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Mapping the critical factors of IoT implementation in the food industry

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The Internet of Things (IoT) is revolutionising the food industry by enhancing efficiency, safety, and sustainability, while food businesses have observed a slow adoption of IoT. This paper delves into the key factors influencing IoT implementation in the food industry. The key factors influencing the implementation of IoT technology in the food industry have been examined using a hybrid Fuzzy-DEMATEL (Decision-Making Trial and Evaluation Laboratory) approach to understand the complex interrelationships. The findings indicate that the company's financial position, managerial support, and competitive pressure are the major causal factors. These causal factors impact the complexity of usage and the existing policies and standards towards the decision to implement IoT in the food industry. The outcomes of this research are highly valuable for researchers, managers, and policymakers in providing insights for effectively strategising the implementation of IoT technology and thereby maximising its potential in the food industry towards traceability, transparency and sustainability as well as further developing models and SDGs.

Sustainability spotlight

This research has implications for researchers, managers, and policymakers regarding the effective implementation of the Internet of Things (IoT) technology, thereby maximising its potential in the food industry towards improved traceability and transparency, as well as social and environmental sustainability. The 'Need for sustainability' factor has been categorised as an influential factor among others. The findings indicate that IoT implementation in the food industry can address various supply chain challenges while improving food safety and also covers various UN SDGs, specifically SDG 3, SDG 9, and SDG 12.

1. Introduction

Despite the vast scale of the food production sector globally, factors such as inadequate control and suboptimal quality management contribute to considerable waste and inefficiency, posing challenges in terms of both economic and operational effectiveness.[1] According to the report of the United Nations, 13% of the global food produced is lost in the supply chain stages of post-harvest to retail, and 17% of the entire global food production gets wasted at the household level, and catering or distribution functions.[2] Food wasted throughout the supply chain results in almost 800 million people undernourished globally.[3] Technologies like the Internet of Things (IoT) have the potential to provide a more flexible and efficient supply structure, which could aid in the solution to the food safety issue.[4] IoT has been established as a vast mix of statistics, processing, communication, and facilities. Over the past years, the IoT has become widely accepted and popular due to its ever-growing relevance, usefulness, ease, and wide range of applications, which include quick, easy, and sustainable solutions.[5] The food industry has seen IoT's slow but steady emergence to maintain food safety standards and find and fix supply chain incompetency by increasing productivity, boosting precision, and reducing labour costs.[6] IoT can help reduce food wastage, maintain safety regulations, monitor food quality, and assess economic, social and environmental issues.[6–8] IoT in the food business has many prospects due to the broad diversity of accessible sensors and the even wider availability of software solutions to examine the data.

The integration of IoT technology facilitates enhanced oversight of the food supply chain across all stages, ranging from procuring raw materials in production to distributing final goods to end users. Additionally, it makes data collection effortless, allowing food companies to guarantee improved levels of safety and traceability throughout the whole supply chain and lowering costs, risks, and waste throughout the process.[7] Like any other industry, the food industry has seen significant changes, and research indicates that the use of IoT utilities in this area is expanding significantly.[5] IoT revolutionises the food industry by enhancing supply chain transparency, optimising production processes, and ensuring food safety. Therefore, information and communication technology has

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become essential to make it more convenient. In supply chain management, IoT can help ensure the traceability and tracking function of the products. An effective food traceability system in the food supply chain should ensure that it gives detailed information to consumers, complies with regulatory requirements, and improves food safety and consumer confidence. Modern food traceability systems are mainly IoT-based due to the rapid development of information and communication technologies, especially IoT.[9] The need for safe and sustainable food production has become more urgent in a world facing the dual challenges of a growing population and changing climate patterns. Most companies have adopted real-time data monitoring systems to ensure quality throughout the supply chain network and address the increasing sustainability problem in food chains. The efficiency of IoT in collecting and sharing information has improved since its development. Recently, developments in data mining technologies have helped uncover vulnerabilities and give early warnings on food safety risks throughout the farm-to-fork process. This led to the development of systems that could analyse food safety risks and give out pre-warnings based on already established food safety and quality assurance guidelines.[10]

Extreme climate events, such as late spring frosts (LSFs), significantly negatively affect plant growth, productivity, and overall crop yields. The scientific community widely acknowledges climate change as one of the most pressing environmental issues of the 21st century and a major factor influencing the sustainable development of agriculture and food systems globally. To address this challenge, adopting digital agricultural technologies (DATs) has become a critical component of this transformative process. These technologies encompass various tools such as communication, information, and spatial analysis systems. By integrating agricultural data from a range of sources, including sensors, weather stations, and drones, into a unified platform, these technologies hold the potential to enhance agricultural practices significantly.

Similarly, in the direction of food processing and safety, various technologies are introduced like a new method of monitoring food adulteration by Gupta and Rakesh, which Raspberry Pi governs that controls all the sensors for temperature, pH, humidity content, oil content, colour, metal, and salt. The user-friendly nature of the device can be used by anyone (farmers, consumers, *etc.*) to test adulteration.[11] Another IoT-based system to avoid contamination and deterioration of food uses a WASPMOTE sensor, which gathers information regarding temperature and humidity and later sends alert notifications to the manufacturer with the help of the Raspberry Pi unit.[12] Chen and colleagues developed an IoT-based cold chain network for perishable food products, which can be adopted to keep them fresh. Temperature, humidity and pressure sensors are deployed in the cold chain products with a new type of RFID application named 2G-RFID-Sys, which further ensures the correctness of the system.[13] IoT has been increasingly used in the food industry to improve efficiency, reduce energy consumption, and enhance food safety. IoT-enabled systems can provide valuable services to the food industry, such as developing automatic machinery to reduce human effort, increasing food safety through ICT-enabled traceability systems, and improving user-friendliness, easy access, cost-effectiveness, and security.[14,15]

