ISSN 2237-8960 (Online)

RESEARCH PAPER

Technology transfer model oriented to industry 4.0: proposal and application in the food industry

Vander Luiz da Silva[1], João Luiz Kovaleski[2], Regina Negri Pagani[1] Myller Augusto Santos Gomes[1]

[1]Federal University of Technology (UTPR), Curitiba, Paraná, Brazil.
[2]University of Grenoble, Genoble, France.

How to cite: Silva, V. L., Kovaleski, J. L., Pagani, R. N. and Gomes, M. A. S. (2024), "Technology transfer model oriented to industry 4.0: proposal and application in the food industry", *Brazilian Journal of Operations and Production Management*, Vol. 21, No. 2, e20241777. https://doi.org/10.14488/BJOPM.1777.2024

ABSTRACT

Goal: This study aimed to propose a Technology Transfer Model oriented to Industry 4.0 (TTM4.0).

Design/methodology/approach. Initially, a systematic literature review was conducted to identify existing gaps in **Technology Transfer models:** Another focus of the review was to determine the requirements for technological implementations in Industry 4.0. Thus, a specific TT model was built. Then, the model was validated through case studies in Brazilian companies (slaughterhouses). The methods employed to measure data and support decisions in the context of TT4.0 were AHP, Likert scale, and Fuzzy-TOPSIS.

Results: Focusing on similar results between Companies A and B, thinking about adopting Industry 4.0, the central strategic needs were product quality, reducing human error, and reducing waste. Among the main factors inhibiting the maximum interest and availability of Industry 4.0 for both companies were high investment, lack of knowledge (procedures or in general), and uncertainties in results. Results indicate Big Data Analytics and artificial intelligence technologies.

Originality/value: The Poultry Industry strengthens the economy and significantly impacts the country's socioeconomic indices. Despite this, the sector has a low level of technological maturity compared to others. Regarding the TTM4.0, while other models start by recognizing opportunities and then select technologies in the market, this model prioritizes phases of organizational self-knowledge for decision-making support. A primary difference between a maturity model and a Technology Transfer model is in their scope, with the latter being broader. It encompasses technology definition, implementation, and management, rather than being limited to diagnosis.

Keywords: Technology Transfer; Smart Factory; Industry 4.0; Broiler chain.

1 INTRODUCTION

Industrial revolutions were the main drivers of changes imposed on the economy and organization of human labor. Migrating from his routine and smooth work of the artisan system, man became a factory worker (Elias, 2006). Since then, new resource extraction and processing methods have been developed, and human labor has begun to receive support from machines (Elias, 2006; Lima, Oliveira Neto, 2017).

In a globalized scenario, constant research and innovations are created to contribute to advances in a particular subject or area. In 2011, a concept called Industry 4.0 was defined at a technology fair in Germany (Lee, Kao, Yang, 2014). Since then, this concept has been the focus of several discussions and research in the scientific community and organizations. Industry 4.0 is presented as the Fourth Industrial Revolution since it sets new procedures and technologies, mainly in Information and Communication Technology (ICT), and imposes changes in the production and management of organizations to generate competitive results in the national and international markets.

Financial support: None.
Conflict of interest: The authors have no conflict of interest to declare.
Corresponding author: luizvnder@gmail.com
Received: 19 February 2023.
Accepted: 27 March 2024.
Editor: Osvaldo Luiz Gonsalves Quelhas.

Industry 4.0 is a concept that encompasses a variety of principles, technologies, and procedures to make production processes more autonomous, dynamic (Tortorella, Fettermann, 2017), flexible, and precise. In Industry 4.0, the process, in addition to being automated, also encompasses digitization operations (human-machine, machine, and machine integrations to the network) (Silva, Kovaleski, Pagani, 2021). This concept aims to make processes intelligent so that machines communicate more easily for information exchange, fault control (Jasiulewicz-Kaczmarek, Saniuk, and Nowicki, 2017), ability to respond to fluctuations in demands for quality products, and operational efficiency (Papadopoulos et al., 2022).

Although Industry 4.0 is a broad concept, it is part of the Smart Manufacturing concept. Smart Manufacturing constantly improves and may include other notions as scientific discoveries emerge.

The technologies that make up the Industry 4.0 concept are solutions in automation, 3D printing, simulation, artificial intelligence, Internet of Things (IoT), Cyber-Physical Systems (CPSs), Big Data Analytics, cloud computing, cyber-security, Augmented Reality, and Virtual Reality (Türkes et al., 2019, Papadopoulos et al., 2022). Because Industry 4.0 has specific characteristics, including expanding Internet functionality and bringing artificial intelligence into organizational environments, companies are interested in understanding it, given its projected advantages (Ortt et al. 2020).

If interested, companies need to invest in the transition to Industry 4.0, which will depend on the successful implementation of technologies (Sigov et al., 2022), but this practice is complex (Facchini et al., 2022). Industry 4.0 is a challenge for companies, as a series of technical issues must be addressed (Dieste, Sauer, Orzes, 2022).

This study presents the following research problem: In theoretical and practical contexts, how can Technology Transfer (TT) help companies towards Industry 4.0? The Technology Transfer (TT) field studies and approaches the absorption and dissemination of technologies (Seaton, Cordey-Hayes, 1993) and the management of elements, such as technologies and technical procedures, among others.

Regarding delimitation and scope of work when linking TT to Industry 4.0, a TT model will be proposed from the perspective of the transferee (the one who absorbs the technology). The model has a broad focus, considering its applicability to different company sectors.

The Poultry Industry presents itself as a practical study scenario, demonstrating the results of applying the Technology Transfer Model of Industry 4.0 (TTM4.0). In this case, the two participating companies operate in the broiler production chain (slaughterhouses) in Brazil. Appendix 1 presents the particularities of the model in relation to other existing TT models.

Some particularities reinforce the originality of this study, including Technology Transfer in Industry 4.0, noting, within the researched universe, the lack of studies on TT operations and procedures, such as the effective implementation of Industry 4.0 in companies. These studies do not focus on TT processes, either theoretically or empirically, whose approaches are limited to largely qualitative, superficial implementations.

2 METHODOLOGY

2.1 Procedures adopted to propose the TT model

The systematic literature review was prepared following the Methodi Ordinatio protocols created by Pagani, Kovaleski, and Resende (2015). The Methodi Ordionatio, unlike other methods, is a multicriteria decision method that allows researchers to reflect on three metrics: Impact Factor (IF), number of citations, and year of publication. The reflection on the metrics generates an index called InOrdinatio (which indicates the scientific relevance of the article). From this index, it is possible to rank papers. The Methodi Ordinatio consists of nine steps, presented as follows.

Steps 1 and 2. Establish the intent of the study and conduct a preliminary search in databases. These steps are essential to bring the researcher closer to their topic, allowing them to adjust the procedures before the definitive review.

Step 3. Define keywords, database, and basic procedures (filters). Based on the previous steps, the researcher defines keywords and/or combinations that best represent their topic and objectives, databases, and filters (search field and time delimitation, for example). The keywords used and other procedures are presented in Table 1.

Table 1 - Gross result of studies for the literature review

Topic	Filters
Industry 4.0 implementations	Scopus, Web of Science and Science Direct: TITLE ("Industry 4.0" OR "smart factory" OR "Fourth Industrial Revolution" OR "smart manufacturing") AND TITLE-ABS-

	KEY (implementation) AND TITLE-ABS-KEY (compan*); PUBYEAR (all years).
Technology Transfer models	Scopus, Web of Science and Science Direct: TITLE-ABS-KEY ("Technology Transfer model"); PUBYEAR (all years).
Technology Transfer in Industry 4.0	Scopus, Web of Science and Science Direct: TITLE-ABS-KEY (("Technology Transfer") AND ("Smart Factory" OR "Industry 4.0" OR "Smart Industry" OR "Smart Manufacturing" OR "Fourth Industrial Revolution" OR "4th Industrial Revolution")); PUBYEAR (all years).

Step 4. Definitive search in the databases. Each database was loaded with the information described above, searching one topic or combination of topics at a time. All materials obtained were collected in the Mendeley® manager.

