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DIGITALIZATION OF THE FOOD SYSTEM AS A MEANS TO PROMOTE FOOD AND NUTRITION SECURITY– A REVIEW

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Abstract: Recently, digitization has become a topic of maximum interest in specialized literature. This is due to current trends and attention to socio–economic issues and population development. As a result, in the agri–food industry as well, digitization is expected to significantly contribute to solving various challenges such as the increasing demand for products and the use of resources. Alternatively, supporting food security is already a global requirement. The food industry is complex and involves various industrial activities such as production, processing, preparation, preservation, packaging and distribution. To maintain food security and ensure products for the ever–growing population, the solution would be the sustainability of agriculture and the food industry. Artificial intelligence–based systems are applicable in almost all stages of automation technology in the agri–food industry, thus ensuring high–quality products. In this paper, we will present digitization solutions in preservation, packaging and distribution processes/technologies in the food industry with the help of artificial intelligence (AI).
Keywords: food safety, internet of things (IoT), digitization in agriculture, artificial intelligence (AI)

INTRODUCTION

Recently, the food industry has faced various challenges related to the ever–changing demands of both customers and suppliers. As a result, new technological methods were implemented in the production systems. These solutions aim to exploit the high economic and innovative potential resulting from the continuous impact of the rapidly advancing information and communication technology (ICT). (*Xi X et al., 2021*). Artificial intelligence (AI), such as methods in machine learning, is increasingly being used in health and healthcare to provide accurate and productive information (*Kamel M.N. et al., 2019*). As food safety increasingly uses digital tools, it is becoming increasingly clear that access to the real–world data that is needed for model development and parameter estimation is a major challenge. Extensive testing of raw materials, processing plants, and finished products for various pathogens and/or indicator organisms may represent an additional cost. The application of the obtained data can be enhanced with digital tools such as agent–based models (ABM) and machine learning (ML) algorithms, which are designed to improve food safety in an establishment (*Marvin H. J. P. et al., 2017*).

The production process in the agri–food industry contains multiple stages, such as harvesting, processing, distribution and storage. These processes have witnessed remarkable changes with the application of science and technology. The first industrial revolution in the early 19th century had a remarkable impact on agriculture and food processing. Demand for labor was increasing, and companies made profits by adding value to local foods, which were often packed, stored and distributed over long distances. Applying the relationship between digital technology and the effectiveness of food safety oversight contributes to a better understanding of the role of digital technology in food safety oversight and how to maximize its influence. In this process, the higher the knowledge level of consumers, the greater the positive promotion effect of digital technology (*Xi et al., 2021*). According to the World Health Organization, approximately 600 million people are affected by foodborne illness each year, of which 420,000 die, resulting in the loss of 33 million years of healthy life (*Scharff et al., 2015*). An appropriate compliance mechanism must be established so that local governments, manufacturers and regulatory bodies understand the importance of their collaboration in achieving high quality and safe products. By applying digital technology, monitoring food safety is made much easier (*Xi et al., 2021*).The development of cross–border infrastructures for digitization supports the global food system by helping find innovative and safe food products. Food manufacturers and processors must adapt to customer demands while maintaining food safety (*Raheem et al., 2019*).

MATERIALS AND METHODS

The continuous development of digital technology is forcing companies in the food industry to restructure their business models. Artificial intelligence is being applied to more and more of the production stages and especially in food safety risk assessment and management. With the adoption of new digital technologies, questions arise regarding the ownership, use, privacy and transparency of the data obtained.

Systems used in modern factories, such as supervisory control and data acquisition (SCADA), manufacturing execution systems (MES), and enterprise resource planning (ERP) create digital models of manufacturing operations. In addition to making the entire production chain more efficient, the data obtained can be applied to improve food safety (*World Food System Centre, 2018*). The industrial revolution in the Internet of Things (IoT) will exploit data collection from precision agriculture, connected factories/logistics and precision food safety to improve microbial risk management. Alternatively, the interaction of public health databases, e–commerce tools, social networks and technologies such as blockchain will improve traceability for food case management (*Donaghy J.A. et al., 2021*). Current global trends will have particular challenges for future global food safety, food security and nutrition. Change will occur from innovation in food production and productivity, the structural and socio–economic impacts on food supply chains to the adaptation of quality and food safety management systems (*King T. Et al., 2017*).

