Road Mapping of Artificial Intelligence Technologies for the Food Industry:

A TDE Approach

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Abstract: This paper discusses the application of the Technology Development Envelope (TDE) as a road mapping tool in combination with the Delphi method and the Analytic Hierarchy Process (AHP). The method helps policy and decision-makers in organizations strategically manage emerging technologies by mapping their anticipated development path. The paper focused on creating a Technology Development Envelope (TDE) for artificial intelligence (AI) technologies in the food industry. In the first step, an expert panel identified a list of AI technologies applicable to the food industry. A hierarchical decision-making model, comprising 5 criteria and 24 sub-criteria for technology evaluation, was extracted from the literature and validated using the Delphi method. The Analytic Hierarchy Process (AHP) was used to determine the relative importance of criteria and sub-criteria for evaluating the identified technologies. At this stage, the most important criteria considered were food safety and social and political acceptance of the technology. The expected value of each technology was calculated over different periods, resulting in the development of the Technology Development Evaluation (TDE) for AI technologies in the food industry within a ten-year horizon. The analysis of the future indicates that technologies

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such as computer vision, robotics, industrial automation, and machine learning will undergo continuous improvements over time and eventually become dominant technologies in the food industry. These advancements can lead to an increase in quality and efficiency within the food industry. Finally, sensitivity analysis was conducted to test the model's sensitivity and explore how policymakers' extreme strategies affect the model's outputs.

Keywords: Technology Roadmap, Technology Development Envelop, Food Industry, Artificial Intelligence Technologies

1. Introduction

With the promotion of healthy foods and the increase in population growth, the demand for nutritious and high-quality food has risen worldwide in recent years. It is predicted that with the global population growth, the demand for food will increase from 59% to 98% by the year 2050 (Elferink & Schierhorn, 2016). The term "food industry" encompasses any company that engages in the design, production, processing, preservation, distribution, and sale of food, beverages, and dietary supplements to customers. The food processing industry is influenced by various factors, such as consumers' awareness and attention to quality, food safety, shelf life, healthy and natural nutrition, quality control, types of food, current trends, consumer psychology, and human health (Lyman, 1989). Ensuring the supply of healthy and high-quality food, especially perishable items, is indeed a concern for organizations operating in the food industry. Additionally, food industry companies face specific sustainability challenges related to the availability and consumption of natural resources, food safety, waste management, and unfair trade relations (Lezoche et al., 2020). Limitations imposed on the food processing industry necessitate the inclusion of technologies to enhance production values, waste management, and estimate market demand (Otterpohl et al., 1997). It should also be noted that the human workforce plays a crucial role in ensuring the smooth production and packaging of food products. Due to human involvement, food industries often struggle with maintaining the supply and demand chain, as well as ensuring food safety (Annunziata & Pascale, 2011). The use of artificial intelligence in the food industry is growing and, for various reasons, is considered the best possible solution to overcome these challenges. The application of artificial intelligence in the food industry is expanding. It includes tasks such as food classification, parameter classification and prediction, quality control, demand planning and supply chain management, food safety control, introduction of new products, and equipment cleaning and maintenance. Using artificial intelligence in the food industry can improve performance and enhance efficiency, accuracy, speed, and quality in various processes. Additionally, this technology enables better prediction and analysis of industry trends and patterns, assisting managers and decision-makers in making informed decisions and addressing challenges and issues in a timely and effective manner. The goal of artificial intelligence is to revolutionize production by automating processes. Artificial intelligence is seen as an excellent opportunity for advancing the food industry. AI-based systems are widely used in almost every sector of the food industry (Mavani et al., 2021). High-quality production at a minimum cost is the goal of most companies. The utilization of modern technologies in the food industry can result in the production of higher-quality food in a shorter timeframe. Technological advancements increase productivity rates in production stages and reduce production costs in various sectors of the food industry.

As a result, products with a higher added value are produced. This is particularly important when there is a high level of competition among producers (Kumar et al., 2021). Timely and accurate information provided by emerging technologies is the foundation for achieving effective supply chain management. The competitiveness of food processing companies depends on factors such as their investment capacity, increased production, the development of new products, and the implementation of processes to differentiate themselves from competitors. Furthermore, the successful implementation of technologies can greatly enhance the competitiveness of companies. However, due to financial constraints, companies need to carefully evaluate technologies before investing in them (Joubert & Jokonya, 2021; Zhao et al., 2019). Most managers have recognized the importance of strategic technology in creating value and gaining a competitive advantage within their organizations. This importance becomes more tangible with increasing costs, production complexities, and the rapid rate of technological change. It is further intensified by the globalization of competition and technological resources (Gerdsri, 2007). The increasing importance of technology has made managing it essential for organizations. In this regard, a technology roadmap serves as a structured tool for discovering and establishing connections between markets, products, and emerging technologies over time. This tool helps organizations maintain and enhance their position in today's dynamic and highly volatile environment by focusing on environmental monitoring and tracking technological changes. It also assists in ensuring future demand by identifying market needs and the necessary technologies to meet them (Partel et al., 2019). This paper analyzes the role of artificial intelligence technology roadmap in the food industry. The study starts by identifying artificial intelligence technologies in the food industry. It then employs a combination of hierarchical analysis process and technology development envelope (TDE) methods to create a roadmap for AI technologies in the food industry.

