Big data in the food supply chain

The technological, organisational and environmental factors that play a role

By Osden Jokonya and Jade Taff

The fourth industrial revolution has redesigned the future of food production and transformed the food supply chain. This advancement and evolution of digitalisation has enabled organisations to modify business models and processes resulting in new and increased revenue and enhanced value-offering opportunities. This has meaningfully altered and advanced the adoption of big data technologies in organisations. OSDEN JOKONYA and JADE TAFF and argue that the adoption of big data in the food supply chain is important to African food systems and analyses the factors that affect its adoption.

Introduction

This study explores the technological, organisational and environmental factors that affect the adoption of big data in the food supply chain. It provides a content analysis of articles published between 2014 and 2022 using a quantitative research method based on the Technology-Organisational-Environmental (TOE) framework. The results suggest that technology factors (compatibility, perceived usefulness and relative advantage), organisational factors (technical skills, resource capacity and organisational readiness) and environmental factors (market structure and government pressure) all affect the adoption of big data in the food supply chain.

In a perfect world, the entire human race would have a satisfying meal every day, sustaining their daily nutrition intake and maintaining an excellent bill of health. This reality, however, does not exist. The World Business Council for Sustainable Development (2019) asserts that an imperative requirement for transformation is needed, as existing food systems exceed the resources available for food production. According to the World Economic Forum (WEF): "Almost two billion people do not have access to safe, nutritious, and sufficient food, while one in five children suffer from stunting and nearly one-third of the food produced each year is uneaten" (2020: 8).

The transformation of food systems is needed to deliver sustainable support for the growing population while concurrently creating opportunities within economies and supportable living for all societies (WEF, 2020). Digital technologies, especially big data, can help alleviate the challenges of food insecurity and improve food production within food systems. When looking at the food supply chain and the transformation of food systems through big data, it is important to investigate the factors affecting their adoption which potentially assists with improving the process and strategy across a food supply chain, known as 'from farm to fork'. This strategy, "addresses comprehensively the challenges of sustainable food systems and recognises the inextricable links between healthy people, healthy societies, and a healthy planet" (European Commission, 2020: 1). The study's objective therefore is to explore factors that affect the adoption of big data in the food supply chain.

Overview of food systems

The main challenge for global food systems is to ensure affordable, sufficient, nutritious and safe food for a growing population while minimising the environmental impacts and addressing climate change. The global number of hungry people increased from 564 million in 2015, when the Sustainable Development Goals (SDGs) were established, to 735 million by 2022 (Vos and Martin, 2024). A sustainable food system is crucial to the United Nation's SDGs, which call for transformative changes in agriculture and food systems by 2030 to end hunger, improve nutrition and ensure food security, requiring coordinated global efforts to make the system more productive, inclusive and environmentally sustainable (FAO, 2018). Fanzo *et al.* (2022:19) add that "sustainable food systems ensure food security and nutrition for all while preserving the economic, social, cultural, and ecological foundations needed to support food security and nutrition for future generations". While food systems have seen significant innovations over the past century, addressing sustainable food security for the growing population requires further technological advancements (Ross & Maynard, 2021). Adopting big data technologies is therefore important to address some of the challenges faced by the African food systems.

Industry 4.0

The fourth industrial revolution has redesigned the future of production and transformed the universal system of invention. This supports the reality that technological alteration is the key driver for the pertinent revolution in society and all industries within. Moreover, this notion emphasises that as the world evolves, new and existing groups of technology arise and merge to create enhanced methods of effectiveness and efficiency within businesses and society. "These rapid advances in technology are doing more than providing us with new capabilities, they are changing the way we live, work, and relate to one another" (Ross & Maynard 2021:159). Lately, the food industry has been challenged by swift and continuous variations due to the fourth industrial revolution, also known as Industry 4.0 or 4IR, which has assisted in altering the changing aspects of the trade inclusively. According to Philbeck & Davis (2018:17):

> *The idea of 4IR is often taken to be a synonym of Industry 4.0, focusing on the application of digital technologies to manufacturing. Industry 4.0 is an important component within the larger framing of 4IR with its narrower, vital focus on the relationship between digitization, organisational transformation, and productivity enhancement in manufacturing and production systems.*

As a result, these revolutions bring about endless opportunities and benefits for the transformation of food systems.

