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Article

Digital Transformation in Beekeeping to Carrying Beehives into the Future

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Abstract: Today, dynamic elements such as producer/consumer supply, demand, presentation, marketing and transportation transformed by technology; It has initiated a rapid change and transformation process in beekeeping, food production and agriculture sectors. Beekeeping activities; Today, it faces challenges such as climate change, disease threats, loss of habitat and bee colonies, and pesticides. It has become necessary to switch to digital transformation for the future, sustainability, efficiency, competitiveness of beekeeping and the general health of the agricultural sector. The digital transformation movement in beekeeping is a movement to bring together traditional beekeeping with modern technologies. This article explores the importance and impact of digital transformation in the beekeeping industry from the perspective of the management information systems (MIS) field. It is aimed to discuss how the transformation can be supported in terms of management information systems and what kind of road map should be followed for future studies. Digital beekeeping; It improves the productivity of bees, monitors the health of bee colonies and optimizes decision-making processes. It also creates positive effects on plant diversity in the agricultural sector and world ecosystem health. The basis of this transformation is industry 4.0, such as IoT, sensors, big data, data management, data analysis, data mining, data security, artificial intelligence and cloud computing. These technologies can be used for disease monitoring, early diagnosis, pollination and plant flowering monitoring. It is thought that this transformation will have positive effects on both beekeepers and environmental factors and will make significant contributions to progress in this field and a more sustainable future.

Keywords: Internet of Things; Beekeeping; Digital Beekeeping; Beekeeping and Technology; Agriculture.

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1. Introduction

Food production and the agricultural sector worldwide are in a continuous process of change and transformation under the influence of dynamic factors such as population growth and changing consumer demands. Beekeeping, which is an important part of this transformation, is of great importance both economically and ecologically. Beekeeping, which has an important place in economic and ecological terms, is considered as an activity that combines plant resources, bees, technical knowledge and labor force in today's world. Beekeeping, which has been an important activity for humanity for centuries, contributes to the economy by producing honey and various honey products and tries to protect the balance of natural life.

When we look at world honey production, Turkey ranks second. While Turkey ranks 3rd in the world with the number of hives it has, it ranks 2nd in the world in terms of production. Beekeeping is a serious source of income and employment for our country. As seen in Table 1, although the number of hives in the world and Turkey has increased, we see from the figures in Table 2 that honey production for our country and the world has decreased. Digital transformation in beekeeping will be a hope for increasing production and country income. Increasing the efficiency and quality of beekeeping will be a solution not only for beekeeping but also for agriculture.

Table 1. World hive assets (thousands).

Countries	2017	2018	2019	2020	2021
India	12.166	12.124	12.348	12.589	12.848
Chinese	9.096	9.158	9.165	9.192	9.217
Türkiye	7.991	8.108	8.128	8.179	8.733
Iranian	6.951	7.466	7.247	7.333	7.527
Ethiopia	6.524	7.075	6.958	6.986	7.106
Tanzania	2.968	3.005	3.012	3.031	3.051
Argentina	2.923	2.966	2.959	2.962	2.965
Spain	2.905	2.966	3.034	2.967	2.953
Russian Fed.	3.317	3.182	3.094	2.982	2.890
USA	2.684	2.828	2.812	2.706	2.696
Other	35.529	38.375	39.290	40.542	41.638
World	93.054	97.253	98.047	99.469	101.624

Source: Product Report Beekeeping 2023 (Agricultural Economics and Development Institute TEPGE

Turkey ranks 3rd in the world with its hive population, after India and China. When we look at it over the years, we see that the number of hives has increased in the world and in our country.

Table 2. World honey production (tons).

Countries	2017	2018	2019	2020	2021
Chinese	542.544	446.879	444.054	458.100	472.700
Türkiye	114.471	107.920	109.330	104.077	96.344
Iranian	72.206	72.796	72.851	74.293	77.152
Argentina	76.379	79.468	78.909	72.441	71.318
Ukraine	66.231	71.279	69.937	68.028	68.558
India	62.810	63.826	64.514	65.250	66.278
Russia	65.167	65.006	63.526	66.368	64.533
Mexican	51.066	64.253	61.986	54.165	62.080
USA	67.596	69.857	71.179	66.948	57.364
Brazil	41.696	42.268	45.801	51.508	55.828
Other	718.142	754.957	675.037	693.299	679.789
World	1.878.308	1.838.509	1.757.124	1.774.477	1.771.944

Source: Product Report Beekeeping 2023 (Agricultural Economics and Development Institute TEPGE

Beekeeping is at the intersection of ecological protection and agricultural sustainability. Pollination activities of bees are indispensable for maintaining plant diversity and increasing the productivity of agricultural products. Therefore, the sustainability and efficiency of beekeeping is also vital for the overall health of the agricultural sector. However, the beekeeping sector has been facing a number of challenges in recent years. Climate change, habitat degradation, the spread of disease and pesticides (the use of chemical insecticides) threaten the health and survival of bee colonies worldwide. These threats lead to beekeepers facing crop losses and deteriorating ecosystem health. However, despite these challenges, we are in a technological era where digital transformation, driven by emerging technology, can offer great potential to the beekeeping sector. In this period, we see digital transformation in beekeeping emerging as a beacon of hope for the beekeeping sector in finding solutions to these problems. The adoption of new technologies in beekeeping is of great importance in terms of increasing productivity in production factors, meeting the increasing demand for food, raising the living standards of farmers and ensuring agricultural development (Gürer & Akyol, 2018). Technology has been changing rapidly in recent years. Production methods and technologies are constantly developing in agriculture. Innovative approaches in the stages of production are offered to the use of farmers. Generally, agricultural farms prefer to continue the current conditions. It is not easy for the farmers to accept the innovations by spreading them over time (Kaya, 2022).

To solve problems related to these factors of interest to beekeeping, systems capable of monitoring the behavior of bees and efficient use of information technologies are required (Anyasi & Imoize, 2010). The development of sensors has enabled improved measurement processes for electronic data collection systems, from traditional to new data analytics systems (Odoux et al., 2014; Clermont et al., 2015). Digital transformation in beekeeping refers to the integration of digital technologies into all aspects of beekeeping, from hive monitoring to data analysis and decision-making. This change promises not only to increase the efficiency and productivity of beekeeping, but also to address and resolve critical issues that jeopardize bee populations and ecosystems.