2. Research Background

2-1. technology Assessment

Technology, in general, is defined as the "science or knowledge applied for a specific purpose." The term "technology assessment" emerged in the 1960s, particularly in the United States. It focused on subjects such as the implications of supersonic transportation, environmental pollution, and genetic screening (Banta, 2009). It is said that this term was first used in the Subcommittee on Science, Research, and Development of the Committee on Science and Astronautics of the U.S. House of Representatives under the leadership of Emilio Daddario (Daddario, 1967). Technology assessment has been and continues to be a very broad field (Banta, 2009). Topics such as technology diffusion (and transfer), factors that contribute to the rapid acceptance of new technology, and the role of technology in society are interconnected subjects that form a significant part of the field of technology assessment. Understanding the technological status of an organization helps its management make better decisions and set more specific goals for future activities. By conducting a technology assessment, the organization can identify the strengths and weaknesses of its technologies and their environment, which in turn enables better decision-making. Technology assessment is a tool or conceptual framework that aids in better understanding technology and making informed decisions about it. Today, technology assessment is a crucial component of a worldwide endeavor to systematically tackle the question of how to advance in the realm of technology (Mohr, 1999). Technology assessment should analyze and evaluate the intended and unintended outcomes, opportunities, and risks of technology, whether they are new or mature technologies. The evaluation process seeks to assist decision-making regarding new technological developments by analyzing their social, economic, technical, cultural, and environmental potentials (Tübke et al., 2001). Technology assessment is another crucial step in formulating a technology strategy and mapping out a technology roadmap. Technology assessment is a process through which organizations and businesses evaluate the attractiveness of technologies they use in their products or potentially have the capability to use, as well as assess their own technological capabilities. Technology assessment should involve analyzing and evaluating the desired and undesired outcomes, opportunities, and risks of both new and established technologies. Technology assessment is a research method in the policy domain that offers decision-makers a comprehensive evaluation of a technology. The technology assessment process identifies relevant factors related to a policy, evaluates them, and provides its findings as guidance to policymakers (Tübke et al., 2001).

2-2. technology Roadmap

A technology roadmap helps a company systematically conduct its research and development activities and create clear plans for the development of technologies, including their timelines and strategies for implementation (Phaal et al., 2004). There are various definitions of the term "roadmap," and developing a roadmap is a flexible approach widely used in the improvement of planning processes. A roadmap provides a structured approach to innovation and strategy and is extensively used as a management technique to achieve goals (Phaal & Muller, 2009). A technology roadmap assists organizations in identifying future market needs and the necessary technologies to meet those needs, ensuring future demand. A technology roadmap is a method for identifying needs and transforming them into technology options and development plans to ensure that the required technology is ready and accessible when needed (Phaal et al., 2004). A technology roadmap helps organizations ensure future demand by identifying future market needs and the necessary technologies to meet them. A technology roadmap is a method for identifying product or acquisition needs and converting them into technology options and development plans. Its purpose is to ensure that the necessary future technology is prepared and accessible when needed (Phaal et al., 2004). A technology roadmap supports the development and implementation of integrated business, product, and technology strategic programs. The goal of a technology roadmap is to generate the necessary information for better decision-making in technology investments (Phaal et al., 2004). A technology roadmap determines critical needs and practical objectives within a specific timeframe, enabling a company to anticipate future product demand and identify the necessary technology to achieve these goals. The technology roadmap assists companies, organizations, and industries in outlining what they need to do to succeed in the market (Ling et al., 2008). Yoon et al. (2008) propose four techniques for structuring technological information in a technology roadmap: summarization, information extraction, clustering, and navigation. Several efforts have been made to find the most effective way to create a technology roadmap. Bray and Garcia (1997) suggested three stages: initial activity, roadmap development, and follow-up activity. Groenveld (1997) developed a seven-stage process. The "T-Plan" development supports the rapid initiation of a roadmap in three stages: planning, roadmap, and extension (Phaal et al., 2001). Additionally, an adapted T-Plan process has been introduced with five key modules (Holmes & Ferrill, 2005). Lee and Park (2005) proposed a framework for customizing the technology roadmap process based on specific objectives. They also suggested eight templates for roadmaps. These roadmap processes typically include one crucial stage: identifying the relationships between layers. Kostoff and Schaller (2001) emphasized the need for measuring functional relationships in technology roadmaps. Since a technology roadmap is a multi-layered diagram consisting of market, product, and technology layers, it is important to identify the relationships between these layers in order to determine the strategies for "when and how" to implement them. Given the inherent uncertainties and evolving requirements in large-scale programs, the structure of a technology roadmap should be flexible enough to accommodate dynamics. This highlights the importance of relevant functional relationships that reflect changes across each node of the technology roadmap to the overall layers of the technology roadmap (Kostoff & Schaller, 2001). However, the task of identifying relationships between layers relies more on expert judgment (Kostoff & Schaller, 2001).

2-3.Technology development envelope (TDE)

There is a significant amount of research on technology forecasting and assessment methods, with most of it focused on the expansion of existing technologies rather than emerging technologies (Gerdseri, 2007; Kockan et al., 2010). The concept of the technology development envelope (TDE) was introduced by Gerdsri and Kocaoglu (2003) as a means of forecasting, evaluating, and selecting appropriate emerging technologies. The main objective of this methodology is to establish a connection between technologies and organizational strategy. By utilizing this model, managers will gain a comprehensive understanding of how technologies align with the organization's strategy and the future role they will assume. This methodology evaluates the value of technology alternatives based on each technology's capability to achieve desired objectives (Daim et al., 2011). This technique is also used to reprioritize technologies in response to changes in the organizational environment or technology landscape. TDE starts by gathering strategic information about technology developments and then uses this information to evaluate the value of each technology based on its impact on the organization's objectives in each period (Gerdsri, 2005). This process leads to the formation of a technology development envelope that identifies the technologies with the highest value over time periods and provides a technology development path.

