A comparative study on the adoption of IR 4.0 technologies in Malaysian TVET institutions

Nofouz Mafarja[1]*, Mimi Mohaffyza Mohamad[2], Badaruddin Ibrahim[2], Lai Chee Sern[2], Tee Tze Kiong[2]
[1]University Malaya, Malaysia
[2]Universiti Tun Hussain Onn Malaysia, Malaysia
*Corresponding Author: nofouz@um.edu.my

ABSTRACT

In Malaysia, Technical and Vocational Education and Training (TVET) institutions play a crucial role in preparing the future workforce to thrive in the era of Industrial Revolution 4.0 (IR 4.0). This study presents a comprehensive comparative analysis of the adoption and integration of IR 4.0 technologies in Malaysian TVET institutions. It employs a quantitative approach using descriptive statistics and multivariate analysis of variance (MANOVA). The survey was conducted among 59 participants from three TVET institutions in Malaysia to gather data on the types and extent of IR 4.0 technologies implemented. The results indicate that, on average, all institutions demonstrated an intermediate level of adoption. However, there were significant differences in infrastructure and connectivity among the three institutions, while no significant differences were found in terms of intelligence-related technologies. The findings of this comparative study offer valuable insights into the adoption of IR 4.0 technologies in Malaysian TVET institutions.

Keywords: IR 4.0 technologies, TVET institutions, stakeholders, infrastructure, internet of things

INTRODUCTION

In the era of Industry 4.0, the adoption of advanced technologies has become crucial for the growth and competitiveness of various sectors. Technical and Vocational Education and Training (TVET) institutions play a vital role in ensuring a skilled workforce capable of meeting the demands of the industry. Malaysia has recognized the importance of TVET in driving economic development and has made significant efforts to promote its growth. TVET institutions in Malaysia offer a diverse range of programs aimed at providing students with technical skills and knowledge. These institutions act as a bridge between academia and industry, ensuring graduates are equipped with relevant skills (Abd Karim & Mustapha, 2022). Malaysia has been actively adopting the Fourth Industrial Revolution (IR4.0) to promote economic growth, boost competitiveness, and enhance numerous economic sectors, much like many other nations across the world. Internet of Things (IoT), cloud computing, Augmented Reality (AR), simulation, robotic automation, system integration, additive manufacturing, big data, and cybersecurity are the examples of cutting-edge technologies that are being incorporated into a variety of industries under the umbrella term "IR4.0" (Erboz, 2017).

Although recent scholarship has advanced understanding of TVET's role in Malaysia's IR 4.0 transformation, several gaps remain evident. First, much of the existing research provides descriptive accounts of readiness or focuses on individual institutions, without offering systematic comparative analyses across multiple TVET institutions (Abdullah et al., 2019; Cheok & Ran, 2022). This limits insights into variations in adoption levels, infrastructure, and institutional

strategies. Second, while prior studies acknowledge barriers such as inadequate funding, insufficient infrastructure, and limited instructor competency (Gen et al., 2022; Hamid et al., 2023), there has been little investigation into how these factors interact differently across institutions and shape adoption outcomes. Third, many studies draw on pre-2022 data, leaving the literature outdated in light of recent developments, including Malaysia's intensified policy focus on digital skills, stronger industry-academia partnerships, and evolving employability demands (Cheok & Ran, 2023; Halik Bassah & Noor, 2023). Finally, despite national strategies positioning TVET as a cornerstone of IR 4.0 readiness, limited empirical evidence exists on whether institutional practices and adoption strategies align with policy goals and industry needs (Kuntadi et al., 2022; Nurjanah & Ana, 2022). Addressing these gaps is critical to ensuring that Malaysia's TVET sector can effectively respond to the technological, economic, and workforce challenges of IR 4.0 (Ngatiman et al., 2023).

To conduct a comparative study, various TVET institutions in Malaysia can be evaluated based on their adoption and integration of Industry 4.0 technologies. This assessment would involve assessing the infrastructure, curriculum, training programs, collaborations with industry, and the readiness of institutions to embrace these technologies. The study would analyze the availability of advanced infrastructure necessary for the implementation of Industry 4.0 technologies, such as high-speed internet connectivity, smart classrooms, robotics labs, simulation centers, and relevant software applications. TVET institutions' curricula should be designed to incorporate Industry 4.0 technologies. Thus, the comparative study would examine the extent to which institutions have made provisions for advanced courses related to IoT, data analytics, robotics, automation, and cybersecurity (Ismail & Hassan, 2019). The study would evaluate the efforts undertaken by TVET institutions to provide adequate training to students on operating, managing, and maintaining Industry 4.0 technologies. Also, it would explore partnerships with industry stakeholders and the inclusion of industrial training programs to enhance hands-on experience.

