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Review

The Success of Technology Transfer in the Industry 4.0 Era: A Systematic Literature Review

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Abstract: Modern innovative models have the possibility of transferring research and development (R&D) output through technology transfer from scientific and research institutions or other enterprises. The complex process of technology transfer is significantly dependent on cooperation among academia, industry, and governments (I4.0) in response to the technological developments driven together through Industry 4.0. As a result, numerous technology transfer factors must be addressed for I4.0 to become a reality. However, the abundance of literature on I4.0 and associated technologies, the key ingredients, and insights for effectively executing I4.0 technology transfer are fairly limited. This study focuses on the success factors of technology transfer for I4.0. The framework is based on systematic literature to outline significant results and factors. Furthermore, this study summarizes, analysis, and criticizes the actual models and their influential variables for I4.0 technology transfer. One of the findings of this study is the significance of cooperation between technology recipients, agents, and inventors for I4.0 technology transfer. Another impressive finding is the significance of the ecosystem component in technology transfer. Combining I4.0 technologies and open innovation is a game-changer, enabling businesses to significantly save time and cost. This article will assist decision-makers in developing policies and strategies to improve the I4.0 technology transfer process. Furthermore, this involves identifying the kind of government assistance that will help accelerate the transition to I4.0 via technology transfer.

Keywords: technology transfer; industry 4.0; systematic literature review; barriers; models

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1. Introduction

Currently, the industry is driven by global competition. Because of constantly changing market demands, this necessitates quick manufacturing adaption. The market has fewer delivery times, more efficient and automated processes, better quality, and customized products. These drive companies towards the so-called fourth industrial revolution, known as Industry 4.0 (I4.0) [1,2]. To meet these requirements, radical technological advances are needed for current manufacturing processes. I4.0, which is characterized by new technologies fused with information and human ingenuity, can drive the next generation of smart production systems. The expected market share of I4.0 is more than 71.7 billion USD and is forecasted to exceed 150 billion USD [3].

I4.0 works on transforming industrial manufacturing using by digitalizing and exploiting new technologies. A flexible production system is required to enable the customization of products [4]. Thus, I4.0 is an interdisciplinary concept with a challenging endeavor [5,6]. This requires combining and integrating humans, technology, and organizations with established manufacturing practices across the entire production value chain. I4.0 refers to the future state of the industry in which economic and production flows have been digitized. This necessitates horizontal integration at every stage of the manufacturing process, including machine interaction [1,7]. Several technological pillars have emerged as enablers of I4.0

technologies, such as the Industrial Internet of Things, modeling and simulation, extended reality (XR), big data and analytics, artificial intelligence, cloud computing, block-chain, cybersecurity, industrial automation and robotics, and additive manufacturing [7–10].

For a successful transition toward I4.0, collaboration between industry and universities is vital. Approximately 2.94 billion USD in licensing revenue was generated in 2018 directly from technology transfer [11]. The Association of AUTM, which is the leading association in technology transfer, defines technology transfer as, "the process of transferring scientific findings (such as academic inventions) from one organization to another (i.e., industry) for further development and commercialization" [12].

In the context of Industry 4.0 technologies and their execution and integration, open innovation appears to be the most suitable system to promote a firm's activities for knowledge exploration and exploitation [13]. Modern innovative models give the possibility of transferring ready R&D solutions both from scientific and research institutions (vertical technology transfer) as well as from other enterprises (horizontal technology transfer) [14]. Technology transfer is a unique multidisciplinary research approach that can be tackled effectively from a variety of scholarly and methodological viewpoints [15]. Consequently, technology transfer's complexity must be addressed in research and practice. By examining it from different points of view, we might learn more about the problems we face. As an interdisciplinary approach, problems are not separated into disciplinary silos [16]. Interdisciplinary research is becoming increasingly important. This is due to a growing focus on research designed to handle major challenges and future trends across disciplines, such as the I4.0.

Successful collaboration between academia and industry can deliver several benefits [17]. Collaboration among organizations and universities can foster knowledge and technology transfer by sharing their intellectual property rights (IPRs), which leads to innovation. These technological and knowledge transfers assist firms in realizing their full potential, motivating them to develop new technology and improve existing ones, resulting in a productive corporate environment [18].

After surveying the published articles, few studies have focused on I4.0 technology transfer. This study seeks to contribute to closing the gap in the existing literature regarding technology transfer and I4.0 and provides useful information to both practitioners and scholars. First, it improves academic and managerial understanding of how technology transfer occurs in I4.0. The second contribution is identifying factors that can improve the effectiveness of technology transfer processes in I4.0. The remainder of the paper is organized as follows. Section 2 provides a systematic literature review (SLR) of the current state of research regarding technology transfer in I4.0. Section 3 describes the factors to success in implementing I4.0 technology transfer. Section 4 synthesizes the main findings of existing models and frameworks related to I4.0 technology transfer. Finally, in Section 5, we discuss our conclusions and future work.

2. Systematic Literature Review Method

The need for the SLR arises from the need to summarize all existing information about technology transfer for I4.0 in a thorough and unbiased manner. This may draw more general conclusions about some factors than are possible from individual studies or be undertaken as a prelude to further research. Thus, in this study, we use SLR to answer two main research questions and systematically identify, evaluate, and interpret all relevant research. Our two main research questions are (Q1) "What are the most important factors affecting the success of technology transfer in I4.0?"; (Q2) "Are there any existing models for technology transfer targeting I4.0?". The overall objective of this SLR is to respond to the aforementioned two research questions and clearly define a path for the development of a conceptual framework comprising recommendations for effective technology transfer in I4.0.

Search Methodology

This section discusses the methodology and strategy used in this study. Figure 1 describes the process of the search methodology that we followed in this SLR. First, we used search terms based on our research questions and identified an initial set of articles whose titles, abstracts, keywords, and subjects matched our terms. Then, we screened the results for relevance by reviewing the contents of the abstracts. If the results were deemed relevant, the full text was reviewed. Articles deemed irrelevant were excluded from the analysis.

