foundations of Workforce 5.0 research by providing a structured basis for competency modeling while offering practical guidance for workforce assessment and training system design in the context of human-centric industrial transformation.

Keywords
Industry 5.0, Workforce 5.0, Human-Machine Collaboration, Competency Framework, Skill Gap Analysis

1. Introduction
The transition from Industry 4.0 to Industry 5.0 marks a significant shift in industrial paradigms, emphasizing human-centricity, sustainability, and resilience alongside technological advancements. Industry 4.0, characterized by cyber-physical systems (CPS), automation, and data analytics, has significantly enhanced manufacturing efficiency and productivity through real-time monitoring and control of processes (Oks et al., 2024; Xu et al., 2021). However, concerns regarding workforce displacement, skill polarization, sustainability, and system resilience have revealed critical limitations of this technology-driven paradigm (Oeij et al., 2024),(Howcroft and Taylor, 2023). Industry 5.0 addresses these limitations by integrating human-centric elements, ensuring that technological advancements do not overshadow the importance of human input and collaboration (Huang et al., 2021); (Breque M et al. European Commission. Directorate General for Research and Innovation., 2021). This evolution is supported by the integration of smart manufacturing technologies such as AI and IoT, which have facilitated innovations across industries, enhancing flexibility and complexity management in manufacturing systems (Haricha et al., 2023). Furthermore, the emphasis on sustainability in Industry 5.0 aligns with the need for long-term solutions that address environmental challenges, as identified in the sustainable manufacturing objectives of Industry 4.0 (Fuertes et al., 2022),(Nahavandi, 2019). The factory of the future, therefore, is envisioned as a collaborative, connected, and cognitive environment that not only boosts productivity but also prioritizes ecological and social considerations (Huang et al., 2021). This holistic approach ensures that technological progress is aligned with broader societal goals, paving the way for a more resilient and inclusive industrial future.

Unlike Industry 4.0, which prioritizes automation and operational efficiency, Industry 5.0 repositions humans as central contributors within socio-technical systems. This shift emphasizes human–machine collaboration, adaptive competencies, and continuous skill development. Consequently, industrial workers have evolved from Operator 4.0—focused on operating and supervising automated systems—to Operator 5.0, who must demonstrate cognitive flexibility, digital literacy, problem-solving capability, and sustainability awareness (Herrmann and Pfeiffer, 2023); (Mourtzis et al., 2022). These changes necessitate fundamental rethinking of workforce development models.

Despite growing discourse on Industry 5.0, existing workforce development models remain fragmented and rooted in Industry 4.0 assumptions. Many studies emphasize technological readiness while providing limited guidance on human-centric competency structures, measurable skill assessment, or systematic gap identification(Howcroft and Taylor, 2023). Furthermore, empirical evidence linking global Workforce 5.0 concepts to industry-specific contexts remains insufficient, particularly across different stages of industrial maturity such as S-curve industries (Saniuk et al., 2022b).

To address these gaps, this study proposes a research framework for a structured model for Workforce 5.0 skill development. The model integrates conceptual foundations with empirical validation through multi-phase analysis: systematic literature review, bibliometric analysis, expert validation, and industry-based skill gap assessment. By combining qualitative and quantitative methods, the model identifies critical competencies, prioritizes skill development needs, and supports evidence-based training design.

This study addresses three research questions:

RQ1: What are the current research trends and methodological approaches in Industry 5.0 workforce development?

RQ2: What are the critical competencies and sub-skills required for Workforce 5.0 across different industrial maturity stages (S-curve positions)?

RQ3: How can systematic competency prioritization and empirical gap analysis inform evidence-based workforce development strategies for Industry 5.0 transformation?

The future paper offers dual contributions. Theoretically, it advances Workforce 5.0 literature by synthesizing human-centric competency constructs within the Industry 5.0 paradigm. Practically, it provides a scalable model for policymakers, educators, and industrial organizations to assess workforce readiness and design targeted skill development strategies for sustainable transformation.

2. Conceptual Background and Definitions

2.1 Industry 4.0 and Industry 5.0

Industry 4.0 integrates digital technologies into manufacturing systems to enable smart, automated, and interconnected production. Core elements include cyber-physical systems, Internet of Things (IoT), artificial intelligence, big data analytics, and advanced automation (Oks et al., 2024; Xu et al., 2021).Primary objectives are operational efficiency, productivity enhancement, flexibility, and cost reduction through technology-driven optimization. Industry 5.0 represents an evolutionary extension rather than replacement of Industry 4.0. It emphasizes a human-centric, sustainable, and resilient paradigm where technologies support and augment human capabilities(Huang et al., 2021). Industry 5.0 focuses on human–machine collaboration, social well-being, environmental sustainability, and system resilience, addressing socio-economic and ethical limitations observed in Industry 4.0 implementations(Fuertes et al., 2022; Ng et al., 2022).