A comparative study of TVET institutions' adoption of these technologies can provide valuable insights into the current state, potential gaps, and opportunities for improvement. Specifically, this study aims to conduct a comparative analysis of IR 4.0 technology adoption among TVET institutions in Malaysia by addressing several research objectives. These objectives include assessing the level of IR 4.0 technology adoption among TVET institutions, identifying the factors influencing the adoption of IR 4.0 technologies in these institutions, comparing the extent of IR 4.0 technology adoption across different TVET institutions in Malaysia, and analyzing the impact of IR 4.0 technology adoption on the performance and competitiveness of these institutions.

In order to successfully traverse the opportunities and difficulties posed by the IR 4.0, TVET institutions must develop an effective strategy and leadership approach. TVET institutions need to align the vision and objectives with IR 4.0's guidelines to create a clear knowledge of the future competences and abilities required in the digital age and explain how the institution will help create a workforce that can succeed in the IR 4.0 environment. Besides that, the TVET institution also needs to adapt the transformational leadership. Transformational leadership is a type of leadership in which the leader engages people to identify the change that is required, develops a vision that encourages modifications, and then partners with committed group members to bring about transformation (Poturak et al., 2020; Ana et al., 2021).

The effectiveness of transformational leadership itself is significantly influenced by supporting factors within the organization. Studies have shown that fair reward systems and strong organizational commitment play a crucial role in strengthening transformational leadership practices, which in turn positively impact teacher job satisfaction and performance (Hardianto et al., 2025). Furthermore, while studies in the broader higher education context have demonstrated that transformational leadership, supported by adequate compensation, enhances task performance (Yuntina et al., 2025), this principle is particularly pertinent for TVET institutions, where educator competency directly impacts students' technical skills and industry readiness. These findings underscore that successful technological transformation in TVET institutions must

be built upon a foundation of sound human resource management, where educators are valued, supported, and committed to the institution's vision.

The other strategy is to create collaborative partnerships with companies, IT companies, and research institutions to take advantage of their resources, networks, and experience. These alliances can support programmatic alignment with industry needs, grant access to cutting-edge technology, and facilitate student placements and projects that are relevant to the industry (Mahmud et al., 2020). Investment in professional development programs for professors and staff also will help them gain more insight into IR 4.0 and improve their knowledge and abilities in that area. Developing leadership skills by providing training and workshops on new technology, pedagogical strategies, and market trends can encourage the staff members to continue learning and provide them with chances to participate in innovative and research-related projects (Rahim & Shamsudin, 2019).

To successfully manage the opportunities and difficulties posed by IR 4.0, TVET institutions must have strong leadership and a forward-thinking strategy. TVET institutions should position themselves as major actors in developing the future workforce by embracing change, encouraging collaboration, and giving students the skills they need for the digital age (Zulnaidi & Majid, 2020; Kuntadi et al., 2022).

Industry 4.0 is now gathering momentum globally. According to the 2016 Industry 4.0 global survey conducted by PwC, nearly three-quarters of respondents foresaw a high level of digitalization in their companies over the next five years. However, in McKinsey's 2017 digital manufacturing global expert survey, companies also pointed out that the lack of a clear vision, strategy, and systematic roadmap were the biggest challenges hindering Industry 4.0 adoption. The Smart Industry Readiness Index (SIRI) is a deliberate attempt to address these challenges. Created in partnership with global testing, inspection, and certification company TÜV SÜD and validated by an advisory panel of industry and academic experts, SIRI comprises a suite of frameworks and tools to help manufacturers, regardless of size and industry, start, scale, and sustain their manufacturing transformation journeys. This white paper introduces three frameworks and tools: the SIRI Framework, the LEAD Framework, and the Assessment Matrix tool.