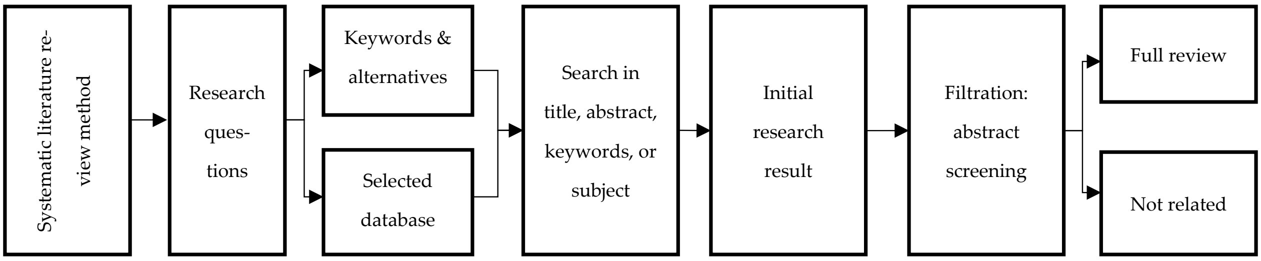

Figure 1. Systematic literature review method.

Based on our two main research questions, we created search terms to form search strings. The search was conducted at the Auburn University Library, which subscribes to over 250 databases. The databases include but are not limited to: Web of Science, IEEE Xplore, ScienceDirect, SpringerLink, and EBSCO databases, to name a few. First, we considered the results of the following search strings: (1) "Technology transfer" AND (2) "Industry 4.0".

Other keywords and possible combinations arose from the first group of publications and were used to improve the literature search. For instance, some scholars from various geographical regions use the term "smart manufacturing" interchangeably with "industry 4.0". Thus, we refined the search to ensure that we did not miss any relevant articles to identify as many primary papers as possible. Table 1 summarizes all the possible combinations of search strings that we used. Finally, all references found in articles relevant to the review's focus were included.

Table 1. Keywords and alternatives.

Keywords	Alternative Keywords
Industry 4.0	Fourth industrial revolution, advanced manufacturing, smart manufacturing
Technology Transfer	Innovation commercialization

The first research question includes the factors affecting the success of the I4.0 technology transfer. The second research question includes existing works related to models or frameworks of technology transfer for I4.0.

In the first search, we used two keywords, "Technology Transfer" and "Industry 4.0". Table 2 lists the search results of 903 peer-reviewed published articles. We then reviewed the field of the title, abstract, keywords, and subject and removed any irrelevant papers. To improve the precision of our results, we conducted an additional search using the following format ("Technology Transfer" OR "Innovation Commercialization") AND ("Industry 4.0" OR "Fourth industrial revolution" OR "Advanced manufacturing" OR "Smart Manufacturing"). The search returned 381 articles.

The strategy we followed for this systematic literature review is illustrated in Figure 2. Our goal was to split and categorize the content of the articles based on our two main research questions.

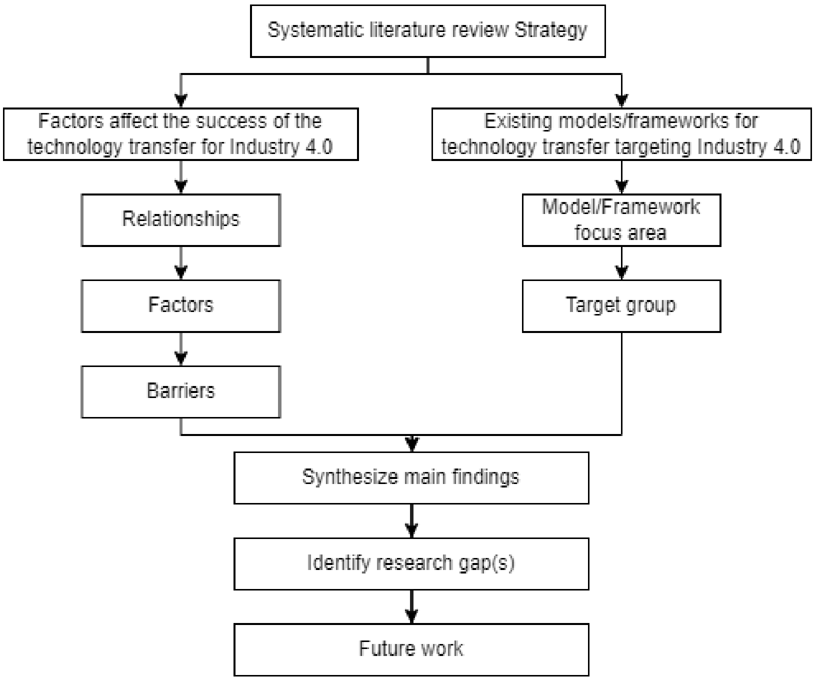

Figure 2. Literature review summary.

Table 2. Article search results.

	Identified Articles	Article Using Precise Search	Articles Post Abstract Review	Article Post Full Text Review
Total	903	381	72	40

For each article, we reviewed the abstract to identify whether it was relevant to the topic to be fully reviewed. Initially, we identified seventy-two relevant articles. However, only forty out of the seventy-two articles were relevant to our research questions and topic and fully reviewed. Figure 3 illustrates the article distribution based on the year of publication from 1985 to 2021. The articles were also categorized as unrelated/related articles. The number of articles thoroughly reviewed in a sequence relevant to the first research question alone, the second research question solely, and both research questions is 23, 12, and 5 articles, respectively.

It is worth noting that the number of articles related to this topic has been significantly increasing since 2016. Several initiatives have been launched worldwide to accelerate the transition to I4.0. The European Union published the "Industry 4.0-European Parliameny" report in 2016. According to the report, many small and medium-sized businesses (SMEs) are unprepared for the structural changes that Industry 4.0 will entail. One way to deal with this problem is to connect these SMEs to global value networks through a comprehensive program for transferring knowledge and technology [19]. Furthermore, the World Economic Forum's 2016 Annual Meeting, which was conducted under the theme "Mastering the Fourth Industrial Revolution", mentioned that technology's role went from supporting to being the main focus [20].

Figure 4 illustrates a word cloud produced by the abstracts of the 40 selected manuscripts. Word clouds are graphical representations of word frequency that emphasize words that occur frequently in a source text. The bigger the term in the figure, the more frequently it appeared in the abstracts The most commonly used terms are innovation, technology, development, manufacturing, industrial, industry 4, technology transfer, knowledge, new, and technological. This indicates that all the articles fell within our scope, which is the technology transfer of Industry 4.0. This involves technological development and knowledge transfer to the industrial sector.

