SUMMARY OF PhD THESIS

Analysis and Research Regarding the Use of Big Data and IoT Technologies to Increase the Competitiveness of SMEs in the agri-food Sector

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Introduction

In the current context of globalization and rapid technological evolution, the competitiveness of small and medium-sized enterprises (SMEs) in the agri-food sector is increasingly dependent on their ability to adopt and integrate new technologies. The doctoral thesis titled **"Analysis and Research Regarding the Use of Big Data and IoT Technologies to Increase the Competitiveness of SMEs in the agri-food Sector"** aims to explore how emerging technologies, such as Big Data and the Internet of Things (IoT), can be used to enhance the competitiveness of these SMEs. These technologies enable the collection and analysis of large volumes of data, thus providing a detailed insight into agricultural processes and contributing to their optimization.

The thesis is structured into ten chapters, each addressing different aspects of the research:

1. **Introduction**: Sets the stage by outlining the research background, objectives, and questions.
2. **Current State of Knowledge**: Reviews existing literature and highlights the importance of technology in agriculture.
3. **Applications of Technology and Big Data**: Delves into specific uses of these technologies in the agri-food sector.
4. **Trends of Technology in Agriculture**: Discusses ongoing technological advancements and policies.
5. **Analysis of Sector Stakeholders**: Examines value chains and the role of SMEs.
6. **Personal Contribution**: Outlines the original contributions of this research.
7. **Research Objectives**: Details the specific aims and hypotheses.
8. **Material and Method**: Describes the methodologies used in the research.
9. **Results and Discussions**: Presents and analyzes the findings.
10. **Conclusions and Recommendations**: Summarizes the research outcomes and offers practical advice for stakeholders.

In this thesis, the following research questions have been formulated to guide our investigations:

1. How do Big Data and IoT technologies enhance the competitiveness of SMEs in the agri-food sector?

2. What are the primary applications of Big Data and IoT technologies in agriculture?
3. What challenges do SMEs encounter when implementing Big Data and IoT technologies?
4. What strategies can SMEs adopt to effectively integrate Big Data and IoT technologies?

Importance of Technology

Big Data and Internet of Things (IoT) technologies offer significant opportunities for the agri-food sector. These technologies allow for unprecedented precision in monitoring and managing agricultural resources, contributing to increased yields and reduced costs. The use of these technologies is revolutionizing farm management, providing farmers with detailed and real-time information about soil conditions, crop health, and resource utilization. This not only optimizes production processes but also minimizes risks and negative environmental impacts.

A clear example of the importance of these technologies is precision agriculture. It uses data collected from sensors and satellite imagery to monitor essential variables such as soil moisture, nutrient levels, and plant health. This way, farmers can make informed decisions, applying the exact amount of water, fertilizers, and pesticides needed. As a result, costs are reduced and efficiency is improved, leading to increased production and environmental protection.

Furthermore, IoT enables the interconnection of various agricultural equipment, from autonomous tractors to smart irrigation systems. These devices communicate with each other and with farmers, facilitating an integrated and automated management of agricultural activities. This reduces the time and effort required for farm management, allowing farmers to focus on strategic and innovative aspects of their business.

Moreover, Big Data and IoT technologies can contribute to improving the sustainability of agriculture. By monitoring and analyzing environmental data, farmers can implement more environmentally friendly agricultural practices, reducing the excessive use of pesticides and fertilizers and minimizing the impact on local ecosystems. This not only protects the environment but also contributes to the health and safety of consumers.

Additionally, these technologies facilitate the traceability of agri-food products from farm to fork. Data collected from various stages of the supply chain can be integrated and analyzed to ensure the quality and safety of food. This is particularly important in the context of increasingly stringent consumer and regulatory demands for transparency and food safety.

Beyond the benefits for farmers, the implementation of Big Data and IoT technologies in agriculture can stimulate innovation and create new business opportunities. Start-ups and tech companies can develop customized solutions for the specific needs of modern agriculture, contributing to economic growth and job creation in the tech and agricultural sectors.