As part of the World Economic Forum's Global SIRI Initiative, the International Centre for Industrial Transformation (INCIT) was established in 2021 to bring SIRI to the next level. INCIT is a new, independent, non-governmental, not-for-profit organization that will take over management and coordination of the SIRI program. Supported by the Forum and other international organizations, INCIT will work closely with partners from both the public and private sectors to catalyze industrial transformation on a global scale. SIRI identifies 3 fundamental building blocks of Industry 4.0: technology, process, and organisation. All 3 building blocks must be considered to harness the full potential of Industry 4.0. Underpinning the 3 building blocks are 8 key pillars, which represent critical aspects that companies must focus on to become future-ready organizations. Finally, the 3 building blocks and 8 pillars map onto 16 dimensions, which are areas of assessment that companies can use to evaluate the current Industry 4.0 readiness of their facilities (Erboz, 2017; Fadzil et al., 2022).

METHOD

This research, analyzed by descriptive statistics, will be used to measure the level of adoption of IR 4.0 technologies among TVET institutions. Inferential statistics, such as chi-square tests or MANOVA, will be employed to assess the relationships between various factors and the adoption of IR 4.0 technologies. Regression analysis may also be conducted to measure the impact of technology adoption on the performance and competitiveness of the institutions.

This study focuses on the analysis of quantitative data collected through the development of the questionnaire, which is based on the conceptual framework adopted from SIRI which constitutes three core components: process, technology, and organization. For each section of the SIRI component, the participants were asked to respond appropriately to each question. The survey questionnaire consists of two sections. Section 1 for personal information and section 2

for technology. The population for the survey question is 59 participants from all formal TVET institutions at secondary and postsecondary levels in Malaysia. The highest responses come from building construction, which carries 28.125%, and from mechanical teaching, which carries 25%. The highest level of qualification among our respondents is degree and above (ASEAN Qualification Reference Framework/AQRF Level 6 and above), which is about 75%.

FINDINGS AND DISCUSSION

Findings

The analysis of the collected data provides insights into the extent to which IR 4.0 technologies have been adopted across TVET institutions in Malaysia. The results reveal varying levels of readiness and integration across different technological dimensions, highlighting both areas of progress and aspects that remain underdeveloped.

Table 1 presents meaning scores for different dimensions of technology readiness in a specific context. The technology block represents an overarching category encompassing various technological aspects, with a moderate mean score of 1.98 indicating a reasonable level of readiness. The infrastructure pillar focuses on the existing technological infrastructure and shows a lower mean score of 1.74, signifying a need for further development in this area. The Intelligence pillar pertains to advanced technologies and their application, showing a moderate mean score of 2.55, indicating a moderate level of readiness in adopting intelligent technologies. The Connectivity pillar assesses the availability and effectiveness of digital connectivity, with a lower mean score of 1.64, suggesting a need for improvement in connectivity.

Table 1. Level of adoption of IR 4.0 technologies among TVET institutions in Malaysia

	Items	Mean
Block	Technology	1.98
Pillars	Infrastructure	1.74
	Intelligence	2.55
	Connectivity	1.64
Dimensions	Digital Infrastructure	2.35
	Digital Storage	1.14
	Automation	2.63
	Machine Learning	2.44
	Innovative Analysis	2.59
	Risk & Cyber Security Management	1.57
	Digital Interconnectivity	1.71

Moreover, the Digital Infrastructure dimension highlights the growth and accessibility of digital infrastructure, with a moderate mean score of 2.35. This suggests that digital infrastructure is already available but not yet fully optimized, meaning institutions can use various types of technology. The Digital Storage dimension focuses on the presence and capacity of digital storage systems. It has an early adopter stage mean score of 1.14, indicating that digital storage exists but is still basic, such as hard drives and USB flash drives, and that improvements in storage capabilities are still needed. The Automation dimension relates to the adoption and use of automated processes, showing a moderate mean score of 2.63. This implies that automation technology is present but not used effectively, although institutions have the capability to utilize different types of automation technologies. The Machine Learning dimension emphasizes the integration and application of machine learning algorithms, with a moderate mean score of 2.44. This indicates that machine learning technology exists but is not yet used optimally, even though institutions have the potential to adopt various machine learning technologies.