In recent years, the beekeeping sector has also come under the influence of digital transformation. The rapid development of digital technologies has the potential to make activities more efficient and help beekeepers make better decisions in the beekeeping sector, as in every sector. This digital transformation process plays an important role in the field of Management Information Systems (MIS). This article discusses why digital transformation is necessary in the beekeeping industry and how it can be used in terms of Management Information Systems (MIS). It is thought that this transformation will have positive effects on both beekeepers and environmental factors, and will make significant contributions to progress in this field and a more sustainable future.

Digital transformation in beekeeping has reshaped the way beekeepers communicate with their hives and manage their colonies. The term digital transformation started with the development of technology and the integration of innovations brought by the 4th industrial revolution into our lives. This paper discusses how digital transformation in beekeeping can integrate digital technologies such as Internet of Things (IoT), sensor technologies, big data, data management, data analytics, data mining, data security, artificial intelligence and cloud computing into the beekeeping sector. In the transformation, sensors are used to collect actionable data from beehives in real time, the collected data is stored in cloud computing, data mining is used to analyze the data, the analyzed data is transformed into meaningful information, and finally the data is secured with information security. Artificial intelligence is used for decision support systems such as diagnosis of diseases, analysis of bee behavior and production forecasts. Decision support systems allow beekeepers to make informed decisions, detect health problems in bee colonies early and implement preventive measures. IoT enables remote monitoring and control of beehives.

In this research; firstly, industry 4.0 and its components are examined. Then, the importance and impact of digital transformation in the beekeeping sector is examined by combining traditional beekeeping practices with modern technology to increase the sustainability and efficiency of the sector and to help beekeepers cope with the challenges they face. Then, how digital technologies such as Internet of Things (IoT), sensor technologies, big data, data management, data analysis, data mining, data security, artificial intelligence and cloud computing, which form the basis of this transformation, can be applied to the beekeeping sector and how they can make a difference in the sector. It also assessed the future potential of this digital transformation and how it can contribute to a more sustainable and efficient management of the beekeeping sector. The paper also emphasizes the future possibilities and promises of digital transformation in beekeeping. It envisions an environment where bee colonies armed with digital tools and knowledge can not only improve the livelihoods of beekeepers, but also contribute significantly to the conservation of bee populations and the overall ecological health of our planet.

The aim of the study to investigate how the digital transformation of the beekeeping sector can be realized more effectively through management information systems and to provide a basis for future work in this area. Digital beekeeping has the potential for beekeepers to make better decisions, manage bee colonies more effectively and maintain ecosystem health. Digital beekeeping is an important element not only for beekeepers, but also for food production and ecosystem health, and advances in this field will contribute to our goals of leaving a more sustainable world for future generations.

2. Industry 4.0 Concept and Components

Industry 4.0 (industry 4.0 or the 4th industrial revolution) was first used in 2011 at the fair organized in Hannover, Germany (Kabaklarlı, 2018). Later, this concept became a state policy in Germany. The 4 main features that distinguish Industry 4.0 from previous industrial revolutions are sensors, data, information and processing elements (Özdoğan, 2018). The concept of Industrial 4.0 or 4th industrial revolution aims to transform the production industry by combining traditional production processes with digital technologies. This concept represents a major transformation in production and uses more efficient, flexible, smart and sustainable production methods. Thus, productivity increases, workforce develops, product quality increases and sustainability is promoted. It has nine components. These:

1. Big Data: It is a term that refers to large volumes of data that are produced quickly and of various structures such as audio, video, photographs and telephone records, for which traditional data management and processing methods are insufficient. Big data is too large and complex to be processed by traditional analysis methods, so it requires the use of special data analytics tools and techniques.

2. System Integration: It is a term that refers to the process of bringing together different information systems, software applications, hardware devices or business processes of an organization or business. Integration aims to ensure that different systems work harmoniously and share data. It helps to gain competitive advantage in every field in the rapidly changing world by increasing efficiency, reducing costs, minimizing errors and improving decision-making processes.

3. The Internet of Things (IoT): It is the concept that refers to the technology that enables physical objects to communicate with each other and/or people over the internet. IoT enables these objects to measure environmental factors, collect and analyze data, and share this data. IoT involves the integration of a range of technologies such as sensors, devices, software, networks and data analytics. These devices are usually equipped with sensors, software and internet connection, and they perceive the physical world around them, collect data and share this data with other devices and/or people over the internet.

4. Cybersecurity: It is a discipline that deals with protecting the security of computers, networks, devices and digital systems and taking protective measures. Its main purpose is to protect against malicious cyber-attacks and data breaches. Cybersecurity covers data security, network security, identity and access management, application security, physical security, and detecting and quickly responding to attacks.

5. Cloud Computing: It is an information technology model in which operations such as data storage, computing power, software and network resources on the computer are shared and presented over the internet. It ensures that these resources are hosted in special data centers instead of traditional computer infrastructures and presented to users via the internet. Users can access these resources as needed.

6. Additive Manufacturing (AM): Also known as 3D printing, it is a manufacturing process in which objects are created in three-dimensional layers. It is a technology that facilitates the production of customized products directly with computer-aided design instead of traditional production methods.

7. Augmented Reality (AR): It is a technology concept used to enrich the real world with various knowledge-based information or virtual objects. AR works through a smartphone or AR glasses that perceive the real world and recognize real-world objects or environment. It then presents additional information to the user, such as information, visual effects, or digital objects. AR bridges the real world and the digital world.

8. Simulation: It is defined as methods or techniques used to model, simulate or emulate real-world events or processes. This is used to better understand how a particular event or system works, predict possible outcomes, provide training, or make decisions. Simulations are often created using mathematical models or computer-based software. Simulations help imitate, learn from, and analyze risky or expensive real-world experiences. This gives decision makers the opportunity to conduct experiments in a virtual environment to evaluate the results of a particular strategy or plan. Today it is used in many industries and disciplines.