The application of smart agriculture tools and data analysis platforms can significantly increase food security with a low environmental impact (*Garnett T.et al., 2013*). Digitizing the food systems applies innovative technology to optimize harvesting, processing, distribution and storage operations along the agri–food value chain. Mechanization at the beginning of the 19th century, automation in the 1970s and the development of the Internet in recent decades have had a significant impact on our activities and implicitly on the agri–food chain. The World Food System Center anticipated that "the dynamics of the entire food value chain are changing, and unintended consequences are entering the economic landscape through digitization¨ (*World Food System Centre, 2018*).

In the food industry, product quality is essential because defects and contamination can be harmful to human health. Digitization with accurate input and output data of the entire process will help guarantee safety and traceability. In a foretold scenario, technological advances emerging from the fourth industrial revolution (Industry 4.0) will benefit the current food system by becoming greener and more sustainable (*Struebi P., 2016*). The application of digital technologies such as artificial intelligence (AI), machine learning, Internet of Things (IoT) and blockchain in supply chain management a phenomenon that has led innovators and practitioners to analyze and make decisions corresponding to customer requirements and organizations in the system. Agri–food supply chains (AFSC) link the point of production and the point of consumption of food products and supply chain management refers to "managing the relationship between the supply of raw materials for agriculture, production, processing and logistics and distribution of products (*Amentae T.K. et al., 2021*).

RESULTS

With increasing customer demands, global health and the environmental crisis, there has been an accelerated need to develop technologies that are as sustainable as possible. All these aspects have led to obtaining new advanced techniques, such as those with stem cells, 3D printing. The agri–food industry is in continuous evolution and the best results are expected (*Ojo O.O. et al.,2018; Jambrak A.R. et al., 2021*). Digitization is expanding in all areas of industry, and the food industry is no exception. The new industrial revolution is often titled with phrases like Industry 4.0 (I4.0), Cyber–Physical Systems (CPS), Internet of Things (IoT), Cloud Computing and so on (*Zimmer M. et al., 2019; Baurina S.B. et al., 2022*). The digitized food industry involves the use of new technologies in all stages of agro–industrial production, from production to processing, marketing and storage of products. Their implementation depends not only on the degree of computerization, but also on the level of use of systems, devices and mechanisms that allow the possibility of autonomy, use (without human intervention) (*Baurina S.B. et al., 2022; Prause L. et al., 2021*). With the help of artificial intelligence, maintaining quality at the same cost has become much easier (*Sharma S. et al., 2021*).

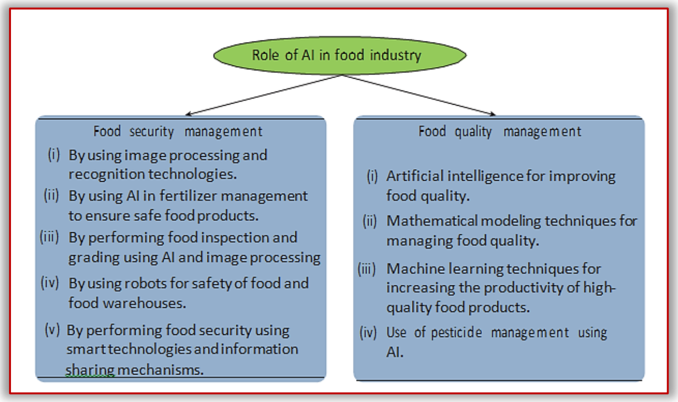

Figure 1 – Role of AI in the food industry (Kumar I. et al., 2021).

Artificial intelligence–based or autonomous systems are applied in almost all stages of technology. They enable the world to efficiently optimize problems, computerize the food industry and transform food products (*Soltani–Fesaghandis G. et al., 2018*). But the use of AI is not only limited to these things, it can be useful in food processing, storage and delivery of food products. Smart gadgets like robotics and smart drones can also play an essential and significant role in reducing packaging costs. It will help deliver food products, performing the task in hazardous environments and providing excellent quality products (*Bera S., 2021*).