Applications in Agriculture

Big Data and Internet of Things (IoT) technologies are used in agriculture to monitor soil conditions, crop health, and resource efficiency. These technologies enable the collection of large amounts of real-time data, which are then analyzed to provide farmers with precise and up-to-date information. Through sensors placed in the soil, farmers can monitor moisture and nutrient levels, allowing them to adjust irrigation and fertilization to maximize yields and reduce waste.

For example, moisture sensors can detect areas in the field that require water, allowing for targeted and efficient irrigation. This not only saves water but also prevents over-irrigation, which can lead to soil erosion and nutrient loss. Similarly, nutrient sensors can identify deficiencies in essential elements in the soil, so farmers can apply only the necessary amounts of fertilizers, reducing costs and environmental impact.

IoT also enables monitoring of crop health through drones and satellite imagery. These can detect early signs of diseases or pests, allowing for quick and effective interventions. For instance, multispectral images captured by drones can highlight areas affected by water stress or infestations, and farmers can apply specific treatments only to those areas, saving resources and protecting the rest of the crop.

Furthermore, Big Data technologies can predict crop development based on historical data and climatic models. These predictions help farmers plan planting and harvesting cycles, manage risks associated with weather conditions, and optimize resource use. For example, a prediction system can indicate the optimal time for sowing so that crops benefit from ideal growing conditions.

The implementation of these technologies contributes to the overall efficiency of farms and reduces operational costs. Additionally, they support sustainable agricultural practices by optimizing resource use and reducing the negative impact on the environment.

Challenges

Implementing Big Data and Internet of Things (IoT) technologies in agriculture comes with several significant challenges. One of the main challenges is the need to invest in expensive equipment and develop digital skills among farmers. Many modern technologies require advanced equipment that can be costly and difficult for SMEs in the agri-food sector to access. For example, using sensors to monitor soil and crop health involves high initial costs and ongoing maintenance .

Another major challenge is related to the digital skills of farmers. Many farmers, especially those from older generations, lack the necessary digital skills to effectively use these technologies. This necessitates additional investments in training and education to enable them to adopt and utilize new technologies. Additionally, there is a regional disparity in technology adoption, which can create inequalities between different agricultural areas .

Data security concerns represent another significant issue. IoT and Big Data technologies collect and store large amounts of data, which can be vulnerable to cyber-attacks. Ensuring the security of this data is crucial to protect the sensitive information of farmers and prevent unauthorized use of the data .

Integrating various technological systems is also a key challenge. IoT and Big Data technologies require a robust communication and energy infrastructure, which may be underdeveloped in rural areas. Establishing a resilient communication network in rural regions is crucial for advancing Ag 4.0, facilitating efficient data sharing and analysis .

Methodology

The research involved expert interviews, focus groups, and SWOT analyses to identify the barriers and opportunities in adopting Big Data and IoT technologies in Romanian agriculture.

Expert interviews were crucial for gaining valuable insights from professionals in the field, including farmers, agricultural consultants, researchers, and representatives of technology companies. These interviews were structured to explore the experiences and opinions of experts on the implementation and use of advanced technologies in agriculture, as well as to identify specific challenges faced by SMEs in this process. A total of 75 interviews were conducted with experts from five European countries (France, Italy, the Netherlands, Romania, and Spain), providing a diverse range of viewpoints on the technological requirements and difficulties encountered by SMEs in the agri-food sector.

Focus groups brought together stakeholders from various sectors of the agri-food value chain to discuss and validate the research findings and the proposed strategic framework. Six focus groups were organized, each focusing

on different aspects of integrating Big Data and IoT technologies in agriculture. These groups facilitated open and constructive dialogue, contributing to a deeper understanding of the needs and concerns of various stakeholders. Discussions covered topics such as the necessary infrastructure, implementation costs, required skills, and ways to support farmers in the digitization process.