The rising forces of sustainability and operational efficiency are compelling the major global industries to exploit the IoT as a transformative influence that can give them unparalleled insights and control. By adopting IoT for supply chain management, companies are revolutionising their approaches toward monitoring, managing, and optimising their operations. IoT refers to an assemblage of devices set up to communicate with each other over the internet, enabling real-time data collection and seamless exchange of information. This increased visibility helps the supply chain function better and more agile while allowing the business to respond to market demands by raising customer satisfaction. IoT for supply chain processes has already proven to be one of the very important means of keeping in line with the new needs of modern markets, as most of them need to be plugged into information regarding their needs in today's fast-changing world.[16] For example, smart RFID tags have been used for real-time tracking and monitoring of the cold and fresh fish logistics chains. IoT-based systems have also been designed to improve logistics to its better version during the transportation, storage, and sale of food products, as well as their safety assessment.[14,15,17,18] IoT technology has been used to monitor real-time food safety and freshness. For instance, IoT sensors have been used in many perishable commodities, including medicine, to ensure they stay out of the "danger zone" of temperature compliance. An IoT-based application has also been used to analyse food ingredients and quantify food nutrition using sensors.[19] In addition, IoT technology has been used in agriculture, such as precision agriculture, which is a sustainable, ecological, and gainful approach to increasing agriculture yields and quality. Cloud computing can also be accommodated with IoT to ensure the quality and sustainability of smart agriculture.[17,18]

Technological development today should be coupled with real-world applications within human-inhabited places, and then public health considerations and energy efficiency should be integrated as key concerns; this understanding is essential for how SDGs will affect the applications of sensors and the Internet of Things in such environments. Energy efficiency and environmental sustainability are closely tied to human health, and the quality of life is increasingly dependent on technology, sensor networks, intelligent systems and IoT applications.[20]

IoT is important for industrialised nations and for pushing sustainable development in developing regions. Regarding efficiency and productivity, IoT has positively impacted advanced economies. It is equally important to advance growth in less-developed regions. In recent years, IoT projects have started to appear in the developing world, especially in sub-Saharan Africa and the southern regions. For example, IoT applications have been integrated with renewable energy systems to monitor and manage their energy. The water sector has tremendous potential, especially in projects providing water for sanitation in rural areas of developing countries.[21]

The emergence of IoT technology presents opportunities for its application within the food industry, though it necessitates the exploration of various dimensions, such as organisational policies and adoption strategies. Only a few businesses have been able to integrate IoT into their business, while many ended up failing; therefore, it is vital to consider that certain key factors drive the implementation of IoT in an organisation.[22] The slow adoption of IoT technology is due to the fact that it comes at a very high cost initially and requires very complex infrastructure, and people fear its usage for security. Furthermore, access to reliable internet and power, lack of technical expertise, and scarcity in the technical sector as a whole are restricting its wider adaptation in these regions. Standardized protocols and interoperability between devices add another complexity to further IoT integration. However, with the reduced cost and awareness regarding the benefits of IoT in health, energy, and water management, adoption is gradually gaining steam across each of these sectors. Therefore, the current study delves into the core issues surrounding the integration of IoT in the food industry, specifically, the key factors driving IoT adoption alongside the underlying motivations of food companies. This study illuminates the factors influencing IoT adoption in the food sector, and thus, the proposed research questions (RQs) are as follows:

RQ 1: What are the critical factors influencing the implementation of IoT in the food industry?

RQ 2: What are the connections among these influential factors in implementing IoT?

The study followed a two-fold approach. Firstly, it conducted a thorough literature review to identify the influential factors affecting IoT implementation in the food industry. Subsequently, the hybrid Fuzzy-DEMATEL method was employed to prioritise these factors and analyse the interrelationship among the IoT adoption factors.

Several authors used the Fuzzy-DEMATEL method to determine the influential factors in adopting IoT in various industries. An example is the work of Mahmoud Zahedian Nezhad when analysing readiness regarding the adoption of IoT and identifying determinants encompassing technology, organisation, and environment.[23] On the contrary, Pant and Palanisamy (2020) revealed that gaps in the infrastructure and cyber-attack threats to the security of their systems formed obstacles to logistics.[24] Similarly, Priyanka Vern researched blockchain adoption in agricultural supply chains, whose main findings, according to her, were technical and regulatory challenges.[25] The studies prove that Fuzzy-DEMATEL effectively deals with complex inter-linkages and ranks critical factors for successful implementation. Out of such results, the present work extends to a similar approach to check IoT adoption in the food industry.

The structure of the paper is as follows: it begins with a comprehensive literature review, which provides an overview of the current state of knowledge and identifies gaps that the study aims to address. This is followed by the methodology section, where the research design, data collection methods, and analytical techniques are detailed, allowing for replication and a clear understanding of the study's approach. Next, the results section presents the study findings, showcasing the data analysis and highlighting significant outcomes. Sections 5 and 6 describe the discussion and implications section. Finally, in Section 7, the paper concludes with a summary of the major findings, offering a concise conclusion that encapsulates the study's contributions. The paper ends with a limitations section, acknowledging the study's constraints and suggesting areas for future research.

2. Literature review

The implementation of IoT in the supply chain and waste management of the food processing industry has been widely studied in recent years. IoT can play a significant role in reducing food waste generation, improving food safety, and increasing the transparency of the food supply chain.[26] IoT can help reduce food waste generation by implementing systems that can reduce waste generation, energy consumption, and water consumption. For instance, a smart garbage system has been developed, which is IoT-based for efficient food waste management.[27] This system uses IoT sensors to track the waste level in the waste bin. It sends signals to the waste management authorities when the bin is filled to the brim, allowing for timely waste collection and reducing the amount of food waste generated. Furthermore, the IoT can improve food safety by increasing risk management and continuous pressure from consumers to deliver high-quality and safe food products. For example, an IoT-based risk monitoring system for managing cold supply chain risks has been developed.[28] This system uses IoT sensors to monitor humidity, temperature, and other environmental factors affecting food quality during transportation and storage. By monitoring these factors in real-time, the system can alert the relevant authorities if any deviations from the optimal conditions are detected, allowing for timely intervention and reducing the risk of foodborne illnesses.