— Digitization solutions in preservation processes/technologies

Companies are employing digital technology to collect more data about their workflow operations and to assure safety and quality in food processing, packaging, and distribution (*Cardei P. et al., 2021; Mircea F., et al., 2022*). Food preservation must be carried out in line with international food safety standards. Pasteurization is an essential step in the food industry because it prevents the product from spoiling, keeping its quality at the highest possible level (*Panchal H. et al., 2018*). To adapt digitization technologies to the pasteurization process, it is necessary to investigate consumer products with appropriate sensors and data analysis. Several European projects in the field of food safety have emphasized the need for stronger and more in–depth education and collaboration as solutions to the field concerns, which include funding problems, professional education and technical competitiveness (*Nenciu F., et al., 2020*). Near–infrared diffuse reflectance (NIR) spectroscopy along with multivariate data analysis (MVDA) was applied to discriminate different fruit and vegetable products. Foods were preserved in glass containers, which are commonly used for pasteurizing fruit and vegetable products. The samples were placed on top of a specially designed and 3D printed sample holder, improving the reproducibility of the measurements (*Zimmer M. et al., 2019*).

The results of the investigation represent progress toward a fully automated and autonomous pasteurization process using NIR and MVDA as the main data recording and processing unit (*Zimmer M. et al., 2019*). Chilling and freezing are methods used to preserve food. Conventional cooling and freezing techniques are ineffective in predisposing food to spoilage. To increase the effectiveness of traditional preservation methods, efforts have been made to discover new solutions to ensure high–quality food. Particular interest has been given to pressure–related techniques such as vacuum cooling (VC), vacuum film cooling (VFC), vacuum spray cooling (VSC), isochoric freezing (ICF) and pressure swing freezing (PSF). Research results show that pressure–related cooling and freezing techniques are effective in improving product quality and have real potential in the food industry, as shown in figure 2 (*Zhiwei Z. et al., 2020*).

ICF is a technique that maintains product integrity without causing structural damage to the protein content. Its operation took a different approach by integrating the locality–sensitive hashing (LSH) technique, to achieve a secure and reliable data publication. Experimental results using the real–world QoS dataset, i.e., WS–DREAM, show the competitiveness of the ICFLSH approach in terms of time cost and accuracy (*Chao Y. et al., 2018; Năstase G. et al., 2017*). Drying is the most common method of preserving agricultural crops. This preservation method is simple and affordable, but time–consuming and affects the quality of the final product.

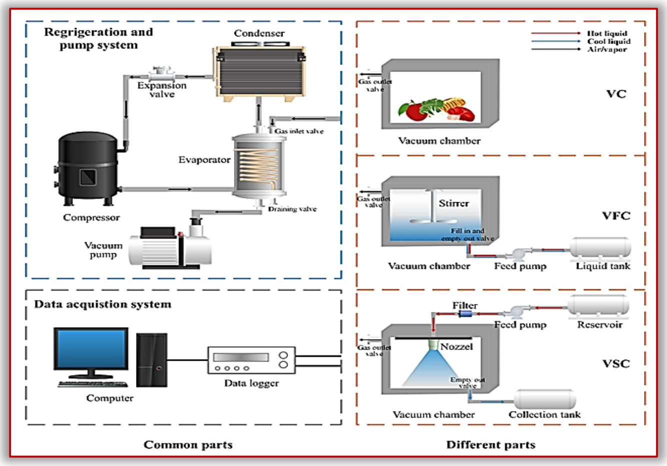

Figure 2 – Schematic of the experimental setup for pressure–related cooling techniques. The red and blue arrows indicate the liquid before and after cooling, and the black arrow indicates air or vapor from the vacuum chamber. VC: vacuum cooling; VFC: vacuum film cooling; VSC: vacuum spray cooling *(Zhiwei Z. et al., 2020)*.

