

Intrapreneurship as a Functional Competency in Production Engineering: An International Comparative Analysis

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Abstract

This study analyzes the skills applicable to the job market for production engineering in the context of Industry 4.0. An exploratory qualitative approach was adopted, based on the document analysis of 528 job advertisements published between 2022 and 2025 in Brazil, Europe, and North America. The results reveal a geopolitical stratification of skills: while mature economies demand disruptive profiles with high intrapreneurial leadership and digital fluency, the Brazilian market prioritizes adaptive profiles focused on operational execution, highlighting a critical "agency gap." The study empirically demonstrates that intrapreneurship has transitioned from a soft skill to a mandatory functional competency. It concludes that global technological convergence has not translated into professional homogeneity, requiring urgent curricular reforms that integrate technical skills with the crucial autonomy needed to overcome the mismatch between academic training and productive reality.

Keywords

Industry 4.0; Engineering Education; Intrapreneurship; Competency Management; Innovation.

1. Introduction

Industry 4.0 represents a paradigmatic transformation characterized by the deep integration of digital technologies into production systems, driving unprecedented levels of automation, connectivity, and data-driven decision-making (Nahavandi, 2019). However, mere technological adoption has proven insufficient to guarantee competitiveness in a volatile market environment. The organizational complexity resulting from this transformation demands more than operational technical proficiency; it requires dynamic capabilities—the ability to reconfigure internal competencies to cope with rapid changes in the competitive environment (Teece, 2018; Kodama, 2019). In this scenario, human capital emerges as the ultimate strategic resource, shifting the focus from physical infrastructure to the intellectual capital and behavioral capabilities of individuals.

Consequently, the role of the production engineer is being redefined: from a traditional technical manager to a strategic articulator, responsible for mediating the interaction between cyber-physical systems, organizational processes, and innovation (Alcacer and Cruz-Machado, 2019; Gorkhali, 2022). Sustainable competitive advantage now depends on the ability of professionals to convert theoretical knowledge into effective action (Nonaka, 1994; Mciver, 2018). However, the literature points to a significant mismatch between the skills required by this new industrial model and those traditionally developed by higher education institutions. While engineering curricula remain largely focused on isolated technical skills (hard skills), the job market signals the need for a hybrid profile that integrates digital fluency, socio-emotional resilience, and systemic vision (Bond *et al.*, 2021; Mrugalska and Ahmed, 2021).

Within this spectrum of skills, intrapreneurship — understood as the predisposition to identify opportunities and lead innovation within established organizations — takes center stage. Traditionally classified as a desirable "soft skill" or personality trait, recent evidence suggests that, in the era of Industry 4.0, intrapreneurship has consolidated itself as a critical and mandatory functional competence (Antoncic and Hisrich, 2001; Kuratko *et al.*, 2014). The ability to exercise decisional autonomy and take calculated risks has become indispensable for the operationalization of intelligent technologies and for the strategic renewal of companies (Zhao *et al.*, 2021).

Despite the theoretical consensus on the need for new skills, a gap persists in the literature regarding empirical evidence on what is actually demanded by employers. Previous studies often address technical and behavioral skills in a fragmented way, failing to capture how these dimensions integrate in recruitment practice (Pokhrel and Chhetri, 2021). Furthermore, there is a scarcity of research investigating regional disparities in these demands, verifying whether the economic maturity of countries influences the complexity of the professional profile required (Macário and Pereira, 2025).

To fill this gap, the present study adopts a descriptive exploratory approach based on Content Analysis. The objective is to analyze the skills demanded by the contemporary labor market for production engineers, specifically investigating the role of intrapreneurship as a technical driver in the era of Industry 4.0. The research is based on the analysis of 528 job postings published between 2022 and 2025 on recruitment platforms in Brazil, Europe, and North America. By triangulating data from different geopolitical contexts, this work seeks not only to map current requirements but also to understand how the "agency gap" and technological maturity influence employability and professional training strategies.

1.1 Objectives

The objective of this study is to analyze the skills demanded by the contemporary labor market for production engineers in the context of Industry 4.0, with particular attention to the role of intrapreneurship in shaping the professional profile required by organizations.

Specific objectives

- To identify the technical and behavioral skills most frequently required in job postings for production engineers.
- To analyze the relevance of intrapreneurship as a competence related to innovation, autonomy, and decision-making in organizational environments.
- To compare skill demands across different geopolitical contexts, including Brazil, Europe, and North America.
- To examine how technological maturity influences the complexity of the professional profile required by employers.