Since its introduction, TDE has been applied to various cases. Gerdsri and Kocaoglu (2007) integrated the Analytic Hierarchy Process (AHP) into the Technology Development Evaluation (TDE) framework to create a roadmap for electronic cooling technologies. Fenwick et al. (2009) applied the Technology-Driven Entrepreneurship (TDE) approach to value-driven road mapping in the case of internet security technologies. Kockan et al. (2010) used TDE to roadmap future powertrain technologies in the automotive industry. Daim et al. (2018) applied Technology Development and Evaluation (TDE) as a strategic tool for technology management in the power sector. Letaba et al. (2018) provided a TDE framework for developing countries that focuses on trends in robotics technology. To the best of our knowledge, the application of the TDE approach to the food industry and artificial intelligence technology is not mentioned in the literature.

3. Research Methodology

The Technology Development Envelope (TDE) focuses on emerging technology trends, organization goals, and assessing technology value based on each technology's ability to achieve desired goals (Daim et al., 2011). We applied a research methodology of 5 steps, which integrated AHP into TDE framework as described in Fig. 1.

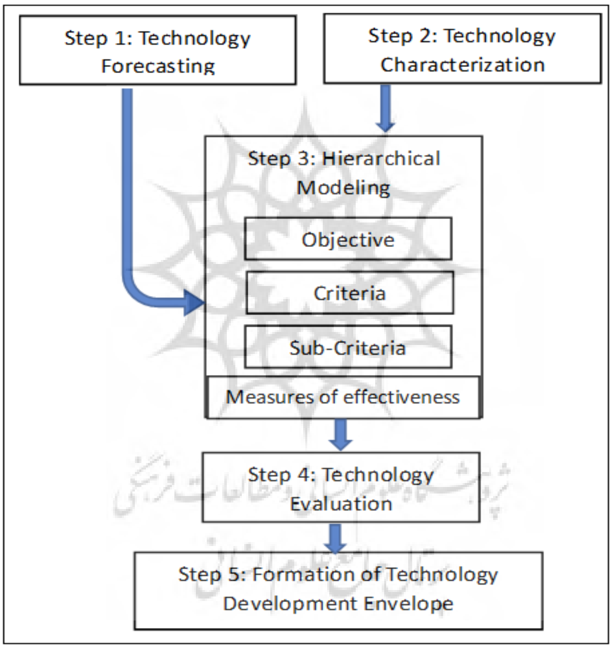

Figure 1. Research Methodology

3-1. Technology Forecasting

One of the common and fundamental steps in the process of formulating a technology strategy and roadmap is technology identification. In this stage, the future trends of emerging technologies and the probable timing for their implementation are predicted. To achieve this, initially, based on research literature, the field of study, and expert opinions, a list of artificial intelligence technologies in the food industry was identified. Preliminary study have shown that some of the identified technologies are currently being used in certain manufacturing processes, while others are expected to be utilized in the industry in the future. An expert panel was formed by experts in technology application. This group consists of managers, supervisors, experts, and technicians from production lines, all of whom are actively involved in the food industry and have knowledge of the technologies used in this industry. This expert panel is responsible for identifying a list of emerging technologies along with the expected time of their availability. The snowball sampling technique was used to complement this group. Using the Delphi technique, experts from the first group (experts in the field of technology application) were requested to predict the feasibility of using selected technologies within a specified time frame based on their knowledge and experience. In the Delphi process, Kendall's correlation coefficient of concordance was used as a measure to determine the level of agreement among panel members

3-2. Technology Characterization

In this stage, the company's objective of evaluating technologies is defined and criteria and sub-criteria are identified according to the objective. In this step, criteria and sub-criteria are defined by experts from the second expert panel. This group includes experts and managers in the field of strategic technology management. This expert panel is responsible for identifying criteria and technological factors relevant to each criterion to assess the organization's objective of achieving a competitive advantage. They determine the relative importance of criteria and sub-criteria.

Based on literature and experts' knowledge of the second expert panel, suitable criteria and sub-criteria for evaluating technologies were determined and defined. Subsequently, a hierarchical structure of the evaluation model was formed at three levels: objectives, criteria, and evaluation sub-criteria.

3-3. Hierarchical Modeling

In this step, through collaboration with experts from the second group, sessions were held to extract the relative importance of criteria and sub-criteria using the Analytic Hierarchy Process (AHP) method.

3-4. Technology Evaluation

Then, the value of each alternative technology (TVn) was calculated using the Eq.(1):

$$TV_n = \sum_{k=1}^{K} \sum_{j_k=a}^{J_k} w_k \, . f_{j_k,k} . V(t_n, j_k, k)$$

Where:

TV_n is value of technology (n), which is determined according to the goal of the company. w_k demonstrates the relative importance of the criterion (k) according to the company's goal. $f_{j_k,k}$ is the relative importance of the sub-criterion (jk) according to the criterion (k). $V(t_n, j_k, k)$ represents the desirability value of the technology (n) along sub-criterion (j_k) for criterion (k).

The value of a technology indicates the degree to which the technology satisfies the organization's objective.