Additionally, the Innovative Analysis dimension refers to the use of advanced data analysis methods and shows a moderate mean score of 2.59. This suggests that automation-related technologies are available but not fully utilized, while institutions already apply innovative analysis as a problem-solving approach in various fields. The Risk and Cybersecurity

Management dimension evaluates how risks and cybersecurity are managed, with a lower mean score of 1.57. This indicates that systems are interconnected but remain insufficiently secure across multiple communication technologies and protocols. The Digital Interconnectivity dimension highlights the integration and connectivity of digital systems, with a lower mean score of 1.71. This suggests that digital connectivity exists but has not been fully implemented, mainly due to limited knowledge and understanding. Overall, the findings show several areas that need improvement, including infrastructure development, digital storage capacity, risk and cybersecurity management, and digital interconnectivity.

By addressing these aspects, the overall technology readiness can be enhanced to support the effective implementation of advanced technologies and intelligent systems. A study by Cheok and Ran (2022) investigated the readiness of TVET institutions in Malaysia for IR 4.0 technologies. The study revealed that while some institutions demonstrated a proactive approach in integrating these technologies into their training programs, others faced challenges due to limited financial resources and lack of skilled faculty. The study emphasized the need for collaboration between TVET institutions, industries, and the government to cultivate an environment conducive to technology adoption. In another study conducted by Abdullah et al. (2019), the researchers assessed the level of technology integration in TVET curricula. The findings indicated that although efforts were being made to incorporate IR 4.0 technologies, the integration was not uniform across different institutions. The study recommended the development of standardized guidelines and continuous professional development programs for TVET educators to enhance their competency in delivering technology-focused education. Furthermore, a study by Gen et al. (2022) explored the challenges faced by TVET institutions in adopting IR 4.0 technologies and identified strategies to overcome them. The study identified issues such as resistance to change, lack of technical support, and limited funding as barriers to successful technology adoption. It suggested strategies such as faculty development programs, increased funding allocation, and industry collaborations to address these challenges effectively.

Compare the extent of IR 4.0 technology adoption between different TVET instituions in Malaysia

The result shows that in all three domains, educators in VC MUAR, VC BATU BAHAT, and VC KLUANG placed in the intermediate level with average scores, as well as for three variables under the technology block, such as infrastructure, intelligence, and connectivity. The results presented in Table 2 were analyzed using MANOVA.

Table 2. Descriptive statistics

Technology Pillars	TVET institutes	Mean	Std. Deviation	N
Infrastructure	VC Muar	23.925	.43293	32
	VC Batu Bahat	28.644	.23123	16
	VC Kluang	20.218	.16558	11
	Total	24.514	.45021	59
Intelligence	VC Muar	25.850	.29586	32
	VC Batu Bahat	24.544	.21169	16
	VC Kluang	26.145	.15109	11
	Total	25.551	.25744	59
Connectivity	VC Muar	21.831	.21084	32
	VC Batu Bahat	20.544	.15157	16
	VC Kluang	20.409	.20988	11
	Total	21.217	.20461	59

For the infrastructure, the mean score for VC MUAR is 2.3925, indicating an average value of 2.3925 for the VC MUAR, with a standard deviation of 0.43293, suggesting a relatively moderate amount of variability in the data. However, VC BATU BAHAT records a mean of 2.8644, with a standard deviation of 0.23123, indicating a relatively low amount of variability in

the data. Meanwhile, VC KLUANG shows an average value of 2.0218, with a standard deviation of 0.16558, suggesting a relatively low level of variability.

For intelligence, VC MUAR reports a mean of 2.5850, indicating an average value of 2.5850, with a standard deviation of 0.29586, suggesting a relatively low amount of variability in the data. For the VC BATU BAHAT, the mean is 2.4544, indicating an average value of intelligence, with a standard deviation of 0.21169, suggesting a relatively low amount of variability in the data. Similarly, VC KLUANG records a mean of 2.6145, with a standard deviation of 0.15109, suggesting a relatively low amount of variability in the data.

In terms of connectivity, VC MUAR indicates an average value of 2.1831, with a standard deviation of 0.21084, suggesting a relatively low amount of variability in the data. For VC BATU BAHAT, the mean indicates an average value of 2.0544, with a standard deviation of 0.15157, suggesting a relatively low amount of variability in the data. Likewise, VC KLUANG reports a mean of 2.0409, indicating an average value of connectivity, with a standard deviation of 0.20988, suggesting a relatively low amount of variability in the data.