Transparency in the food supply chain is another area where the IoT can significantly impact. By increasing transparency, the IoT can help build trust between consumers and food manufacturers and improve supply chain efficiency. For instance, an IoT-based system has been developed to improve logistics during the shipment, storage, and sale of wine bottles, including their safety assessment.[26] This system uses IoT-integrated sensors to monitor the location and condition of wine bottles during transportation, allowing for real-time tracking and ensuring that the bottles are stored and transported under optimal conditions. However, implementing IoT technology in the FSC is not without challenges. Limitations on scalability, new technologies, and the lack of regulatory frameworks are a few challenges.[29] Therefore, supply chain authorities must provide information promptly and properly to win end-users' trust. The IoT can also contribute significantly to reducing food waste generation, improving food safety, and increasing the transparency of the FSC.[30]

2.1 Factors affecting the implementation of IoT in the food industry

IoT is gradually getting recognition in the food industry for its various benefits, but different factors affect its implementation

Table 1 Critical factors affecting IoT implementation in the food industry

	Factors	Description	Sources
A1	Financial position of the company	Investment capacity, financial stability of the company	31–34
A2	Infrastructure and equipment	Basic need for automation and compatibility with the existing system	22 and 35–37
A3	Managerial support	Acceptability of IoT; support from top management	38–40
A4	Competitive pressure	Pressure to keep up with competitors in the industry	31, 32 and 41
A5	Source of differentiation	Differentiation from the others in the marketplace	42
A6	Skilled human resource	Training; availability of skilled force; knowledge	43 and 44
A7	Need for sustainability	Having some effects on the environment, and the organisation needs sustainability	45 and 46
A8	Established government policies and standardisation	Compatibility with government laws; incentives offered by the government	47–51
A9	Complexity of usage	The complexity of usage and implementation of IoT in the food industry	52

in the food industry. An extensive literature review identified nine critical factors for implementing IoT in the food industry, as discussed in the subsections below and summarised in Table 1.

2.1.1 Complexity of usage. The complexity of usage is a critical technical factor that significantly impacts the implementation of IoT technologies. The complexity of IoT adoption can act as a barrier, emphasising the need to simplify the setup and maintenance of IoT infrastructure to enhance user acceptance and facilitate widespread adoption.[52] IoT adoption often involves integrating various devices, sensors, and data analytics systems. The complexity of this process can deter organisations from adopting IoT solutions. Factors contributing to this complexity include the lack of user-friendly interfaces, difficulties in integrating IoT systems with existing infrastructure, the need for specialised technical expertise, and challenges in scaling up the IoT system to meet evolving needs.[52] Organisations can leverage IoT technologies effectively by addressing the complexity of usage and simplifying the IoT implementation process. This can enhance operational efficiency, reduce waste, improve safety, and optimise overall performance.

2.1.2 Established government policies and standardisation. The authenticity of a food product can be confirmed by the diversity of standards implemented by governmental, inter-governmental, and non-governmental organisations and by national and international laws.[47] By implementation of blockchain technology, the authenticity of food supply chain-related records can be verified without any legal authority requisite and, in turn, fulfils governmental regulations, brings in ingenious ideas and perfects the existing governance.[48] Blockchain technology needs standardisation, though standardisation of data *via* IoT is often foreseen as a challenge leading to difficulty in data analysis, transmission and allocation.[49] The challenge of standardisation encountered is explained *via* an example of India. Prominent aid is being provided by the government to the agricultural sector, for, in 2017 and 18, USD 4.9 billion was provided as a budgeted subsidy. Still, poor blockchain policy and unstructured mechanisms provided improper data regarding its reach to intended recipients.[50] Thus, government authority has been considered an essential part of the food supply chain as it eliminates the gap between international and domestic firms by creating regulatory policies and promoting R&D.[51]

2.1.3 Need for sustainability. The complexity of the supply chain and the involvement of various entities, including the high number of stakeholders and shareholders, perishability of food, irregularity in yield and fluctuating demand-supply ratio, make it challenging to ensure the sustainability of the environment. To attain environmental sustainability, the focus should be on the utilisation of the utmost quantity of food along with attaining almost zero food wastage, as wastage does not only limit itself to it not being utilised but also leads to the emission of greenhouse gases in warehousing and transit.[45] Eco-efficiency, *i.e.*, manufacturing more produce whilst having lower environmental consequences and lower degradation of bioresources, is one of the important contexts against which OECD (Organization for Economic Cooperation and Development) sets various standards for evaluating environmental efficiency with the help of IoT sensors. By tracking variables such as temperature, rain and humidity, an environmental performance index is measured using sensors to increase efficiency and reduce wastage.[46]

2.1.4 Skilled human resource. The availability of skilled human resources plays an important role when adopting any form of IoT in an industry. They are important for the selection, design, implementation, and maintenance of IoT devices, as well as for maintaining the required productivity and outcome of the processes for which the systems are employed. Employing the right expertise and skills, they can optimise processes, boost efficiency and innovation, and uncover new business opportunities in technology. Professionals with knowledge of IoT technologies recommend new updates that can be implemented in IoT to gain more productivity.[43] Human resources with subject-specific knowledge are vital to implementing solid security measures like encryption, authentication, and protection against cyber threats. The availability of professionals with expertise, particularly in IoT technologies and the unavailability of expertise in some affect the decision-making process of businesses during the selection and implementation of IoTs.[44] IoT devices generate complex and vast data, requiring individuals' proficiency and experience to manage and analyse it precisely and extract applicable insights. These formulate algorithms to derive valuable information to drive decision-making and improve operational efficiency. Expert technicians troubleshoot the concerns and assist the users while understanding the complexities of connecting various devices, sensors, and networks to ensure seamless communication and data exchange.[43]