3-5. Formation of Technology Development Envelope (TDE)

Then the results of the previous step is used to form the TDE. By connecting the technologies that have gained the highest value in any given period of time, the technology development envelop is formed, which is defined as the technology development envelop. Finally, sensitivity analysis was conducted.

4. Analysis OF Findings

As mentioned in the introduction section, the purpose of this study is to evaluate artificial intelligence technologies in the food industry and to identify the future development strategy in this industry using the TDE approach. In this section, along with the above method, it shows how to evaluate alternative technologies and how to identify future development strategies. At first, a preliminary study was conducted in order to familiarize and understand the use of artificial intelligence technology in the food industry. Based on this, a number of practical articles and reports were studied. Also, in order to properly understand the artificial intelligence technologies used in the food industry, the production lines of a number of companies engaged in the food industry were visited.

4-1. Technology Forecasting

In this step, a forecasting model was created using Delphi to identify the trends of artificial intelligence technologies in the food industry and determine the time horizon for achieving each technology. Experts were identified, taking into account their experience and expertise in the food industry, and their input was sought in formulating and implementing strategies. This involved seeking assistance from industry experts in the food industry to predict technological advancements. The Delphi method was used to obtain expert opinions for generating strategic information about emerging technologies, including estimating the introduction date and features of these technologies. The output of this stage includes a list of emerging technologies and the time of their occurrence. To predict the timeline of each technology, a questionnaire consisting of eight technologies (as described in Table 1) was developed based on research literature and industry needs. This questionnaire was sent to the experts to assess their availability to contribute to the formulation of the technology roadmap.

Table1. List of technologies related to the food industry

Symbol	Technology	Main Function	Application area
AI1	**biometric**	Biometric systems are used in the food industry as a method of identifying and authenticating a person based on physiological or behavioral characteristics. These systems help to recognize and identify people in the food industry by taking advantage of their unique characteristics of people such as fingerprints, facial recognition, hand vascular scanning, eye cornea scanning and others.	Access control, attendance management, and authentication in production processes
AI2	**Smart sensor**	In the food industry, artificial intelligence sensors are used to control and monitor production processes, and product quality, improve productivity and safety	Temperature sensor, Metal magnetic sensor humidity sensor.

Symbol	Technology	Main Function	Application area
AI3	**Robotics and industrial automation**	Automation and industrial robots improve the performance of production processes, and product quality, and improve safety and productivity.	production lines , Access systems, Processing and packaging, Quality Control, Warehousing and logistics
AI4	**machine vision**	Machine vision is a branch of artificial intelligence that allows machines and systems to perceive and interpret images and videos. In fact, machine vision allows machines to extract useful information from images and videos using relevant algorithms and models. This possibility includes object recognition, face recognition, image analysis, 3D image processing and many others.	**Quality Control** **Classification of raw materials and products** **Monitoring and supervision of production** **Detection of food fraud** Warehouse management and food chain supply
AI5	**machine learning**	Machine learning is a set of algorithms and computational methods that allow a computer to learn from data and make predictions without being explicitly programmed.	**Demand forecasting and optimization,** **Quality Control,** **Forecasting the quality of raw materials,** **Improving the performance of the production process,** Prediction of environmental factors,
AI6	**virtual assistant**	Virtual assistants have capabilities such as answering questions, performing various tasks such as setting reminders and schedules, playing music, searching the Internet, and executing user commands. They are also able to coordinate and communicate with other applications and online services of users	**Guidance and training, Quality Control,** Predicting defects in production lines, Virtual operator, Monitoring and follow-up,

Symbol	Technology	Main Function	Application area
AI7	**neural network**	Artificial neural networks, as one of the advanced technologies in the field of artificial intelligence, play an important role in the food industry. These networks are based on the structure of nerve cells in the human brain and are capable of learning and recognizing complex patterns.	**Quality Control, Demand forecasting,** Optimizing production processes, Forecasting the quality and useful life of products, Optimization of product formulation
AI8	**Autonomous system**	Autonomous system in the food industry means the use of technology and automatic software to perform processes related to the production, preparation and distribution of food products. These systems are able to automatically perform activities such as ordering, preparing and packing, dividing and transporting products from warehouse to customers.	Health and safety, **Food Production** **Packaging and storage** Increase speed and efficiency

For this purpose, a questionnaire was distributed among 40 experts in the food industry. These experts represent a group of individuals who are involved in the development of future technologies in the food industry. The Kendall correlation coefficient was used to determine whether there is a significant difference between individual responses in different courses or not. The result of the first stage correlation test was 0.361, and the Delphi technique was continued. After the first round of Delphi, none of the experts suggested any new technologies, so the research continued with the same 8 technologies. In this research, Kendall's correlation coefficient was used to determine whether to stop or continue the Delphi rounds. Kendall's coefficient of concordance is a non-parametric test used to determine the level of agreement between opinions. The coefficient, represented by the symbol w, is a value between 0 and 1. If the Kendall coefficient is zero, it means there is no agreement, and if it is 1, it means that there is complete consensus. Therefore, in the second step, the questionnaire was distributed to the same individuals with an explanation that they were requested to reread the guide before proceeding with the questionnaire. A standard form, as shown in Table 5, includes an informative description to help experts understand the meaning of each criterion. This enables them to estimate the progress of each technological alternative in each two-year period. Based on their insight into a specific alternative technology, experts provide metrics and measurements as input. The result of the Kendall correlation test for the second stage was 0.781. According to the definition of the Kendall correlation test, this value is considered suitable. Therefore, the Delphi courses were completed.