2.2 Operator 4.0 and Operator 5.0

Operator 4.0 emerged alongside Industry 4.0 to describe workers in highly automated and digitized environments. This role is characterized by ability to interact with digital systems, monitor automated processes, and respond to system alerts using digital interfaces and decision-support tools. Primary skill requirements emphasize technical proficiency, digital literacy, and compliance with standardized procedures (Oks et al., 2024). Operator 5.0 expands this role significantly within the Industry 5.0 paradigm. Beyond technical and digital skills, Operator 5.0 must possess cognitive adaptability, problem-solving capability, creativity, ethical awareness, and sustainability-oriented thinking. Human–machine interaction evolves into collaboration, where operators actively co-create value with intelligent systems, requiring continuous learning, cross-functional competencies, and resilience (Howcroft and Taylor, 2023; Mourtzis et al., 2022; Othman and Yang, 2023).

2.3 Workforce 5.0 Concept

Workforce 5.0 extends Operator 5.0 from individual roles to organizational and systemic levels. It represents a workforce model integrating human-centric competencies, sustainable skill development, and adaptive capability across job levels—operators, engineers, managers, and decision-makers (Carminati et al., 2025; Oeij et al., 2024; Xu et al., 2021). Workforce 5.0 emphasizes aligning skills with Industry 5.0 principles through structured competency models, measurable indicators, and continuous upskilling and reskilling mechanisms (Abina et al., 2022), Figure 1 Workforce 5.0 Concept.

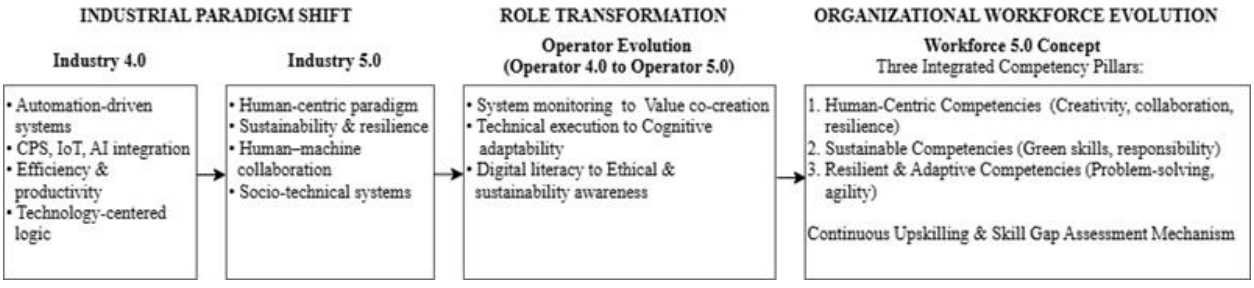

Figure 1. Workforce 5.0 Concept

2.4 Implications for Skill Development

The shift from Industry 4.0 to Industry 5.0 fundamentally alters skill development priorities (Abina et al., 2022). While technical and digital competencies remain essential, they are insufficient. Organizations must incorporate soft skills, cognitive abilities, and sustainability-related competencies into workforce strategies. Traditional competency-based employee evaluation models (Golec and Kahya, 2007) provide foundational approaches for systematic skill assessment, though these require extension to address Industry 5.0's multidimensional requirements. This transition necessitates structured models capable of identifying skill requirements, measuring readiness, and systematically addressing gaps (Papacharalampopoulos et al., 2025; Saniuk et al., 2022b, 2022a). However, existing models lack integration across these dimensions, failing to provide holistic competency assessment or industry-specific guidance—creating the imperative for the proposed Workforce 5.0 model.

3. Challenges in the Transformation toward Workforce 5.0

Although Industry 5.0 has gained increasing attention in academic and policy discussions, practical transformation toward Workforce 5.0 remains highly challenging (Tyson and Zysman, 2022). Industrial organizations struggle to translate human-centric principles into actionable workforce strategies. Additionally, the concept of Industry 5.0 emphasizes humanization and sustainability, addressing the dehumanization seen in Industry 4.0. This shift requires a focus on employee skill development and the role of humans in smart factories, which are critical for achieving a more human-centric industrial environment (Grabowska et al., 2022). Several critical challenges hinder effective transition from Workforce 4.0 to Workforce 5.0.