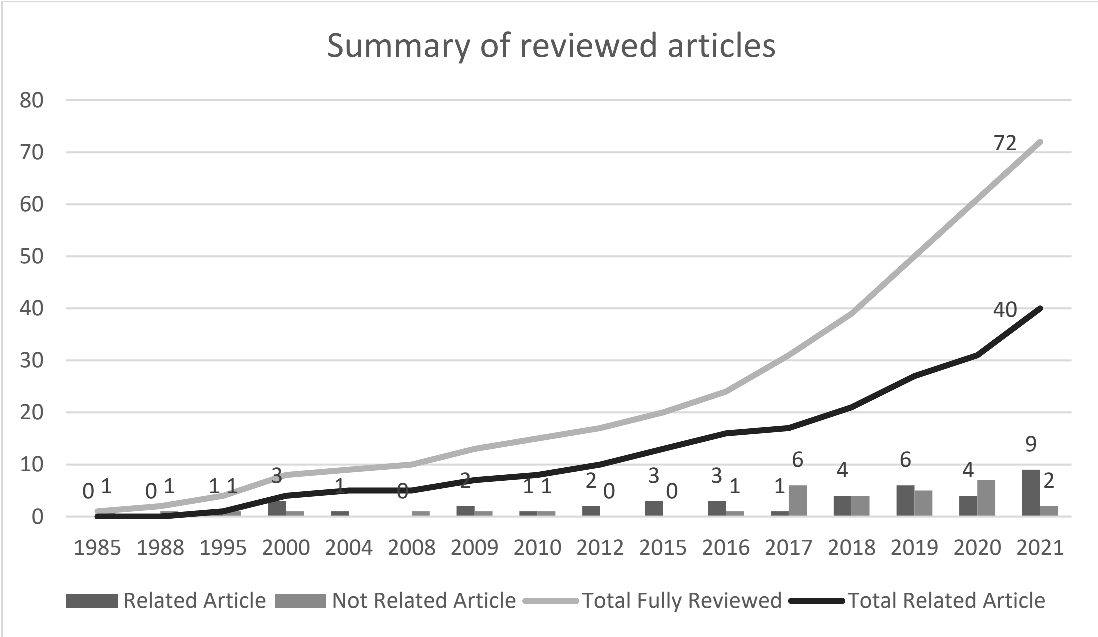

Figure 3. Summary of article reviewed.

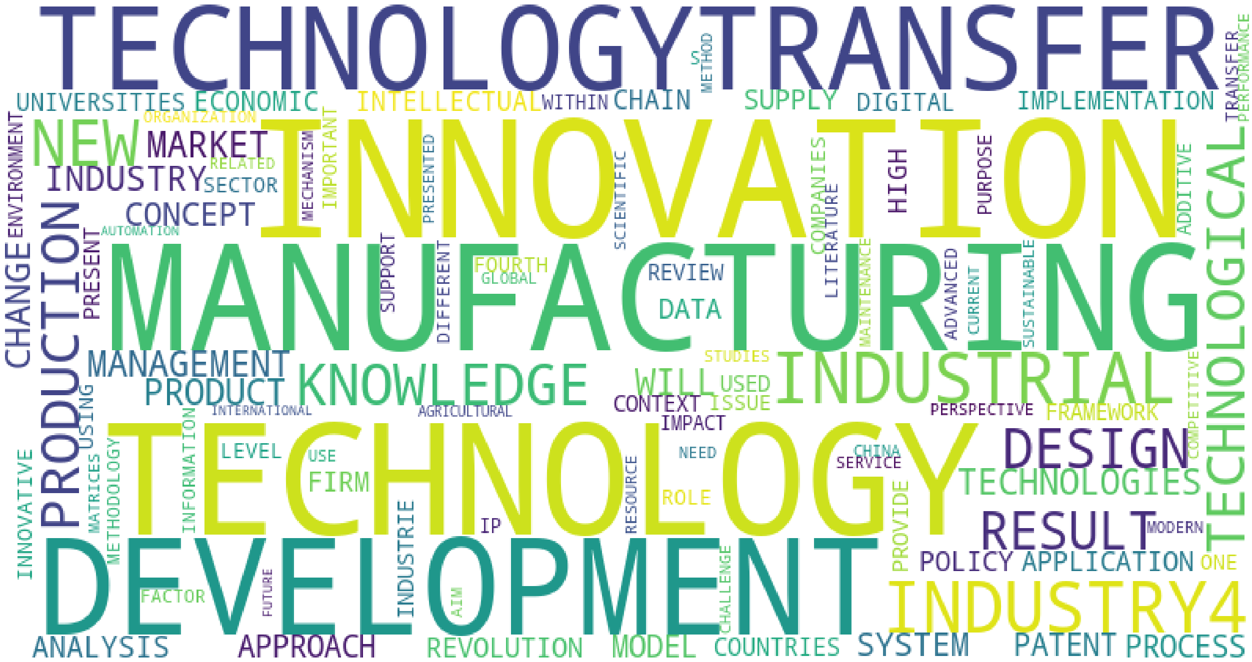

Figure 4. Word cloud produced by the selected abstracts.

3. Factors Affect the Success of the Technology Transfer for I4.0

Section 3 discusses in depth the essential aspects influencing the effectiveness of I4.0 technology transfer. These factors were classified into five categories: the I4.0 technology transfer relation, the excellence and innovation center, the manufacturing culture, human capital technical experience, and legal protection. Each factor is described in depth below.

3.1. Industry 4.0 Technology Transfer Relation

The focused path of technology transfer has changed over time, according to [21]. Before 1980, most technology transfer research concentrated on cross-national technology transfer. At the beginning of the 1980s, research shifted to domestic technology transfer. In the US, interdisciplinary research holds great promise for creativity and innovation, which has become the new focus of technology transfer.

The goal of technology transfer is to bring university outcomes into the market. The relationships among universities, industries, and the government are essential. These three partners must work effectively to establish a successful process. This relationship must be contextualized because of the significant changes in productive and organizational systems in I4.0. The technology transfer process in I4.0 will mobilize the entire country based on [22] research. [23] focus on technology-enhancing innovation in I4.0. Firms should be more adaptable and flexible in responding to changes in client demand and market needs. The flexible and adaptable process is aided by new technologies of I4.0 such as 3D printing. In this vein, technology transfer is seen as a way to give small businesses and countries with less advanced industries a fair chance.