Table 2. Results of Kendall's correlation coefficient test

Number of steps	The result of the Kendall test
1	0.361
2	0.781

The results of the Delphi technique were shown in Figure 2. The expert group agreed that 5 out of 8 technologies will be ready for implementation by 2028

Figure 2.Time of occurrence of each technology

4-2. Technology Characterization

In this step, the objective of the evaluation model was defined as "selecting AI technologies that are most useful in the food industry." Then, the criteria and sub-criteria related to the purpose of technology evaluation were identified through a literature review and verified by an expert panel. 42 sub-criteria were extracted from the literature. The expert panel acknowledged that there were 5 criteria containing 21 sub-criteria that were relevant for assessing AI technologies in the food industry. Besides, they suggested three sub-criteria (removal of water pollutants, removal of soil pollutants, and reduction of energy consumption) to be considered as sub-criteria of the “environmental” criterion. The list of selected criteria and sub-criteria is presented in Tables 3 and 4.

Table 3. List of criteria

Icon	Criteria	row
C1	Technical	1
C2	Social and political	2
C3	environmental	3
C4	Economic	4
C5	Safety and health	5

Table 4. List of sub-criteria

row	Criteria	Icon	Sub-criteria
1	Technical	F11	Expert force
2		F12	maintainability (Fixing defects and repairs and preventive maintenance and repairs)
3		F13	Upgradable The potential for technological advancement
4		F14	Production capability (use and effective control of technology in the main and supporting processes)
5		F15	Efficiency (maximum output power) / mass production technology (high volume)
6		F16	Credibility
7		F17	Launch time

row	Criteria	Icon	Sub-criteria
8	Social and political	F21	Social and political acceptance of technology
9		F22	Localization industrial facilities (acquisition ability)
10		F23	Human-robot interoperability (adaptation to the status quo: mass employment)
11		F24	Regulations / legal framework
12	Environmental	F31	Reducing waste and hazardous materials
13		F32	Recycle
14		F33	Removal of water pollutants
15		F34	Removal of soil pollutants
16		F35	Reducing energy consumption
17	Economic	F41	Startup capital
18		F42	Operation and maintenance cost
19		F43	Cost of products and services
20		F44	Operational life
21	Safety and health	F51	Food safety
22		F52	Improve product quality
23		F53	Traceability and transparency
24		F54	Detect and reduce fraud

4-3. Hierarchical Modeling

Once the evaluation model was established in a hierarchical structure with three levels (goal, criteria, and sub-criteria), the next step involved conducting sessions in collaboration with experts from the second group. These sessions were aimed at determining the relative importance of criteria and sub-criteria using the Analytic Hierarchy Process (AHP) method. Considering the hierarchical model, each expert provided 59 pairs of comparative judgments. The results indicate that the experts placed the most attention on economic, social, political, and technical criteria, as shown in Table 5. Additionally, Figure 3 displays the hierarchical structure of the approved criteria, along with the scores of the criteria and sub-criteria.

Table 5. Scores of each sub-criterion

Criteria	Weight criteria	symbol	Factors	weight sub-criteria
C1: Technical	0.172	f11	Expert force	**0.032**
		f12	maintainability (Fixing defects and repairs and preventive maintenance and repairs)	**0.031**
		f13	Upgradable The potential for technological advancement	**0.023**
		f14	Production capability (use and effective control of technology in the main and supporting processes)	**0.027**
		f15	Efficiency (maximum output power) / mass production technology (high volume)	**0.021**
		f16	Credibility	**0.016**
		f17	Launch time	**0.022**
C2: Social and political	0.175	f21	Social and political acceptance of technology	**0.069**
		f22	Localization industrial facilities (acquisition ability)	**0.036**
		f23	Human-robot interoperability (adaptation to the status quo: mass employment)	**0.031**
		f24	Regulations / legal framework	**0.038**
C3: Environmental	0.144	f31	Reducing waste and hazardous materials	**0.031**
		f32	Recycle	**0.011**
		f33	Removal of water pollutants	**0.045**
		f34	Removal of soil pollutants	**0.035**
		f35	Reducing energy consumption	**0.021**
C4: Economic	0.371	f41	Startup capital	**0.083**
		f42	Operation and maintenance cost	**0.093**
		f43	Cost of products and services	**0.082**
		f44	Operational life	**0.113**
C5: Safety and health	0.138	f51	Food safety	**0.068**
		f52	Improve product quality	**0.035**
		f53	Traceability and transparency	**0.017**
		f54	Detect and reduce fraud	**0.02**