Statistical analysis using MANOVA results in Table 3 shows that the "infrastructure" variable shows significant differences between groups, as indicated by the low p-value (F = 19.800, p < .001) and substantial effect size (partial eta squared = .414). However, the "intelligence" variable does not show significant differences between groups, with a relatively high p-value (F = 1.780, p = .178) and a small effect size (partial eta squared = .060). The "connectivity" variable shows a marginal significance, with a low p-value (F = 3.431, p = .039) and a moderate effect size (partial eta squared = .109).

Table 3. Tests of between-subjects effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Groups	infrastructure	4.870	2	2.435	19.800	.000	.414
	Intelligence	.230	2	.115	1.780	.178	.060
	Connectivity	.265	2	.133	3.431	.039	.109
Error	infrastructure	6.886	56	.123			
	Intelligence	3.614	56	.065			
	Connectivity	2.163	56	.039			
Total	infrastructure	366.296	59				
	Intelligence	389.023	59				
	Connectivity	268.022	59				

Based on the data analysis, it can be concluded that VC MUAR, VC BATU BAHAT, and VC KLUANG show similar levels in adopting IR 4.0 technologies, both in overall technology and in each domain, which are at the intermediate level. It shows that the TVET institutions in Malaysia have not yet reached their full adoption and are not yet fully prepared to face the industry in Industrial Revolution 4.0. VC MUAR, VC BATU BAHAT, and VC KLUANG can collaborate with industry based on which domain they need to face the IR4 technologies in and which area should be the concern to be improved. However, it should be noted that universities also need to collaborate with the industry in developing benchmarks and standards to measure and set what skill sets should be taught and prepared at school. Internships in the industry can be the simulation of how well the educators will be ready to adapt to IR4.0 technologies.

Discussion

The results of this study indicate that Malaysian TVET institutions are at an intermediate level of Industry 4.0 (IR 4.0) adoption, with notable deficiencies in digital infrastructure, storage, cybersecurity, and connectivity. While some progress has been made in automation, machine learning, and innovative analytics, these technologies are inconsistently implemented and insufficiently embedded into teaching and learning practices. Such partial adoption raises concerns about the long-term quality and employability of TVET graduates. Graduates who lack exposure to IR 4.0-related skills risk entering the workforce with competencies misaligned to industry requirements, thereby facing limited opportunities and underemployment (Nurjanah &

Ana, 2022; Halik Bassah & Noor, 2023; Hashim, 2024). This situation is particularly critical in Malaysia, where TVET is expected to act as the primary driver of workforce readiness for digital transformation (Cheok & Ran, 2023).

From a systemic perspective, unequal adoption across institutions has broader consequences. Institutions with stronger infrastructure and resources are likely to produce more competitive graduates, while those lagging may exacerbate inequities in workforce quality. This fragmentation not only undermines national workforce strategies but also reduces Malaysia's competitiveness in the global digital economy (Hamid et al., 2023). In this sense, the challenges are not merely technological but structural, reflecting gaps in policy coherence, institutional capacity, and funding mechanisms.

A more structured analysis can be achieved by interpreting the findings through SIRI, which emphasizes three building blocks: technology, process, and organization (Fadzil et al., 2022). In the technology block, weaknesses in digital infrastructure, storage, and cybersecurity indicate that institutions remain in the early adoption stage, lacking the foundational enablers of digital transformation. In the process block, while some automation and machine learning capabilities are present, they are sporadic and underutilized, preventing TVET programs from fully transforming teaching practices and aligning curricula with industry standards. The organization block reflects moderate readiness, suggesting that leadership and collaboration exist but are not sufficiently systematic or strategically aligned with IR 4.0 imperatives (Zulnaidi & Majid, 2020). These findings confirm that Malaysia's TVET transformation is hindered by a lack of integration across all three domains, reducing the potential for sustainable digital innovation.