3.1 Skill Mismatch and Fragmentation

A prominent challenge is the mismatch between existing workforce skills and competencies required under Industry 5.0 (Abina et al., 2022). Current skill sets emphasize automation operation and technical efficiency aligned with Industry 4.0 requirements. However, Industry 5.0 demands additional cognitive, adaptive, and sustainability-oriented skills (Saniuk et al., 2022a). The absence of integrated competency models results in fragmented training initiatives that fail to address holistic workforce readiness.

3.2 Lack of Human-Centric Competency Models

Most existing workforce models remain technology-centric, with limited emphasis on human-centric dimensions such as creativity, ethical awareness, resilience, and collaboration (Ley, 2023). Organizations therefore lack structured references for defining, measuring, and developing Workforce 5.0 competencies across job roles (Herrmann and Pfeiffer, 2023). This gap constrains systematic design of training programs aligned with Industry 5.0 values.

3.3 Limited Readiness Assessment and Measurement Tools

Another significant challenge is the absence of standardized and validated tools for assessing Workforce 5.0 readiness. Organizations rely on qualitative judgments or isolated skill assessments, which provide limited insight into actual competency gaps (Markaki et al., 2021). Without quantitative prioritization methods or longitudinal measurement mechanisms, evaluating training effectiveness or tracking workforce development progress becomes difficult.

3.4 Industrial Diversity and S-Curve Challenges

Industries evolve through S-curve stages—early adoption, rapid growth, and maturity—each characterized by different technological and organizational capabilities (Branca et al., 2022). Industries operating at varying S-curve positions make uniform workforce development approaches ineffective. Organizations in early, growth, and maturity phases require differentiated competency priorities, yet existing models rarely account for this diversity, reducing applicability and scalability of current workforce models.

4. Research Framework and Methodology

This study adopts a structured, multi-phase framework to systematically develop and validate a Workforce 5.0 skill development model aligned with Industry 5.0 principles. The framework integrates conceptual synthesis, empirical analysis, and validation processes to ensure theoretical rigor and practical relevance. Four main phases comprise the framework. Figure 2 Concept of Research Framework.

4.1 Phase 1: Conceptual Foundation and Literature Synthesis

The first phase establishes the conceptual foundation of Workforce 5.0 through a PRISMA-based systematic literature review. Relevant publications on Industry 4.0, Industry 5.0, Operator 4.0, Operator 5.0, and workforce development will be collected from major academic databases. Bibliometric analysis, including keyword co-occurrence and thematic mapping, will be applied to identify dominant themes, research trends, and conceptual gaps.

The findings provide a consolidated understanding of Workforce 5.0 and identify key competency domains. A multi-criteria decision-making (MCDM) approach will then be used to explore the relative importance of identified competencies and sub-skills. The prioritized competencies are translated into structured survey instruments to support subsequent empirical investigation.

4.2 Phase 2: Workforce 5.0 Competency Model Development

Building on insights from Phase 1, Phase 2 develops a structured Workforce 5.0 competency model. Competencies will be organized into core dimensions reflecting human-centric, technological, and sustainability-oriented perspectives. Expert consultation will be conducted to refine competency definitions, ensure clarity, and confirm industrial relevance.

This phase results in a validated competency framework that supports systematic prioritization and decision-making for workforce development. Multi-criteria decision-making (MCDM) will be applied as a supporting analytical approach to structure competency evaluation and guide model development and to systematically prioritize competencies across multiple criteria. The framework integrates multi-attribute decision-making (MADM) techniques (e.g., AHP, TOPSIS) for ranking alternatives and Multi-objective decision-making (MODM) concepts for addressing multi-objective optimization contexts (Figure 2).