2. Literature Review

2.1 Industry 4.0, Labor Market and Professional Skills

Industry 4.0 is characterized by the deep integration of digital technologies into production systems, promoting unprecedented levels of automation, connectivity, and data-driven decision-making (Spinelli *et al.*, 2022). This context intensifies organizational complexity and reinforces the need for dynamic capabilities, understood as the ability to integrate, build, and reconfigure internal and external competencies in response to changes in the competitive environment. The technological transformations associated with this paradigm have redefined industrial processes and business models, requiring organizations and professionals to have a continuous capacity for adaptation and innovation (Wahab *et al.*, 2024).

The sustainable performance of companies increasingly depends on the ability of individuals to transform knowledge into action (Nahavandi, 2019). In this scenario, competitive advantage is no longer anchored solely in organizational stability, but rather depends on the articulation between technical, digital, and behavioral skills, which are essential for dealing with the uncertainty of contemporary production environments (Narong and Hallinger, 2024).

Consequently, the production engineer assumes a new strategic role as an articulator between productive systems, emerging technologies, and organizational processes (Maldaner, 2021; Gorkhali, 2022). Traditionally, such articulation requires not only technical mastery but also high levels of emotional intelligence and leadership to manage the relational complexities of the digital era (Goleman, 1998; Palos-Sanchez *et al.*, 2024). Global reports, such as those published by the World Economic Forum (2024), highlight the progressive replacement of operational functions by activities requiring greater autonomy, systemic vision, and advanced cognitive skills. This trend is corroborated by empirical academic studies on digital transformation and professional requalification (Vilalta-Perdomo *et al.*, 2022; Mrugalska and Ahmed, 2021).

2.2 Technical, Digital, and Behavioral Skills in Industry 4.0

In the context of Industry 4.0, professional demands go beyond the isolated mastery of technologies and now require an integrated set of skills. Technical and digital skills involve mastery of computational tools, automation, data analysis, and systems integration, while behavioral skills include communication, collaboration, flexibility, and continuous learning (Alhloul and Kiss 2022).

These skills allow professionals not only to adapt to new processes but also to actively contribute to organizational innovation and the continuous improvement of production systems (Frank *et al.*, 2019; Tortorella *et al.*, 2021). Contemporary studies reinforce behavioral and cognitive skills, such as self-efficacy and initiative, play a mediating role between professional training and performance in the labor market (Nowinski *et al.*, 2019; Haddoud *et al.*, 2022). In this process, commitment acts as the binding force that drives the individual to act even in the face of conflicting motivations or technological uncertainties. The literature also indicates that the ability to continuously learn and apply technical knowledge in practical contexts becomes essential to maintain competitiveness in the face of global market demands (Kim and Park, 2021).

2.3 Entrepreneurial Intention and Intrapreneurship

Entrepreneurial intention, predominantly manifested through intrapreneurship, is recognized as an antecedent of innovative behavior, reflecting a predisposition to identify opportunities, take initiatives, and generate value within organizations (Urban and Galawe, 2020). Professionals with this profile contribute significantly to organizational adaptation in complex technological contexts, especially by exercising greater decision-making autonomy, a central element for organizational learning and continuous innovation (Wibawa *et al.*, 2021; Yang *et al.*, 2018).

Recent evidence indicates that entrepreneurial intention constitutes a cognitive and volitional state that increases the likelihood of engaging in entrepreneurial behaviors (Neneh, 2019; Haddoud *et al.*, 2024). However, the transformation of intention into action does not occur automatically; it is mediated by psychological factors, such as resilience and social support. In contexts marked by previous failures and high instability, these factors are crucial to reactivating entrepreneurial intention and the willingness to resume innovative initiatives (Alzahrani and Al-Alawi, 2025).

In the context of Industry 4.0, intrapreneurship becomes even more relevant, since professionals capable of transforming technical fluency into applicable solutions strengthen organizational competitiveness. Market data indicate that the skills associated with intrapreneurship are among the most recurring requirements on recruitment platforms. This movement is also linked to global sustainable development agendas, since Industry 4.0 technologies contribute to the optimization of resources and sustainable industrial practices (Fontenele *et al.*, 2025; Schneider *et al.*, 2019).

To consolidate the theoretical discussion presented in this section, Table 1 summarizes the main skills required of professionals in the context of Industry 4.0, as identified in recent literature.

Table 1. Production Engineer Skills in Industry 4.0.