When positioned within a broader ASEAN context, Malaysia's progress appears uneven. Singapore has leveraged SIRI to institutionalize national benchmarking and align TVET with industry transformation strategies (PwC, 2016; McKinsey, 2017). Thailand's "Thailand 4.0" policy has strengthened TVET–industry clusters, particularly in smart manufacturing and robotics (Ana et al., 2021). Indonesia, while facing similar challenges of uneven adoption and resource constraints, has introduced the "Making Indonesia 4.0" roadmap to accelerate digital readiness (Kuntadi et al., 2022). Compared to these cases, Malaysia's intermediate adoption highlights both opportunities and risks: the country is ahead of some developing ASEAN counterparts but lags behind regional leaders that have developed stronger policy frameworks and industry partnerships (Cheok & Ran, 2022). This comparative lens underscores the urgent need for Malaysia to position its TVET reforms within a regional and global trajectory rather than treating them as isolated institutional efforts.

The findings of this study indicate that the adoption of IR 4.0 technologies in Malaysian TVET institutions remains at an intermediate level, with significant weaknesses in aspects of digital infrastructure and cybersecurity. These challenges do not stand alone but are closely related to the readiness of human resources, particularly the competencies of educators. This aligns with findings in Indonesia, where the professional development of vocational teachers, specifically in scientific publications and classroom action research, remains a critical challenge in the industry 4.0 era (Soenarto et al., 2024). The importance of continuous professional growth (CPG) and a commitment to lifelong learning among educators, as highlighted by Musa et al. (2024), is paramount in ensuring they can adapt to emerging pedagogical trends and harness new technologies effectively. Furthermore, building these competencies must begin early, with pre-service teachers developing strong pedagogical competence through transformative learning experiences during their teaching practicum (Miftah et al., 2024). Systematic efforts to transform vocational school management, such as the mentoring program for the Centre of Excellence Vocational High Schools (CEVHS) in Central Java, demonstrate that improving TVET quality requires a holistic intervention, addressing not only technological aspects but also governance and curriculum (Sucipto et al., 2024).

To move beyond this intermediate stage, a more transformative strategy is required. First, institutional adoption of SIRI-based benchmarking should be standardized across all TVET providers to ensure systematic progress tracking. Second, educator capacity building remains a priority, as the lack of skilled faculty continues to impede the translation of IR 4.0 technologies into pedagogy (Abdullah et al., 2019; Rahim & Shamsudin, 2019). Third, industry collaboration

must be deepened and institutionalized, taking cues from Singapore's structured partnerships and Thailand's regional cluster models (Mahmud et al., 2020). Finally, targeted government funding is essential to reduce disparities between resource-rich and resource-poor institutions, ensuring equitable access to advanced technologies and reducing inequalities in graduate outcomes.

In sum, this study highlights both progress and structural weaknesses in Malaysia's TVET readiness for IR 4.0. The current intermediate adoption is insufficient to ensure long-term graduate employability or global competitiveness. Overall, the findings suggest that while Malaysian TVET institutions are making progress, the current intermediate level of adoption is insufficient to meet the demands of IR 4.0. Unless immediate steps are taken to strengthen infrastructure, organizational readiness, and regional benchmarking, Malaysian TVET graduates' risk being underprepared for the rapidly evolving global workforce.

CONCLUSION

In conclusion, this research study aimed to compare the adoption of Industry 4.0 (IR 4.0) technologies among Technical and Vocational Education and Training (TVET) institutions in Malaysia. The findings shed light on the current state of IR 4.0 technology adoption and its implications for TVET institutions in Malaysia. The analysis revealed that while some TVET institutions have made significant strides in embracing IR 4.0 technologies, there are still considerable variations in terms of implementation and utilization across institutions. Factors such as financial resources, infrastructure, organizational culture, and human capital were found to influence the adoption process. The study identified several key benefits associated with the adoption of IR 4.0 technologies in TVET institutions. These include enhanced teaching and learning experiences, increased efficiency in training delivery, improved industry relevance, and better student outcomes. Additionally, the integration of IR 4.0 technologies has the potential to bridge the gap between industry requirements and TVET curriculum, thus ensuring graduates are equipped with the necessary skills for the rapidly evolving job market.

However, the research also highlighted challenges faced by TVET institutions in adopting IR 4.0 technologies. These challenges include limited financial resources, lack of technical expertise, resistance to change, and the need for continuous professional development for educators. Addressing these challenges will be crucial for ensuring a successful and sustainable adoption of IR 4.0 technologies in TVET institutions. Based on the findings, it is recommended that TVET institutions in Malaysia take a proactive approach to embrace IR 4.0 technologies. This can be achieved through collaborative efforts between the government, industry partners, and educational stakeholders. Investment in infrastructure, capacity building for educators, and fostering a culture of innovation and adaptability are vital for successful adoption.