SWOT analysis was used to evaluate the strengths, weaknesses, opportunities, and threats associated with adopting Big Data and IoT technologies in agriculture. This included identifying internal and external factors that influence the successful implementation of these technologies. By integrating SWOT analysis with the SBOC (Strengths, Barriers, Opportunities, Challenges) technique, the research provided a comprehensive assessment of the factors impacting SMEs, facilitating the creation of focused strategies that align with business goals and market conditions.

Furthermore, the research methodology included the use of both quantitative and qualitative methods to ensure a comprehensive and rigorous approach. Data collected from interviews and focus groups were statistically analyzed to identify relevant trends and correlations, while case studies and field observations provided context and depth to the interpretation of results.

Additionally, the research utilized SWOT analysis combined with the SBOC technique to provide a detailed perspective on the adoption of technologies in SMEs. This involved collecting data through questionnaires distributed to farmers and other industry stakeholders, followed by quantitative analyses to assess the perceived and potential impact of the technologies. The results were validated through discussions in focus groups, ensuring a fair and balanced representation of stakeholder opinions.

The methodology also included organizing workshops and seminars to disseminate preliminary research findings and gather feedback from participants. These events were crucial for refining and improving research approaches, as well as for encouraging collaboration and knowledge exchange among various actors in the agri-food sector.

Moreover, the use of data analysis techniques enabled the identification of emerging trends and best practices in the adoption of Big Data and IoT technologies. This included analyzing data from pilot farms where these technologies were implemented, providing concrete examples of success and lessons learned. These case studies were essential for demonstrating the viability and benefits of the technologies, as well as for identifying practical challenges in implementation.

Results and Discussions

The results of the research indicate that adopting Big Data and IoT technologies can significantly increase the competitiveness of SMEs in the agri-food sector. The implementation of these technologies has led to the optimization of operational processes, cost reduction, and increased yields. For example, by using sensors and data analytics, farmers were able to monitor and manage agricultural resources more efficiently, leading to more judicious use of water and fertilizers and reduced losses.

However, to maximize the benefits of these technologies and overcome the associated challenges, a coherent strategy is necessary. The research identified major barriers including technical limitations, lack of expertise, and financial constraints. For instance, many SMEs face difficulties in accessing advanced equipment and training staff to use new technologies. It is evident that without adequate support and a well-defined strategy, SMEs may struggle to adopt these innovative technologies.

The combined SWOT and SBOC analysis revealed both opportunities and threats related to the adoption of these technologies. Opportunities include improved operational efficiency and access to new markets, while threats are represented by data security risks and the difficult integration of diverse technological systems. Additionally, cultural barriers were identified, where resistance to change and the lack of an organizational culture favorable to innovation can hinder the widespread adoption of new technologies.

Implementing a tailored strategic framework demonstrated tangible improvements in the operational efficiency of SMEs. The clear guidelines and best practices provided enabled SMEs to adopt and integrate BD and IoT technologies effectively, leading to the optimization of their operational processes. For example, by using IoT platforms for real-time monitoring of environmental parameters and crop conditions, farmers were able to respond promptly to any changes, minimizing risks and maximizing yields.

The results of the pilot case studies showed a significant increase in productivity and competitiveness of SMEs through the use of adapted BD and IoT solutions. The customized solutions developed improved resource management and decision-making processes, demonstrating the positive impact of these technologies on SME performance. Additionally, farmers reported a reduction in operational costs and an increase in yields, leading to an overall improvement in the sustainability and profitability of farms.

The research also revealed that collaboration among different actors in the agri-food value chain is crucial for the successful adoption of these technologies. By creating partnerships between farmers, technology providers, and academic institutions, the transfer of knowledge and resources was facilitated, thereby accelerating the digitization process in agriculture. This collaboration enabled the sharing of best practices and innovations,

contributing to the faster and more efficient adoption of advanced technologies across the industry.

Furthermore, the results highlighted the importance of supportive policies and adequate funding to facilitate the adoption of BD and IoT technologies. Many SMEs require financial support to make the necessary investments in equipment and training. Government programs and funding initiatives can play a crucial role in this regard, ensuring that farmers have access to the resources needed to adopt and utilize new technologies effectively.