2.1.5 Managerial support. Technology has been a thrust that, among other drivers, has enabled service innovations to be technically feasible and economically viable. However, strategies and decisions taken by a firm regarding service innovation call for top management support.[38] Top management promotes innovation by creating a friendly environment that fosters creativity and strategic decisions to ensure knowledge generation and its practical application. Organisational structure has received much attention from researchers and practitioners in management, mainly because it helps an organisation perform its functions.[39] When a disruption or risk in the supply chain is observed, top management support takes responsibility for developing a supply chain system by integrating IOT that is flexible with future risks and helps in information transfer within management.[40]

2.1.6 Infrastructure and equipment. It has been observed that the biggest barriers to IoT adoption in the food industry are the operational and maintenance costs of the equipment and smart devices for maintaining and getting them repaired. Due to the absence of the proper infrastructure for the adoption, the staff members in the FSC do not have adequate knowledge about the IOT systems, and the cost of training them is also very high.[36,37] Therefore, robust infrastructure support is important for IoT implementation.[35] Proper infrastructure with the availability of tools, protocols, and applications is required to create an environment for IOT adoption. Many previous studies have proposed and developed various IOT architectures showing how significant equipment and infrastructure are in adopting IoT at the industrial level.[22]

2.1.7 Competitive pressure. Contemporary organisations actively pursue advanced technological innovations to address the intricate and dynamically evolving business landscape and customer preferences. Such innovations are increasingly recognised as potent instruments for attaining enduring and sustainable success in the long term.[41] Researchers have highlighted the significance of aligning IoT strategies with prevailing market trends to capitalise on emerging opportunities and mitigate potential risks. For instance, the growing emphasis on data-driven decision-making and predictive analytics in response to market demand for personalised experiences has fuelled investments in IoT platforms capable of generating actionable insights from vast volumes of sensor data.[31] The IoT enhances competitiveness by streamlining operations, thereby reducing risks of product discontinuation. It further enhances supply chain management and reduces costs. Using IoT applications, businesses stand to benefit by achieving real-time tracking of assets, monitoring material flow, managing transportation, and managing risk. This means we aim for a self-sustaining supply chain platform requiring minimal human input.[41] Researchers have also documented how the fear of falling behind rivals and losing market share motivates firms to invest in IoT technologies to boost productivity, streamline operations, and provide superior customer experiences.[32]

2.1.8 Financial position of the company. In recent years, extensive research has consistently demonstrated that financial factors significantly influence firms' investment decisions.[33] The successful implementation of Internet of Things (IoT) technologies needs substantial investment in infrastructure, innovation, and expertise. However, not all companies have equal financial resources to support IoT initiatives.[34] The literature on IoT implementation acknowledges the significant impact of financial factors on adopting and utilising IoT solutions. Research has revealed that money is the main obstacle to adopting IoT, especially for small and medium-sized businesses (SMEs) with restricted financing access. The literature also highlights the importance of financial stability and investment capacity in enabling organisations to commit to IoT projects. Companies with robust financial positions are better positioned to allocate resources for IoT infrastructure, data analytics platforms, and skilled personnel, thereby gaining a competitive advantage in the marketplace.[31,32]

2.1.9 Source of differentiation. IoT systems collect and transfer data to provide new insights, monitor critical operations, boost efficiency, and allow businesses to make better decisions. Quick data processing enables businesses to deliver the results to decision-makers within the company. This helps generate higher revenues and improve the quality of an organised work environment. Several factors can bring differentiation through the implementation of IoT systems, as these play a crucial role in recording and transmitting data to monitor critical processes, providing new insights, enhancing efficiency, and enabling companies to make more informed decisions. By leveraging connected devices across various industries, businesses gain valuable insights into operations and customer behaviour, improving the overall customer experience. These devices facilitate increased efficiency and productivity by seamlessly connecting key business processes while enabling asset tracking and reducing waste through real-time or near-real-time data on process flows and material consumption. IoT empowers organisations to innovate and create new business models by quickly providing information on customer needs and preferences. This valuable data allows companies to offer tailored services based on product interconnectivity, often offsetting the initial costs of IoT implementation and opening up new revenue streams.[42] So, implementing smart systems can help a business gain an advantage over its competitors in the marketplace and transform old business models into new ones to generate reliable and efficient results and profits.

3. Methodology

The implementation of IoT in the food industry has escalated surplus in the past years. Several factors influence the adoption and implementation of IoTs within a company. This study was conducted to determine the major influential factors in IoT implementation in the food industry and to find the interrelation between the factors. The study was conducted in two phases, using a qualitative and a quantitative approach.

Phase 1: identifying the factors influencing the implementation of IoT in the food industry.

Phase 2: Fuzzy-DEMATEL approach to analyse the cause-and-effect relation between factors.

A systematic review approach was adopted to determine and conclude the influential factors affecting the implementation of IoT in the food industry, and the hybrid Fuzzy-DEMATEL approach was applied to study the interrelation between the factors (Fig. 1).

Phase 1 of the study consisted of different stages to identify the most concise and crisp group of key influencing factors.

Stage I (literature search): over 50 research studies were reviewed, including work on IoT implementation and adoption in the past years. These studies were conducted across various industries like manufacturing, healthcare, food, agriculture, energy, construction, retail, transportation and logistics, management, *etc.*, reflecting the application, benefits and challenges of IoT implementation.

Stage II (search strategy; keywords search): the search strategy included the identification of keywords that could be considered as influencing factors of IoT implementations. These included the beneficial factors, limitations, internal factors of the company, and external factors such as political, social, technological, *etc.*

Stage III (selection): a thorough analysis of the above outcome was done to bring all the factors under a few heads to proceed with the study more precisely.