Category	Key Competency	Key Competency Strategic Relevance in Industry 4.0	Main References
Cognitive	Solving Complex Problems	Advanced analytical capabilities for interpreting data and resolving systemic failures in smart factories.	Alalwan and Alzahrani (2020); Santos et al. (2021)
	Critical Thinking and Agility	Ability to filter information and make autonomous decisions in decentralized environments.	Medeiros and Neto (2024); Fero (2021)
T�chnical/ Digital	Cyber-Physical Systems and VR	Operational domain of digital twins, simulation, and human-machine interfaces.	Rajnai and Kocsis (2017); Alalwan and Alzahrani (2020)
	Data Analysis and Digital Literacy	Transforming raw data into strategic insights (Big Data/IoT integration).	Zhou et al. (2021); Hern�ndez-de Men�ndez et al. (2020)
Socioemotional	Emotional Intelligence (EQ)	Managing human-centered interactions amidst automation is crucial for talent retention.	Prentice et al. (2020); Laur & Sharma (2021)
	Resilience-and Continuous Learning	Ability to continuously adapt to rapid technological obsolescence.	Soh and Connolly (2021); Medeiros and Neto (2024)
Entrepreneur	Intrapreneurial Leadership	Proactive behavior to identify internal opportunities and lead innovation projects without direct supervision.	Kuratko et al. (2015); Nascimento et al. (2021)
	Corporate Entrepreneurship	Strategic renewal and value creation within established industrial ecosystems.	Rigtering and Weitzel (2013); Rigtering et al. (2013)

This synthesis provides the conceptual basis for the methodological procedures described in the next section, which empirically examine how these skills are reflected in the demands of the labor market in the 4.0 era.

2.4 Synthesis and Research Gaps

However, a critical gap persists between the skills demanded by the market and those traditionally developed in academic curricula. Recent studies indicate that educational institutions still struggle to structure competency-based frameworks aligned with Industry 4.0 demands (Weichbroth, 2022). Additionally, the literature remains fragmented, as many investigations address technical and behavioral competencies separately, without proposing systemic integration models (Arek-Bawa and Reddy, 2022; Grzybowska, 2022).

Contrary to traditional perspectives that classify behavioral skills as complementary, emerging research argues that intrapreneurial competence has become structurally embedded in technological systems, functioning as a prerequisite for effective digital transformation (Bouchard, 2022). The synthesis presented in Table 1 demonstrates that, although there is theoretical consensus regarding the relevance of these competencies, curricular implementation remains inconsistent, reinforcing the empirical and conceptual contribution of this study.

3. Methods

3.1 Study design and approach

This study adopts an exploratory descriptive approach based on Content Analysis. This methodological choice allows the systematic transformation of qualitative data (unstructured text from job advertisements) into quantitative indicators (frequency and intensity) to identify structural patterns. Based on documentary research, this approach is justified by the need to measure the intensity of market demands, filling the gap in empirical evidence on functional competencies (Pokhrel; Chhetri, 2021).

3.2 Data Collection and Sampling Strategy

Data collection covered the period from January 2022 to September 2025. From this population, a stratified purposive sample of 528 job postings was selected. To ensure the reliability of the comparative analysis and mitigate biases arising from generic descriptions, rigorous exclusion criteria were applied based on the Information Density Criterion. Thus, only postings that explicitly specified the requirements in the three domains analyzed—technical, digital, and behavioral—were included in the sample, while vacancies with vague or incomplete descriptions were discarded.

As shown in Table 2, the sampling strategy sought a balanced distribution across different geographic regions, ensuring the statistical comparability of the data. Information sources were triangulated from global recruitment platforms (LinkedIn, Indeed, and Glassdoor) and regional databases (Catho in Brazil and Eures in Europe) to reduce bias associated with a single platform.

Table 2. Sample demographics: Distribution of analyzed job postings by region and industry sector

Region / Context	Sample Size (n)	% of total	Predominant Sectors Identified
North America (USA/Canada)	176	33,3%	Automotive, Tech/Software, Aerospace
Europe (Germany/France/UK)	176	33,3%	Manufacturing, Pharma, Energy
Brazil (South/Southeast)	176	33,3%	Agro-industry, Consumer Goods, Logistics
Total	528	100%	

To contextualize the formal labor market and ensure the analysis of recruitment patterns, secondary institutional data from the International Labour Organization (ILO, 2023) were used as a complementary source, without direct integration into the sample of job postings found.

3.3 Data Analysis

Data analysis followed a Quantitative Content Analysis protocol. First, the textual requirements were coded into categorical variables. Second, the relative relevance of each competency was derived from its frequency of recurrence. To allow for inter-regional comparison, the raw frequencies were normalized and mapped onto an ordinal scale of Maturity Levels (0 to 4). This scale functions as a taxonomy to classify the intensity of demand: Level 2 indicates an operational/adaptive requirement, while Level 4 indicates a strategic/disruptive requirement. This consolidation enabled the identification of competency maturity patterns among the analyzed contexts. Levels 0 and 1 correspond to pre-digital and initial digitalization stages, which were not significantly represented in the analyzed sample, as the study focused on organizations already engaged in Industry 4.0-related activities.

4. Results

The analysis of the 528 job postings shows that the digital transformation associated with Industry 4.0 has not only altered the technical content of the functions but has also structurally redefined the required professional profile. Industry 4.0 implies systemic integration between cyber-physical systems, digital infrastructures, and organizational architectures, promoting decentralized decision-making and restructuring value chains.