Several countries have determined the importance of technology transfer in the transition to I4.0. The UK government invested in Advanced Manufacturing (AM) research and technology transfer £95.6 million. A total of £20.5 million was invested in industry-academia collaboration projects. From 2007 to 2016, the UK government thought that technology transfer would help close the gap between what people knew about AM technology in theory and what they actually knew about it in practice [24].

According to [25], the Taiwanese government plays a significant role in shaping the automation industry. The Taiwanese government established technology transfer infrastructure as part of a strategy for promoting automation, industry, infrastructure, and innovation growth. The government worked through tax incentives, favourable financing, technology development, education and training, product and equipment development, and technical assistance. The government mechanism began by transferring the core product/process technology. The transfer is from universities through licensing to automation engineering and service industries to build up supporting industries. The second is to support research and development (R&D) organizations. These organizations worked as technology providers, initiating technology transfer to receivers. The main factor that affects achieving the technology transfer strategy is government and industry commitment.

Switzerland also has a government effort to support the transition to I4.0 using technology transfer. According to [26], Switzerland is well-known for creating and applying innovative and high-value-added products. The federal government established a program targeted at technology transfer in the digitalization field. The production infrastructure must be modernized using the most advanced and efficient available technologies, focused on the I4.0 paradigm. In addition, for a more efficient approach, new and optimized manufacturing strategies were developed. As a result, Switzerland continues to rank among the top countries in this regard.

The Indonesian government realized the importance of I4.0 in agriculture (Agriculture 4.0 or Smart Agriculture). According to [2], they developed several applications to support the transition toward agriculture 4.0. The applications used I4.0 technologies. The application's targeted to monitor the cows' health, planting calendars, and plant cultivation. In addition, millennial farmers can access several sources of innovation through social media.

Another example of government involvement in I4.0 is the biotechnology sector in Ireland and Turkey. According to [27], market growth models use a variety of approaches. The governments of both countries contributed the most to enhancing the biotech sector's competitiveness. In Ireland, this was accomplished through a favorable tax regime. The profit tax is among the lowest in Europe. High-tech companies can take advantage of intellectual property (IP) tax depreciation, reimbursable R&D tax credits (25%), and patent box deductions (6.25%).

On the other hand, Turkey focuses more on the strategic level. Turkey's biotechnology strategy and action plan (2015–2018) have significantly promoted R&D. Turkey focuses on supporting innovative companies for I4.0. The R&D expenditures of commercial enterprises increased significantly between 2016 and 2019. Almost three-quarters of all spending in 2019 came from SMEs [27].

According to [28], technology transfer plays a pivotal role in the commercialization of new technology and skill development for students and university staff. Technology transfer creates a collaborative environment for university-industry relations. A proactive approach is required for technology transfer to involve researchers, promote technology, and encourage industrial companies to use I4.0 technologies. Technology transfer can occur through a license agreement. The license agreement lets the university keep the IP while giving the industrial party the right to develop and use the I4.0 technology under certain conditions.

On the contrary, commercialization opportunities increased if collaboration started between universities and industry as early as filing a patent application for technology development. Collaborative applications have a higher chance of success in marketing and selling technologies than technology transfer without collaboration with industry (after university technology development). The main reason is that technology development and patent applications raise various market values in several aspects of the patent, resulting in a greater possibility of commercializing the technology [29].

South Africa implemented a technology transfer road map. [24] mentioned that universities must cooperate more in research with AM industries. According to the results of his survey, technology transfer creates an enabling environment to incorporate students, academics, and industry partners into AM. The road map for technology transfer will improve and accelerate industry-university collaborative research. As a result, product quality and performance will improve. Collaboration between universities and industries can also lead to new business opportunities, such as the mass customization of AM products. South Africa has a lot of titanium (Ti), and technology transfer makes it possible to make medical implants and prosthetics made of Ti.

Ref. [28] stated that technology transfer also includes disseminating theoretical knowledge and hands-on experience of AM processes and technologies to broader users (students, academics, and industry professionals). When it comes to AM, more collaboration between universities and the business world can improve the quality and performance of AM products.

According to [30], the collaboration between universities and Turkey's industrial sector may produce new knowledge to solve performance problems. This research focused on how universities may help implement I4.0 technologies by developing various research and administrative policies. Digital transformations have gained momentum owing to increased digital innovations. New knowledge creation and technology transfer approaches have become critical components of innovation ecosystems.

Universities establish different units and organizations to facilitate technology transfer, such as technology transfer offices (TTOs), science parks, business incubators, and venture funds. These facilities aim to commercialize research output while dealing with challenges. Universities have the choice to commercialize technology through start-ups. Another way to do this is by developing and commercializing digital infrastructures, which are part of I4.0 technologies. Innovators need to establish multistakeholder partnerships across industries [30]. The role of universities in economic growth has altered dramatically under the I4.0 settings. Universities are considered the main engine of economic development and the critical actor in the knowledge economy. Universities have become centers for developing new high-tech enterprises [31].

India works on the collaboration between industry and higher education institutes (HEIs). [32] mentioned that there is evidence to advocate how the role of HEIs has changed. In addition, HEIs participation in commercial activities has grown through technology transfer and start-ups. The focus of technology transfer is the commercialization of academic research results through the licensing and leasing of technology. There are several types of relationships between HEIs and industries for knowledge supply:

(1) Industry may look for universities as problem-solution providers.
(2) Start collaborating with the industry by submitting a research proposal from the HEIs to the industry.

(3) Industry can outsource a third party to search for the best research centers in HEIs; and
(4) The industry can receive proposals by working with a third party. The third party is the link between local R&D institutes.

Society 5.0 is a technology-driven, human-centered society that integrates cyber-physical systems and employs modern technologies to improve daily life [9]. Past and contemporary queuing systems, such as those found in supermarkets, are being replaced by Society 5.0. The private sector also has a major role in accelerating technology transfer in Society 5.0 based on [2].