The potential of using a CV imaging system along with a laser diode in monitoring and predicting the quality properties of sweet potato during drying was investigated. Overall, this innovative quality inspection method could provide a solid basis for current trends in non–destructive monitoring of the drying process of agricultural crops. The results obtained for sweet potato can also serve as a basis for other tropical tuber crops, as well as in other post–harvest processing and plant disease detection. The digital imaging system is shown in figure 3 (*Onwudea D.et al., 2018*).

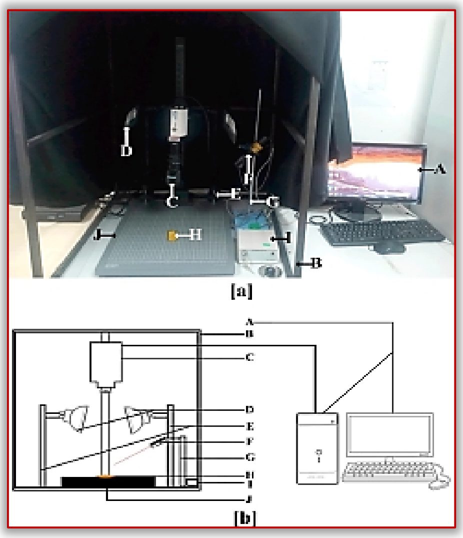

Figure 3 – [a] RGB digital and backscattering imaging system; [b] Schematics of combined RGB digital and backscattering imaging system (A = computer system; B = supporting frame; C = CCD camera; D = halogen lamps; E = Lamp holders; F = laser light emitter; G = laser light emitter's holder; H = sweet potato sample; I = laser diode control box; J = sample capturing platform (*Onwudea D.et al., 2018*).

— Digitization solutions in food packaging

Food packaging is a stage in the food industry that is increasingly facing the demand from consumers and government organizations. This stage must solve the problems related to theft and counterfeiting, food quality and safety, but also the reuse and recycling of packages (*Vanderroost M. et al., 2017*). The global smart packaging market is in continuous development. Growth in 2017/2018 was estimated at USD 44.3 billion and is expected to reach USD 26.7 billion by 2024. Figure 6 shows the estimated growth rate of the global market by 2026 (*Schaefera D. et al., 2018*).

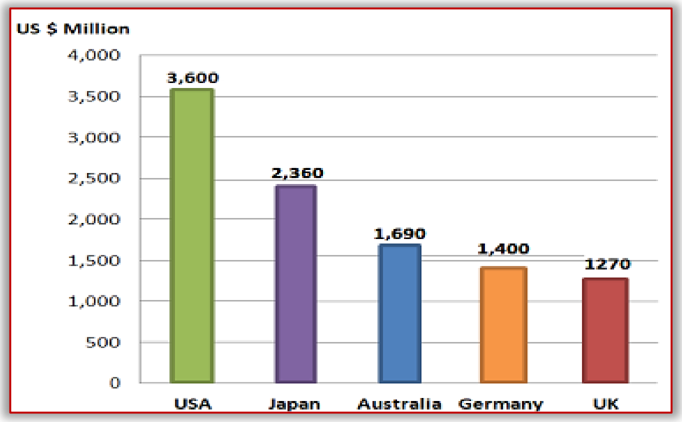

Figure 4 – Predicted global market growth rate *(Schaefera D. et al., 2018).*

The potential of digitizing the life cycle of a food package was studied, and can be used as a model for future research. The creation of new, innovative and quality food packages is inherently linked to uncertainty and risk. Packaging functions and their interrelationships realized with the help of various computer systems are presented schematically in figure 5 (*Vanderroost M. et al., 2017*).