9. Autonumous Robots: These are robots that can perform tasks without the need for human intervention or control. They can perceive their environment, make decisions and perform certain tasks. Autonomous robots perceive their environment using a series of sensors and software and act using this information. These robots often make decisions using technologies such as artificial intelligence, machine learning and deep learning. Autonomous robots enable tasks to be carried out safely and effectively without the need for human intervention.

Today, the concept of Industry 4.0 is used as an umbrella concept to express all of the concepts such as big data, artificial intelligence, cloud computing, robotics, nanotechnology, 3D printers, cybernetic physical systems, the Internet of Things, that is, newly developed technologies (Kabaklarlı, 2018; Öztuna, 2017). Developments such as the development of the Internet, fiber optic networks and automation in production play a major role in the development of smart production and Internet of Things technologies that stand out in the fourth industrial revolution (Kabaklarlı, 2016: 39). Rapidly expanding industrial automation, combined with internet technology, is moving towards the era of smart production called Industry 4.0 or the 4th Industrial Revolution (Brettel et al., 2014). The concept of Industry 4.0 is defined as the integrated operation of each part of the supply chains in the production stage beyond the automation of each part in itself and the communication of machines with each other and with suppliers and customers, called smart production, and the abandonment of centralized production and the transition to flexible production (Kabaklarlı, 2016: 13). With the 4th Industrial Revolution, the products produced will be constantly connected to the internet just like the machines they are made of, they will be able to examine their environment thanks to their sensors and react physically to the extent of their own capabilities when necessary, and while doing so, they will be able to exchange information in real time with other devices connected to the internet all over the world (Ege, 2014).

Banger criticizes that Industry 4.0 is generally perceived as a technological evolution, which causes the transformation of business models, business policies and strategies and organizational factors due to the emergence of new technologies and their integration with businesses to be overlooked (Banger, 2018). In this study, the effects of Internet of things, simulation, augmented reality, Cloud Computing, CyberSecurity, Big Data and Analytics are examined in terms of digital transformation in beekeeping.

Intelligent sensor devices used in IoT have the ability to identify themselves, network and transfer the information they collect to publicly available cloud services capable of storing and analyzing it (Miorandi et al., 2012). Rapid developments in IoT have attracted the attention of companies trying to improve production quality and efficiency (Li et al., 2014). The concept of the Internet of Things was first used in 1999 by Kevin Ashton, co-founder of the Massachusetts Institute of Technology (MIT) Auto-ID Center, as the title of a presentation on the benefits of Radio Frequency Identification (RFID) technology for P&G (Ashton, 2009). In 2005, the International Telecommunication Union (ITU) published "The internet of things. ITU Internet Reports" report published by the International Telecommunication Union (ITU) in 2005, the concept of "Internet of Things" were announced (ITU, 2005). However, the first Internet of Things application in history was used by a group of academics at the University of Cambridge in 1991 by sharing images of a coffee machine with a camera system over the Internet (Armentia et al., 2012). This expansion of the Internet leads to the emergence of new paradigms, and in this context, the Internet of Things, one of the new paradigms, is one of the hottest and most curious topics in information and communication technology today (Lee,et al., 2013). Although there are equivalents in terminology such as Internet of Things (IoT), Internet of Everything (IoE), Network of Things (WoT), Network of Everything (WoE), Machine to Machine (M2M), the Internet of Things is used as the most popular nomenclature (Gözüaçık, 2015). Internet of Things, Internet of Everything, Web of Things, Web of Everything, Web of Everything, Cyber Physical Systems are all called smart systems (Çamurcu et al., 2014).

The Internet of Things (IoT) is a concept that has grown in popularity thanks to the development of modern wireless communication technologies. The basic formation of this concept is the development of applications to facilitate human life by enabling objects in the world to communicate with each other (Guisto et al., 2010). The traditional internet communication infrastructure connects end users with different communication systems. With new developments in technology, a large number of sensor devices can be integrated into the internet environment through WSN (Wireless Sensor Networks) systems (Akyıldız et al. 2002). IoT is the ability of objects built on standard communication protocols and addressable objects to communicate via the internet (Bassi & Horn, 2020). In the coming years, it is predicted that production will be carried out in this way, production will be carried out 24 hours a day even in the dark, and many objects from furniture to paper documents, from foodstuffs to electronic devices will be connected to the internet. Robot vacuums, airfries, smart kitchen appliances, smart home appliances that we have started to use in our daily lives and cannot give up are products of this technology. Internet of Things is defined as a network structure in which devices or machines communicate data among themselves, collect information and make decisions with the collected information without the need for human intervention and manual input of any data (Aktaş et al., 2014). Today, the Internet of Things is used in many areas where we add the word smart to the beginning for the majority. These are smart home applications, smart city applications, smart agricultural production applications, smart health applications, smart banking and financial applications, smart scientific study applications, IT sector applications, smart energy applications, smart public sector applications. In all these areas, digital transformations are taking place, including the transformation from classical processes to technology.

In today's world where there is so much information, big data is all the data collected from different sources, transformed into a meaningful and processable form. The term big data was first coined in 1998 by J.R. Mashey, chief scientific officer of Silicon Graphichs International, in a presentation titled "Big Data... and the Next Wave of InfraStress" (Mashey, 1998), later by Weiss & Indurkya in a book titled "Predictive Data Mining" (Weiss & Indurkya, 1998) and academically by Dieobold at the 8th World Congress of the Econometric Society in Seattle in 2000. World Congress of the Econometric Society in Seattle in 2000 (Diebold, 2000) in the paper titled "Big Data Dynamic Factor Models for Macroeconomic Measurement and Forecasting" (Çelik, 2015). Big data can be broadly defined as the transformation of processed or unprocessed data provided from different sources into data, i.e. information, and then into knowledge, organized in accordance with the demands and expectations of users by data analysts or data experts in devices that can develop solutions according to complex systems (Baran, 2017). In other words, the term big data defines massive amounts of high-speed, complex and variable data that require complex methods and technologies for data management and analysis (Iqbal et al., 2018).