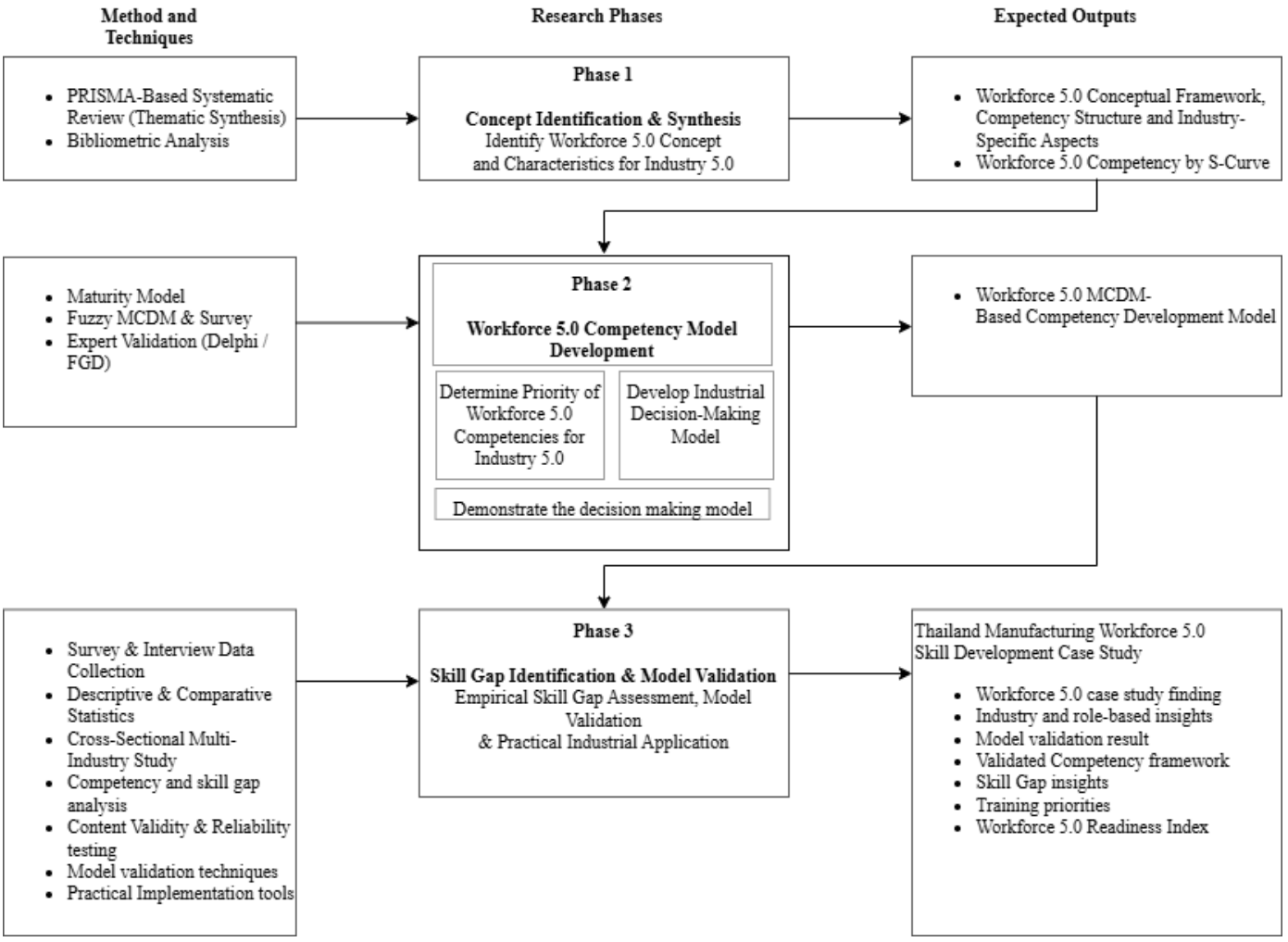

Figure 2. Concept of Research Framework

4.3 Phase 3: Skill Gap Identification and Model Validation and Practical Application

Phase 3 focuses on validating the proposed framework through empirical application and practical analysis. Skill gap analysis compares expected competency levels with existing workforce capabilities across industries and job roles. This enables identification of priority development areas and variation in workforce readiness.

The proposed model will be evaluated through field data collection and comparative analysis to ensure practical applicability. The findings provide evidence-based insights for competency development and workforce planning. The final outcomes include validated competency insights, skill gap identification, and practical implications for workforce readiness and training prioritization in Industry 5.0 contexts.

The three-phase framework functions as an integrated gap operationalization mechanism that systematically connects conceptual synthesis, competency prioritization, and empirical validation. This mechanism translates Industry 5.0 principles into measurable skill indicators through: (1) conceptual gap detection via literature synthesis, (2) structural prioritization via MCDM techniques, and (3) empirical validation via cross-industry surveys. Dynamic feedback between phases ensures framework adaptability to evolving organizational contexts.

5. Anticipated Research Challenges and Mitigation Strategies

The successful implementation of this Workforce 5.0 framework faces several methodological and practical challenges requiring systematic mitigation strategies.