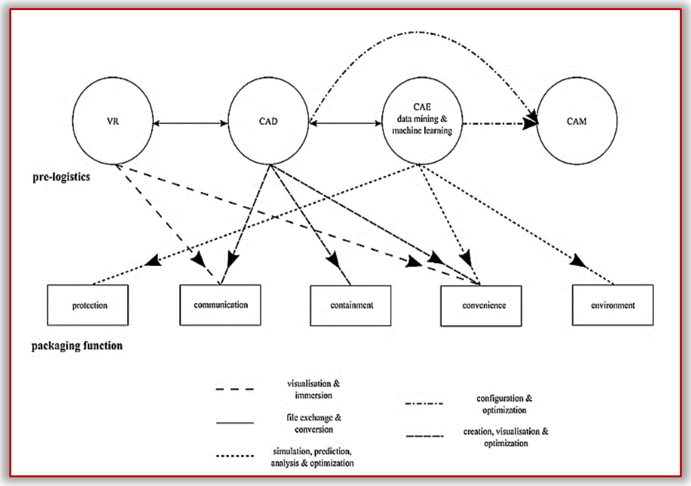

Figure 5 – The scheme of the different computer systems applied in the research, design and production stage, their role in the realization of the different packaging functions and their interrelationships *(Vanderroost M. et al., 2017).*

In the specialized literature, the existing challenges in research and the technical problems that reduce the efficiency of logistics operations regarding food packaging and their interaction with consumers, the reuse or recycling of food packages are exposed. Connecting smart food packaging to the IoE, of course, requires the development of new–cyber–physical systems (CPS) that automate, control and optimize operations related to logistics and the sale and consumption stage of the life cycle of a food package (*Vanderroost M. et al., 2017*). Due to its versatile applications, the Internet of Things (IoT) and blockchain are also gaining attention in the food industry and can help automate tasks and save time (*Waqas Khan P. et al., 2020; Zhang J. et al., 2020*). FoodSQRBlock, a blockchain–based framework that digitizes food production information and makes it more accessible, traceable and verifiable by consumers and producers by using QR codes to embed the information, was studied. Integrated FoodSQRBlock into Google Cloud Platform to replicate a real food production scenario using pumpkins and milk as examples of products from real UK farms. Experimental analysis demonstrates the feasibility and scalability of deploying the FoodSQRBlock in the cloud. To design the BT framework, a three–layer and multi–level system is presented, the architecture of which is represented in Figure 6 (*Dey S. et al., 2021*).

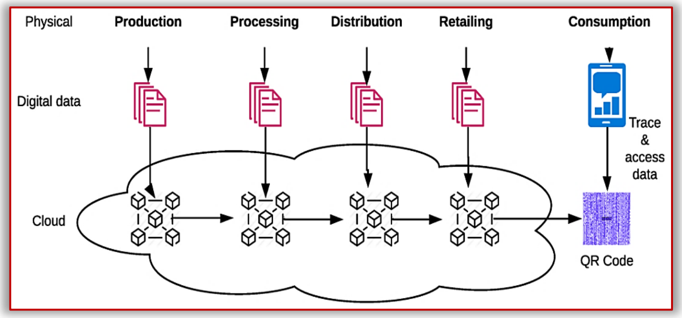

Figure 6 – Overview of the system architecture of the Food Safety Quick Response Block (FoodSQRBlock) based on the farm–to–fork supply chain

The conceptual design procedure of packaging with customized and adapted geometries based on the digitization of fresh food, in this case, apples, was analyzed. Through 3D scanning techniques, reliable digital elements were obtained that could be used in advanced technologies. In this sense, it was possible to define a procedure for reverse engineering different types of food, detailing the specific parameters according to size and finish. After analyzing the results, it can be said that the final solution obtained is positive. The parameterized design was made possible by the virtual evaluation of the digitized fruits, as exhibited in figure 7 (Rodríguez–Parada L. et al., 2019).

The production of high–quality packaging in accordance with today's requirements is necessary. Digital packaging is characterized by the advantages of digital printing in packaging (*Velichka M., 2021*). An example of food machines in Industry 4.0 is vacuum processing machines (figure 8) that produce food products. The vacuum processing system combines homogenization technology, the highest reproducibility, short batch times and high profitability with ease of use (*Afam I.O. Jideani et al., 2020*).