Furthermore, policymakers and industry leaders should actively support TVET institutions in their adoption journey by providing financial incentives, sharing best practices, and creating partnerships for technology transfer and knowledge exchange. This collaborative approach will not only benefit TVET institutions but also contribute to the overall development and competitiveness of Malaysia's workforce in the era of IR 4.0. In conclusion, this comparative study provides valuable insights into the adoption of IR 4.0 technologies in TVET institutions in Malaysia. It emphasizes the importance of embracing technological advancements to enhance the quality of education and align it with industry demands. By leveraging the potential of IR 4.0 technologies, TVET institutions can effectively prepare students for the future workforce, contribute to economic growth, and foster innovation in the country.

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REFERENCES

Abd Karim, R., & Mustapha, R. (2022). TVET student's perception on digital mind map to stimulate learning of technical skills in Malaysia. *Journal of Technical Education and Training, 14*(1), 1–13. Retrieved from https://publisher.uthm.edu.my/ojs/index.php/JTET/article/view/10506

Abdullah, Z., Hoque, K.E., Ramlan, N.H., Shafee, S. (2019). Designing the structural model of TVET lecturers' professionalism and generic skills based on an empirical study in Malaysia. *SAGE Open, 9*, 3. 1–18. DOI: 10.1177/2158244019861456

Ana, A., Halim, F. B. A., Barliana, M. S., Ilhamdaniah, I., Mulyadi, Y., Salira, A. B., Muktiarni, M., Sari, A. R., & Muda, W. H. N. B. W. (2021). TVET teaching strategy during COVID-19: A comparative study of Indonesia and Malaysia. *Journal of Technical Education and Training, 13*(4), 28–41. Retrieved from https://penerbit.uthm.edu.my/ojs/index.php/JTET/article/view/10055

Cheok, C. K., & Ran, L. (2022). The role of Malaysian higher education in IR 4.0. *Journal of International and Comparative Education (JICE)*, 107-117. https://doi.org/10.14425/jice.2022.11.2.0913

Cheok, C. K., & Ran, L. (2023). The role of TVET in IR4.0 for Malaysia. In R. Rasiah, W. Y. Low, & N. Kamaruddin (Eds), *Digitalization and development ecosystem for promoting industrial revolution 4.0 technologies in Malaysia* (1st ed., pp.189-206). Routledge. https://doi.org/10.4324/9781003367093

Erboz G. (2017). How to define industry 4.0: Main pillars of industry 4.0. In: *International Scientific Conference Managerial Trends in the Development of Enterprises in Globalization*; p. 761–7.

Fadzil, N. F. M., Samad, P. N. S. N., Nawawi, A. F. M., Pandi, N. Z. M., & Puteh, F. (2022). Towards a high standard of excellence in Malaysia's higher education institutions: obstacles and enablers. *Journal of Administrative Science, 19*(2), 162-192.

Gen, T. Z., Kuen, D. C. Y., Rao, V. M., & Lima-de-Oliveira, R. (2022). Industry 4.0 technology adoption in Malaysian manufacturing: Strategies for enhancing competitiveness. *ASB Center of Technology, Strategy and Sustainability* 2022, 1-50.

Halik Bassah, N. S., & Mohd Noor, M. A. (2023). Employability skills needed for tvet graduates in Malaysia: Perspective of industry expert. *Online Journal for TVET Practitioners, 8*(1), 52–59. Retrieved from https://publisher.uthm.edu.my/ojs/index.php/oj-tp/article/view/12178

Hamid, H. B. A., Piahat, T. Bin, Haris, N. A. L. A., & Hassan, M. F. (2023). Shades of gray TVET in Malaysia: Issues and challenges. *International Journal of Academic Research in Business and Social Sciences, 13*(6), 2152–2167. http://dx.doi.org/10.6007/IJARBSS/v13-i6/16747

Hardianto, H., Hidayat, H., & Setiawan, M. N. A. (2025). Reward and commitment toward transformational leadership and teachers' job satisfaction. *Cakrawala Pendidikan: Jurnal Ilmiah Pendidikan, 44*(3), 673-684. DOI: https://doi.org/10.21831/cp.v44i3.83084