3.2. Excellence and Innovation Centers

Technology transfer is vital to implementing I4.0, especially for developing countries. According to [33], developing countries are not established with the characteristics of I4.0. An ongoing and evolutionary process for technology transfer is needed to adopt new technologies. The resource of technology can be from specialized suppliers or their main offices. Developed countries produce knowledge and technology through contracting research centers, internal improvements, and R&D investments.

On the other hand, innovation has also played a key role in technology transfer in the new era of I4.0. [29] talk about how closed innovation strategies differ from the global open innovation trend, which is getting even stronger with I4.0. On the contrary, patent commercialization empowered by open innovation increases the chance of commercialization through technology transfer. The empowerment comes from the technical and economic values of the patents.

The role of the excellence centers in I4.0 discussed by [34] shows that most SMEs do not have R&D units to support their research activities. Significant efforts are being made to upgrade students' qualifications through specialization and enhancement of local universities and excellence centers. They are also working with local businesses to determine the grads' most significant problems. Two critical factors considered are: (a) The level of excellence of technology centers and universities to have a solid foundation of both primary and applied research, and (b) an appropriate level of transfer between research outcomes and industry to eliminate the interference between the production activity at the companies' and to decrease transfer cost and time.

This concept, supported by [23], focused on small firms and less industrially advanced countries. The upgraded innovation model focuses on technology with an emphasis on technology transfer. Technology acquisition allows these organizations to enter the technological frontier and operate in I4.0. I4.0 technologies, on the other hand, broaden the search space, formalizing the distributed network concept and expanding on a previous open Innovation model.

Based on [35], entrepreneurial technology in the field of I4.0 can be delivered and supported by technology transfer. Technology transfer has a significant role in the emerging technological paradigm, where strategies to address disruptions of I4.0 require coordinated activities. It should be supported by innovation spaces that offer an early access point to technological innovation. It can come from academic research and help start-up businesses grow faster by providing a variety of resources and services.

Another example of success for better technology transfer achievements is the virtual reality laboratory "Astana Innovations" [36]. The objective is to achieve a broad and more effective use of virtual reality technologies following the latest trends. It is crucial to create appropriate conditions and promote cross-sectoral innovation culture in the private and public sectors. Based on [27], Ireland established a R&D support program with a budget of 2 million euros. The Medical and Engineering Technologies Centre was set up to encourage technology transfer and the growth of new businesses. The growth is supported by simplified drug certification procedures, a high-quality business environment, a favorable tax regime, the absence of a language barrier, and the ease of access to the European market.

Innovation centers played a key role in transferring technology to farmers in the era of Agriculture 4.0; according to [2], Innovation centers aim to accelerate technology transfers to farmers. The main pillars are technology, studies to develop site-specific technology, and counselling to apply technology in the field. The location of laboratories is also essential in terms of accelerating technology transfer. Having several locations of innovation centers near farmers could help them understand, adapt, and integrate I4.0 technology.

3.3. Technology Transfer in the 4.0 Industrial Revolution, and Open Innovation

One of the primary drivers of open innovation and subsequent technology transfer is an innovation environment that focuses on dynamics and co-evolution [37]. Open innovation allows businesses to establish a structured innovation ecosystem that leverages external partner networks while focusing on developing core internal competencies [13]. Although the phrase "open innovation" was coined in the previous decade, the concept is not new. Open innovation is partly reflected in terms such as open source, user co-creation, user-centered innovation, and distributed innovation [13]. Dynamic open innovation is based on interactions that traverse company boundaries. Some ideas and knowledge originate from outside the company, while others are licensed to outsiders for commercialization [38].

Firms can capitalize on opportunities beyond their boundaries and limited internal resources to enhance the innovation rate in high-velocity marketplaces. Firms must have access to the resources of other organizations in addition to their own. Firms seek new ideas outside of their organizations and develop relationships with other enterprises that depend on each other [23,39–41].

I4.0 stimulates open connections between technology and the market through open innovation [42]. I4.0 emphasized the significance for government agencies, research institutions, consultancy businesses, non-profit organizations, and entrepreneurs to form collaborative networks [43]. The most effective methods for I4.0 are dynamic open innovation business models and an open innovation culture. It is extremely beneficial to businesses in this technological era. Consequently, company collaboration may spur creativity and innovation, as well as develop novel ideas and concepts [44].

Combining I4.0 technology with open innovation is a game changer, allowing firms to drastically reduce costs and time [45]. Companies often adopt an open-source approach to building the networks associated with their products rather than a closed-source strategy [46]. The strength of local and regional research and innovation (R&I) processes regularly influences the innovative capability of SMEs. Cooperation and networking at the business and organizational levels are crucial for the growth and knowledge transfer at the core of R&I for SMEs [47]. Companies with a high level of open innovation, such as in the robotics sector, have a better chance of commercializing their patents via technology transfer [29].

Technology transfer has been a foundation of open innovation as the economic and digital industrial eras have accelerated Open innovation improves the innovative performance of digital innovation [48–50]. By transferring knowledge, skills, technologies, and technological transfers, this type of innovation can significantly improve foreign-domestic connections and contribute to development [51]. This will boost the firm's ability to innovate and adopt new technologies [47] Open innovation also makes it simpler and less expensive for small and medium-sized businesses (SMEs) to use resources from outside their organization. This decreases risk and increases the use of external knowledge sources [23,51].

Indeed, the era of Industry 4.0 technologies prioritizes open innovation since incorporating external knowledge is more vital than ever in driving organizational innovation [52]. Ninety-four percent of the world's major innovators perform part of their research and development (R&D) efforts abroad [53]. This indicates that companies should not depend entirely on their own ideas and in-house research but should also invite other sources to contribute. This is the outside-in branch of open innovation, sometimes called inbound open innovation [54].

3.4. Manufacturing Culture

The industry represents the transfer recipient in the technology transfer process. Manufacturing culture is one factor that affects the success of technology transfer. According to [55], manufacturing culture consists of firm behaviour, routines, norms, and attitudes that shape it. Culture works as the link bundled with norms, traditions, and social conventions as part of informal or 'soft' institutions [56]. Manufacturing culture has a significant impact when we focus on technological changes, such as the transmission toward I4.0 [55]. This required an alignment between several business entities, industries, and technology strategies [57].

Manufacturing culture must be considered a key factor for a successful technology shift [55]. Based on research done by [56], culture and formal institutions (rules, laws, and regulations) produced specific institutional settings. Culture is highlighted as the key element that leads to spatial variations in economic activities and performance.