Step 5. Filtering procedures. The bibliographic material was submitted to the following procedures: i) Eliminate duplicate works; ii) Eliminate works outside the scope; and iii) Eliminate conference papers. Then, only journal papers move on to the next step, as they present metrics that can be converted into InOrdinatio values, according to Pagani, Kovaleski, and Resende (2015, 2018). The results from Step 5 are presented in Table 2.

Table 2 - Number of studies per topic, after filtering

Filtering procedures		**Industry 4.0 implementations**	**Technology Transfer models**	**Technology Transfer in the Industry 4.0**
Scopus	(=)	403 documents	166 documents	116 documents
Web of Science	(=)	279 documents	73 documents	27 documents
Science Direct	(=)	97 documents	21 documents	1 document
Gross total	(=)	779 documents	260 documents	144 documents
Duplicities	(-)	260 documents	69 documents	40 documents
Book chapter	(-)	5	12	0
Conference paper	(-)	139	59	48
Journal article	(=)	375	120	56
Out of scope and/or lower InOrdinatio values	(-)	281	50	12
Total	(=)	94 papers	70 papers	44 papers

Step 6. Identify the metrics: Impact Factor (IF), number of citations, and year of publication of each article. The publication year is provided by the database itself, the number of citations is obtained from Google Scholar®, and the IF is given by the most recent Clarivate Analytics® list from Web of Science. The metrics of each paper are organized in an electronic spreadsheet.

Step 7. InOrdinatio analysis: InOrdinatio is a value generated from the year of publication (publication of new research), the IF (indicates the journal's rating and its degree of scientific rigor), and the number of citations (citations of the paper by the scientific community). Thus, the papers are ranked based on their scientific relevance regarding metrics (Pagani, Kovaleski, Resende, 2015). Equation 1 is necessary to calculate the InOrdinatio of each paper.

In the Methodi Ordinatio: IF is the Impact Factor, α is a weighting factor ranging from 1 to 10 to be assigned by the researcher, ResearchYear is the year in which the RSL was developed, PublishYear is the year the selected paper was published, and Ci is the number of times the paper was cited. Therefore, it is possible to obtain relevant studies regarding the metrics mentioned. It should be noted that together with the analysis of InOrdinatio (papers with higher values) and topic relevance criterion.

Steps 8 and 9. Find the texts in full format and read the papers systematically. After finding each paper, their content was read and analyzed.

Based on the systematic literature review, a model focusing on TT from the transferee's perspective was proposed, oriented to Industry 4.0 (TTM4.0). The TTM4.0 has six phases and was applied in a practical study. Figure 1 presents the core development constructs of the model.

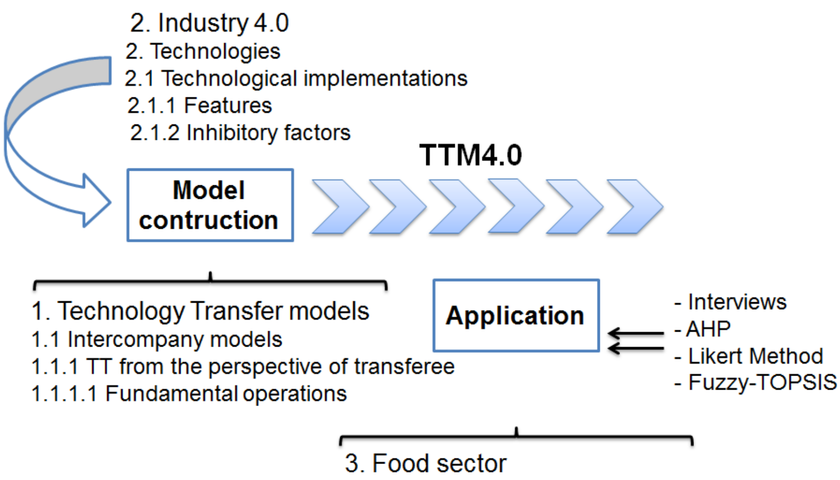

Figure 1 - Main contents and procedures in the development of the TTM4.0

2.2 Procedures adopted to validate the TT model

2.2.1 Population and sample

The study was conducted in two chicken slaughtering companies in the broiler farming sector in the Southern Region of Brazil. Both companies are large in terms of number of collaborators. They were selected to generate results from two companies with similar productive focus and size. The practical study was conducted individually in each company, with equivalent methodological procedures and number of specialists.

Two production operation coordinators participated in the study per company. The procedures are detailed as follows. All judgments had consensus among the specialists.

2.2.2 Data collection instruments

Table 3 presents the data collection instruments and the respective validation procedures of the TT model.

Table 3 - Data collection instruments and their respective procedures

Procedures
Construction of Instrument 1
Advantages projected by Industry 4.0 that were feasible to reach in the organizations were identified, according to the literature. After discarding ambiguities, a total of 12 advantages were defined to be later judged by the specialists.
Application of Instrument 1
In each company, two specialists, in consensus, were invited to judge the advantages listed. In this case, the judgments were made based on Saaty's (2008) Fundamental Scale of the AHP method.
Construction of Instrument 2
Following Likert scale patterns, questions were structured to reflect the understanding of levels of interest, availability, technological capability, and conditions that the companies have for Industry 4.0 implementations. The literature review was crucial, alongside the technical knowledge in the area.
Application of Instrument 2
The specialists should mark a single alternative per question (on a scale from 1 to 5).
Construction of Instrument 3
Following Likert scale patterns, questions were structured to reflect the understanding of barriers to Industry 4.0, according to the literature.
Application of Instrument 3
The specialists should mark a single alternative per question (on a scale from 1 to 5).
Construction of Instrument 4
Following Fuzzy-TOPSIS fundamentals, it was necessary to define criteria (Part A) and compare them to some alternatives (Part B). In this study, in Part A, given the broad theoretical discussion, the following criteria were defined: Criterion 1 (C1) (meeting the specific strategic need, overlapping the several advantages of Industry 4.0); Criterion 2

(C2) (company capability, in terms of technological prerequisites already available); and Criterion 3 (C3) (technical complexity of the target technology / components and operationalization, in general). In Part B, nine anchor technologies of Industry 4.0 were listed and associated with the criteria.
Application of Instrument 4
The Fuzzy-TOPSIS method initially required attributing weights to the criteria (based on linguistic variables described in Table 5) and analyzing the performance of each technology against them (Table 6). The attribution of weights to each criterion (Part A) occurred from the perception of the specialists in consensus (per company). The analysis of each technology compared to the criteria (Part B) occurred based on: i) Performance analysis of the target technology (Tx) regarding Criterion 1 (meeting the largest possible number of organizational needs (the four central ones)); ii) Tx regarding Criterion 2 (available technological capability), and; iii) Tx regarding Criterion 3 (technology complexity in terms of features, components, and operationalization modes).

2.2.3 Data analysis

After the data were collected in each company, they were analyzed.

In particular, this study employed the AHP, Likert, and Fuzzy-TOPSIS methods. It should be noted that these procedures are part of the model's validation. Therefore, other sources of data and methods can be included if pertinent, as long as they are suitable to measure TT elements and decision management.

According to Table 3, the first support method used was Saaty's Fundamental Scale, which is part of the AHP. It was chosen because it includes pairwise comparisons between criteria and alternatives. In this context, using this method, it was possible to verify which advantages of Industry 4.0 (Appendix 2) stand out by analyzing one over the other (V1 in relation to V2, V1 in relation to V3, and so on), converting them into strategic needs of the company. In addition, at the end, the Consistency Ratio (RC) is calculated, which indicates the coherence between the judgments. After eliminating ambiguities, 12 main advantages for judgments were included in this study.

In Companies A and B, two production operations coordinators were invited to judge the listed advantages based on the particularities of their company. In this case, the Saaty scale was used (Table 4). The judgments were conducted by consensus among the experts.

Table 4 - AHP fundamental scale

Weight	Description
1 - Equal importance	Two items contribute equally to the decision-making process
3 - Slight importance	Experiences or judgments slightly favor one item over the other
5 - Strong importance	Experiences or judgments strongly favor one item over the other
7 - Very strong importance	An item is strongly favored, and its mastery is demonstrated in practice
9 - Absolute importance	The evidence that favors one item over the other is of the highest level
2, 4, 6 and 8 - Intermediate values	-

Source: Adapted from Saaty (2008).