This structural movement had already been signaled by Lovato *et al.* (2018), who indicated that industrial digitization requires professionals with articulate technical knowledge combined with a systemic vision and adaptive capacity.

Complementarily, Veiga (2020) argues that competitiveness in Industry 4.0 depends on the incorporation of strategic competencies that transcend operational execution, shifting the focus from purely technical qualification to hybrid profiles. Zheng et al. (2021) reinforce this perspective by demonstrating that digital transformation reorganizes organizational demands, requiring greater autonomy and decision-making capacity in complex and automated environments. Empirical results confirm this structural inflection: modern technical and behavioral skills are taking on a functional character, appearing in response to the central technical demands of Industry 4.0.

4.1 Skills

The analysis of the evolution of required skills, summarized in Figure 1, shows that the profile of the production engineer in Industry 4.0 is characterized by the simultaneous integration of technical and intrapreneurial skills. The radar diagram demonstrates that, although there are common core skills — such as ERP/MES systems integration and data analysis — these skills appear to be articulated with selected dimensions related to autonomy, initiative, and critical thinking.

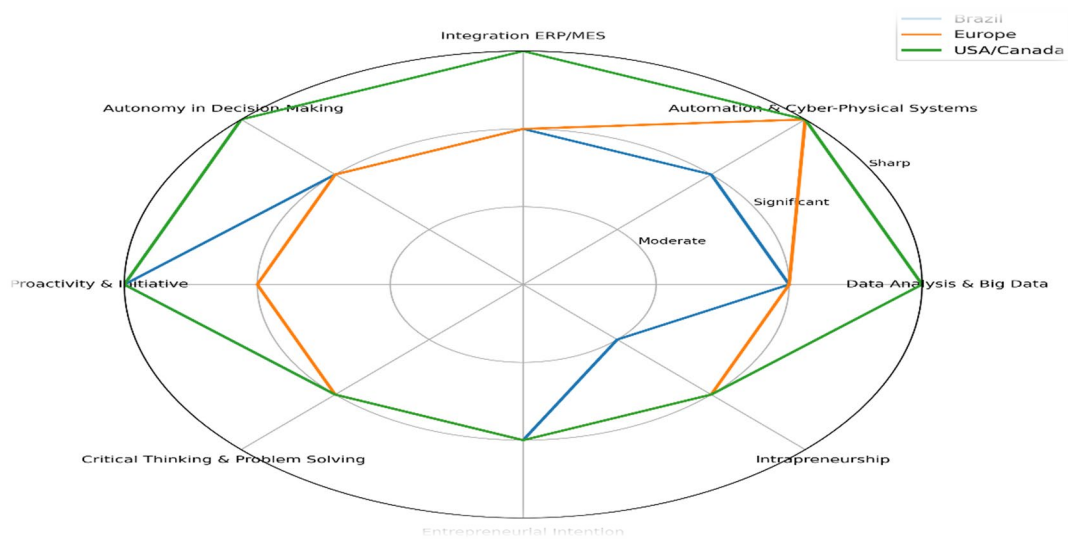


Figure 1. Evolution of skills applied to the production engineer in the context of Industry 4.0

Table 3. Details the relative frequency between technical and intrapreneurial skills.

Skill Dimension (Radar Axis)	Brazil (%)	Europe (%)	North America (%)
Intrapreneurship	35%	85%	92%
Entrepreneurial Intent	20%	45%	88%
Autonomy in Decision Making	40%	82%	95%
Proactivity and Initiative	55%	78%	90%
Cyber-Physical Systems Autonomy	60%	88%	96%
Data analysis	65%	85%	95%
ERP/MES Integration	70%	90%	92%

Source: Elaborated by the author (2026).

A combined reading of Figure 1 and Table 3 reveals consistent patterns of competition between technical and intrapreneurial skills in the three regions analyzed. The variations observed refer to the intensity of demand, and not to the absence of any specific dimension. These results describe the empirical distribution of skills explicitly required in job advertisements and underpin the aggregate competency analysis presented in the following section.

4.2 Competencies as a Structural Requirement in Industry 4.0

4.2.1 Integration of Competencies and Maturity Levels

The previous section presented the frequency and co-occurrence of the skills explicitly demanded in the analyzed job postings. This stage moves towards understanding these skills from an aggregate perspective, considering their articulation as integrated competencies in the context of Industry 4.0. The analysis is not limited to the isolated presence of technical or intrapreneurial skills, but seeks to understand how these dimensions combine structurally in the configuration of the required professional profile.