5.1 Data Collection and Industry Access

Accessing sufficient respondents across diverse S-curve industries, particularly in early-stage sectors lacking formal workforce development structures, presents significant difficulty. To address this, the study will establish partnerships with industry associations and chambers of commerce to facilitate organizational access. Stratified sampling combined with snowball techniques will ensure representation across S-curve stages. Participating organizations will receive customized skill gap reports and benchmarking insights as reciprocal benefits that incentivize participation. Multiple data collection modes (online surveys, phone interviews, on-site assessments) will accommodate varying organizational contexts and technological capabilities.

5.2 Competency Definition and Measurement Standardization

Workforce 5.0 competencies lack universally accepted definitions and validated measurement scales, creating potential inconsistencies across industries and cultural contexts. The research will conduct multiple Delphi-method rounds with industry practitioners and academics to refine competency definitions and reach consensus. Pilot surveys will identify definitional ambiguities before full-scale deployment. Psychometric validation techniques including Cronbach's alpha and factor analysis will ensure measurement quality, while concrete behavioral indicators and industry-specific examples in survey instruments will reduce interpretive variability across respondents.

5.3 Cross-Industry and Cross-Stage Comparability

Industries at different S-curve stages possess fundamentally different technological infrastructures, organizational cultures, and workforce baselines, complicating direct comparisons. Industry-normalized scoring approaches will account for baseline differences while enabling meaningful comparisons. The study will conduct separate within-stage analyses before attempting cross-stage comparisons to identify stage-specific patterns. Multivariate statistical techniques (ANOVA, regression analysis) will control for confounding variables such as organizational size, automation levels, and workforce education baselines, emphasizing relative skill gaps within industries rather than absolute scores across industries.

5.4 Longitudinal Validation Constraints

As a conceptual framework study, longitudinal validation of skill development interventions falls outside the research timeline, limiting the ability to demonstrate causality between competency development and organizational outcomes. The research will explicitly acknowledge this limitation while emphasizing the framework's foundational contribution as an essential precursor to future studies. Assessment instruments will be specifically structured for before-after comparison, enabling future researchers to replicate measurements and track intervention effectiveness. Selected organizations willing to implement pilot interventions will be identified as partners to track outcomes beyond this study's timeframe, establishing groundwork for follow-up research.

6. Expected Outcomes and Contributions

This study is anticipated to generate substantial theoretical and practical contributions to the emerging discourse on Workforce 5.0 within the broader Industry 5.0 paradigm. By integrating conceptual synthesis with empirical validation, the proposed framework addresses critical gaps in existing workforce development research, particularly the absence of structured competency architectures and empirically grounded assessment mechanisms aligned with human-centric industrial transformation.

6.1 Expected Outcomes and Contributions

The principal outcome of this research is the development and validation of a comprehensive Workforce 5.0 skill development framework. The framework establishes a structured competency taxonomy organized into three foundational pillars, encompassing technological proficiency, human-centric capabilities, and sustainability-oriented competencies. Each pillar is operationalized through measurable sub-skills, enabling systematic competency modeling and quantitative assessment.

In addition, the study generates a prioritized hierarchy of competencies using Multi-Criteria Decision-Making (MCDM) techniques combined with expert validation. This prioritization mechanism facilitates the identification of high-impact skills that are strategically critical for Industry 5.0 transformation.

Empirically, the research provides statistically validated evidence of skill gaps across industries positioned at different stages of the S-curve development trajectory. The proposed assessment instruments enable organizations to evaluate workforce readiness, benchmark competency levels, and quantitatively monitor skill progression before and after targeted capacity-building interventions. This evidence-based approach enhances the rigor of workforce planning and supports data-driven human capital strategies.

6.2 Theoretical Contributions

From a theoretical standpoint, this study fortifies the conceptual underpinnings of Workforce 5.0 research by integrating previously disparate constructs from Industry 4.0, Industry 5.0, and human-centric production systems into a coherent and operationalizable model. The framework advances prior workforce models by shifting the analytical focus from technology adoption to the co-evolution of human capabilities, intelligent systems, and sustainability objectives.

Furthermore, the study contributes methodologically by embedding measurable competency structures within a validated empirical assessment model. This integration bridges the gap between conceptual discourse and quantifiable workforce evaluation, thereby enhancing the explanatory and predictive capacity of Workforce 5.0 scholarship.

6.3 Practical and Managerial Contributions

From a managerial perspective, the proposed framework provides actionable and evidence-based guidance for policymakers, educational institutions, and industrial organizations. It supports the design of targeted training programs, the prioritization of strategic skill investments, and the alignment of workforce development initiatives with Industry 5.0 objectives.

By enabling systematic competency assessment and skill gap identification, the model facilitates informed decision-making in human capital planning and contributes to the advancement of sustainable, resilient, and human-centric industrial transformation.

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