According to Saaty (2008), other AHP procedures applied include: – Building AHP decision matrices and – Determining: Eigenvector values (obtained through the arithmetic mean of the values of each row of the matrix for each criterion) and normalizing them; the main number of Eigenvector (λmax) (sum of the product of the Eigen vector by the sum of the respective column of the comparative matrix); Consistency Index, and; Consistency Ratio (RC).

Next, as described in Table 3, the Likert Scale was used, allowing to verify the interest and availability of each company for Industry 4.0, as well as the capacity and conditions for technological adoption. In addition, factors that inhibit the company's maximum interest and willingness to adopt Industry 4.0 were identified.

Subsequently, an attempt was made to evaluate Industry 4.0 technologies following the foundations of the Fuzzy-TOPSIS Method. This choice is justified by the applicability of this method to complex and/or uncertain situations (Chen, Lin, Huang, 2006), as is the case of Industry 4.0, in which much is still difficult to measure, and effective implementation is scarce. In addition, the method employs linguistic variables (Table 5, for example), which facilitates the measurement of alternatives concerning the set of criteria (Magalhães, Lima Júnior, 2021). For modeling, the fundamental equations are described in Chen (2000) and Chen, Lin and Huang (2006).

Following the principles of Fuzzy-TOPSIS, it was initially necessary to define criteria, assign weights (based on Table 5), and analyze the performance of each technology in relation to them (Table 6).

Table 5 - Linguistic variables for criteria

Variable	Fuzzy number
Very Low (VL)	(0.0, 0.0, 0.25)
Low (L)	(0.0, 0.25, 0.50)
Medium (M)	(0.25, 0.50, 0.75)
High (H)	(0.50, 0.75, 1.0)
Very High (VH)	(0.75, 1.0, 1.0)

Source: Lima Júnior (2013), Siddiquie, Khan and Siddiquee (2017), Patias (2017), Magalhães and Lima Júnior (2021).

Table 6 - Linguistic variables for alternatives

Variable	Fuzzy number
Very Poor (VP)	(0.0, 0.0, 2.5)
Poor (P)	(0.0, 2.5, 5.0)
Medium (M)	(2.5, 5.0, 7.5)
Good (G)	(5.0, 7.5, 10.0)
Very Good (VG)	(7.5, 10.0, 10.0)

Source: Adapted from Lima Júnior (2013), Siddiquie, Khan and Siddiquee (2017), Patias (2017), Magalhães and Lima Júnior (2021).

In this study, given the extensive theoretical discussion about the advantages of Industry 4.0 to adopters, the requirements necessary to obtain Industry 4.0, and the technical and operational complexities of technologies, the following criteria were defined: Criterion 1 (C1) (meet the specific strategic need, overriding the various advantages of Industry 4.0); Criterion 2 (C2) (company capacity, in terms of technological prerequisites already available), and; Criterion 3 (C3) (technical complexity of the technology, in terms of components and operationalization, in general).

The attribution of weights to the criteria occurred based on the perception of specialists for each criterion, carried out in consensus. The analysis of each technology concerning the criteria was based on: i) Results from Phase I of the model for Criterion 1, that is, considering meeting the highest possible number of strategic needs (four strategic needs); ii) Results from Phase III to Criterion 2, that is, considering the company's capacity in the technical and technological aspects, and; iii) Knowledge of technical characteristics of each technology for Criterion 3.

Finally, after analyzing the data through the collection and application of specific methods, a strategic analysis was carried out, which consisted of reflecting and discussing the Transfer of Technologies of Industry 4.0 in a specific sector.

Considering the proposed model, TT4.0 was not performed in terms of analyzing technologies in the supplier market, negotiations, installation, and management of technologies, as these operations depend exclusively on companies and extend over longer periods.

3. TECHNOLOGY TRANSFER ORIENTED TO INDUSTRY 4.0

3.1 Conceptual model

After identifying and analyzing 70 TT models, 15 models made greater contributions to the proposed model. These models deal with TT from the transferee's perspective, or even present elements that apply to the different contexts studied (Table 7).

Table 7 - Main Technology Transfer models

Collaborative link: Company – Company, in general	
Author	**Main features or approaches**
Bessant and Rush (1995)	The model presents TT phases from the transferee's perspective: initial recognition of the opportunity or need, technology selection, market acquisition, and implementation.
Deitos (2002)	The model presents some steps for TT, focusing on the transferee. These are technology selection, supplier selection, acquisition, implementation, assimilation of transferred technology, and adaptation and improvements.
Grange and Buys (2002)	Description of the basic steps of a conceptual TT project. These include recognizing a need for technology, researching, assessing, acquiring, customizing, implementing, and managing the technology.
Baek et al. (2007)	The model focuses on a specific stage of TT, the technology assessment, which occurs before its movement and implementation. The variables analyzed were the return of technology in terms of financial gain and profit, contributions of technology due to its functions, and impacts on the market.
Jagoda and Ramanathan (2009)	Six steps are proposed through a model, starting with the detection of opportunities and needs and finishing with the impact assessment entailed by TT. At the end of each stage, there is a gate for decision-making by company representatives interested in the technology.
Collaborative link: TT between companies from developed countries and developing countries	
Author	**Main features or approaches**
Di Benedetto, Calantone, Zhang (2003)	Model that considers the influence of factors (attitudes, behaviors, intentions and stimuli) in the TT process. It measures the attitude formation of managers and behavioral intentions that lead them to transfer technology.
Cavalheiro and Joia (2014)	Information technology can be adopted from a process with nine stages: problem perception, choice of technology, purchase and installation, technological and managerial capabilities to accommodate technology, adaptation, technology adoption, diffusion and innovation by the receiver, sender feedback, and technology management.
Collaborative link: University – Company	
Author	**Main features or approaches**
Gorschek et al. (2006)	Model containing seven stages, based on reports of experiences. Initially, it is necessary to explore where to apply improvements in TT processes. Researchers should develop a research agenda and action plan in the company, define a target operation or technology, perform feasibility tests in both scenarios – TT in the perspectives of sender and receiver, execute the actions through a pilot test, improve the actions and, finally, perform the TT.
Wang (2010)	The model comprises six stages. The first stage involves understanding the need for technology, followed by analyzing its feasibility, searching for technologies, adapting the technology for reasons such as legislation, capacity, etc., implementing the technology, and managing its life cycle.
Sabeti et al. (2020)	Description of factors and sub factors inserted in four stages of TT. Focusing on technologies and knowledge solutions in automotive industries, sets of political, environmental, social and economic factors comprise the stages of technology recognition, absorption, use and dissemination.
Collaborative link: Company – Community	
Author	**Main features or approaches**
Davies-Colley and Smith (2012)	The TT model is structured in six stages: construction of the relationship between actors and stakeholders in technology; planning of actions for TT; sensitivity (analysis of variables and factors that may affect TT); selection of technology; implementation and adaptation; and assessment of the adopted TT process.
Collaborative link: Several organizations	
Author	**Main features or approaches**

Gibson and Smilor (1991)	The model had its elaboration based on three types of classical models, the ownership model, dissemination model and knowledge utilization model. In this context, the three levels of TT are technology development, acceptance of technology and application of technology, respectively.
Sung and Gibson (2000)	It is an adaptation of the model proposed by Gibson and Smilor (1991). Four TT scope levels are encompassed. The development and commercialization of technology requires creating, sharing, implementing and commercializing.
Bozeman (2000)	This model encompasses five dimensions of technology transfer: characteristics of the transfer agent, characteristics of the transfer means, characteristics of the transfer object, demand environment and characteristics of the receiver.
Rani et al. (2018)	The definition of stages of the life cycle of a technology (development and assimilation until abandonment) can be supported by a variety of TT models. Some models inserted in this cycle are reported.

A complex TT process emerges with Industry 4.0, dependent on the intense integration of universities, companies, and government (Silva, Kovaleski, and Pagani, 2019; Alharbi, 2020). Universities engage in various areas of knowledge development and training of people, the company creates partnerships with new suppliers in adopting technological solutions and project development, and the government acts mainly as a facilitator of investments (Veile et al., 2019). According to Ayentimi and Burgess (2019), Technology Transfer to Industry 4.0 (TT4.0) has a few requirements, such as interested parties and strong links created between them, changes in organizational behavior, investments in technologies, among others.