Company-wide acceptability can be obtained only if senior management is explicitly committed to implementing I4.0. It is required to make faster and more effective decisions. Collaboration between departments and groups, even beyond business borders, is essential for a successful Industry 4.0. A clear strategy and suitably trained employees can increase employee acceptance and decrease employee uncertainty about the unknown as well as the unfamiliar use of new media [58].

3.5. Human Capital Technical Experience

I4.0 technology transfer is a complex, interdisciplinary environment. The staff must have the knowledge and skills to deal with its complexity. The experience of the TTO staff is essential. According to [59], these technologies can be (1) highly implicit or (2) the commercial application is difficult and complex, or both. This concept was supported by [60]. She stated that special emphasis should be placed on people's involvement in technology transfer and selection. The staff includes people working on the TTO and the technology recipient (industry).

The lack of skilled staff and the necessary know-how to implement I4.0 was a crucial success factor; it counted as a vital barrier [58,61]. The workforce was cited as a barrier to the adoption of nearly all smart manufacturing [62], which arises with the change in the manufacturing scenario and the new technologies [63].

3.6. Legal Protection

However, with the deployment of I4.0, the focus was on IP protection for intangibles. Some protection methods include virtual system setup, data ownership, management, storage, processing algorithms, and brand recognition. Therefore, this protection must be broadened. The deployment of I4.0 puts the existing knowledge and application of IP protection and commercialization methods to the test [64].

The creation of new techniques requires a better suited to fast-changing, highly linked corporate networks. Businesses must carefully consider ways to protect their IP. The consequences of installing interconnected communications and using application programming interfaces are more collaborative inter-company models. I4.0 outcome is a novel environment that is highly collaborative and interoperable. China recognizes that with the I4.0 technologies, countries that do not care about protecting these technologies will be less competitive and place themselves out of the world's stage for exporting end products [64].

Ref. [18] emphasized the need to protect I4.0 products and techniques. The protection comprises a pressing need to preserve innovative products and procedures from being easily imitated. It also erodes an organization's competitive advantage. As a result, IPRs may preserve an invention's originality, which can subsequently be marketed to promote knowledge and technology transfer for public purposes. However, a national technology transfer framework has not yet been developed. Universities and public research organizations have been recognized as having significantly contributed to technology transfer policies in numerous nations. They are both actively engaging in capacity-building and allowing the commercial application of IPs.

4. Industry 4.0 Technology Transfer Models and Conceptual Framework

4.1. Industry 4.0 Technology Transfer Models

Several institutions have successfully used a technology transfer approach for commercial profits. One of the goals of practical research on new technology innovation is to commercialize inventions. Universities have witnessed an increase in the identification of possibilities and their capacity to take inventions by boosting TTOs and innovation spaces [35].

Ref. [65] examined the role of open innovation, technological crowding, and technological diversity in the relationship between competitive behaviors and firm performance. The model used in the panel set evaluates the role of the independent, moderating, and control variables on firm performance. The results showed that the inbound open innovation mitigates the negative effects of vulnerability on firm performance and that external innovation through technology transfer the positive effects of competitive initiatives on firm performance. External outsourcing of technology is better suited for commercializing a technology owned by the company or incorporating it into in-house applications [65].

On the other hand, [66] presented a conceptual model of the technology delivery system (TDS). TDS offers an essential framework for collecting information, organizing it, and concluding results regarding the implications that can be used for decisions regarding emerging technology supply chains. The TDS is a core part of the "Forecasting Innovation Pathways" (FIP) approach. FIP combines a range of future-oriented technology analysis tools to assist decision-makers in discovering opportunities (and threats) to achieve successful innovation while recognizing the inherent uncertainties of innovation pathways.

In this research, [66] built a TDS model for big data and analytics to emphasize technology mining as an approach to provide insights into TDSs. The model focuses on the actors and activities of institutions involved in producing and pushing to develop a new technology to emerge as a potential option for markets and society. It involved efforts to collect data, construct theories, and develop new methods to analyze technological development. A common need within these approaches is to identify the key actors and stakeholders and recognize how these elements fit together and operate as a system. The TDS model is useful in its own right. It is also connected with other frameworks to contribute to a robust analysis of the broader socio-technical system contributing to socio-economic impacts.

Ref. [67] conducted an analytic hierarchy approach and correlation analysis. This approach highlights the most important factors in technology transfer adoption (TTA). The factors studied were TTO capabilities, technological validity, and business feasibility. The most important factors are related to business feasibility in (1) commercialization related to the profitability of the technology, and (2) marketability, including the market environment and market competitiveness.

Technical characteristics are also crucial from the technological application perspective. Their conclusion led to increased profitability through technology purchases, which is the worst criterion for a company's CEO to adopt the technology. The intangible TTA factors and dimension measurements must be used to enhance the full potential to commercialize exceptional technology with low cost and high efficiency [67].

Ref. [68] emphasized technology transmission during the current digital revolution. His research reveals that technology transfer provides new characteristics and methods for disseminating technical innovation, posing new legal theory and practice issues. Legal instruments must be adapted to address these challenges. Modern technology transfer methods include the purchase of technology, license agreement, patent pool, right to integrated technology in the legal system, direct investments, establishment of a joint venture, know-how transfer, commercial activity, and R&D agreements. Furthermore, the study showed that developing, distributing, and applying sophisticated technologies is challenging without legal IP transfer mechanisms. A vital aspect of sustainable development during the digital technology revolution is the incentive to produce and transmit new technologies.

According to [64], new technologies establish a new ecosystem with new practices and tactics to secure and commercialize IP. Interdisciplinary collaboration is accessible through modern technologies. These collaborations could occur across the entire supply chain. Devices collaborating with various businesses will provide additional functionality, data analytics, or both to companies and customers.

This concept involves a multi-faceted and versatile IP strategy. The authors [64] developed an IP strategy based on the company strategy and business model. Multiple businesses are involved within the I4.0 value chain. It is necessary to maintain control over the business value offers. It also maintains technological ownership, reputation, brand, and joint technological innovation. Meanwhile, preserve options for a fast route to customization, configuration, and the market.