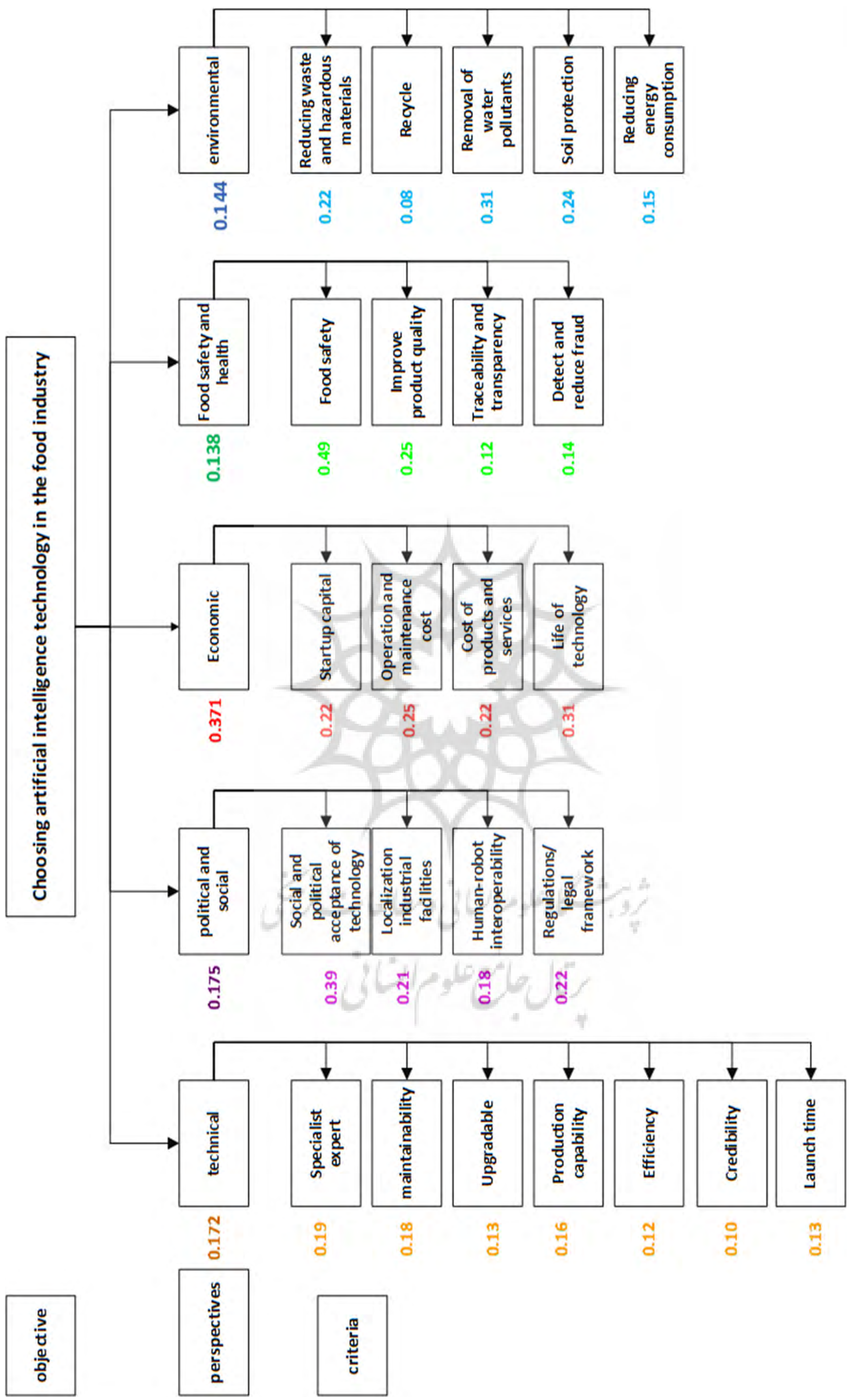

Figure 3. Hierarchy of choosing artificial intelligence technology in the food industry

4-4. Technology Evaluation

At this stage, experts were asked to determine the expected desirability value of each technology in all sub-criteria in different periods by a 5-point scale. The final value of the 8 AI technologies for each time period was calculated through the weighted average of the expected benefits in each sub-criterion as described in Table 6.

Table 6. The importance of each technology in the time period

	2022-2024	2024-2026	2026-2028	2028-2030	2030-2032	2032 onwards
Biometric	2.25	2.14	2.19	2.08	2.15	2.25
Smart sensor	2.87	2.91	3.61	3.47	4.08	4.08
Robotics and industrial automation	3.19	3.20	**3.78**	3.67	**4.19**	**4.30**
Machine Vision	**3.24**	**3.43**	3.66	3.85	3.97	4.09
Machine Learning			3.58	**3.93**	3.97	4.14
Virtual Assistant			2.63	3.08	3.55	3.80
Neural Network						3.97
Autonomous System						3.82

4-5. Formation of the Technology Development Envelope

Regarding the results of the preview steps, the TDE was created as shown in Figure 4. Each line represents the projected development path of a specific technology over different time periods. The dotted line represents the Technology Development Envelope (TDE), which connects the technologies with the highest values in each time period. The Technology Development Evolution (TDE) is a progression that connects various fields of technology. It starts with Machine Vision in 2022 and continues with Robotics and Industrial Automation in 2026-2028. Machine Learning is then incorporated in 2028-2030, followed by Robotics and Industrial Automation again in 2032.

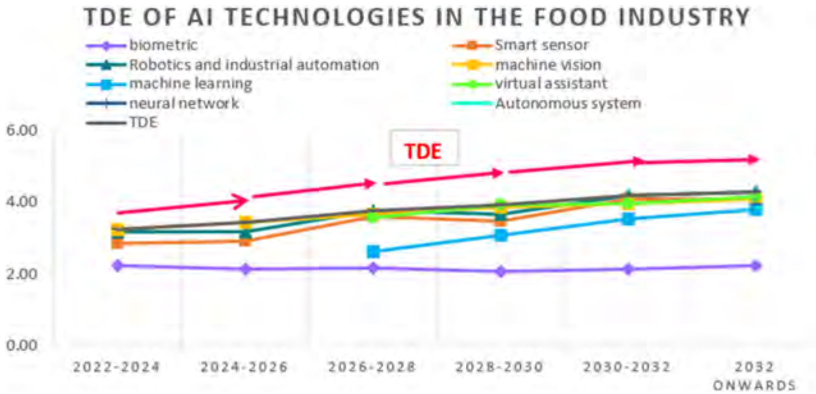

Figure 4.TDE of AI technologies in the food industry

4-6. Sensitivity Analysis

There is a lot of uncertainty surrounding both technology and industry. Therefore, any future changes will impact the calculated values. Scenarios (Amer et al., 2013 and Cinar et al., 2010) are used to demonstrate the sensitivity of models, including the model presented in this research. In Table 7, scenarios were defined based on expert opinions. The results of these scenarios can be seen in Figures 6-8. These scenarios show the extent to which technology alternatives meet the objectives under extreme strategies.