A model was proposed to support the technological implementation (Figure 2). In this case, albeit conceptual, the target scenario was large companies in the Poultry Industry. The model's structure maintained conventional TT operations, but it was necessary to remodel them according to the particularities of the Industry 4.0 concept.

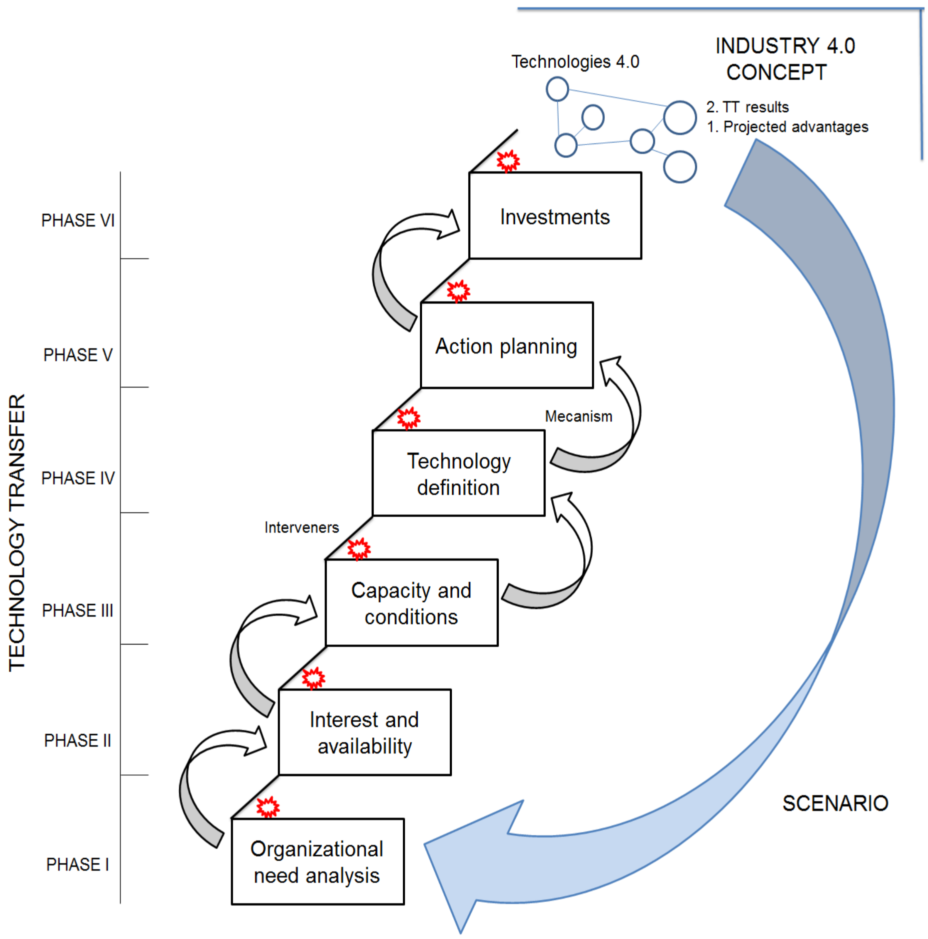

Figure 2 - Technology Transfer Model oriented to Industry 4.0 (TTM4.0)

Industry 4.0 is an integral part of the Intelligent Industry concept. It includes specific principles and technologies to make business processes, business models, and supply chains more dynamic. In Industry 4.0, the core technologies belong to the ICT and robotics fields.

Since this is a broad and still recent concept, companies have been gradually adopting changes that prioritize projects and actions. According to the proposed TTM4.0, given the different challenges presented by Industry 4.0 and the realities of companies, they can carry out technological implementations according to their priorities, recommending subsequent complementary projects and possible expansions. According to Bhatia and Kumar (2022), companies need to move step by step to implement technologies 4.0. The transition to Industry 4.0 is gradual, and each company prioritizes areas, departments, and technologies (Ghobakhloo and Fathi, 2019). Adopting technologies 4.0 can also be observed as a learning process leading to applications and adjustments (Stentoft et al., 2020; Zangiacomi et al., 2020).

Each phase of the TTM4.0 is described below:

- **Phase I. Organizational need**: Advantages projected by Industry 4.0 are presented to companies and redirected according to their strategic needs. In other words, a set of advantages may be attractive as it meets certain specific needs. Of course, the more advantages a company obtains, the better it will be. However, adopting all technologies 4.0 at once, realistically, is not possible (Bhatia and Kumar, 2022);
- **Phase II. Interest and availability**: The company acquires knowledge in Industry 4.0 and positions itself with certain levels of interest. Differently, albeit complementarily, the interest refers to the fact that a company seeks the concept, while the availability consists of the company being willing to invest in Industry 4.0. If interested, the company must be open to the changes imposed by Industry 4.0 (Bhatia and Kumar, 2022). A technological implementation depends on the intense support and availability of company managers and the collaboration of employees (Kiel et al., 2017; Dieste, Sauer, Orzes, 2022);
- **Phase III. Capacity and conditions**: Includes the company's available capacity of distribution, technology styles, and process characteristics. It also makes it possible to understand how much this company is prepared to absorb technologies 4.0 from a technical and operational point of view. According to Dieste, Sauer, and Orzes (2022), Industry 4.0 requires high investments in the case of less developed digital infrastructure. Another aspect included in this phase is whether the company has any limitations and conditions, such as access to financing and partnerships, among others;
- **Phase IV. Technology definition**: Consists of prioritizing one or more technologies 4.0 based on technology response capacities to the company's needs and other implications resulting from previous phases, such as facilities due to existing technological prerequisites, if pertinent to the company. According to Bhatia and Kumar (2022), when focusing on Industry 4.0, it is essential to define and prioritize strategic objectives. The transition to Industry 4.0 is gradual; companies prioritize areas, departments, and technologies (Ghobakhloo and Fathi, 2019);
- **Phase V. Action planning**: Outlines actions for the target technology, such as team formation and distribution of functions and schedules, among others. These actions constitute a technological implementation project that requires extensive knowledge of Industry 4.0. According to Dieste, Sauer, and Orzes (2022), it is necessary to understand technologies 4.0, capabilities, and limitations. Knowledge needs to be produced continuously (Kiel et al., 2017; Dieste, Sauer, Orzes, 2022; Romanello and Veglio, 2022);
- **Phase VI. Investments**: Consists of the company investing financial and other resources, such as time and effort, to operationalize the technology. This phase includes technical and legal TT operations, such as the installation and operationalization of the technology. Silva (2019) reports that TT is not limited to moving technology. Moreover, TT is only effective when employed by the transferee (Grange and Buys, 2002). Adopting technology 4.0 can also be observed as a learning process, leading to applications and adjustments (Stentoft et al., 2020; Zangiacomi et al., 2020). Finally, the advantages combined with the proper functioning of the technology are achievable in the form of TT results.

3.2 Case studies

The model proposed (Figure 2) was validated through its application in two companies in the food sector, more precisely in the poultry production chain. Both companies are large. The main results generated by running each phase of the model (TTM4.0) are presented as follows.

3.2.1 Phase I. Organizational needs

Initially, it was verified what the company wants with Industry 4.0 (concept and/or technologies). Twelve projected advantages were listed, according to Table 8, followed by peer-to-peer comparisons.

Table 8 - Projection of the advantages of Industry 4.0 in the company studied

Code	Advantages
tsc	"transparency in the supply chain"
pq	"product quality"
cd	"more consistent decision"
rrf	"rapid response to failure"
pc	"product customization"
es	"energy saving"
rpdt	"reduction in product delivery time"
rma	"reduction of monotonous activity"
rei	"reduction of environmental impact"
dp	"data privacy"
rhe	"reduction of human error"
wr	"waste reduction"

In slaughterhouses, unlike companies from other segments, the needs for technologies 4.0 may be different (Tables 9 and 10).