In big data, data grows rapidly and takes up a lot of space on disk; how and where to store them and storage costs have brought along the problems. At this point, cloud computing solutions have been produced. Cloud technology is a set of technologies and services that enable computer systems and data storage resources to be moved to remote servers on the internet and these servers to be accessible by users on demand. This technology is based on the idea of sharing and utilizing resources such as advanced data storage, processing power, application services and network access over the internet. The wide network and high rate of data sharing that comes with Industry 4.0 has brought the need for cyber security and personal security of companies to the agenda. Cyber security measures must be taken to protect products, data and intellectual property against unauthorized and malicious persons, and existing security systems must be continuously improved to adapt to Industry 4.0.

Additive Manufacturing is a type of manufacturing technology, also known as 3D printing. This technology enables the production of products using a process where objects are built layer by layer. Unlike traditional manufacturing methods, parts do not need to be cut or shaped in additive manufacturing; instead, layers of material are assembled together using a digital design file. With a wide range of applications from prototype to mass production, Additive Manufacturing is used in the automotive, aerospace, medical, defense, fashion, food industry and many other sectors. This technology makes design freedom, customization and production processes more efficient, flexible and sustainable. For now, it is not widely used due to its low production speed and cost. In the future, it is predicted that even human cells and organs can be produced with electronic parts integrated with 3D printing by overcoming cost and speed constraints (Schwab, 2016). With

Additive Manufacturing, many new products/products can be produced in beekeeping with different purposes and methods.

3. Beekeeping and Digital Transformation in Beekeeping

Beekeeping is a nature-dependent livestock breeding activity that uses plant resources, bees and labor together to produce products such as honey, beeswax, pollen, royal jelly, propolis and bee venom, as well as living materials such as queen bees and swarm bees (Aksoy and Öztürk, 2012). Bees are important creatures that benefit our world in many different ways and are an important part of the agricultural sector. Einstein said, 'If bees disappeared from the earth, man would have only 4 years to live, without bees there would be no fertilization, no plants, no animals and no humans'. Bees carry the pollen of plants and carry out the pollination process, a critical step for the reproduction of fruits, vegetables, flowers and other plant species. Without bees, many plant species would not be able to reproduce. Similarly, when pollination is low, the yield, or production, of plants would be low. Therefore, bees are indispensable for agriculture and natural ecosystems. Many agricultural crops grow and become productive thanks to the pollination of bees. Bees are also an important food source for wildlife. Especially birds, bats and some insects prey on bees. Honey produced by bees is a nutritious and delicious food source. Honey is consumed by humans and is also used for some medicinal purposes. Bees collect pollen from plants, which is used to produce products such as nutritional supplements and medicines. Bees remove decaying organisms. This helps to keep natural environments clean and balanced. Bees increase plant diversity. Through pollination, the growth of different plant species is encouraged and the world ecosystem is enriched. Beekeeping is a sector that contributes to the economy of many countries. Income is generated by selling bee products such as honey, beeswax, propolis and bee venom. Bee venom and other bee products have been the subject of research in the field of medicine. Especially bee venom is used in the treatment of some health problems. Alternative health healing is practiced with apitherapy. Bees play a vital role in the functioning of our ecosystems and provide benefits in many areas, from food production to natural environmental cleanliness. It is therefore in the interest of humanity and the natural world that bees are protected and live healthy lives.

Today, the beekeeping sector is facing some challenges. Bees are vulnerable to various diseases and pests. Parasites such as Varroa destructor mite and microorganisms such as Nosema pose a threat to bee colonies. These pests impair the health of bees and lead to colony deaths. The unexpected disappearance of bees is known as "Bee Collective Collapse". This negatively affects beekeepers' business and threatens the stability of bee colonies. Pesticides (chemical drugs) used in the agricultural sector harm the health of bees. When bees collect these pesticides, which leave harmful residues on flowers and plants, their lives are threatened. Climate change affects bees' natural habitats and plant flowering periods. Extreme changes in weather conditions make it difficult for bees to find food and sustain their colonies. Reduced sources of pollen and nectar suitable for bees cause nutritional problems. Urban development, especially in cities, limits bees' access to natural food sources. Monoculture agricultural practices, where monoculture plant production is common, cause limited food resources for bees. This negatively affects the health of bees.

As these problems threaten the sustainability of the beekeeping sector, beekeepers need to manage their colonies more carefully and consciously. Beekeepers should take various measures to protect the health of bees and develop resistance to these problems. This is where digital beekeeping comes into play. It is important for beekeepers to utilize technology in bee health and disease diagnosis. This is a critical factor for early detection and prevention of bee diseases. Beekeepers using technology will be less affected by these dangers. Digital beekeeping is a transformation movement that combines traditional beekeeping with modern technologies. This transformation enables beekeepers to better monitor their hives, maintain bee health and increase honey production.

It is stated that the main factors determining the choice of beekeeping technology are management, availability, cost and capacity of the technology (Muriuki, 2016). Studies have shown that the quantity and quality of honey obtained from modern hives with modern beekeeping activities is more quantity and quality than honey obtained from traditional hives. Affognon et al. (2015) stated that the use of modern hives will increase honey production. It was also found that more honey was produced from modern hives than from traditional hives and net income increased with the adoption of new technologies (Muya, 2014; Keiyoro et al., 2016). According to the results of a study conducted in Ethiopia, honey yield per hive was 18.03 kg in modern hives and 5.15 kg in traditional hives. The study found that modern apiary owners earned significantly (198.3%) higher income than the estimated average annual income from traditional apiaries (Belayhun, 2014). Over time, various studies have been carried out to control the movement of bees and understand their life in the hive in order to increase production (Crane, 1990). This is achieved by using electronics and information systems to ensure continuous traceability (Nääs et al., 2006). The application of precision animal husbandry for beekeeping is thought to reduce workload and increase honey yield (Zacepins et al., 2015).