Table 7. Future Scenario

	Technical	Social & political	environmental	Economic	Safety & health	Total
Base Case	0/172	0/175	0/144	0/371	0/138	1
Scenario1	0/83	0/04	0/06	0/04	0/04	1
Scenario2	0/07	0/8	0/05	0/04	0/04	1
Scenario3	0/07	0/04	0/8	0/04	0/04	1
Scenario4	0/07	0/04	0/05	0/8	0/04	1
Scenario5	0/07	0/04	0/05	0/04	0/8	1

Scenario 1

According to this scenario, the strategic focus is on the technical dimension. The importance of the technical dimension is 0.8. From the beginning of the year 2022 to the beginning of the year 2026, smart sensors are at high priority for use and investment. From the year 2026 to the beginning of the year 2032, automation and industrial robots are in priority for investment. Finally, from the year 2032 onwards, machine vision is proposed as an option agreed upon by experts.

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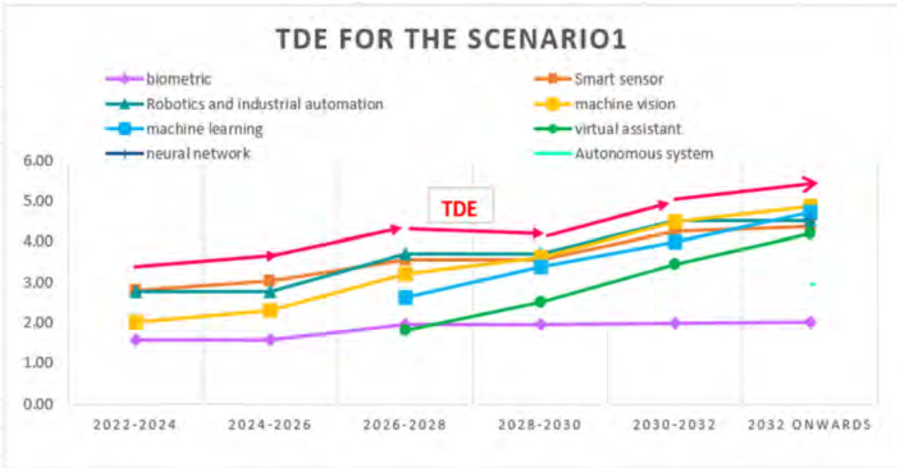

Figure 5. TDE for the scenario 1

Scenario 2

According to this scenario, if the strategy of focusing on the social and political dimension is considered, the main focus in the first to fourth periods (from 2022 to the beginning of 2030) is on artificial intelligence sensors. From 2030 to 2032, there was a significant focus on machine vision technology. In general, social and political criteria can be used as tools to evaluate the impact of new technologies on societies and political systems.

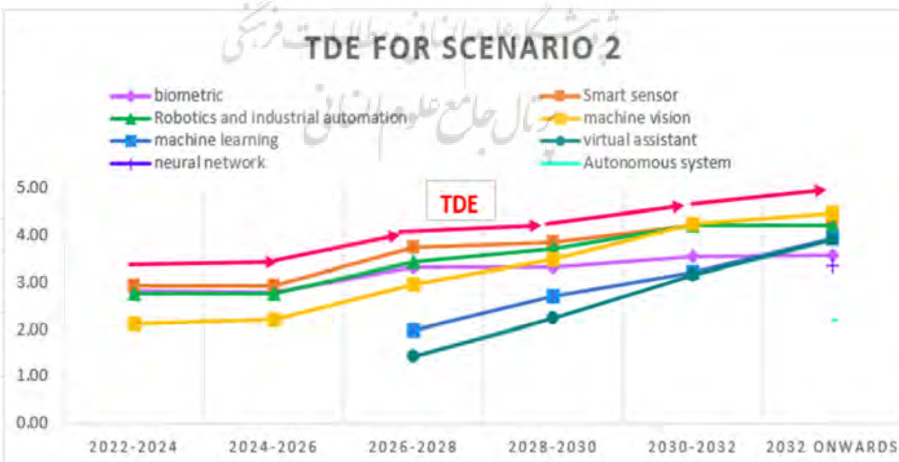

Figure 6. TDE for the scenario 2

Scenario 3

Fig. 5 depicts the results when focusing solely on the environmental dimension. In this scenario, from 2022 to early 2032, the main focus is on automation and industrial robots. In the time periods from 2032 onwards, the focus shifts to machine vision technology.Scenario 4

The strategy focused on the economic dimension would lead to the highest value for machine vision from 2022 to the beginning of 2026. In the time period from 2026 to the beginning of 2032, the focus is on machine learning. From 2032 onwards, the main focus shifts to autonomous systems.