The combined interpretation of the graph and the table, from a systemic perspective, allows the identification of three central findings. First, a structural convergence is observed in the articulation between technical skills — such as Automation and Cyber-Physical Systems, Data Analysis, and ERP/MES Integration — and intrapreneurial skills (Liao et al., 2022; Solymosy & Gross, 2015), reflecting the increasing integration between technical and behavioral competencies in Industry 4.0 environments (Marques et al., 2022; Eyal-Cohen, 2019), albeit with different intensities among the analyzed sets (Arslan, 2014). Second, the intensity of this articulation varies according to the degree of technological integration identified, suggesting different levels of functional maturity. Finally, a consistent coexistence between technical and behavioral dimensions is identified across all contexts examined, indicating that this phenomenon is not a regional exception but rather a convergent trend in the Industry 4.0 scenario (Hecklau et al., 2017; Tortorella et al., 2021).

Figure 2 presents the classification of these patterns into maturity levels, based on cluster analysis. The groupings show progressive configurations, in which the articulation between digital fluency and intrapreneurial agency evolves from partial integration to systemic incorporation, characterizing differentiated stages of consolidation of competencies.

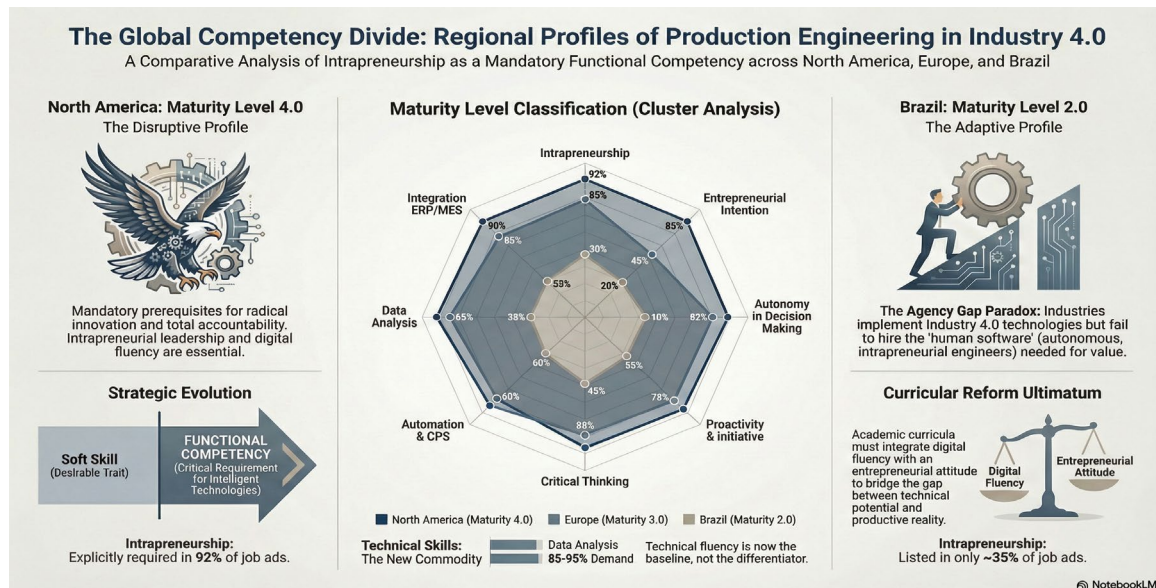


Figure 2. Classification of maturity levels of essential competencies in Industry 4.0, based on cluster analysis

The consolidation of Industry 4.0 has been widely associated with the incorporation of advanced digital technologies into production systems. However, the results of this research indicate that this transformation is not limited to the technological dimension, implying a structural reconfiguration of the professional skills required. Hernandez-de-Menendez et al. (2020) argue that the context of Industry 4.0 requires professionals capable of integrating technical, cognitive, and social skills, overcoming the traditional segmentation between hard and soft skills. This integration stems from the complexity of cyber-physical systems and the need for continuous data interpretation in highly automated production environments. Complementarily, they emphasize that technological and organizational interdependencies make human coordination a constitutive part of systemic functioning.

This perspective is reinforced by Xu et al. (2021), who highlight that the evolution towards human-centered approaches demonstrates the importance of autonomy and decision-making capacity in intelligent systems. Convergingly, Marques et al. (2017) demonstrate that smart manufacturing environments operate with decentralized decision support, requiring professionals capable of interpreting information in real time and proposing strategic adjustments. Lin, Wang, and Sheng (2020), when discussing dynamic capabilities applied to smart manufacturing, emphasize that continuous adaptation to digital technologies requires skills that articulate technical knowledge, systemic vision, and strategic initiative. In addition, recent research has highlighted that intrapreneurial behavior, supported by creative self-efficacy and organizational support, plays a critical role in enabling professionals to integrate technical and behavioral competencies in production engineering contexts (Liao et al., 2022; Marques et al., 2022).