Digital beekeeping involves the use of digital technologies to monitor and analyze data from beehives. This data includes a range of parameters such as temperature, humidity, hive weight, weather conditions, bees' behavior, sound signals, internal conditions of the hive and plant flowering periods and more. Digital beekeeping offers many benefits, such as monitoring the health of bees and detecting diseases early, optimizing pollination efficiencies and increasing honey yields. It also helps beekeepers increase their productivity by making data-driven decisions. This allows beekeepers to stay informed about the health status of their bees and intervene when necessary. Furthermore, digital technologies can be used to increase bees' honey productivity. For example, drone technology can be used to enable bees to utilize flower fields more efficiently. Digital beekeeping can make beekeeping activities more efficient and enable beekeepers to get their work done more easily. However, the use of digital technologies should be done in an environmentally friendly way and in accordance with the nature of beekeeping activities. Digital beekeeping allows beekeepers to better manage and protect their colonies using realtime data on the status of bee colonies.

4. Key Elements of Digital Beekeeping

1. Data collection with sensors in smart hives: The most fundamental element of digital beekeeping is the ability to regularly collect, monitor and effectively utilize data from beehives. At the heart of digital beekeeping are sensors installed in beehives. The sensors placed in the hives ensure that the hives are smart. These sensors continuously collect data such as temperature, humidity, weight, number of entries/exits, pollination activities inside the hive. This data gives beekeepers access to real-time information about their hives, allowing beekeepers to learn about the health and performance of the hives. In beekeeping, it is reasonable not to disturb the colony by opening the beehives as little as possible while inspecting and maintaining the colonies (Ünal, 2006). In beekeeping, frequent opening of beehives located far from where we live for control purposes will cause financial, moral and time losses. It may also cause subjective interpretations to be made and erroneous information to be obtained. Therefore, the use of sensors is the ideal method to solve these problems and collect the necessary data. With the data obtained from the sensors, it is possible for beekeepers to monitor their hives remotely and intervene when necessary.

Some sensors and sensor systems used in beehives can include Hive weight sensors can continuously measure the weight of the hive. These sensors give beekeepers information about the bees' honey making and production. Temperature and humidity sensors provide information about the temperature and humidity level inside the hive, helping beekeepers to learn about the bees' living conditions inside the hive. Noise sensors provide information about the behavior of bees by measuring their buzzing and other sounds. Camera sensors are used to monitor the activity and movement of bees inside the hive and provide beekeepers with information about the health and productivity of the bees. Air quality sensors measure the air quality inside the hive and provide information about the respiratory and health status of the bees. These sensors help a beekeeper to collect important data about the bee colony. This data provides beekeepers with information about the health and productivity of the bees, helping them to better manage their bee colonies.

2. Wireless Communication: Sensors transmit the data they continuously collect wirelessly. With this method, beekeepers can access the data from anywhere and at any time. Wireless communication enables real-time monitoring and remote access of data. Wireless communication technologies also enable the secure transmission of this data. Continuous data from sensors is transmitted using wireless communication technologies to a centralized data storage or analysis platform that includes a server or cloud computing technology. The transmitted data forms big data, and then the security of that data comes into play.

3. Mobile Applications: Critical temperature, humidity and soil values that need to be controlled in the hives are stored, evaluated and can be controlled by mobile users through their phone applications or web accesses after machine-to-machine transmission as part of the IoT system and configured on a central computer or internet environment (Zhao et al, 2010). In the digital beekeeping system, some mobile applications have been developed for beekeepers to view and analyze hive data, real-time data tracking and easy reporting. These applications allow beekeepers to access hive data at any time and place without the problem of time and place. Since beekeepers have instant access to data, their decision-making processes are accelerated. Thus, beekeepers can monitor their hives remotely and intervene when necessary. Today, the existing applications developed for digital beekeeping are limited in number and can perform limited operations. There is a big gap in this area and existing applications cannot offer beekeepers the opportunity to perform all digital beekeeping operations in one application.

4. Data Analysis - visualization and artificial intelligence: The collected data can be processed through data analysis and artificial intelligence (AI) algorithms. Artificial intelligence comes into play at the point where electronic items connected to each other with the Internet of Things communicate with each other. Artificial intelligence, which is used to provide big data from existing information, is an artificial operating system that is expected to exhibit high cognitive functions specific to human intelligence, such as thinking, problem solving, communication, inference and decision making (NTV Bilim, 2009). Data from sensors can be analyzed through mobile applications or computer-based software capable of visualizing, reporting and analyzing specially designed data. Big data analysis and artificial intelligence can help beekeepers better understand the data they collect. For example, beekeepers can analyze this data to determine the honey harvest time or monitor the health of bee colonies. The data collected can be analyzed and visualized through specialized software or mobile apps. Through these apps, beekeepers can access instant information about the status of their hives. This helps beekeepers to extract meaningful insights from the data, such as predicting bee behavior or detecting signs of disease early, and to predict future bee behavior.

Digital tools such as Tableau, Microsoft Power BI and Google Data Studio can be used for data analysis and reporting. There is limited research and applications related to digital beekeeping. Future studies are needed especially on early diagnosis of bee diseases and analysis of bee behavior. Artificial intelligence and machine learning applications can be used for bee disease diagnosis, pollination predictions and data mining. Image analysis can be used for bee disease diagnosis. Image analysis algorithms can be developed to recognize disease symptoms using cameras that examine the bodies of bees. In this way, early diagnosis of diseases becomes possible. Pollination prediction and plant flowering can be monitored. AI algorithms can use meteorological data and plant species information to predict plant flowering periods and pollination events. These studies can help beekeepers' direct bees to the best flowering periods.

5. Data Storage and Cloud Computing: The Internet of Things (IoT) is a technology that enables physical objects, such as beehives, to be connected over the internet and data to be collected, shared and analyzed. Sensors, the IoT element in beekeeping, collect data instantaneously and continuously. The collected big data is transferred over the Internet to cloud-based platforms or servers. This data is stored, shared and processed. IoT technology allows beekeepers to access hive data remotely and instantaneously. Transferring data to cloud-based platforms and remote monitoring allows beekeepers to monitor their hives even when they are not physically near them and receive instant notifications of important events. These push notifications, such as when the hive weight falls below a certain limit, enable instant and rapid response to incidents. Since historical data can also be accessed through cloud-based platforms, it ensures that data can always be analyzed. Beekeepers can browse this data, examine trends and make future decisions based on this data.

6. Feeding Vending Machines: Digital beekeeping includes automatic feeding systems to feed the bees. These systems can automatically fulfill the bees' nutritional needs.