Ref. [2] discussed a technology transfer methodology that was employed for agriculture 4.0. I4.0 may be used in a variety of industries, not just those associated with manufacturing. Where the change to agricultural digitization is concerned, agriculture may be part of it. They define agricultural digitization as developing, adopting, and enhancing digital technology in the agricultural industry. Knowledge-transfer technology has advanced significantly in recent years. Applications range from autonomous supply chain management to data and information processing as a foundation for agricultural management decision-making. The paradigm offered a partnership between the government, technology transfer (both public and commercial), and farmers, who represent technology recipients.

4.2. The Conceptual Framework for Industry 4.0 Technology Transfer

After finishing the I4.0 for technology transfer review. The main factors identified in this review are listed in Table 3. This table presents the factors, main remarks, and references.

Table 3. Technology Transfer for I4.0 models key factors.

Key Factors	Remarks	References
Government support (financial)	National research funding.	[24,26,66]
Government support (strategic)	National promotion policies.	[2,25,27,66]
Government support (Incentives)	Tax incentives	[27,66]
Type of collaboration	Level of collaboration. Private or public. Internal or external.	[2,9,24,28–30,32]
Source of technology	Type of technology source: Excellence innovation center, research center, or university. Connection with other frameworks.	[23,27,29–31,33–36]
Manufacturing culture	Manufacturing culture includes: Firm behaviour, routines, norms, and attitudes	[55,56]
Human capital technical experience	The staff's experience and knowledge related to technology in the technology agent and recipient.	[59–61,67]
Market factors	Productivity, profitability, marketing (this related to the effectiveness measure)	[67]
working capital funds	Fund to support the transition for the technology recipient.	[67]
Incentive mechanism	The incentive mechanism is essential for creating and transfer of new technology.	[68]
Modern legal tools	Modern legal tools support the technology transfer process to match the new technology related to the I4.0.	[18,64,68]
Flexible IP strategy	Implement a multi-faceted and adaptable IP strategy. The goal is to ensure they have control over the business value offer, the brand, the ownership of the technology, their reputation, and the joint development of new technologies. Preserve options for a fast route to market, configuration, and customization in light of the involvement of multiple businesses within the I4.0 value chain.	[64]

Based on our review, the conceptual framework was developed. The framework is based on the available contingent effectiveness model by [21] to match our finding for the I4.0 technology transfer. The framework summarized the literature on what work was done related to factors that enhance the success of the technology transfer process, elaborated in Figure 5. The contingent effectiveness model was created by [21] and revised by [69]. The model is wide enough to cover the technology transfer process. There are two main parts of this model; (1) our major concern is the factors that influence the success of technology transfer, and (2) the measure of success (effectiveness) of technology transfer.

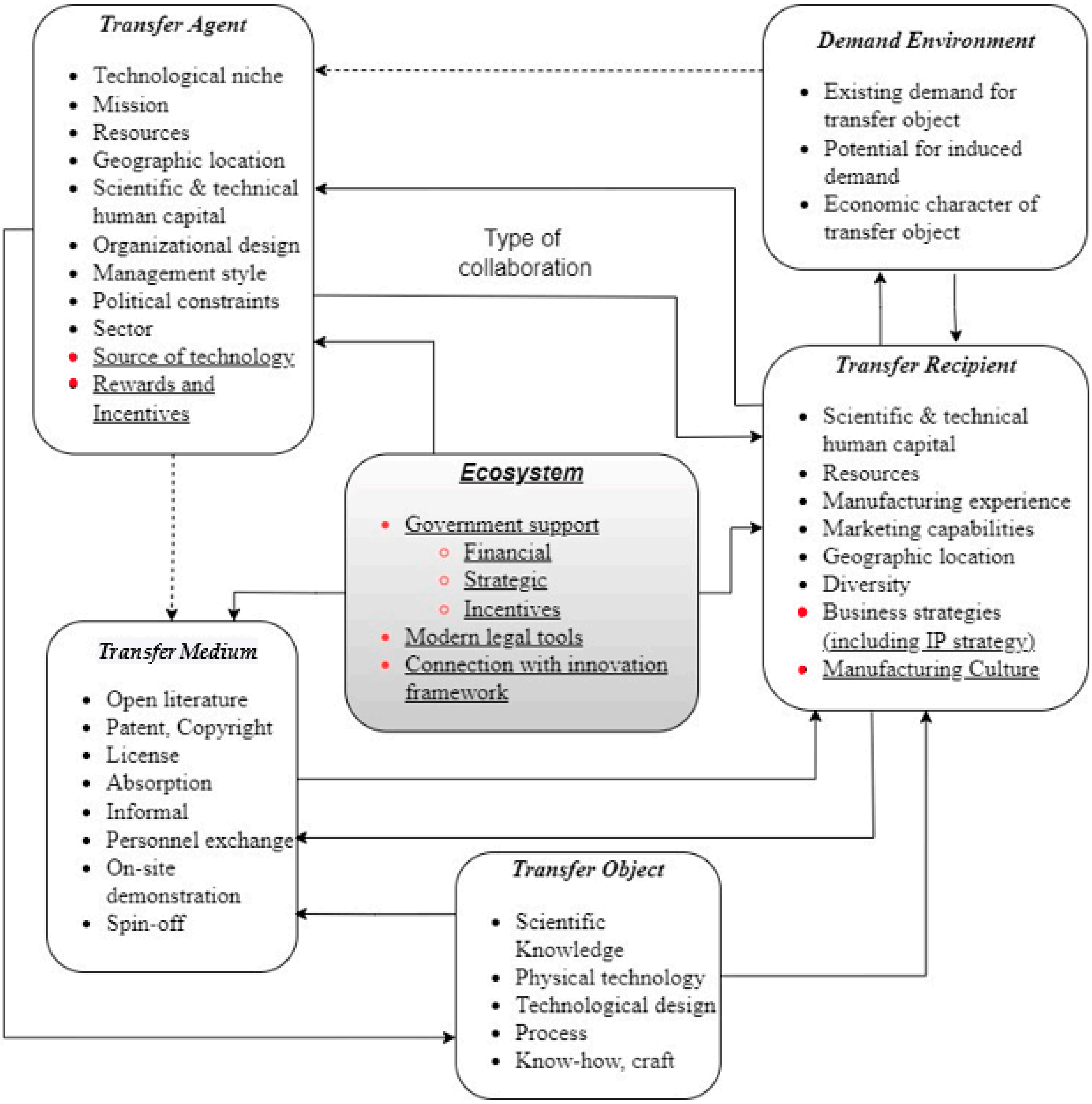

Figure 5. A conceptual framework of technology transfer for I4.0.