Finally, the literature survey of various studies broadly concluded the nine influential factors affecting the implementation of IoT in the food industry, as presented in Table 1, along with a description and literature source.

Phase 2 consisted of selecting experts to rate each factor's impact on another in implementing IoT and to study the interrelation between the factors through the Fuzzy-DEMATEL method. The Fuzzy-DEMATEL approach suggests that a group of five to ten experts with relevant subject knowledge and experience is adequate to provide input according to the standardised matrix.[53–56] Selection of experts: eight experts were

Fig. 1 Methodology (source: authors).

consulted for this study. This group included three experienced professionals currently working in the food industry and five academicians selected based on their specific fields of expertise. Among the academicians, three specialised in business management, and two had expertise in the IoT's technicality. The experts were approached to evaluate the influence of various factors on each other. Developing linguistic scale for evaluation: the rating of the influence of each factor on another was performed on a linguistic perception scale containing the items in the group decision-making proposed by Li (1999) mentioned in Table 2.[57]

Rating of factors: all eight experts were asked to rate the influence of one factor on another on the linguistic perception scale mentioned above in a 9 × 9 matrix with all the nine factors on horizontal and vertical axes. The data was further analysed using the Fuzzy-DEMATEL method to study the interrelation between the factors.

3.1 Fuzzy-DEMATEL method

DEMATEL model: the DEMATEL concept was first developed by the Geneva Research Centre in The Battelle Memorial Institute.[58] This approach converts complex structures into simpler and direct forms. The basic purpose of this method is to have a comparative study of the different factors based on their influence on each other and to make more structured decisions. Fuzzy theory: fuzzy set theory, developed to resolve uncertainty of several complex situations, was proposed by Zadeh,[59] as he believed that humans' perception and understanding are vague in such complex problems because of internal factors like demographic and cultural aspects. Fuzzy theory has shown effective and positive outcomes in various fields like weather forecasting, environmental assessment,[60] social sciences, production management,[61] inventory control, logistics, banking and finance, marketing.[62]

Fuzzy-DEMATEL is the extended method of DEMATEL for more complex situations to get more precise values.[63] This method is used to study the complex factor's dependency on each other and the cause-and-effect relationships among them. In recent years, DEMATEL has been practised by various industries and fields in decision-making and problem-solving processes. Muhammad Nazir Muhammad and Nadire Cavus used this method to evaluate LMS (Learning Management Systems) evaluation criteria. They concluded the three most important criteria among the 12 considered criteria.[64] M. N. Mokhtarian used this method to address the appropriate segmentation of required managers' competencies to promote global competency among managers.[65]

3.1.1 Implementation of Fuzzy-DEMATEL

3.1.1.1 Step 1. The factors affecting IoT implementation in the food industry were identified through a literature analysis. The experts with knowledge and experience in the relevant field were identified and approached to collect the responses. The experts were asked to highlight the influence of each critical factor on others using a linguistic scale mentioned in Table 2.

The number of experts is defined as 'n'.

3.1.1.2 Step 2. A 9 × 9 matrix of a direct relation matrix was formed, and the responses were converted to the quantitative terms described in the linguistic perception scale table. The triangular fuzzy number represents the values of the individual linguistic term, handling the vagueness/ambiguity of the expert opinions. The diagonal values were marked 0 as there was no relation between the two identical factors.

3.1.1.3 Step 3. The fuzzy assessment matrices were de-fuzzified and transformed to integrated crisp values using the equations given below.

$$xl_{ij}{}^{k} = (l_{ij}{}^{k} - \min l_{ij}{}^{k})/\Delta_{\min}{}^{\max} \tag{1}$$

$$xm_{ij}{}^{k} = (m_{ij}{}^{k} - \min m_{ij}{}^{k})/\Delta_{\min}{}^{\max} \tag{2}$$

$$xu_{ij}{}^{k} = (u_{ij}{}^{k} - \min u_{ij}{}^{k})/\Delta_{\min}{}^{\max} \tag{3}$$

$$\text{where, } \Delta_{\min}{}^{\max} = \max u_{ij}{}^{k} - \min l_{ij}{}^{k} \tag{4}$$

Then, Ls & Rs were calculated with the help of,

$$x\mathrm{Ls}_{ij}{}^{k} = xm_{ij}{}^{k}/(1 + xm_{ij}{}^{k} - xl_{ij}{}^{k}) \tag{5}$$

$$x\mathrm{Rs}_{ij}{}^{k} = xr_{ij}{}^{k}/(1 + xr_{ij}{}^{k} - xm_{ij}{}^{k}) \tag{6}$$

Crisp values were calculated by:

$$x_{ij}{}^{k} = [x\mathrm{Ls}_{ij}{}^{k}(1 - x\mathrm{Ls}_{ij}{}^{k}) + x\mathrm{Rs}_{ij}{}^{k^2}]/[1 - x\mathrm{Ls}_{ij}{}^{k} + x\mathrm{Rs}_{ij}{}^{k}] \tag{7}$$

Finally, the total normalised crisp values:

$$z_{ij}{}^{k} = \min l_{ij}{}^{k} + x_{ij}{}^{k}\cdot\Delta_{\min}{}^{\max} \tag{8}$$

3.1.1.4 Step 4. The integrated crisp values were calculated using the formula

$$Z_{ij} = \frac{1}{n}\left(z_{ij}^{1} + z_{ij}^{2} + z_{ij}^{3} + z_{ij}^{4}\ldots + z_{ij}^{n}\right) \tag{9}$$

3.1.1.5 Step 5. To obtain the total relation matrix:

$$P = \frac{1}{\max\sum_{j=1}^{n} Z_{ij}} \tag{10}$$

P is the column matrix of the reciprocal of the maximum values of each row (j) of the matrix $M = [\mathrm{Zi}_j]$

Table 2 Linguistic scale for evaluation

Code	Linguistic terms	Normal scale	Fuzzy scale
NI	No influence	0	(0,0,0.25)
VLI	Very low influence	1	(0,0.25,0.5)
LI	Low influence	2	(0.25,0.5,0.75)
HI	High influence	3	(0.5,0.75,1)
VHI	Very high influence	4	(0.75,1,1)

$$N = P \times M \tag{11}$$

Finally, the total relationship matrix R can be calculated with the formula:

$$R = N \times (I - N)^{-1} \tag{12}$$

3.1.1.6 Step 6. The cause-and-effect groups were formed, and the factors were sorted according to the $(D - R)$ values obtained from the result.