7. Decision Support Systems: Artificial intelligence can be used to process and understand the data collected from beehives and make better decisions based on the data. Artificial intelligence can analyze big data collected from beehives, process this data, make recommendations and create decision support systems by extracting patterns, trends, patterns, relationships and meaningful information from this data. Using AI, beekeepers can better understand bee behavior, pollen collection trends, honey production and colony health. They can also predict future bee behavior. These predictions can help beekeepers identify future problems in advance. For example, when to move hives, when to supplement bees, plan pollination activities, adjust irrigation and feeding strategies, or determine the timing of interventions based on the health of their colonies. Decision support systems (DSS) in digital beekeeping optimize data-driven decision-making processes and help beekeepers make more informed and effective decisions. Business intelligence and reporting tools can also be used to analyze big data datasets and understand the results.

8. Disease Monitoring and Early Diagnosis: Since bees can be continuously monitored in digital beekeeping, it is possible to diagnose bee diseases early and take precautions. Temperature and humidity sensors, air quality sensors and hive weight sensors can be used to monitor bee health. Hive weight sensors monitor the activity inside the hive. A rapid decrease in hive weight can indicate that bees are leaving the colony due to predation or disease. Visual recognition and sensors can help monitor for signs of disease. Bee diseases can be detected early using digital tools. Sensors and image analysis can help identify signs of disease. Beekeepers can capture microscopic images of bees' bodies and wings. These images can be analyzed with computer vision (image processing) algorithms to detect signs of disease. For example, damage caused by the varroa mite or pale discoloration of bees can be signs of disease. Some bee diseases can be diagnosed by DNA tests. Digitally recorded DNA data can be used to identify disease types and identify disease carriers. When data is tracked over time, time series analysis can reveal signs of behavioral changes or activity irregularities in bee colonies. For example, a sudden bee death event can be detected. Digital beekeeping will help prevent the spread of diseases by early detection and timely intervention in colonies. Preventive measures such as chemical control, cleaning hives and strengthening bees can be taken. Digital beekeeping is a powerful tool for monitoring bee health and diagnosing diseases. Data analytics and artificial intelligence help beekeepers detect signs of disease early, make sound decisions and protect bee colonies.

9. Pollination and Plant Flowering Monitoring: Bees are the most effective tool in plant flowering and pollination, a critical process for the reproduction of agricultural crops. Monitoring pollination and plant flowering in digital beekeeping is of great importance for the beekeeping industry and the environment. Pollination is a critical part of the reproductive process of plants. Bees and other insects carry pollen from the flowers of plants, helping to produce plant offspring. This process is essential for the sustainability of biodiversity, crops and natural ecosystems. Pollination monitoring leads to increased productivity and quality for both farmers and beekeepers. IoT sensors and cameras can be used to monitor plant flowering and pollination. Artificial intelligence can analyze this data and assess which plants bees are visiting, which areas are experiencing more pollination and ecosystem health.

In digital beekeeping, the Internet of Things (IoT) can be used to monitor and predict the flowering periods of plants. This helps beekeepers direct their bees to the best food sources. Digital beekeeping helps beekeepers and farmers work more sustainably and efficiently by addressing important issues such as monitoring pollination and predicting plant flowering. It also contributes to the conservation of natural ecosystems and biodiversity. Bees, butterflies, birds and other pollinators pollinate plant flowers, affecting fruit and seed production. Meteorological data and soil sensors can be used to predict plant flowering. Artificial intelligence models can be trained to identify the species and behavior of pollinators, especially using image recognition and object recognition algorithms. Artificial intelligence and machine learning can be an important tool for monitoring pollination and plant flowering. Sensors and data collection are one of the cornerstones of digital beekeeping, helping beekeepers to develop more efficient, sustainable and healthy beekeeping practices. However, the security and privacy of this data is a critical issue that needs to be considered and appropriate measures should be taken.

10. Data Management and Security: Data management and security are of paramount importance in digital beekeeping. Beekeepers and farmers must store and manage data securely to protect sensitive data and manage it effectively. A reliable data storage solution should be used to securely store sensitive data. This can include different options such as cloud-based or local servers. It is important that data is encrypted when stored and transmitted. Data should be secured using secure communication protocols and end-to-end encryption. Data should be classified according to its importance and stored in secure areas accessible only to authorized persons. For example, beekeeper health information or financial data are examples of sensitive data.

User roles and authorization should be established for data security and privacy measures. Each user should be authorized to access only the data that is necessary for him/her, and users' access to data should be controlled. Strong authentication and encryption policies should be used. Users should use strong passwords and change their passwords periodically. Up-to-date software and security updates should be obtained. It is important that the software and operating systems used are up to date and up-to-date with security patches. Firewalls and antivirus software should be acquired to protect against malicious software. Monitoring systems should be used to track the use of data and detect potential security breaches. For example, abnormal access attempts or data leaks can be monitored. To tightly control data, data should be encrypted during storage and transmission. Encryption will prevent unauthorized persons trying to access the data from understanding it. Each user must have access to the data for authorized operations. This control can be achieved using authentication and authorization mechanisms.

Backup Strategies and Data Access: The acquired data should be backed up regularly. This prevents data loss and facilitates data access. Backing up data both online (cloud) and offline (local storage) will minimize data loss. In case of data loss, a fast restore strategy should be established. The frequency of data backup should be adjusted according to the importance of the data. Data should be prioritized and separated from other data. This helps to determine who has access to the data and at what level it needs to be protected. Data management and security in digital beekeeping plays a critical role for business sustainability and data privacy. Making sure data is secure ensures the success of a trusted digital beekeeping practice and provides a more reliable experience for farmers, beekeepers and other stakeholders. Artificial intelligence and machine learning can be combined with cloud computing to provide effective solutions in data management and security, such as developing cybersecurity measures to protect data.