Table 9 - Normalized eigenvector and result, in percentage, for each item analyzed

Item	Eigenvector	ANV	Result
tsc	0.7284	0.0405	4.05%
pq	2.5544	0.1421	14.21%
cd	2.0384	0.1134	11.34%
rrf	1.7586	0.0978	9.78%
pc	0.4973	0.0277	2.77%
es	0.2830	0.0157	1.57%
rpdt	3.1146	0.1732	17.32%
rma	0.2658	0.0148	1.48%
rei	0.2495	0.0139	1.39%
dp	0.5972	0.0332	3.32%
rhe	3.1731	0.1765	17.65%
wr	2.7219	0.1514	15.14%
Study at Company A			

Table 10 - Normalized eigenvector and result, in percentage, for each item analyzed

Item	Eigenvector	ANV	Result
tsc	1.5478	0.0935	9.35%
pq	2.7366	0.1654	16.54%
cd	0.9325	0.0564	5.64%
rrf	2.6164	0.1581	15.81%
pc	0.5376	0.0325	3.25%
es	0.2475	0.0150	1.50%
rpdt	0.8341	0.0504	5.04%
rma	0.2475	0.0150	1.50%
rei	0.3636	0.0220	2.20%
dp	2.0536	0.1241	12.41%
rhe	2.6466	0.1600	16.00%
wr	1.7825	0.1077	10.77%
Study at Company B			

Focusing on the similar results between Company A and Company B, for example, the central needs were product quality (14.21% and 16.54%, respectively), reduction in human error (17.65% and 16.00%, respectively), and waste reduction (15.14% and 10.77%, respectively).

Considering the adoption of Industry 4.0, the reduction of environmental impact (1.39% and 2.20%, respectively, for Companies A and B), reduction of monotonous activity (1.48% and 1.50%, respectively), energy savings (1.57% and 1.50%, respectively) and product customization (1.77% and 3.25%, respectively) are not a priority for companies. In the case of the automotive sector, for example, product customization is more in demand.

3.2.2 Phase II. Interest and availability

Interest and availability encompass the company's position in obtaining Industry 4.0. If interested and available, there is greater collaboration by the company through investments.

In the practical study, Company A was very interested and highly available for Industry 4.0, and Company B showed little interest and low availability for Industry 4.0 implementations. The main inhibitory factors are described in Figure 3 e 4 for Companies A and B, respectively.

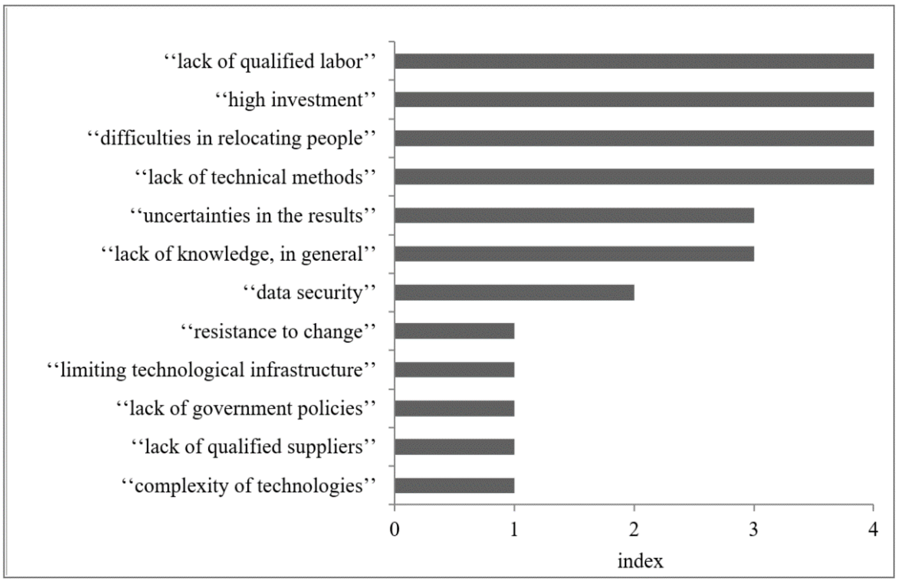

Figure 3- Factors influencing Company A's maximum interest and availability in Industry 4.0

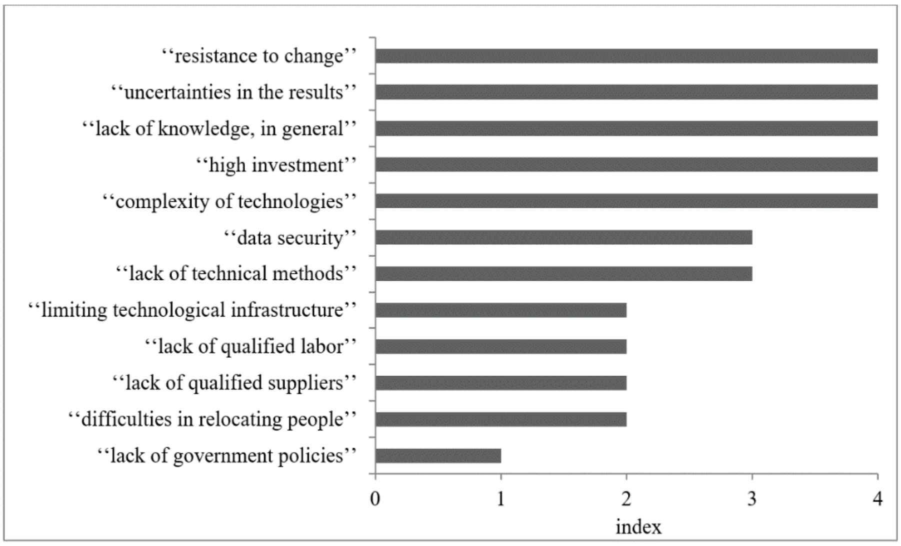

Figure 4 - Factors influencing Company B's maximum interest and availability in Industry 4.0

Among the main factors inhibiting both companies to display maximum interest and availability in Industry 4.0 were high investment, lack of knowledge in Industry 4.0, uncertainties in results, and difficulties in relocating people to work. The lack of government policies was the least influential factor among the others. None of the factors showed any influence.

3.2.3 Phase III. Capacity and condition

In terms of infrastructure in the technical and technological aspects, the company's capacity to accommodate the concept of Industry 4.0 was verified. The main results are presented in Table 11 e 12 for Companies A and B, respectively.

Table 11 - Capacity of Company A, in the technical and technological aspects

Aspect	Capacity
Automation of production processes	61 to 80% of processes
Sensor technology	They are frequently distributed at some stages of broiler meat production
Smart tag	Being studied for probable execution
Self-adaptive technology	Machines are used to meet the small fluctuations in products
Artificial Intelligence	Two robots, at least two different points in production
Machine connected to the internet	61 to 80% of production machines
Data collection	Very common, at each stage of production some type of data is collected
Combination of data	Frequently
Modeling and Simulation	Rarely, covering a single area (Production Control)
Traceability	It is carried out for each product variety
Integrated platform	Being studied for probable execution

Table 12 - Capacity of Company B, in the technical and technological aspects

Aspect	Capacity
Automation of production processes	From 21% to 40% of the processes
Sensor technology	They are frequently distributed at some stages of broiler meat production
Smart tag	A type of smart tag is used on a specific product
Self-adaptive technology	No machine meets product fluctuations without intervention.
Artificial Intelligence	This technology is not used
Machine connected to the internet	Up to 20% of production machines
Data collection	Hardly accomplished
Combination of data	Seldom
Modeling and Simulation	Does not apply
Traceability	It is carried out for each product variety
Integrated platform	A platform was installed, but the data volume is low

Regarding technical and technological capacity, sensor technologies are common and distributed at certain stages of meat production. There is also traceability for each product variety produced in both companies.

In addition to the ability to manage new concepts and/or technologies, the company must present proper conditions, which go beyond financial resources and include knowledge and accessibility, among others, as shown in Table 13 (Company A, for example).

Table 13 - Conditions for Company A to act in favor of Industry 4.0

Aspect	Condition
Knowledge	The professionals are constantly being trained. In terms of internal knowledge in Industry 4.0, there is intermediate knowledge for positions at a strategic level.
Internship	Many internships are carried out by students, in different departments of the company
Partnering	There are partnerships with national universities
R&D Department	Multiple units in the country, including a local unit
Organizational culture	Several new technologies are adopted, but in the same department
Funding	Easy access
Government incentive	High incentive

The companies studied adopt several new technologies but in the same department. This fact is one of their conditions; there is experience with new technological implementations, but when it comes to Industry 4.0, technology is more complex. TT4.0 is complex, both because of the TT elements and processes and because of the inclusion of Industry 4.0 approaches, which are now being disseminated.