4. Analysis and findings

A total of nine factors were identified for the implementation of IoT in the food industry. The experts were approached using the methodology mentioned in Section 3, and a five-point linguistic scale was selected, *i.e.* 'no influence', 'very low influence', 'low influence', 'high influence', and 'very high influence'. A membership function is assigned to each linguistic term to handle ambiguity or vagueness in opinion. The corresponding relationship between language and fuzzy numbers is given in Table 3.

The expert's response was taken individually from eight experts as a direct relation matrix. These direct relation matrices were converted to fuzzy assessment matrices using triangular fuzzy numbers (lower, middle and upper values). The fuzzy data was then converted to crisp values using the eqn (1)–(9), which were further converted to an integrated crisp matrix following the abovementioned process. The total direct relation matrix is obtained using the eqn (12) and Table 4.

The sum of the individual rows and columns were labelled as 'D' and 'R' values, respectively. 'Prominence' $(D + R)$ and 'Relation' $(D - R)$ values were calculated. The factors with negative $(D - R)$ values were categorised into the effect group, and factors with positive $(D + R)$ values were categorised into the cause group. A $(D + R)$ and $(D - R)$ graph was plotted for a causal relationship. The analysis revealed five factors in the effect group and four factors in the cause group, as mentioned in Table 5. Table 5 provides all the values for the analysis, *viz.* D, R, $(D + R)$, and $(D - R)$.

The Fuzzy-DEMATEL analysis reveals the cause-and-effect relationships among these critical factors. The results show that the financial position of the company, managerial support, and competitive pressure are the primary causes of the implementation of IoT in the food sector. These factors have a direct impact on the availability of infrastructure and equipment, the availability of skilled human resources, and the felt need for sustainability. On the other hand, implementing IoT technology affects the complexity of usage and the established government policies and standards. The availability of infrastructure and equipment influences these factors, such as the availability of skilled human resources and the need for sustainability.

Table 3 Linguistic perception table

Linguistic terms	*L*	*M*	*U*
No influence	0	0	0.25
Very-low influence	0	0.25	0.5
Low influence	0.25	0.5	0.75
High influence	0.5	0.75	1
Very high influence	0.75	1	1

5. Discussion

The successful implementation of IoT in the food sector is crucial for enhancing food safety, quality, and efficiency. However, the integration of IoT in this sector is influenced by various critical factors that can either facilitate or hinder its adoption. This study employs the Fuzzy-DEMATEL method to identify and analyse these factors, providing insights into their cause-and-effect relationships. The analysis reveals nine critical factors that significantly impact the implementation of IoT in the food sector. The importance of the Factors can be observed as A6 > A3 > A2 > A1 > A4 > A5 > A9 > A7 > A8 based on $(D + R)$ values. The cause factors influence the effect group factors. Table 6 summarises the division of factors between casual and effect groups, depicted in Fig. 2.

Following are the factors affecting the implementation of IoT in the food industry arranged according to their importance:

(a) Skilled human resources (A6): amongst all the factors, skilled human resources have the highest $(D + R)$ value and second highest $(D - R)$ value in the effect group. This implies that it has a significant impact on other factors. The availability of skilled personnel with expertise in IoT technology and its applications is essential for implementing IoT in the food sector. Skilled human resources can ensure that the technology

Table 4 Total relation matrix

	A1	A2	A3	A4	A5	A6	A7	A8	A9
A1	1.17547	1.72174	1.68875	1.07093	1.11177	1.71962	1.26859	0.71429	1.07967
A2	1.2927	1.5759	1.67118	1.06027	1.11649	1.7585	1.22355	0.71997	1.15268
A3	1.45028	1.90021	1.72537	1.22395	1.224	1.93005	1.42623	0.80967	1.17579
A4	1.40494	1.90249	1.84175	1.12136	1.29787	1.911	1.39071	0.8135	1.14559
A5	1.3398	1.8194	1.78797	1.26444	1.12482	1.85062	1.3327	0.77331	1.14098
A6	1.43631	1.88	1.88515	1.19607	1.24456	1.77422	1.3499	0.78381	1.26364
A7	1.0881	1.4857	1.48016	0.92854	0.98299	1.46833	1.01496	0.71887	0.92101
A8	1.34848	1.83062	1.84507	1.1969	1.26577	1.89574	1.44428	0.75022	1.16665
A9	1.28138	1.7775	1.73104	1.16234	1.19425	1.8302	1.23481	0.75259	1.04801

Table 5 Values of $(D - R)$ and $(D + R)$

Reference	Factors	D	R	$D + R$	$D - R$	Group
A1	Financial position of the company	11.5508	11.8175	23.3683	−0.2666	Effect
A2	Infrastructure and equipment	11.5713	15.8936	27.4648	−4.3223	Effect
A3	Managerial support	12.8656	15.6564	28.522	−2.7909	Effect
A4	Competitive pressure	12.8292	10.2248	23.054	2.6044	Cause
A5	Source of differentiation	12.434	10.5625	22.9966	1.8715	Cause
A6	Skilled human resource	12.8137	16.1383	28.9519	−3.3246	Effect
A7	Need of sustainability	10.0887	11.6857	21.7744	−1.5971	Effect
A8	Established govt. policies/ standardisation	12.7437	6.8362	19.58	5.9075	Cause
A9	Complexity of usage	12.0121	10.094	22.1061	1.9181	Cause

Table 6 Cause and effect division of factors

Cause	A4	A5	A8	A9	
Effect	A1	A2	A3	A6	A7

is implemented correctly and efficiently. A business should retain and capitalise on skilled human resources and invest in providing training to them to enhance the technology implemented in their organisation.