11. Training and Resources: Digital beekeeping training will help beekeepers to use digital technologies effectively and manage their colonies better. The practical applications of the training programs give beekeepers real-world experience, enabling them to adopt digital beekeeping more effectively. They will also support beekeepers to regularly update themselves and keep up with technological developments. There are not enough academic studies on training and resources on beekeeping with the Internet of Things (IoT). To access resources on digital beekeeping and

IoT, it is important to follow the developments in the beekeeping sector and visit the websites of associations, universities and technology companies interested in the topic. Educational resources include universities and research institutions, Coursera, Udemy, edX online courses and training platforms, beekeeping associations and organizations, and agricultural and technology associations. For current research and news, academic research articles, scientific meetings, and technology newsgroups, especially in the agriculture and environmental IT categories, can be followed.

Digital training for beekeepers is important to integrate traditional beekeeping with modern technologies and to enable beekeepers to become competent in digital beekeeping practice. Trainings for beekeepers can be based on four pillars and training models. These are:

Digital Beekeeping Basics Training: Definition and importance of digital beekeeping, benefits and potential applications of digital beekeeping, impact of digital technologies on the beekeeping sector.

Data Collection and Sensors Training: Methods of collecting data from beehives, types of sensors and how to use them, data security and privacy issues

Mobile Applications Training: How to use mobile applications, introduction of useful mobile applications for beekeepers, mobile applications for data analysis and reporting and their uses

Artificial Intelligence and Data Analysis Training: Fundamentals of artificial intelligence and machine learning, how to analyze beekeeping data, practical applications of extracting information from data

5. Accessing and Evaluating Information from Data in Digital Beekeeping in terms of Management Information Systems

The basic steps used in digital beekeeping for extracting information from data, transforming the data into knowledge and evaluating the information are as follows

Data Collection: First of all, IOT devices automatically collect data from beehives with various sensors such as temperature, humidity, hive weight, bee activity, etc. and store them in the cloud system.

Data Cleaning: The collected data is cleaned of noise or missing information by data cleaning. Missing data is filled in and outliers are corrected.

Data Storage: Cleansed data is securely stored using options such as cloud-based storage or local servers. Big data is created.

Feature Engineering: Appropriate features are extracted to analyze the data, such as the ability to calculate an average temperature value from temperature data.

Machine Learning and Artificial Intelligence Model Selection: Artificial intelligence relies on trained models to analyze data and recognize patterns. Machine learning algorithms can be used to predict bee behavior, disease symptoms and honey production. The type of data to be analyzed is determined and an appropriate machine learning or artificial intelligence model is selected. For example, LSTM (Long Short-Term Memory) for time series data or support vector machines for data classification.

Model Training: The model is trained with data to ensure that the selected model understands the data and can be used for future predictions.

Prediction and Analysis: Future events are predicted using the trained model. Or the data can be analyzed and used in decision-making processes such as predicting the behavior of bees or bee diseases.

Application Development: An application or interface may need to be developed to integrate the AI model. This application provides users with the ability to view and analyze data and make decisions.

Continuous Monitoring and Improvement: The system should continue to monitor the beehives on a continuous basis. The performance of the AI model should be regularly evaluated and improvements made where necessary. This should include collecting new data and retraining the model.

Data Security and Privacy: Data security and privacy are of paramount importance in digital beekeeping. Appropriate security measures must be taken to protect sensitive data and safeguard it from unauthorized access. Digital beekeeping with AI helps beekeepers make better decisions, monitor bee health more closely and increase the productivity of bee products. However, this process involves complex steps such as data collection, model training and application development and requires expertise.

6. Digital Beekeeping Operations with Artificial Intelligent and Machine Learning

With Artificial Intelligent and Machine Learning, the following methods and techniques can be used in digital beekeeping and the results that can be obtained from them can be as follows:

Data Preprocessing: Cleaning and organizing the collected data is the beginning of the analysis process. Missing or outlier data is corrected and noise filtering is performed. Data cleaning, data standardization, data transformation, outlier processing, data merging, data dimension reduction, data visualization, and data splitting are performed respectively. Data preprocessing analysis makes data more meaningful and usable, helping you to make better decisions in areas such as beekeeping management, disease monitoring and production planning.

Data Visualization: Visual representation of data is important to better understand and interpret trends and patterns. Data are visualized using visual tools such as graphs, charts and maps. Examples include a graph of honey production, the relationship between bee population and air temperature, and a graph of beehive weight. Data visualization analysis helps beekeepers understand data more quickly and effectively. These visualizations enable better decisions on beekeeping management, disease monitoring and production strategies.

Regression Analysis: Regression analysis can be used in beekeeping to examine the relationship between data and to understand the effect of a dependent variable on other independent variables and to model the relationship between them. Examples include the relationship between temperature and bee activity, honey production predictions and bee lifespan. Regression analysis is a useful tool to better understand beekeeping data, identify relationships and predict future events. These analyses can help beekeepers make better decisions, monitor hive health and optimize their production.

Classification: Classification is used to sort data into specific classes or categories. For example, classification algorithms can be used to classify the health of beehives into classes such as "healthy," "sick," or "in danger." Examples include bee disease diagnosis, the impact of weather conditions and hive health status. Classification analysis can help beekeepers to better understand data, group it according to specific criteria and make decisions based on these groupings. This analysis is important for beekeeping management and monitoring of bee health.

Clustering: Cluster analysis can be used in beekeeping to organize data into groups or clusters and group together data points with similar characteristics. This can be used to identify similar behavior and health status of beehives. Examples include beehive classification, disease diagnosis, pollination monitoring. Cluster analysis is a useful method for better understanding and categorizing beekeeping data into specific groups. These groups can help beekeepers make better decisions, monitor health status and optimize their production.

Time series analysis: Time series analysis is used to study data that changes over time. Data that changes over time is modeled, predicted and analyzed. This is an important and powerful tool for understanding time-varying data such as bee activity or hive weight. Examples include monitoring hive weight, honey production forecasts, identifying trends. Time series analysis is an important tool for understanding beekeeping data and predicting future events. These analyses can help beekeepers make better decisions, monitor hive health and optimize their production.

Artificial Neural Networks (ANNs): Artificial neural networks are used to analyze complex data, make predictions and learn. Especially with deep learning networks (Deep Learning), they can model complex relationships. Examples include monitoring the health of the hive, the relationship between bee activity and weather conditions. Artificial Neural Networks are useful for processing beekeeping data and modeling complex relationships. However, they should be applied with caution, as large data sets and model training are often required to obtain accurate results.