Food 4.0

Immense quantities of products with huge variety are produced within the food sector, while concurrently having to generate high expectations relating to quality and care, improved shelf lifespan and providing continuous consumer brand assurance. Organisations within the food supply chain sector are accountable for upholding and obeying high governing standards which are rigorously established as consumers constantly expect products to be safe, of high quality and readily accessible. Sandeep *et al.* (2021) state that the demand for food products is higher than ever before and resilience must be created within this sector for a variety of diverse food products to be provided. They add that it is unavoidable for organisations to tackle these circumstances and their services and offerings should be swiftly developed without any compromise on the excellence of these products. Consequently, food supply chains and the food sector must display flexibility and agility, and act speedily to respond to these ever-evolving conditions while simultaneously displaying efficiency and delivering products of high quality at the right time which are reasonably priced. These characteristics are all attainable through the implementation of technologies provided by Industry 4.0. According to Sandeep *et al.*:

> *The adoption of Industry 4.0 technologies is anticipated to revolutionise the food industry similar to automotive, aerospace, and other manufacturing. It will potentially substitute human intelligence and labour with technologies such as 3D printing, Robotics, automation, etc. The application of these technologies in the food sector is termed Food 4.0.* (2021:1138)

As a result, these revolutions bring about endless opportunities and benefits for the evolution of the food supply chain.

Overview of big data

The emergence of the big data era is not just associated with improved storage, but also with other factors such as advancements in increased computer processing power, the emergence of new technologies and the growth of the internet that made data more accessible, leading to a significant rise in data generation (Clissa *et al.*, 2023). Due to this, the model of industrialisation is being altered using smart technologies, namely, Artificial Intelligence, Robotics, Drones, the Internet, Blockchain and Big Data. These emerging technologies give rise to enhanced food production, processing, allocation and consumption. This study focuses on big data technologies as it is of utmost importance to understand the adoption of big data, its advantages and disadvantages, as well as the impact and possibilities within the food supply chain. When referring to big data, the distinguishing factor that is known to most is the data size (Manyika *et al.*, 2011). However, it can be defined as having the technological capacity to gather, collect, store, organise, process and distribute large amounts of data sets. "While at beginning, big data was defined by the 3Vs: volume, velocity, and variety. Volume refers to the exponential growth in the amount of data collected. Velocity refers to the speed of data collection. Variety refers to a large number of data sources and formats, the number of Vs has increased substantially to more than thirty" (Shekhar, *et al.*, 2017).

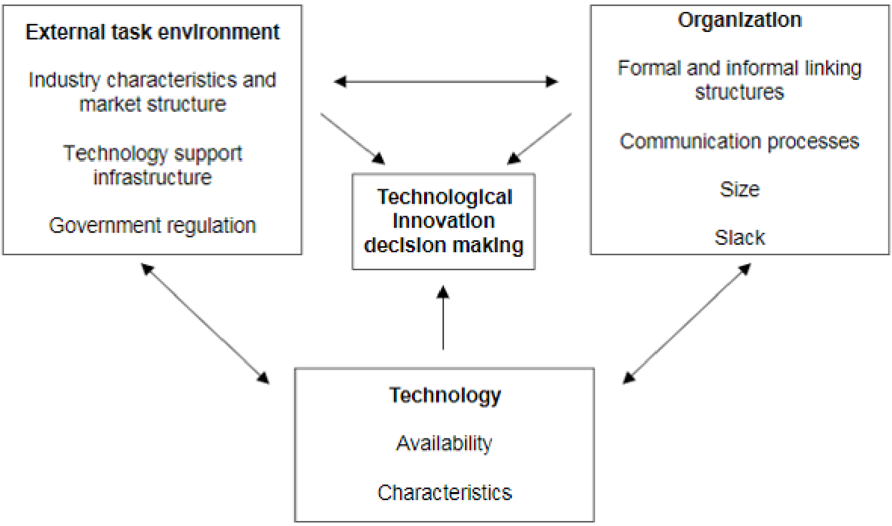
Talari *et al.* (2021) refer to big data as huge measures of speedily formed and collected, intricate online data gathered from numerous sources such as business studies, organisations, available online data records and social media platforms. "Big data is a term that describes large volumes of high velocity, complex and variable data that require advanced techniques and technologies to enable the capture, storage, distribution, management, and analysis of the information" (Clissa *et al.*, 2023). The capturing of new data will permit an improved decision-making process, promote an understanding of origination and optimise procedures within the food supply chain. Furthermore, it is seen to be a significant enabler in the use of value creation in businesses and government entities (Ylijoki & Porras, 2016:70).