(b) Managerial support (A3): it has the second highest $(D + R)$ value and third lowest $(D - R)$ value, 28.522 and −2.7909, respectively. This signifies that "Managerial support" is an important criterion influenced by other factors. The level of managerial support and commitment to IoT implementation is essential for overcoming potential challenges and ensuring the project's success. Managerial support can provide the necessary resources and expertise to overcome technical and operational hurdles. The organisation's leaders' endorsement of IoT can accelerate the adoption process.

(c) Infrastructure and equipment (A2): it has the third highest $(D + R)$ value and smallest $(D - R)$ value in effect value, *i.e.* −4.3223, which implies that other factors impact this. The availability and quality of infrastructure and equipment necessary for IoT implementation are critical factors in the project's success. Adequate infrastructure and equipment can ensure seamless integration of IoT technology, while their absence can lead to delays and increased costs. Investing in state-of-the-art infrastructure and the latest equipment is essential, with frequent infrastructure audits for acquiring new technologies for supply chain, packaging, and processing can help eliminate increased costs and delays.

(d) Financial position of the company (A1): it has the smallest $(D - R)$ value in the effect group, depicting this factor as least impacted by the other factors. The company's financial health plays a role in determining its ability to invest in IoT technology and infrastructure. A strong financial position can facilitate the implementation of IoT, while a weak financial position can hinder it. Therefore, a company should have a robust financial position to implement IoT. This can be achieved by allocating funds to R&D, establishing strategic partnerships, utilising government grants and subsidies, and adopting IoT technologies while maintaining liquidity.

(e) Competitive pressure (A4): the second highest $(D - R)$ value is of the factor "Competitive pressure". The competitive landscape of the food sector, including the pressure on competitors, drives the adoption of IoT technology. Companies that fail to adopt IoT technology may struggle to remain competitive. Benchmarking the process flow against the industry leaders can inspire creative IoT applications and detect leakages and gaps.

(f) Source of differentiation (A5): the sixth most important factor is the "Source of differentiation". It has the lowest $(D - R)$ value among the cause group. The ability of IoT technology to

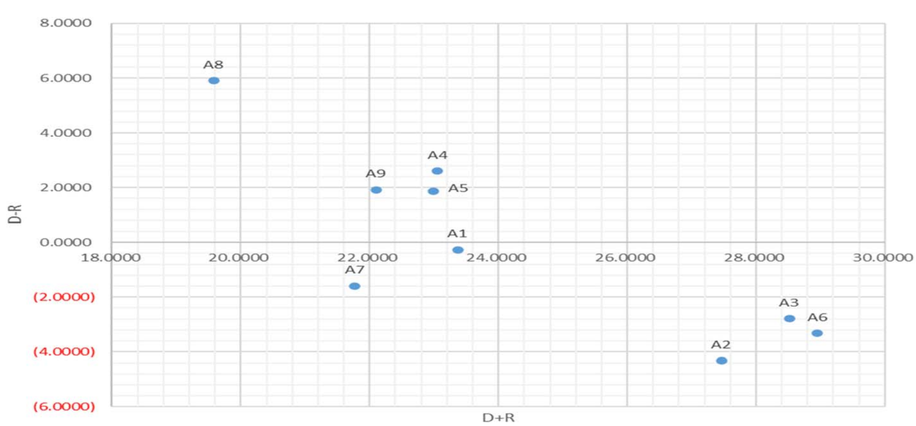

Fig. 2 Cause–effect relationship (source: authors).

differentiate a company's products and services from competitors is a critical factor in its adoption. Companies leveraging IoT technology to differentiate their offerings are more likely to succeed.

(g) Complexity of usage (A9): it has a positive $(D - R)$ value, which groups it with the cause factors that influence other factors. The complexity of IoT technology and its applications can hinder its adoption, particularly for smaller companies or those with limited technical expertise. Companies that struggle to understand and implement IoT technology may face delays and increased costs. Businesses should prioritise choosing IoT platforms and solutions that are easy to use. Operations can be simplified by ensuring the technologies adopted are scalable and adaptable to the company's needs. Providing staff with comprehensive documentation, ongoing assistance, and practical training will lessen opposition to IoT adoption.

(h) Need of sustainability (A7): the $(D - R)$ value for this factor is −1.5971, making it a factor that others can influence, though the measure of impact on it may not be as large as infrastructure and equipment. The food industry is adopting IoT technology due to growing customer demand for sustainable practices and goods, which helps businesses minimise waste and lessen their environmental impact. Businesses should implement IoT solutions that monitor energy usage, lower spoilage through intelligent packaging, and increase supply chain transparency. Showcasing these programs can also improve the company's reputation as a sustainable brand.

(i) Established govt. policies/standardisation (A8): among all the factors in the cause group, the "Established govt. policies and standards" have the highest $(D - R)$ value, which signifies it has a significant impact. Its degree of influential impact is 12.7437. Positive and negative government policies and standards related to food safety and food quality, as well as industry standards for IoT implementation, significantly influence the adoption of IoT technology in the food sector. Companies that fall short of complying with these standards may face regulatory challenges and reputational damage. Hence, staying informed about the latest governmental policies and standards is crucial. Businesses and policymakers must actively collaborate to ensure compliance with the regulations and discuss the favourable policies that support the integration of IoT in food processing, transportation and storage.

From Fig. 2, it is evident that the factor A8, Established government policies/standardisation, is an independent factor and influences the other factors responsible for implementation of IoT in food industry, being an external factor beyond the control of the business its $D + R$ value is low and thus has low importance, factors A2, A3 and A6, Infrastructure and equipment, Managerial support and Skilled human resource respectively, have lowest $D - R$ values, which signifies high impact of other factors on them. They also have a high $D + R$ value, which signifies the importance of these factors over others.