The empirical data from this research corroborate this theoretical framework. The recurring presence of autonomy in decision-making, critical thinking, proactivity, and intrapreneurship in the analyzed advertisements indicates that such dimensions are not merely desirable, but formally required and functionally associated with the core technical skills of Industry 4.0 (Eyal-Cohen, 2019; Solymossy & Gross, 2015). While the previous section detailed specific skills, Graph 2 consolidates this data into three aggregate dimensions.

Identified Maturity Structure

Instead of presenting crude frequency averages—susceptible to sampling variations—the analysis mapped the data onto a consolidated Ordinal Maturity Scale. In this taxonomy, the analyzed contexts were classified into whole levels based on the structural intensity of the identified requirements:

- **Level 2.0 (Adaptive):** Competence is required predominantly for operational execution, with a lower degree of decisional autonomy.
- **Level 3.0 (Consolidated):** Competence is demanded for process optimization, with moderate autonomy.

- **Level 4.0 (Disruptive):** Competence is a prerequisite for strategic innovation, involving high autonomy and decisional capacity.

The application of clustering revealed consistent patterns of integration between technical fluency, digital complexity, and intrapreneurial agency. The results indicate internal homogeneity in each identified grouping. No cases were observed in which the technical requirement was dissociated from the behavioral or intrapreneurial requirement. On the contrary, higher levels of technical maturity tend to be accompanied by a greater demand for autonomy, resilience, and leadership (Arslan, 2014; Liao et al., 2022).

The visualization shows that the integration between competencies occurs proportionally, configuring distinct stages of functional incorporation in the context of Industry 4.0. Thus, the variation observed between the groupings does not point to a geographical hierarchy, but to different structural levels of organizational complexity and competency requirements. The results indicate that intrapreneurship plays a key role in connecting the technical and behavioral dimensions identified in the analyzed groups. Based on this integration, the following section delves deeper into the interpretation of this structural pattern.

4.3 Entrepreneurship and Intrapreneurship as Functional Dimensions of Industry 4.0

The document analysis of the 528 job postings reveals the systematic recurrence of competencies associated with decisional autonomy, project leadership, innovation-oriented initiative, and responsibility for results. Although not always explicitly classified as "intrapreneurship," these dimensions appear as functional requirements in job descriptions, indicating that intrapreneurial behavior has become integrated into the core architecture of competencies demanded in Industry 4.0.

Recent analyses suggest that digital transformation restructures human capital by shifting emphasis from isolated technical execution to the strategic orchestration of digital systems (World Economic Forum, 2020, 2023). Within this context, entrepreneurial competencies assume a structural role in sustaining organizational adaptability and performance.

Literature shows that digitized industrial environments require professionals capable of integrating technical knowledge, decision-making under uncertainty, and value creation through internal innovation (Naumann *et al.*, 2021; Guzman *et al.*, 2020). This movement reinforces the interpretation that intrapreneurship, in Industry 4.0, operates as a functional competence applied to the mobilization of cyber-physical systems, data analysis, and intelligent automation.

From the comparative analysis of the three structuring dimensions of the study — Technical and Digital Fluency, Intrapreneurial Leadership, and socio-emotional Resilience — three predominant professional profile configurations emerge:

• Disruptive Profile

It is characterized by high simultaneous demands in the three dimensions analyzed. Intrapreneurial leadership appears as a mandatory competence, associated with responsibility for innovation projects, implementation of advanced technologies, and reconfiguration of operational models.

This profile aligns with evidence that organizations embedded in mature digital ecosystems demand professionals capable of generating continuous innovation and creating a competitive advantage through the strategic exploitation of technology (SChiele *et al.*, 2021; Shet; Pereira, 2021). In this configuration, the production engineer acts as an active agent of organizational transformation.

• Consolidated Profile

Presents a balance between technical depth and intrapreneurial skills. Leadership is valued, but predominantly directed towards continuous improvement, systemic integration, and optimization of production processes.

Studies on digital maturity indicate that, in contexts of structured technological transition, innovation tends to take on an incremental character, focused on operational efficiency and systems integration (Low et al., 2021; LI *et al.*, 2021). Intrapreneurship, in this case, manifests itself as the capacity for strategic adaptation within already consolidated industrial structures.

- **Adaptive Profile**

Indicates a predominance of the technical dimension, with less emphasis on strategic autonomy. The descriptions suggest functions oriented towards execution, control, and support for technological implementation.

Even so, the presence of terms such as initiative and adaptability demonstrates that intrapreneurial behavior is not absent, but assumes reduced intensity. As argued by Teng et al. (2019) and Whysall *et al.* (2019), even environments oriented towards operational efficiency demand interpersonal skills and the capacity for continuous learning as a condition for sustainable employability in the Fourth Industrial Revolution.