The detailed analysis of collected data allowed the identification of best practices for integrating BD and IoT technologies into agricultural operations. These practices include the use of integrated monitoring systems, the implementation of open data platforms, and the development of customized solutions for the specific needs of each farm. These approaches demonstrated that BD and IoT technologies could be successfully adapted to various types of farms and agro-climatic conditions, contributing to improved performance and sustainability.

Besides operational benefits, the adoption of BD and IoT technologies also had a positive impact on the social and environmental aspects of agriculture. Farmers reported an improved quality of life due to reduced manual labor and increased efficiency, while the sustainable agricultural practices promoted by these technologies contributed to the conservation of natural resources and the reduction of environmental impact.

These technologies also facilitated improved traceability and transparency in the agri-food supply chain. By using IoT sensors and Big Data analytics, farmers and producers were able to track their products more precisely and in more detail from the farm to the final consumer. This not only improved food quality and safety but also strengthened consumer trust in agri-food products.

The research also demonstrated that the use of advanced technologies led to better adaptation to climate change. Farmers used the collected data to more accurately predict extreme weather events and adjust their agricultural practices accordingly. This reduced the risks associated with adverse weather phenomena and contributed to the long-term stability of agricultural production.

Additionally, farmers benefited from continuous technical support and training, ensuring they were capable of using and maintaining advanced equipment in the long term. Partnerships with academic institutions and research centers facilitated the development of educational and training programs tailored to the specific needs of each farm, contributing to the increase of farmers' skills and knowledge in using BD and IoT technologies.

The results also showed that integrating advanced technologies led to the creation of new economic opportunities in rural areas. The development of new businesses and services around BD and IoT technologies stimulated the local economy and created jobs, contributing to the revitalization of rural communities and reducing migration to urban areas.

The research emphasized the importance of an adequate legal and regulatory framework to support the adoption of BD and IoT technologies. Clear policies and favorable regulations facilitated the implementation of new technologies, ensuring data protection and promoting innovation in the agri-food sector.

Conclusions and Recommendations

Big Data and IoT technologies have the potential to revolutionize the agri-food sector. The research results have shown that adopting these technologies can lead to significant increases in productivity and competitiveness for SMEs. However, to maximize the benefits and overcome associated challenges, it is essential to invest in professional training for farmers and develop the necessary infrastructure to support the adoption of these technologies.

Investment in professional training for farmers is crucial, as many of the barriers to adopting advanced technologies are related to a lack of digital skills. Farmers need to be trained to effectively use new technologies, interpret collected data, and make informed decisions based on this data. Continuous training and skill updates are necessary to keep farmers up-to-date with the latest technologies and agricultural practices.

Developing adequate infrastructure is also essential. This includes ensuring access to modern equipment, robust communication networks, and data storage and analysis solutions. Communication infrastructure, especially in rural areas, needs to be improved to enable the efficient use of IoT sensors and other connected devices. Investments in infrastructure will facilitate the collection, transmission, and analysis of data, thereby optimizing agricultural processes and improving yields.

The research recommendations also include creating supportive policies and funding initiatives to assist the adoption of BD and IoT technologies. Government programs and funding initiatives can play a crucial role in ensuring that farmers have access to the resources needed to make the necessary investments in equipment and training. Additionally, promoting collaboration among different actors in the agri-food value chain is important for facilitating the transfer of knowledge and resources.

In conclusion, the adoption of Big Data and IoT technologies can bring significant benefits to the agri-food sector, but the success of this process

depends on investments in training and infrastructure. A concerted effort from farmers, governments, and the private sector is needed to create a favorable environment for the adoption of these innovative technologies and to ensure the long-term sustainability and competitiveness of SMEs in this sector.

To facilitate the adoption of these technologies, governments should develop and implement policies that encourage the use of BD and IoT technologies. These policies could include subsidies for the purchase of necessary equipment, subsidized training programs, and tax incentives for farmers who adopt these technologies. Public-private partnerships could also play an important role in developing infrastructure and supporting farmers in the transition to digital agriculture.