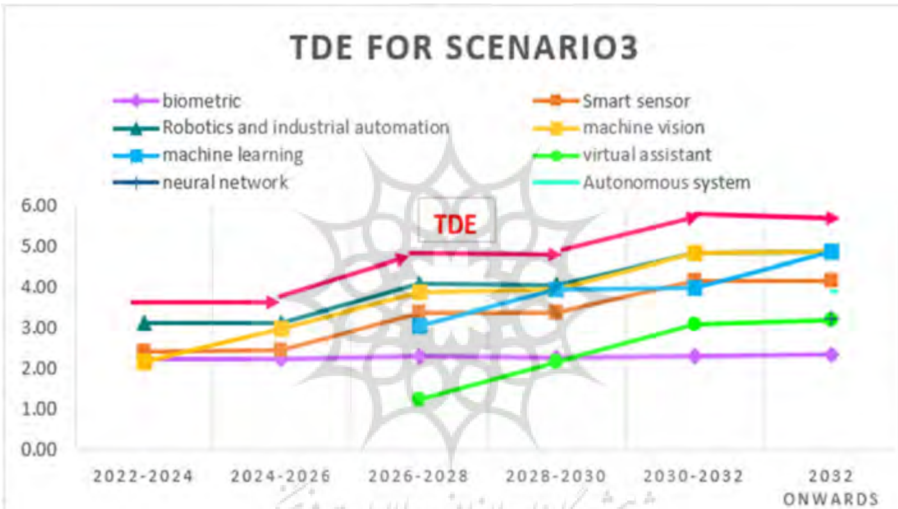

Figure 7. TDE for Scenario 3

Scenario 4

In the strategy focused on food safety standards, the main focus from 2022 to the beginning of 2026 is on machine vision. In the time period from 2026 to the beginning of 2030, the focus is on machine learning. From 2030 to 2032, the focus shifts to machine vision.

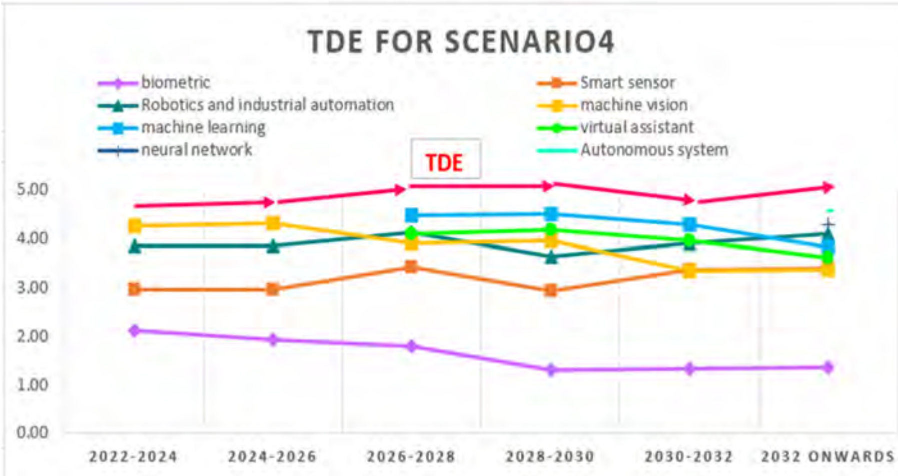

Figure 8. TDE for Scenario 4

5. Discussion and Conclusion

This paper has utilized the Technology Delphi Evaluation (TDE) method in conjunction with the Delphi and Analytic Hierarchy Process (AHP) methods to assess emerging technologies in the food industry and determine the most beneficial technologies for this sector within a ten-year timeframe. A hierarchical evaluation model was developed through a literature review and with the assistance of an expert panel. This model includes 5 main criteria and 24 evaluation sub-criteria. The results of AHP show that in the studied industry, the economic, technical, and social and political dimensions are the most important ones in the evaluation of AI technologies. The economic and performance aspects were also considered the most important evaluation criteria in previous research (Gerdsri and Kocaoglu, 2007; Tugrul et al., 2011; Daim et al., 2018). The expected value of AI technologies was calculated for six time periods, and the total economic impact (TDE) of the food industry was determined. The results showed that machine vision technology and industrial robots were in close competition in five periods. However, in the period of 2028-2030, machine learning has been identified as the top priority. By reducing human intervention in the processing chain, these technologies can lead to the production of healthier and higher quality foods. With a closer look, it becomes evident that artificial intelligence sensor technology is also crucial in this industry. It should be noted that changing conditions and the strategies of policymakers can have a significant impact on the evaluation results and the output of TDE. This issue was addressed in the sensitivity analysis section, where extreme scenarios were defined for each of the five evaluation dimensions to investigate the impact of different strategies on TDE results.

Considering the ever-increasing developments in the field of artificial intelligence and its applications in various industries, it is expected that artificial intelligence will play an important role in the food industry. In the future, AI could bring about significant changes to the food supply chain, manufacturing processes, quality control, operational optimization, and customer experience. The analysis of the future indicates that technologies such as computer vision, robotics, industrial automation, and machine learning will undergo continuous improvements over time and eventually become dominant technologies in the food industry. These advancements can lead to an increase in quality and efficiency within the food industry. Based on this analysis, companies can develop appropriate strategies to effectively manage these technologies in the food industry. Furthermore, they can make investment decisions to accelerate the development of these technologies. This study is limited to AI roadmapping in the food industry of Iran. However, it is proposed that further research should investigate the AI roadmap in other industries and develop an integrated roadmap for future studies.

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