In general, the data confirm that intrapreneurship is not presented as a peripheral attribute, but as a recurring component of the architecture of the required competencies. Empirical evidence converges with studies that indicate that, in Industry 4.0, technical competence incorporates strategic, cognitive, and decisional dimensions, configuring a hybrid profile oriented towards the generation of organizational value (Reiman *et al.*, 2021; Ciarli et al., 2021).

Thus, what emerges is not merely an expansion of behavioral demands, but a structural redefinition of professional competence itself: mobilizing technology, making decisions under uncertainty, and leading innovation processes become inseparable dimensions of contemporary technical performance.

5. Results and Discussion

The results of this research indicate that the digital transformation associated with Industry 4.0 not only alters the technical content of the functions, but also structurally reconfigures the architecture of professional competence in Production Engineering. The empirical evidence obtained from the analysis of the 528 job openings reveals the consolidation and expansion of the T-Shaped model, with the explicit incorporation of strategic agency and intrapreneurship. The identified differences do not represent a hierarchical evaluation between countries. Instead, they reflect structural variations in industrial ecosystems, levels of digital integration, and economic positioning within global value chains.

5.1. Expansion of the T-Shaped Model and Functional Redefinition of Competence

The results indicate not only the consolidation of the T-shaped profile in Production Engineering, but also the expansion of its functional meaning in the context of Industry 4.0. Traditionally, the T-shaped model describes professionals who combine technical depth (vertical axis) with systemic vision and interdisciplinary capacity (horizontal axis) (Hecklau *et al.*, 2016; Alvarez-Aros and Bernal-Torres, 2024). In contrast, the traditional I-shaped model is characterized by isolated vertical technical specialization, with limited transversal integration.

This expansion aligns with the literature on entrepreneurial competencies, which defines intrapreneurship as resource mobilization, decision-making under uncertainty, and systematic value creation (Bacigalupo *et al.*, 2016; Tittel and Terzidis, 2020). The data demonstrate that terms traditionally classified as behavioral—proactivity, autonomy, and initiative—operate, in the context of Industry 4.0, as functional antecedents of this intrapreneurial agency. Thus, the T-shaped model is not only confirmed but expanded. The horizontal axis now integrates not only relational capabilities but also competencies oriented towards strategic innovation and the reconfiguration of technological processes. The traditional distinction between hard skills and soft skills proves insufficient to explain the hybrid nature of the required competence.

What emerges is a redefinition of technical competence: not only mastering automated systems but acting strategically on them, integrating technical depth and intrapreneurial capacity in the same professional architecture (Figure 3).

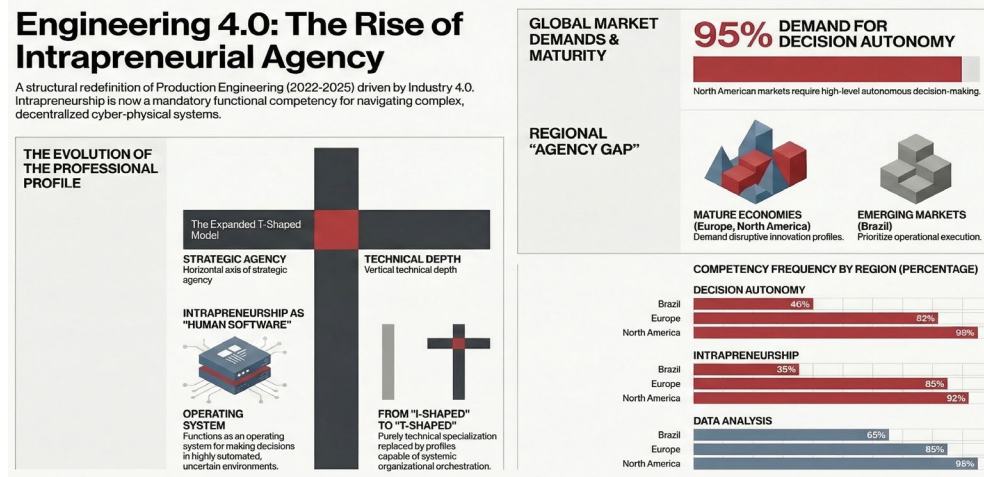


Figure 3. Expansion of the T-Shaped Competency Model in Industry 4.0: Evidence from 528 Job Openings (2022–2025)

The empirical results presented in this section converge with the structural logic of the expanded T-shaped competency model (Figure 3). While the findings confirm the consolidation of a robust vertical axis—characterized by deep technical specialization—they simultaneously reveal a growing demand for strengthening the horizontal axis through intrapreneurial activity and strategic autonomy (Mehmood et al., 2020). This integration enables the transition from a predominantly operational profile to a systemic and strategic professional configuration, capable of generating value in the complex environments of Industry 4.0.