3.2.4 Phase IV. Technology definition

Based on evaluations from experts and following Fuzzy-TOPSIS fundaments, the normalized and weighted judgment matrix, FPIS and FNIS, and distances were obtained, respectively. Table 14 presents the CCi admitted by each alternative.

Table 14 - Approximation coefficient for each alternative

Technology	CCi*	CCi**
T1. Big Data Analytics	0.5688	0.6037
T2. Cloud computing	0.3903	0.4154
T3. Internet of Things (IoT)	0.5158	0.3340
T4. Artificial intelligence	0.5593	0.5534
T5. Additive manufacturing	0.2143	0.3052
T6. Augmented Reality	0.3290	0.3950
T8. Simulation	0.4525	0.4445
T7. Cyber-security	0.2457	0.4083
T9. Cyber-Physical System (CPS)	0.3574	0.3151

*Study at Company A; **Study at Company B

Results commonly indicate Big Data Analytics and AI technologies to Companies A and B. Other technologies alternate between the companies studied.

3.2.5 Phase V. Action planning

At the beginning of technological implementations, the use of pilot projects to analyze the viability of investments is fundamental. Another practice is to map the effects and benefits of phased implementation and apply adjustments (Zangiacomi et al., 2020). In this context, after defining the technology, it is necessary to draw up an initial action plan regarding team formation, schedule, and definition of other TT activities and operations.

Given the results obtained, the company can intensify the presence of sensors and actuators in its production processes, implement Big Data technologies, and start to include as much data as possible from different sources and formats in continuous improvement analyses. Another step is to start the digitalization of their processes gradually, as well as of areas and departments. It is also essential to create process intelligence.

As for the Internet of Things, it is not enough to connect machines to the Internet or collect data through sensors. Machines and devices must exchange data simultaneously and autonomously in real time. Given the complexity, the adoption of the IoT requires more detailed planning.

Regarding TT-related planning actions, each project may present a certain complexity. After defining the technology, it is up to the organization to establish an action plan, which can be prepared in partnership with other organizations, proceeding with investments in TT.

3.2.6 Phase VI. Investments

This phase was not carried out, as it governs operations and technical procedures in TT, such as negotiation, organizational adjustment, movement and installation of technology, and operational adjustments and technology management, respectively. These operations require investments (financial resources, time, among others), depending exclusively on the company.

4 SYNTHESIS AND DISCUSSION OF RESULTS

Industry 4.0 is promising because it employs smart manufacturing technologies and principles. However, until it becomes a reality in organizations, a complex process and a range of decisions must be managed. In Technology Transfer oriented to Industry 4.0, organizational self-knowledge (need, interest, capacity, and conditions) is fundamental, as it influences the definition of technology and the planning of actions and investments.

In slaughterhouses, unlike companies in other sectors, the need for technology 4.0 can differ. Focusing on similar results between Company A and Company B, for example, the core necessities were product quality (14.21% and 16.54%, respectively), reduction of human error (17.65% and 16.00%, respectively), and waste reduction (15.14% and 10.77%, respectively). In the case of food, companies are more concerned about the quality of the product. That quality can be perceived by the consumer in terms of practicality. In other words, achieving quality reflects competitiveness and profitability for the sector. These companies also expressively employ human labor.

Thinking about the adoption of Industry 4.0, it is not a priority for companies to reduce the environmental impact (1.39% and 2.20%, respectively, for Companies A and B), reduction of monotonous activity (1.48% and 1.50 %, respectively), energy savings (1.57% and 1.50%, respectively) and product customization (1.77% and 3.25%, respectively, for Companies A and B). In the case of the automotive sector, product customization is more requested, for example.

Among the central factors that inhibit maximum interest and availability for Industry 4.0 in both companies were high investment, lack of knowledge in Industry 4.0, uncertainties in results, and difficulties in reallocating people at work. The lack of government policies was the least influential factor among the others. Similarly, in 39 companies of different sizes and sectors, Calabrese, Ghiron, and Tiburzi (2020) identified the main fears in Industry 4.0 implementations. They identified high investment, lack of qualification, and uncertainties in the results.

Stentoft et al. (2020) analyzed Industry 4.0 stakeholders in 190 Danish companies. In the study, the factor most commonly cited by managers was the absence of technical procedures and specialized labor.

Yüksel (2020) addressed questions about Industry 4.0 adoption in 84 companies of different sizes in Turkey. The results revealed the main factors to be defined: lack of training, high investment, and lack of knowledge. For the author, companies are generally interested in the concept, although the return in the form of results is not entirely clear.

In a survey of 270 small and medium-sized companies, the factors that inhibit the adoption of integrated technologies based on IoT and Cloud Computing are high costs, poor technological infrastructure, and data security issues (Narwane et al., 2019).

In general, companies still do not fully apply the Industry 4.0 concept, mainly for financial reasons, because even if the financial resources are available, they cannot allocate so many in an intense and revolutionary way. In this context, it is significant that technologies 4.0 are adopted gradually, always aiming at later expansions.

Reallocating people is another inhibiting factor of interest and availability for Industry 4.0. In broiler slaughterhouses, the thought creates fears due to the high number of people employed. Therefore, a challenge for companies is to make processes intelligent without strongly affecting human labor. Technology needs to be a significant ally of work, and people need to be qualified and reallocated so that everyone wins.

To support the transition to Industry 4.0, it is essential to present the feasibility of technology implementation. In addition, companies need technical and technological knowledge. Their lack negatively shapes interests in Industry 4.0.

As for the capacity in technical and technological aspects, sensor technologies are common and distributed in a few stages of broiler meat production. There is traceability for each product variety produced in both companies. It is a characteristic of poultry farming to use a series of sensors throughout the entire production chain, although the Industry 4.0 concept goes beyond the use of sensors, requiring significant adjustments in physical and digital technological infrastructure.

In five companies in the automotive sector, Zheng and Ming (2017) found that none have the complete development of all dimensions for intelligent production in terms of automation, digitalization, and integrated systems. Focusing on a specific technology 4.0, artificial intelligence, multiple case studies in large companies in the clothing sector revealed that these companies have incipient maturity levels in AI in strategy, organizational management, data management, and technological infrastructure (Ellefsen et al., 2019). According to Müller (2019), relevant technological developments considering Industry 4.0 include the intensification of process automation, the digitization of operations, and the interconnection between machines, products, departments, and companies.

In Companies A and B, several new technologies are adopted but in the same department. This fact is one of the conditions they have, that is, there is experience with new technological implementations. However, in the case of Industry 4.0, the technological complexity is greater. TT4.0 is complex both because of the TT elements and processes and because of the insertion of Industry 4.0 approaches, which are becoming widespread.

Finally, results commonly indicate Big Data Analytics and artificial intelligence technologies for Companies A and B. Other technologies alternate between the companies studied. Zangiacomi et al. (2020) surveyed 20 companies from the same supply chain through interviews with managers. The authors found that each company showed interest in adopting specific technologies, especially IoT and collaborative robots.

Chiarini, Belvedere, and Grando (2020) identified technologies 4.0 already used by Italian companies (sensors, intelligent robots, 3D printing, augmented reality, simulation, Big Data Analytics, cloud computing, and the Internet of Things). Two hundred company managers answered a questionnaire. According to this study, 25.6% of companies are implementing these technologies, 18.9% are preparing projects, and 18.1% have concluded implementations.

Regarding TT-related planning actions, each project can present a certain complexity. Thus, after defining the technology, it is up to the organization to establish an action plan, which can be prepared in partnership with other organizations, proceeding with investments in TT.

5 CONCLUSION

This study proposed to address the Technology Transfer of Industry 4.0. A TT model was proposed (TTM4.0), which analyzes TT from the transferee's perspective. Conventional TT operations were inserted into the model, but it was necessary to redirect them according to the respective particularities of Industry 4.0. The six phases of the model, called TTM4.0, are strategic need analysis, interest and availability, capacity and conditions, technology definition, action planning, and investments.

Among all the phases of the TTM4.0, the investment phase is the most complex as it conducts the technological implementation, including negotiation operations regarding the target technology, organizational adequacy, technology movement, operational adjustments, and technology evaluation and management.