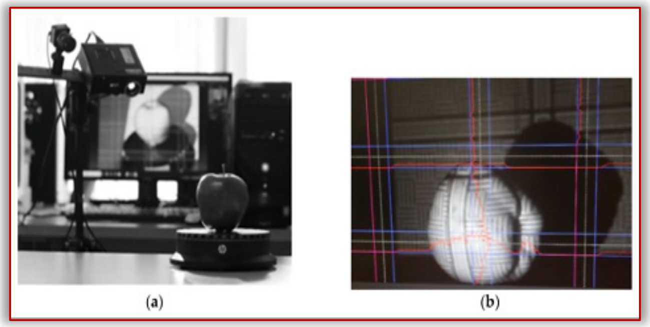

Figure 7 – (a) Scanning procedure using the SLS–1 David® V5 scanner, (b) Visualization of the apple through the software (HP 3D Scan David®, version Pro V5, HP inc., Palo Alto, CA, US)

Figure 8 – A Maxx vacuum processing machine

Unlike the human factor, robotic software can run rule–based steps in a fraction of the time it takes a human to do so. RPA software can record multiple steps between multiple systems. SMI is a software application that was developed according to the principles of Industry 4.0 and IoT. The SWM supervisor is based on a modular web portal that can be customized for any application domain. Thanks to this innovative SMI system, the main causes of bottling or packaging line downtime are easily identified order to improve the entire line. Implementing RPA in the industrial brewing process has resulted in significant cost savings (*Hradecká M., 2019*).

— Digitization during storage

AI in the food industry enables analysis of needs and requirements and focuses on creating high–quality packaging with better shelf life (*Raghavendra G.S. et al., 2022*). During storage, heating and cooling processes make food more prone to microbial spoilage by bacteria or fungi, thus affecting microbial stability (*Tomašević I. et al., 2021*). To maintain as much as possible the quality of food products, it is essential to implement a storage environment monitoring system. In this sense, the use of different sensors with the help of IoT is presented as a viable solution for reducing product losses and increasing food safety (*Si–Wen G. et al., 2021*). The use of the IBM SPSS software platform was analyzed, which provides an easy–to–use interface and a robust set of functions that allows the rapid extraction of useful information (*Raghavendra G.S. et. al., 2022*). The IBM SPSS platform was applied to assess the quality during storage of Nile tilapia filets after ozonated water treatment. The obtained results showed that pretreatment of ozonated water partially improves the quality and extends the shelf life of tilapia filets (*Yongqiang Z. et al., 2015*).

In the literature, the analysis of data obtained using IBM SPSS indicates that the influence of workaholism on food waste (eg food reuse, food storage, etc.) by consumers has a positive influence. The conceptual framework used is presented in figure 9 (*Cantaragiu, R.E. et al., 2020*).

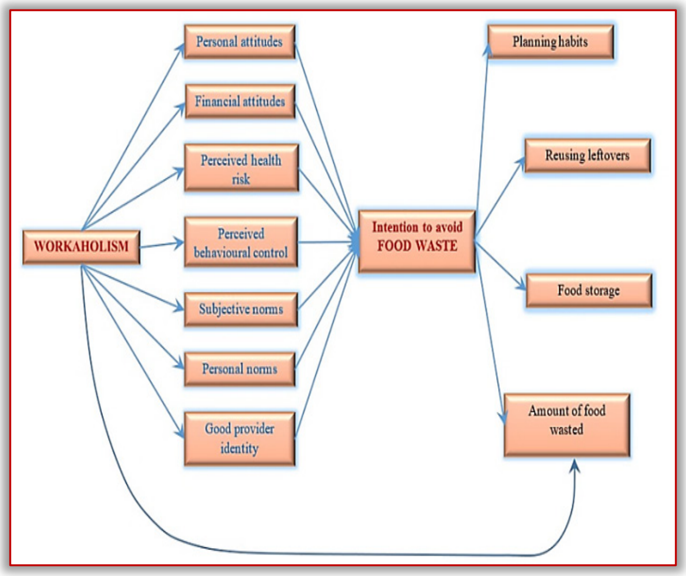

Figure 9 – The conceptual framework *(Cantaragiu, R.E. et al., 2020).*

IBM SPSS software was also used to identify hygienic practices for the storage of cooked food among school food vendors in Nigeria. Hypothesis testing established that the health education intervention had a positive influence on hygiene practices ($p<0.05$) (*Odikpo L. et al., 2020*).