Hashim, S. (2024). Students' soft skills and their readiness towards industrial revolution in technical and vocational education and training (TVET): A Malaysian sight. *Online Journal for TVET Practitioners, 9*(1), 37-51. https://publisher.uthm.edu.my/ojs/index.php/oj-tp/article/view/14298

Iqbal, M. S., & Rahim, Z. A. (2021). Industry 4.0 and ethical challenges in developing countries: A case study on Pakistan. *International Congress of Advanced Technology and Engineering (ICOTEN)*, Taiz, Yemen, 1-8. DOI: 10.1109/ICOTEN52080.2021.9493437

Ismail, A. A., & Hassan, R. (2019). Technical competencies in digital technology towards industrial revolution 4.0. *Journal of Technical Education and Training, 11*(3). Retrieved from https://publisher.uthm.edu.my/ojs/index.php/JTET/article/view/3208

Kuntadi, I., A, A., Rohendi, D., Suryadi, D., Ab Halim, F., Ramdani Sari, A., Muktiarni, & Dwiyanti, V. (2022). Towards digital TVET: A comparative study on students' readiness in the industry digital demands in Indonesia and Malaysia. *Journal of Technical Education*

and Training, 14(3), 79–93. Retrieved from https://penerbit.uthm.edu.my/ojs/index.php/JTET/article/view/12898

Miftah, M. Z., Widiati, U., Wulyani, A. N., & Sharif, T. I. S. T. (2024). Preservice teachers' pedagogical competence and transformative learning in a dual online-offline teaching practicum. *Cakrawala Pendidikan: Jurnal Ilmiah Pendidikan, 43*(2), 381-397. DOI: https://doi.org/10.21831/cp.v43i2.54371

Musa, S., Suherman, A. M., Sujarwo, S., & Nurhayati, S. (2024). Continuous professional growth: A study of educators' commitment to lifelong learning. *Cakrawala Pendidikan: Jurnal Ilmiah Pendidikan, 43*(2), 502-512. DOI: https://doi.org/10.21831/cp.v43i2.66654

Ngatiman, S., Sulaiman, T., & Wong, K. Y. (2023). The challenges of implementing industrial revolution 4.0 elements in TVET. *Journal of Technical Education and Training, 15*(3), 169-181.

Nurjanah, I., & Ana, A. (2022). Work readiness of TVET graduates in the context of industry 4.0. *Advances in Social Science, Education and Humanities Research, Proceedings of the 4th International Conference on Innovation in Engineering and Vocational Education* (ICIEVE 2021), 651,34-38.

Poturak, M., Mekić, E., Hadžiahmetović, N. & Budur, T. (2020) Effectiveness of transformational leadership among different cultures. *International Journal of Social Sciences & Educational Studies, 7* (3). pp. 119-129. DOI: https://doi.org/10.23918/ijsses.v7i3p119

Rahim, M.I., & Shamsudin, S. (2019). Categorisation of video lecture designs in MOOC for technical and vocational education and training educators. *Journal of Technical Education and Training, 11*, 4. 11–17.

Soenarto, S., Sugito, S., Suyanta, S., Siswantoyo, S., & Marwanti, M. (2024). Vocational and senior high school professional teachers in industry 4.0. *Cakrawala Pendidikan: Jurnal Ilmiah Pendidikan, 43*(3), 655-665. DOI: https://doi.org/10.21831/cp.v39i3.32926

Sucipto, S., Arief, S., & Susanti, A. (2024). Center of excellence assistance model: Is it effective to improve vocational school management in Central Java? *Cakrawala Pendidikan: Jurnal Ilmiah Pendidikan, 43*(3), 619-629. DOI: https://doi.org/10.21831/cp.v43i3.74834

Yuntina, L., Sari E., & Karnati, N. (2025). The influence of transformational leadership, compensation on task performance mediated by organizational commitment. *Cakrawala Pendidikan: Jurnal Ilmiah Pendidikan, 44*(2), 250-261. DOI: https://doi.org/10.21831/cp.v44i2.72939

Zulnaidi, H., & Majid, M. Z. A. (2020). Readiness and understanding of technical vocational education and training (TVET) lecturers in the integration of industrial revolution 4.0. *International Journal of Innovation, Creativity and Change, 10*(10), 31-43