The model was applied in two slaughterhouses in the Poultry Industry (Meat Production). The result of a hands-on approach reveals steps for implementing technology throughout each phase of TTM4.0.

Although the sector and main product supplied are equivalent, and both companies are large, they have different realities. Thus, while Company A was technologically well-developed, Company B had greater limitations in smart manufacturing.

A limitation of the study is that Phase V was only partially developed and Phase VI was not developed, that is, planning and application of investments, respectively. Phase VI demands an investment of effort, financial resources, and more time from the company.

Industry 4.0 strongly focuses on the concept of smart industry, which features connectivity between technological resources, people, departments, and companies. Data collection is also expressive, through which data gain value and facilitate decisions. In this context, studies on TT and Industry 4.0 are suggested, presenting results of technological implementations.

In a simplified way, a strong particularity of the model can be highlighted, that is, the organizational self-knowledge that starts to be analyzed as a significant decision-making process for complex and difficult-to-measure concepts.

REFERENCES

Alharbi, O. (2020), "Industry 4.0 operators: Core knowledge and skills", *Advances in Science, Technology and Engineering Systems Journal*, Vol. 5, No. 4, pp. 177-183.

Ayentimi, D.T. and Burgess, J. (2019), "Is the fourth industrial revolution relevant to sub-Sahara Africa?", *Technology Analysis & Strategic Management*, Vol. 31, No. 6, pp. 641-652.

Baek, D.H., Sul, W., Hong, K.P. and Kim, H. (2007), "A technology valuation model to support technology transfer negotiations", *R&D Management,* Vol. 37, No. 2, pp. 123-138.

Bessant, J. and Rush, H. (1995), "Building bridges for innovation: the role of consultants in technology transfer", *Research Policy,* Vol. 24, No. 1, pp. 97-114.

Bhatia, M.S. and Kumar, S. (2022), "Critical Success Factors of Industry 4.0 in Automotive Manufacturing Industry", *IEEE Transactions on Engineering Management*, Vol. 69, No. 5, p. 1.

Bozeman, B. (2000), "Technology transfer and public policy: a review of research and theory", *Research Policy,* Vol. 29, No. 5, pp. 627-655.

Calabrese, A., Ghiron, N.L. and Tiburzi, L. (2020), "'Evolutions' and 'revolutions' in manufacturers' implementation of industry 4.0: a literature review, a multiple case study, and a conceptual framework", *Production Planning & Control,* pp. 1-15, doi:10.1080/09537287.2020.1719715.

Cavalheiro, G.M.C. and Joia, L.A. (2014), "Towards a heuristic frame for transferring e-government technology", *Government Information Quarterly*, Vol. 31, No. 1, pp. 195-207.

Chen, C. (2000), "Extensions of the TOPSIS for group decision-making under fuzzy environment", *Fuzzy sets and systems*, Vol. 114, No. 1, pp. 1-9.

Chen, T., Lin, C. and Huang, S. (2006), "A fuzzy approach for supplier evaluation and selection in supply chain management", *International journal of production economics,* Vol. 102, No. 2, pp.

289-301.

Chiarini, A., Belvedere, V. and Grando, A. (2020), "Industry 4.0 strategies and technological developments. An exploratory research from Italian manufacturing companies", *Production Planning & Control*, Vol. 31, No. 16, pp. 1385-1398.

Deitos, M.L. (2002), "Technology Management in Small and Medium Enterprises, Edunioeste, Brazil".

Davies-Colley, C. and Smith, W. (2012), "Implementing environmental technologies in development situations: The example of ecological toilets", *Technology in Society,* Vol. 34, No. 1, pp. 1-8.

Di Benedetto, C.A., Calantone, R.J. and Zhang, C. (2003), "International technology transfer", *International Marketing Review,* Vol. 20, No. 1, pp. 1.

Dieste, M., Sauer, P.C. and Orzes, G. (2022), "Organizational tensions in industry 4.0 implementation: A paradox theory approach", *International Journal of Production Economics*, doi:10.1016/j.ijpe.2022.108532.

Elias, N. (2006), "Tecnização e civilização", *Revista Gestão Industrial*, Vol. 2, No. 2, pp. 1-33.

Ellefsen, A.P., Oleśków-Szłapka, J., Pawłowski, G. and Toboła, A. (2019), "Striving for excellence in AI implementation: AI maturity model framework and preliminary research results", *LogForum*, Vol. 15, No. 3, pp. 363-376.

Facchini, F., Digiesi, S. and Pinto, L.F.R. (2022), "Implementation of I4.0 technologies in production systems: opportunities and limits in the digital transformation", *Procedia Computer Science*, Vol. 200, pp. 1705-1714.

Ghobakhloo, M. and Fathi, M. (2019), "Corporate survival in Industry 4.0 era: the enabling role of lean-digitized manufacturing", *Journal of Manufacturing Technology Management*, Vol. 31, No. 1, pp. 1-30.

Gorschek, T., Garre, P., Larsson, S. and Wohlin, C. (2006), "A model for technology transfer in practice", *IEEE software*, Vol. 23, No. 6, pp. 88-95.

Grange, L.I. and Buys, A.J. (2002), "A review of technology transfer mechanisms", South African *Journal of Industrial Engineering*, Vol. 13, No. 1, pp. 81-100.

Jasiulewicz-Kaczmarek, M., Saniuk, A. and Nowicki, T. (2017), "The Maintenance Management in the Macro-Ergonomics Context", *Advances in Intelligent Systems and Computing*, Vol. 487, pp. 35-46.

Kiel, D., Müller, J.M., Arnold, C. and Voigt, K. (2017), "Sustainable Industrial value creation – Benefits and challenges of Industry 4.0", *International Journal of Innovation Management,* Vol. 21, No. 8, p. 1740015.

Lee, J., Kao, H.A. and Yang, S. (2014), "Service innovation and smart analytics for Industry 4.0 and big data environment", *Procedia CIRP,* Vol. 16, pp. 3-8.

Lima, E.C. and Oliveira Neto, C.R. (2017), "Revolução Industrial: considerações sobre o pioneirismo industrial inglês", *Revista Espaço Acadêmico*, Vol. 1, No. 194, pp. 102-113.

Magalhães, W.R. and Lima Junior, F.R. (2021), "A model based on FMEA and Fuzzy TOPSIS for risk prioritization in industrial processes", *Gestão & Produção*, Vol. 28, p. 1.

Müller, J.M. (2019), "Business model innovation in small-and medium-sized enterprises", Journal of *Manufacturing Technology Management,* Vol. 30, No. 8, pp. 1127-1142.

Narwane, V.S., Raut, R.D., Gardas, B.B. and Kavre, M.S. (2019), "Factors affecting the adoption of cloud of things", *Journal of Systems and Information Technology*, Vol. 21, No. 4, pp. 397-418.

Ortt, R., Stolwijk, C. and Punter, M. (2020), "Implementing Industry 4.0: assessing the current state", *Journal of Manufacturing Technology Management*, Vol. 31, No. 5, pp. 825-836.

Pagani, R.N., Kovaleski, J.L. and Resende, L.M. (2015), "Methodi ordinatio®: a proposed methodology to select and rank relevant scientific papers encompassing the impact factor, number of citation, and year of publication", *Scientometrics*, Vol. 105, No. 3, pp. 2109-2135.

Pagani, R.N., Kovaleski, J.L. and Resende, L.M. (2018), "Avanços na composição da Methodi Ordinatio para revisão sistemática de literatura", *Ciência da Informação*, Brasília, Vol. 46, No. 2, pp. 161-187.

Papadopoulos, T., Singh, S.P., Spanaki, K., Gunasekaran, A. and Dubey, R. (2022), "Towards the next generation of manufacturing: implications of big data and digitalization in the context of industry 4.0", *Production Planning & Control*, Vol. 33, No. 2, pp. 101-104.

Rani, S.S., Rao, B.M., Ramarao, P. and Kumar, S. (2018), "Technology Transfer - Models and Mechanisms", *International Journal of Mechanical Engineering and Technology*, Vol. 9, No. 6, pp. 971-982.

Romanello, R. and Veglio, V. (2022), "Industry 4.0 in food processing: drivers, challenges and outcomes", *British Food Journal*, Vol. 124, No. 13, pp. 375-390.