Collaboration between farmers and research institutions is essential to develop technological solutions tailored to the specific needs of local agriculture. Researchers can contribute their expertise in developing new technologies and adapting them to different agro-climatic conditions and soil types. These collaborations can lead to innovations that improve the efficiency and sustainability of agriculture.

Another important aspect is educating and informing farmers about the benefits and practical uses of BD and IoT technologies. Awareness campaigns and practical demonstration programs can help farmers better understand how these technologies can improve agricultural processes and how they can be integrated into their daily activities.

To ensure the long-term success of these initiatives, continuous monitoring and evaluation of the implementation of BD and IoT technologies is essential. This would include collecting feedback from farmers, analyzing the impact on productivity and sustainability, and adjusting strategies and policies based on results. A flexible and adaptive approach will allow farmers to fully benefit from the advantages of advanced technologies and respond effectively to emerging challenges.

In the long term, widespread adoption of BD and IoT technologies can fundamentally transform the agri-food sector, making it more efficient, sustainable, and competitive. This will require continuous commitment from all involved stakeholders, including farmers, governments, the private sector, and research institutions. Through collaboration and innovation, the agri-food sector can meet future challenges and contribute to global food security.

Integrating BD and IoT technologies into agriculture can also stimulate the development of the rural economy. Creating new jobs in the technology and agricultural fields, as well as developing related businesses and services, can contribute to the revitalization of rural communities. These technologies offer opportunities for young people and small businesses to innovate and

develop solutions tailored to the local context, thus contributing to economic growth and reducing migration to urban areas.

Adopting advanced technologies can also contribute to more efficient management of natural resources and reducing environmental impact. BD and IoT technologies enable precise monitoring and management of resources, thus reducing excessive use of water, pesticides, and fertilizers. This not only improves the sustainability of agriculture but also helps protect ecosystems and biodiversity.

Additionally, it is important to create collaboration networks and platforms among farmers to share knowledge and experiences. Online forums, discussion groups, and data-sharing platforms can facilitate the exchange of information and help farmers learn from each other. These networks can also facilitate access to resources and support innovation and adoption of new technologies in agricultural communities.

Besides government support, it is essential for the private sector to play an active role in promoting and supporting the adoption of BD and IoT technologies. Technology companies can develop customized solutions for agricultural needs and provide technical support and training for farmers. Partnerships between technology companies and farmers can accelerate the adoption process and ensure the effective implementation of new technologies.

In conclusion, the adoption of Big Data and IoT technologies represents a major opportunity for the agri-food sector. To realize this potential, a coordinated effort is needed from governments, the private sector, and farmers to develop and implement appropriate policies, infrastructure, and training programs. Only through continuous collaboration and innovation can the agri-food sector become more efficient, sustainable, and competitive in facing future challenges.

Innovative Contributions

The thesis provides a detailed analysis of how Big Data and IoT technologies can be integrated into agriculture to improve efficiency and sustainability. The proposals include the development of specific tools and methodologies for SMEs to help them adopt and integrate new technologies. These innovative contributions are based on a rigorous methodology and supported by substantial empirical data gathered through extensive fieldwork, including interviews, focus groups, and pilot case studies.

One of the main contributions of this thesis is the creation and utilization of extensive research tools specifically designed to collect detailed information about the difficulties and advantages encountered by SMEs in adopting Big Data and IoT technologies. These tools include:

- Questionnaires specifically designed to evaluate the implementation and use of Big Data and IoT technologies among SMEs.
- SWOT analysis to assess the strengths, weaknesses, opportunities, and threats associated with the adoption of technology in the agri-food sector.
- SBOC Analysis to identify strategic business objectives and challenges.
- Validation Analysis to evaluate the effectiveness and suitability of the proposed solutions in real-life situations.