5.2 Redefining Competencies and Training Implications

The functional expansion of the T-Shaped model implies a necessary review of how competencies are structured within Production Engineering curricula. When technical competence is integrated with strategic and intrapreneurial agency, fragmented curricula tend to develop predominantly the vertical axis of the "T," placing less emphasis on the consolidation of the expanded horizontal axis. This discussion does not attribute structural inadequacy to academic institutions; rather, it recognizes that the acceleration of technological transformation generates permanent pressure for curricular renewal and pedagogical innovation.

Recent literature emphasizes that contemporary engineering education requires the integration of digital fluency, critical thinking, collaboration, and entrepreneurial competencies as structural dimensions of professional development (Van Laar et al., 2020; Cattaneo et al., 2022). In this sense, the perspectives presented by Bond et al. (2021), Muzulon et al. (2025), Audrin (2023) reinforce the argument that sustainable transformation in higher education requires institutional agility and strategic governance mechanisms (Poszytek, 2021).

The findings of this study further reinforce this perspective by demonstrating that professional competence in Industry 4.0 environments cannot be reduced to technical specialization alone. Instead, it requires the systemic articulation of technological expertise, strategic agency, and adaptive decision-making capabilities. In this context, active methodologies and project-based learning emerge not merely as pedagogical alternatives, but as institutional mechanisms capable of fostering the expanded horizontal axis of the T-shaped profile. These methods enable professionals to operate under conditions of uncertainty while effectively generating organizational value (Teng et al., 2019). Thus, curriculum revision does not represent a mere technological update, but a conceptual reconfiguration of the very notion of professional competence in the Industry 4.0 era.

6. Final Considerations

The results of this study demonstrate that Industry 4.0 represents a structural redefinition of the role of Engineering, moving beyond a mere technological transition. The analysis of 528 job postings reveals that the "skills gap" is not limited to a technical shortage; rather, it reflects a transformation in the functional architecture of required capabilities. Although technical knowledge remains indispensable, it is no longer a sufficient condition for professional

sustainability. The contemporary market now demands the articulation of technical fluency, strategic autonomy, systemic vision, and socio-emotional skills across different academic and professional levels.

In this scenario, the T-shaped model evolves: its horizontal expansion incorporates the ability to make decisions under uncertainty, the mobilization of organizational value, and the functional competence of intrapreneurship. Evidence suggests that initiative and accountability for results are now structural components of professional legitimacy in digital environments. The typology of Disruptive, Consolidated, and Adaptive profiles reinforces that professional maturity is not homogeneous, reflecting varying levels of technological integration and strategy. This classification organizes competency patterns observed in the market and illuminates a macroeconomic paradox: the coexistence of a labor surplus with a shortage of specific qualifications (Bennett and McWhorter, 2021), highlighting the misalignment between educational institutions and the evolutionary logic of industrial production. Given this, curricular reconfiguration becomes urgent (Goleman, 2001). Training focused on vertical specialization limits strategic action in integrated systems; therefore, educational reform must transcend technological content, encompassing interdisciplinary integration and project-based methodologies.

In short, this work repositions intrapreneurship as a structural dimension of Engineering 4.0, offering an empirical basis for strategic alignment between academia and talent management.

Concluding Synthesis

In practical and conceptual terms, this study consolidates the following conclusions:

- **Model Replacement:** Vertical technical specialization alone no longer sustains a career; the "I" model is definitively being replaced by the "T" model. This transition aligns with the perspectives of Frey and Osborne (2023), who argue that while technology reconfigures the labor market, the future of employment depends on the ability to perform non-routine tasks that require high cognitive and social complexity.
- **"Human Software":** Intrapreneurship functions as an operating system, allowing engineers to make decisions in uncertain environments—an intrinsic characteristic of Industry 4.0.
- **Demystification of the Concept:** The 4.0 job market is changing the narrative of a concept that was previously limited.

Traditionally, intrapreneurship was often reduced to:

1. **Heroic Action:** The "savior" of companies in crisis.
2. **Survival Action:** Opening one's own business out of necessity.
3. **Owner Profile:** Something exclusive to those who hold a CNPJ (Brazilian Business Tax ID).

Unlike this traditional view, this study reveals that in Industry 4.0, the focus has shifted from "possession" to "ownership." Intrapreneurship has ceased to be a subjective behavioral trait and has become an indispensable technical-operational competence for maintaining professional legitimacy. As automation advances over technical functions, the intrapreneurial capacity for innovation and strategic problem-solving ensures long-term employability (Frey and Osborne, 2023). In short, Industry 4.0 removes intrapreneurship from the field of "business self-help" and definitively places it within the field of Applied Production Engineering.

Future Research Future research should delve deeper into the longitudinal applications of the proposed competency model in Engineering curricula, as well as investigate the ethical implications of AI-supported decision-making in intrapreneurial contexts (Zhou et al., 2023).

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