Support Vector Machines (SVM): SVM is used for classification and regression problems. It is especially effective for classification problems. Examples include bee disease diagnosis, monitoring bee behavior. SVM can be a powerful tool for classification and analysis of beekeeping data. However, training the SVM and fitting the model to the data must be done carefully to obtain accurate results.

Decision Trees: Decision trees are used to classify or regress data in a tree-like structure. They produce simple and understandable models. Decision trees can be used for various processes in beekeeping and can explain decision-making processes in a simple and understandable way. Examples include hive health assessments, weather sensitivity analysis and understanding communication between bees. Decision trees can be a useful tool for understanding beekeeping data and optimizing decision-making processes. In particular, the results of these models can be easily interpreted, facilitating information sharing and decision making among beekeepers.

Deep Learning: Includes complex neural network models that can produce results on large and complex datasets. It is particularly effective for visual data analysis. Analyzing beekeeping data may require different methods depending on the data types, questions and objectives. The data analysis process should be adapted to suit the characteristics of the data and the analysis requirements. These methods can help beekeepers to better understand the health, behavior and environmental impact of bee colonies. Examples include disease diagnosis, weather sensitivity, pollination and plant monitoring. In beekeeping, deep learning is a powerful tool that can be used for complex data analysis and understanding bee behavior. With its ability to model complex relationships on large and complex data sets, deep learning can offer a variety of applications in the beekeeping industry. However, the model training and data collection processes should be carefully planned.

7. Conclusion and Recommendations

Beekeeping is an important part of the natural world and has provided honey production and other bee products for humans for centuries. The rapid advancement of technology has enabled the transition from traditional beekeeping to digital beekeeping. Digital beekeeping promotes the modernization of the beekeeping industry and the use of more sustainable beekeeping practices. These technologies increase beekeepers' incomes, reduce environmental impacts and ensure the sustainability of beekeeping. Data analysis and environmental monitoring tools help beekeepers to better understand environmental impacts and optimize their beekeeping accordingly.

Research shows that digital beekeeping represents an important transformation in the beekeeping sector and that these technologies are an effective tool to improve bee health and the productivity of colonies. The paper discusses how these new technologies can be integrated into the beekeeping sector. Digital beekeeping technologies such as IoT sensor technologies, big data, data management, data analytics, data mining, data security, artificial intelligence, cloud computing and big data analytics are increasing beekeepers' ability to remotely monitor beehives, diagnose diseases earlier and make more informed decisions. The research reveals that digital beekeeping practices can increase beekeepers' incomes and contribute to environmental sustainability.

In the future, digital beekeeping technologies need to be developed, improved and facilitated. In particular, it is important to make IoT sensors more sensitive, durable and energy efficient. Digital beekeeping training programs and resources for beekeepers need to be developed and made more widely available. Digital beekeeping training resources and seminars should be organized to help beekeepers use technology more effectively and learn how to use these technologies. Digital beekeeping should be made more widespread among beekeepers so that beekeepers adopt digital technologies and understand the applications. Help beekeepers to invest more in digital technologies and see them as an essential part of their business.

Communication and collaboration between technology companies, research institutions and beekeepers will pave the way for further innovation in digital beekeeping. Efforts should be made to standardize and share digital beekeeping data at national and international level. This will create a broader database for monitoring the health of bee colonies and environmental impacts. Processing the database with data analytics will contribute to more effective implementation of big data projects. This will guide further progress in the field of digital beekeeping and the adoption of these technologies by more beekeepers.

3D printers can offer innovative and customizable solutions in the field of digital beekeeping. However, the impact of materials on food safety and the health of bees should be considered before use. Appropriate materials and design guidelines should be used. In digital beekeeping, 3D printers can be used to make hive equipment, sensor assemblies, pollen traps, feeding equipment. These can be used both as production and educational tools. Digital beekeeping experiences can be realized using augmented reality and virtualization. With this method, more information, educational resources and field experience in digital beekeeping can be accessed.

For data security and confidentiality in beekeeping, measures should be taken to protect beekeepers' data and protect against its use by malicious persons. Beekeepers should take the necessary security measures for secure storage and processing of data from hives. Digital beekeeping practices should be further integrated into sustainable beekeeping practices. This will help reduce the environmental impacts of beekeeping. Collaborations and intra-sectoral cooperation should be encouraged. Communication and cooperation between technology companies, research institutions and beekeepers should be ensured and information should be shared.

Academic studies and literature on the Internet of Things (IoT) and Decision Support Systems (DSS) in beekeeping are very limited, and digital transformation and technological developments in this field are only recently becoming the subject of research. Important interdisciplinary studies are needed in the literature in terms of computer, electrical electronics and information systems engineering, agriculture and animal husbandry related fields. The topics to be covered by these studies can be Internet of things (IoT) and beekeeping in terms of MIS, decision support systems and beekeeping, data analysis and beekeeping, security, privacy and beekeeping, digital beekeeping field applications. In the academic world, more research should be done on how the topics covering these areas can be integrated with beekeeping. The studies to be carried out will contribute to making the beekeeping sector more sustainable and more effective with data-based decisions. Researchers and academicians should work to produce new information and findings in this field.

The technologies developed will facilitate the beekeeping activity, allowing the number of businesses operating in this sector to increase. At the same time, by adopting these new technologies, existing beekeeping businesses can increase the amount they produce and obtain higher quality bee products, thus providing added value to the sector. New technologies such as artificial intelligence and machine learning will help beekeepers analyze data more effectively and predict future problems. Furthermore, digital beekeeping will continue to play a vital role in beekeeping as a critical tool to protect bee health and provide beekeepers with opportunities for higher profits.

As a result, beekeepers should adopt digital beekeeping technologies and equip their hives with these technologies. Digital beekeeping will continue to play an important role in the future of the beekeeping sector. The adoption and development of these technologies will bring great benefits to both beekeepers and the industry as a whole. Future work should focus on the further improvement and dissemination of digital beekeeping technologies.

Conflicts of Interests

Authors declare that there is no conflict of interests

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Statement contribution of the authors

This study's experimentation, analysis and writing, etc. all steps were made by the authors.

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