Six dimensions are used to categorize factors: technology agent, technology media, technology object, technology recipient, demand environment, and ecosystem. The arrows in the model indicate relations among the dimensions (dash lines indicate weaker links). These dimensions are:

1. The transfer agent is an entity capable of generating and transferring technology. It functioned as a transmitter. The agent can be the TTO, an institution, or an organiza-

tion working on transferring technology to another entity. It includes technological niche, mission, resources, graphic location, scientific & technical human capital, organizational design, management style, political constraints, and sector [21,69,70].

The key elements of I4.0 technology transfer are: (1) source of technology and (2) rewards and incentives. Incentives are one of the most essential aspects that encourage people to work harder [71,72]. According to this review, the type of organization that produces the technology can affect the success of the transition for I4.0 technologies and can increase the potential of marketing the technology object, especially for SMEs (transfer recipients). Another critical factor is the incentive mechanisms. These incentives will encourage researchers to commercialize their innovations. The remaining factors are covered by scientific and technical human capital, which is the technical experience of the TTO staff.

The transfer agent interacts with the rest of the five dimensions. The interaction between the transfer agent and recipient is through collaboration. The earlier the collaboration starts, the better the chance of commercialization. In addition, the recipient and inventor's participation level in technology development can enhance success.

2. Transfer recipient: To whom technology is transferred. It is represented by the organization or institution that receives the transfer object. An industrial company or spinoff can be the recipient. The factors are related to scientific & technical human capital, resources, manufacturing experience, marketing capabilities, graphic location, diversity, and business strategies.

This review concludes that a key factor in a successful I4.0 technology transfer is industrial culture. Another aspect is the flexible IP strategy; it is necessary to implement a flexible and multi-faceted IP strategy to ensure control over the business value offer and other aspects. This factor can be covered by the business strategy. The transfer recipient reacts with the all dimensions.

3. Transfer medium defines the method to transfer technology. For example, a medium could be a license agreement. It can also be formal or informal. The main points cover open literature, patent, copyright, license, absorption, informal, and personal exchange [21,69,70].
4. A transfer object is the content and format of what is transferred from one entity to another. It can be scientific knowledge, physical technology, technological design, process, know-how, and craft [21,69,70].
5. Demand environment refers to the factors that influence transfer, for example, factors of nonmarket and market about the need for the transferred object. The main is existing demand for the transfer object, the potential for induced demand, and the economic character of the transfer object [21,69,70].
6. Ecosystem: This is an additional dimension that coveres elements of the ecosystem for I4.0 technology transfer. The primary factors that influence and improve technology transfer performance for I4.0 are:
    - Government support: This support might be in the form of financial, strategic, incentive, or a combination of these. According to [62], government programs and funding can play a significant role in lowering organizational adoption barriers, and one of the recommendations is that the U.S. government should develop a smart manufacturing adoption plan.
    - Modern legal tools: The legal tools need to match the new technologies related to I4.0 and support the technology transfer process.
    - Connection with the innovation framework: this will facilitate the adoption of I4.0 technology. Lack of awareness was one of the barriers to the adaptation of big data and artificial intelligence [62]. To overcome adoption challenges, innovation will assist in raising awareness of I4.0 technologies.
    - This dimension interacts with the transfer agent, recipient, and media.

5. Conclusions

The technology transfer for I4.0 is reviewed in depth in this manuscript. The purpose of this article is to assist in the identification of success elements in I4.0 technology transfer, which will aid in industry, infrastructure, and innovation growth. The SLR approach was applied in this study. A conceptual framework for the I4.0 technology transfer, including the ecosystem factors, was established. The primary findings for these factors are as follows:

- The government plays a significant role in encouraging the industry to strive towards I4.0 through technology transfer. The government can facilitate the transition toward I4.0 via technology transfer by enacting legislation, financing support, and offering incentives for this transition.
- A more collaborative environment must be established to enhance the effectiveness of the technology transfer process. The type and level of collaboration between technology recipients, technology agents, and inventors are required for I4.0 technology transfer. Collaborations that begin before submitting a patent application are more likely to succeed in marketing and selling inventions.
- Under I4.0, the role of universities in economic growth has shifted dramatically. Universities' duties extend beyond the commercialization of inventions to include the transfer of knowledge and skills. Universities are considered the main engine of economic development.
- The source of this technology is critical. Excellence innovation centers and laboratories support the industry (especially SMEs) in transitioning to I4.0.
- Dynamic open innovation and open innovation culture are the most effective ways to address I4.0. Technology commercialization, aided by open innovation, enhances the likelihood of commercialization via technology transfer.
- The I4.0 technology transfer environment is complex and multidisciplinary. The skills and expertise of related employees in TTO directly impact the technology transfer process of I4.0 technologies. The more availability of the skills and knowledge, the better the performance. Furthermore, the TTO requires a financial incentive structure to motivate inventors to participate and follow up on innovation commercialization. Incentives are one of the essential aspects in motivating individuals to perform harder.
- Manufacturing culture influences the success of I4.0 technology transfer when we focus on technological advancements such as the transition to I4.0. It is vital to make quicker and more effective choices, to collaborate between departments and groups, to have a clear strategy, and to have appropriately trained staff. Consequently, employee adoption of the technology will increase, as will employee uncertainty.
- The legal tools available to protect the I4.0 technologies are inadequate. A modern legal tool is required to cover the intangibles technology with IP. These tools should have better suited for rapidly evolving technologies.
- New technologies establish a new ecosystem with new practices and tactics for securing and commercializing IP. This will facilitate the adoption of I4.0 technology.

These findings provide a roadmap for decision-makers in governments, industries, and universities, including TTOs, to establish policies and programs that will promote technology transfer for I4.0 across the board. Technology transfer is critical for assisting in the transition toward I4.0. This conclusion is supported by references from numerous nations and may be applied to various industries, including agriculture. The critical flaw is that no model focuses on predicting the success of the I4.0 technology transfer. More research is required in the future, particularly to determine how each component influences technology transfer success and how they all interact.

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