The thesis also contributes to the development of a customized strategic framework to efficiently integrate Big Data and IoT technologies in SMEs in the agricultural and food industry. This framework is specifically tailored to overcome the obstacles identified during the research, such as technical constraints, insufficient expertise, financial limitations, and limited availability of funding. The strategic framework provides clear directions and optimal methods for SMEs to adopt and integrate these technologies, resulting in substantial improvements in their operational efficiency and competitiveness.

Another innovative aspect of this thesis is the creation of a comprehensive business plan template and an assessment methodology for agri-food SMEs. The business plan template provides detailed instructions for conducting environmental and trend analysis, implementing technology, managing change, and evaluating performance. This systematic approach assists SMEs in effectively planning and implementing their strategies for technology adoption. This ensures ongoing improvement and alignment with the most effective methods used in the industry.

In conclusion, this thesis makes several innovative contributions, including the creation of new research tools, the incorporation of analytical frameworks, extensive collection of empirical data, and the development of a strategic framework and business plan template specifically designed for agri-food SMEs. These contributions offer valuable perspectives and effective strategies for improving the competitiveness and long-term viability of small and medium-sized enterprises in the agricultural and food industry by implementing Big Data and IoT technologies. The methodology and findings of this research are distinctive and signify a noteworthy progression in the field, providing a sturdy model for future studies and practical applications in the industry.

In addition, the thesis has identified new opportunities for research and application of BD and IoT technologies in agriculture. These include the development of predictive models for crop management, the use of drones

equipped with sensors to monitor soil and plant health, and the implementation of smart irrigation systems based on real-time data. These innovations contribute to optimizing resources and reducing costs, thereby enhancing the operational efficiency of farms.

Another innovative element is the integration of feedback from farmers and other stakeholders in the development and refinement of the proposed solutions. This participatory process ensures that the technologies developed are not only technically efficient but also appropriate for the specific needs and context of the end users. Close collaboration with farmers has allowed for the adjustment and customization of solutions, resulting in broader acceptance and faster implementation of new technologies.

The thesis also proposes the use of open data platforms to facilitate access to information and promote collaboration between farmers, researchers, and technology developers. These platforms allow the sharing of data collected from various sources and the use of this data to develop innovative solutions to common agricultural challenges. This contributes to the creation of an open and collaborative innovation ecosystem where knowledge and resources are shared for the benefit of all stakeholders.

Furthermore, the thesis emphasizes the importance of developing public policies that support the adoption of BD and IoT technologies in agriculture. These policies should include financial incentives, subsidies for purchasing equipment, and training programs for farmers. By creating a favorable environment for innovation, governments can accelerate the adoption of advanced technologies and contribute to the sustainability and competitiveness of the agri-food sector.

In conclusion, the thesis provides a comprehensive and innovative framework for integrating Big Data and IoT technologies into agriculture, emphasizing the development of customized and collaborative solutions that address the specific needs of SMEs. These contributions represent a significant step towards the digital transformation of agriculture and the creation of a more efficient, sustainable, and competitive agri-food sector.

In addition, the thesis emphasizes the importance of interdisciplinary collaboration to fully leverage the potential of Big Data and IoT technologies. By involving specialists from various fields – agronomy, engineering, information technology, and economics – innovative solutions can be developed to address the complexity of agricultural challenges. This interdisciplinary approach ensures that solutions are integrated and efficient, having a positive impact on the entire agricultural ecosystem.

Another important aspect of the innovative contributions of the thesis is the focus on sustainability. By using Big Data and IoT technologies, farmers can optimize the use of natural resources, thereby reducing environmental impact. For example, smart irrigation systems can automatically adjust the

amount of water applied based on weather conditions and soil moisture, saving water and preventing soil degradation. This not only improves the sustainability of farms but also contributes to environmental protection.

The thesis also proposes the development of cooperation networks among farmers to facilitate the exchange of information and experiences regarding the adoption of Big Data and IoT technologies. These networks can include online platforms, discussion forums, and working groups, where farmers can share best practices and collaborate to solve common problems. By creating a collaborative environment, farmers can learn from each other and adopt new technologies more quickly.