Saaty, T.L. (2008), "Decision making with the analytic hierarchy process", International Journal of *Services Science,* Vol. 1, No. 1, pp. 83-98.

Sabeti, M., Hashemzadeh, G., Gelard, P. and Rabiei, M. (2020), "Designing a knowledge based technology transfer model using the fourth generation approach in the automotive industry", *Revista Gestão & Tecnologia,* Vol. 20, pp. 106-125.

Seaton, R.A.F. and Cordey-Hayes, M. (1993), "The development and application of interactive models of industrial technology transfer", *Technovation*, Vol. 13, pp. 45-53.

Siddiquie, R.Y., Khan, Z.A. and Siddiquee, A.N. (2017), "Prioritizing decision criteria of flexible manufacturing systems using fuzzy TOPSIS", *Journal of Manufacturing Technology Management,* Vol. 28, pp. 913-927.

Sigov, A., Ratkin, L., Ivanov, L.A. and Xu, L.D. (2022), "Emerging enabling technologies for industry 4.0 and beyond", *Information Systems Frontiers,* 2022, pp. 1-11.

Jagoda, K. and Ramanathan, K. (2009), "Backward integration through international technology transfer: a case study from the textile industry of Sri Lanka", in Annual Conference of the Administrative Sciences Association of Canada, Ontario Bissett School of Business, Canada.

Lima Júnior, F.R. (2013), "Comparação entre Fuzzy TOPSIS e Fuzzy AHP no apoio à tomada de decisão para seleção de fornecedores", Dissertação (Mestrado em Engenharia de Produção), Universidade Federal de São Carlos, São Carlos, Brasil.

Patias, J. (2017), "Aplicação dos métodos AHP e fuzzy Topsis em incubadoras de empresas", Dissertação (Mestrado em Engenharia de Produção), Universidade Federal de Santa Maria, Rio Grande do Sul, Brasil.

Silva, V.L. (2019), "Analysis of External Technology Transfer oriented to the Industry 4.0: collaborative links between supplier and manufacturing industry", Dissertação (Mestrado em Engenharia de Produção), Universidade Tecnológica Federal do Paraná, Ponta Grossa, Brasil.

Silva, V.L. (2023), "Industry 4.0 Technology Transfer Model to support technological implementation in the poultry industry", Tese (Doutorado em Engenharia de Produção), Universidade Tecnológica Federal do Paraná, Ponta Grossa, Brasil.

Silva, V.L., Kovaleski, J.L. and Pagani, R.N. (2019), "Technology Transfer and Human Capital in the Industrial 4.0 Scenario: A Theoretical Study", *Future Studies Research Journal: Trends and Strategies*, Vol. 11, No. 1, pp. 102-122.

Silva, V.L., Kovaleski, J.L. and Pagani, R.N. (2021), "Fundamental elements in Technology Transfer: an in-depth analysis", *Technology Analysis & Strategic Management,* pp. 1-20, doi:10.1080/09537325.2021.1894328.

Smilor, R.W., Gibson, D.V. and Avery, C.M. (1989), "R&D consortia and technology transfer: Initial lessons from MCC", *The Journal of Technology Transfer*, Vol. 14, No. 2, pp. 11-22.

Stentoft, J., Adsbøll Wickstrøm, K., Philipsen, K. and Haug, A. (2020), "Drivers and barriers for Industry 4.0 readiness and practice: empirical evidence from small and medium-sized manufacturers", *Production Planning & Control,* pp. 1-18.

Tortorella, G.L. and Fettermann, D. (2017), "Implementation of Industry 4.0 and lean production in Brazilian manufacturing companies", *International Journal of Production Research,* Vol. 56, No. 8, pp. 2975-2987.

Türkes, M.C., Oncioiu, I., Aslam, H.D., Marin-Pantelescu, A., Topor, D.I. and Căpusneanu, S. (2019), "Drivers and Barriers in Using Industry 4.0: A Perspective of SMEs in Romania", *Processes*, Vol. 7, No. 3, pp. 1-20.

Veile, J.W., Kiel, D., Müller, J.M. and Voigt, K.I. (2019), "Lessons learned from Industry 4.0 implementation in the German manufacturing industry", *Journal of Manufacturing Technology Management*, Vol. 31, No. 5, pp. 977-997.

Yüksel, H. (2020), "An empirical evaluation of industry 4.0 applications of companies in Turkey: The case of a developing country", *Technology in Society,* Vol. 63, p. 101364.

Zangiacomi, A., Pessot, E., Fornasiero, R., Bertetti, M. and Sacco, M. (2020), "Moving towards digitalization: A multiple case study in manufacturing", *Production Planning & Control*, Vol. 31, No. 2, pp. 143-157.

Zheng, M. and Ming, X. (2017), "Construction of cyber-physical system-integrated smart manufacturing workshops: A case study in automobile industry", *Advances in Mechanical Engineering*, Vol. 9, No. 10, pp. 1-17.

Sung, T.K. and Gibson, D.V. (2000), "Knowledge and technology transfer: levels and key factors", in *International Conference on Technology Policy and Innovation,* Texas.

Wang, J.F. (2010), "Framework for university-industry technology transfer: View of a technology receiver", in *International Conference on Communication Systems,* Networks and Applications, IEEE, India.

APPENDIX 1

Table 1A - Particularities of the proposed model, in general

Description
Greater emphasis on exploratory Technology Transfer. While other models start with the recognition of opportunities, and proceed to the selection of technologies in the market and effective implementation, the model prioritizes phases of organizational self-awareness for decision support.
The model addresses phases not presented in other TT models, namely interest and availability and conditions for obtaining the technology. Those phases arise when dealing with more complex concepts, technology cases, and situations of uncertainty.
Other models, in the same category and TT focus (TT between companies and perspective of the transferee), only define the phases or steps of TT, and there is no quantitative analysis as performed in this study.
Focus on Industry 4.0 Technology Transfer (a widely discussed concept, despite the lack of studies on the effective technological implementation in organizational scenarios).
Definition of candidate technologies for companies, based on the criteria of strategic need, the company's technological capacity (facilities in terms of prerequisites), and technology complexity. Another particularity is the definition of technology when considering a set of very different technologies despite belonging to the same concept (smart manufacturing / Industry 4.0).
The model generates important content for decision support, such as what is a priority for the company (need), what has prevented it from adopting such a set of technologies or concepts (inhibiting factors of interest and availability), what is available that can be added (capacity in the technical and technological aspects), among others.
The purpose of the model is to assist companies in the technological implementations of Industry 4.0, starting with the technology that best meets the established criteria for later expansion so that Industry 4.0 is adopted as completely as possible.

APPENDIX 2

Table 2A - Technologies addressed by case studies and advantages.

Technology	Associated advantage
Cyber-Physical System (CPS)	Improvements in process operational efficiency and environmental impact management.
	Support for subsystem, machine and/or production process control.
	Monitoring machine health, increased productivity, reduced resource consumption and waste. Supply of versatile and flexible products.
	Technical solutions in machine maintenance. Production monitoring
	Operations optimization, flexibility of production, decision-making processes.
Collaborative robots	Process automation. Flexibility. Increased accuracy in execution of tasks.
Cyber-security	Cyber threat Management. Reduce or prevent attacks and risks of improper data access.
Artificial intelligence	Data processing, process automation, decision making support.

	Automation and operations optimization, decision making support.
Cloud computing systems	Storage of data. Accessibility to data, information and computational resources.
	Sharing information. Collaboration made easy between companies.
Augmented Reality (AR) Technologies	Operations optimization.
Big Data and Analytics	Providing data processing and analysis capabilities for diagnostics and interventions.
	Better decision.
	Knowledge generation. More efficient operations.
	Improved information sharing, decision making, operations optimization
Internet of Things (IoT)	Data collection. Greater robustness in understanding events.
	Interconnection of objects. Transmission of data.
	Communication between objects. Product monitoring. Product tracking.
	Improved information sharing.
Additive manufacturing	Improved design and product structure assimilation,
3D printing technologies	Customization of products.
	Prototyping.
Modeling and simulation technologies	Operations optimization

Source: Silva (2023).

Author contributions: VLS: Conceptualization, collection, data analysis and editing; JLK: Supervision and review; RNP: Supervision, editing and review; MASG: Conceptualization and review.