6. Implications

The rapidly changing and evolving food industry faces numerous challenges, and effective implementation of IoT is further challenging. The financial position of the company is affected majorly by implementing IoT, the best example being in Saudi Arabia, where the increased revenue is predicted to grow at an average annual growth rate of 10.85% through the years 2023 to 2028.[66] The potential of trending infrastructure and equipment is to be considered "machine to machine", working soon *via* matrix interaction of millions of devices for information sharing.[67] Top management is the backbone of the industry, thus significantly improving the linkage between organisations and the interactiveness of the supply chain, hence keeping the supply chain a step ahead of competitors. However, it depicts itself as one of the effects as it affects the organisation in case of some loss during IoT implementation decisions.[40] The literature suggests that even though competitiveness can bring a company on edge, by re-sculpturing the approaches, a company can gain a business advantage, which is also supported by the theory of business ecosystem.[68] Hiring and increasing the proficiency of human resources to utilise the expected results of IoT implementation is crucial for the survival of the industry and majorly cost efficient as per the case mentioned cited research paper of buying a 3D printer for machinery-part manufacturing for significant cost reduction.[69]

The developed Fuzzy-DEMATEL is one of the distinctive tools used to depict crucial influences on IoT by capturing the cognitive ambiguity of experts in the mentioned contextualisation. The study wrapped factors affecting decision-making during IoT implementation by quantifying various factors in a fuzzy environment and understanding their spontaneous interaction.[37] The result shows that "Competitive pressure" (A4), "Source of differentiation" (A5), "Established govt. policies and standards" (A8), and "Complexity of usage" (A9) are cause variables. These variables determine the framework, and their execution can directly influence the research. Researchers can continue forming related theories and models based on the developed framework and cross-sectional analyses of the food industry to achieve optimum efficiency in implementing IoT. Therefore, this study holds significant value for researchers, managers, and policymakers, offering insights to formulate efficient strategies to implement and adopt IoT and leverage its potential in the food industry. The study also listed "Established governmental policies and standardisation" (A8) as a factor reflecting policymakers' role in implementing IoT in the food industry. The government and industry can work collectively to address the issues or barriers to implementing IoT successfully. Managerially, the study enriches comprehension of the interplay among IoT implementation factors in the food sector. Theoretically, it presents a systematic prioritisation methodology to address these factors. The results add information about the food sector, IoT implementation, and its influential determinants.

7. Conclusion

As the research depicts, IoT implementation in the food industry can address the various supply chain challenges, maintaining transparency while improving food safety. IoT also aids in waste management. Although the implementation of IoT in the food industry offers numerous benefits, a comprehensive literature review has identified several significant factors that can influence its successful adoption. These factors highlight the complexities and obstacles that must be overcome to utilise IoT properly in the food industry. Building upon this, the current study has identified the key factors influencing the implementation of IoT in the food industry.

This paper identifies the factors influencing the adoption of IoT in the food industry. Initially, nine factors were identified, *i.e.*, "Financial position of the company", "Infrastructure and equipment", "Managerial support", "Competitive pressure", "Source of differentiation", "Skilled human resources", "Need for sustainability", "Established government policies and standardisation", "Complexity of usage", based on literature analysis and consultations with domain experts which also provided an elaborate answer for RQ 1. To address RQ 2, the hybrid Fuzzy-DEMATEL method was introduced to analyse the identified variables. This comprehensive approach meticulously evaluated the importance of each variable and uncovered the causal relationships among the nine identified variables. Through detailed analysis, these nine complex influencing factors were systematically categorised into two distinct groups, cause and effect and ranked by their importance in implementation. This classification allowed for a deeper understanding of how these variables interact and influence one another. Subsequently, a causal diagram was developed to represent these interactions and dependencies. Five influential factors, the Financial position of the company (A1), Infrastructure and equipment (A2), Managerial support (A3), Skilled human resources (A6), and Need for sustainability (A7), were categorised as effect variables. The findings also indicate that, in a general context for the food industry, key factors such as Competitive pressure (A4), Source of differentiation (A5), Complexity of usage (A9), and Established government policies and standards (A8) fall under the cause group and play a crucial role in impacting other factors. Integrating smart technologies and systems helps enhance efficiency and productivity, supporting sustainable development across advanced and developing regions. These technologies are increasingly being applied in renewable energy systems and waste management, significantly contributing to global development goals.

The results of this study can also be a valuable foundation for further research on IoT implementation in industries other than the food industry by adapting and evaluating the critical factors and exploring how these factors may change or remain constant with changing sectors. Further, the study can also help explore new factors and refine the Fuzzy-DEMATEL. This study can help policymakers and business leaders develop and customise IoT implementation strategies.

8. Limitations and future scope

Future studies could focus on assessing various factors such as affordability and infrastructure, improving network connectivity, security & privacy of the IoT systems and reducing complexity for ease of usage and developing framework. As a new era has ascended with IoT implementation in the food industry, ageing processes are being turned into smart processes through improved manufacturing and monitoring of aptly optimised processes, creating a better-controlled environment and easing real-time data detection. They thus could be investigated for understanding various operations and their interrelationships using multimethod approaches. Like any research, this study also has its limitations, particularly regarding the sample size, knowledge, and bias of the participants; a large sample size could help with a mixed-method approach and ensure some in-depth insights. Further research on the refinements of these limitations of Fuzzy DEMATEL can be conducted, which could lead to more nuanced models and IoT adoption, with deeper insights into direct and indirect factor relationships. More constraints include the source of literature, selection of experts, setting, and techniques employed; therefore, further research may be necessary.

Data availability

The data supporting this article have been included in the article, or no new data were generated as a part of this research.

Conflicts of interest

There are no conflicts to declare.

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