— Palletizing digitization solutions

In today's society, one cannot understand the mass production of a product without the use of artificial intelligence, as is the case with palletizing. Robots are used in various fields of activity (agriculture, transport, food production, packaging and delivery) (*Hamann E., 2020*). Automated systems can be controlled and monitored remotely, which benefits food packaging and palletizing processes where speed and consistency are needed. Even more so, in the context of food safety, where human interaction with food is desirable. Examples of robots used in palletizing are shown in figures 10 and 11.

Figure 10 – A robot palletizing eggs (Walker J., 2019)

Figure11 – Robots performing the process of palletizing (Shriya S. et al., 2021)

— Key Technologies– Beverage Distribution Software

Like the other steps in the food industry, distribution knows a continuous development and must be adapted to the current requirements related to volume, speed and handling in food safe conditions. Technologies offered by Bastian Solution help increase system capacity, efficiency and order flow. Gain better visibility of orders and inventory and increase storage capacity and eliminate the use of offsite warehouses.

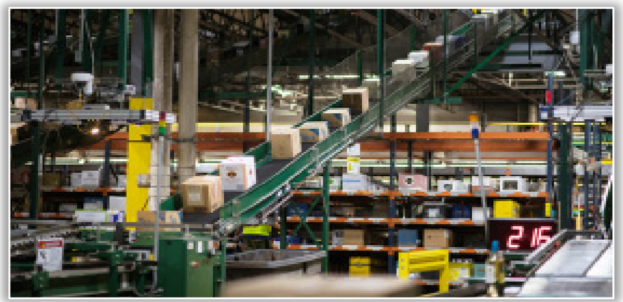

Figure12 – Wine and Spirits Distribution Center Southern Glazer's Wine and Spirits of America

Figure13 – Exacta software provides complete, real–time visibility of orders throughout the system

ExactaBev beverage distribution software features 4–part ordering and automatic order routing. Exacta software provides complete, real–time visibility of orders throughout the system. This technology is used by the world's largest wine and spirits distribution center Southern Glazer's Wine and Spirits of America which has operations in 44 states (figures 12 and 13).

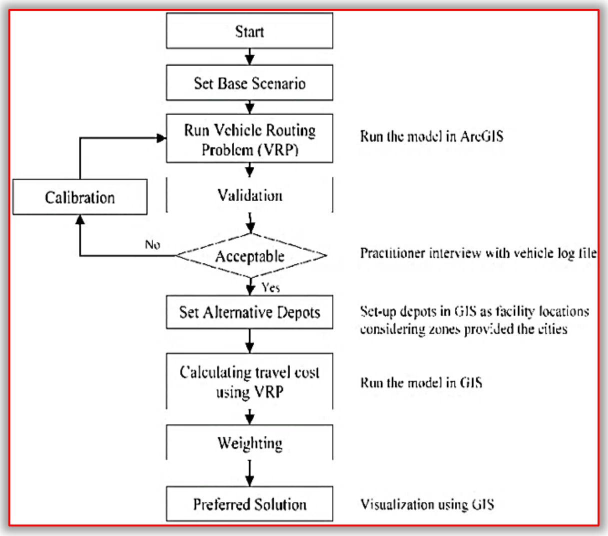

Figure 14 – The research framework of the study (EunSu L. Et al., 2015).

Another method that can be easily applied to distribution companies for long–term and medium–term strategic planning is described in figure 14 (*EunSu L. Et al., 2015*).

CONCLUSIONS

There is an urgent need to have a change in our food system that encourages food security and sovereignty. The technology foundation behind digitization, as described in this paper, when clearly aligned to the food industry, can revolutionize the industry. Digitization in the food system will positively affect food safety and security, thereby ensuring human security. Cross–border collaboration at the regional level that encourages sustainability, transparency and efficient resource management will improve with digitization.

In the current scenario, the food industry is using the basic level of artificial intelligence. Every day, the role of AI becomes vital due to its ability to escalate hygiene, food protection and waste management systems. In the future, AI will transform the food processing industry because it has so much potential to drive reasonable and healthier productivity for customers and employees.

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