The term big data was first introduced in the 1990s and interest has been amplified due to the substantial quantity of data produced during the 2000s (Clissa *et al.*, 2023). Data sets gathered consistently increase as data is continuously created from more devices and sources daily. These foundations of data sets produce enormous volumes of data and as technology evolves, more data will be gathered and collected as civilisation becomes increasingly reliant on technology. White *et al.* (2021) state that the use of big data can enhance farm cost-effectiveness, alleviate ecological risk and provide support in reaching the worldwide food security necessity. This could be a substantial disturbance within the technological space for businesses and academic environments in our current time (Agarwal & Dhar, 2014), as the immense measurements of the data collected can assist in dealing with problems that could not have been dealt with before (Oracle South Africa [OCI], n.d). "In the agriculture community, big data is often viewed as a combination of technology and analytics that can collect and compile novel data and process data in a more useful and timely way to assist decision-making (Shekhar *et al.*, 2017:7318)." However, the disadvantages of big data do exist, such as data errors, remoteness of the data, impracticable data, data mismatch, the lack of hardware and software to manage large data sets, and the non-existence of broadband infrastructure in distant areas which affect the adoption of big data in African food systems (White *et al.*, 2021).

TOE framework

Tornatzky and Fleischer (1990) established the TOE framework (Figure 1) to define the choice of technological innovation adoption by organisations grounded on the technological, organisational and environmental settings. The TOE framework is widely used in technology acceptance studies by delivering a beneficial view of e-solutions. This study uses the TOE framework to evaluate the adoption of big data technologies in digital food systems. The TOE framework identifies three categories of features that impact the methods businesses approve, implement and innovate into technological, organisational and environmental.

Figure 1: Technology, organisation and environment framework



Source: Oliveira & Martins, 2011:112.

Technological factors that influence the adoption of big data in the food supply chain

The technology context within the TOE framework is defined as the internal and external technologies that apply to an organisation, including the existing internal equipment and processes, as well as the external technologies that an organsation can access (Oliveira & Martins, 2011). Additionally, this refers to the existing technology settings within an organisation as well as the envisioned modernisation of technology that will act as an influential component in adopting the innovative technology that is on offer (Salleh & Janczewski, 2016). Hence, the core prominence is how the process of adoption can be influenced by the characteristics of the technology itself. Worldwide matters relating to food security and safety, sustainability and productivity enhancement are only some of the matters that the application of big data can potentially address. The potential benefits and capacity big data could offer the food supply chain are quite appealing, but the above challenges need to be addressed and alleviated to allow for an increased acceptance and application of big data as a technology to enhance these processes and procedures.

Organisational factors that influence the adoption of big data in the food supply chain

The organisational context is defined as the procedures related to the organisation such as the size, scope and decision-making processes (Oliveira & Martins, 2011). This setting encompasses numerous features that generally are representative of an organisation. Furthermore, these features may consist of strategy, values, principles and rules, which can either be seen as an organisational limitation or can act as an enabler when adopting innovative technology (Salleh & Janczewski, 2016). As more and more data sets grow and are formed daily and data customs become increasingly prevalent, they will become an important factor in our lives. Therefore, “the ability to access, analyse, and manage vast volumes of data is increasingly critical to successful operations of leading agribusinesses” (Ribarics, 2016:33). Manyika *et al*. (2011) advocate that big data may turn out to be a significant source of competition, supporting innovative growth in production and consumer excess if an organisation embraces the correct strategies and enablers.

Environmental factors that influence the adoption of big data in the food supply chain

The environmental context within the TOE framework is defined as the ground on which an organisation carries out its day-to-day operations, specific trade, competition as well as government interaction (Oliveira & Martins, 2011). Oliveira & Martin say it is the way “[I]n which a firm conducts its business – its industry, competitors, access to resources supplied by others, and dealing with the government” (2011:1120). Additionally, this context suggests that effects from the environment in which an organisation functions will occur when embarking on the adoption of technology (Salleh & Janczewski, 2016). Environmental factors affecting big data adoption include the government regulations to collect data from various sources, guarantee data safety and consumer unwillingness to share the data (Banica & Hagiu, 2015). This data collected can be a valuable aspect in product redesign and enhancement, reduction of costs and customer-centricity. Banica and Hagiu (2015) note that big data could act as a huge contributing factor in the documenting and understanding of consumer preferences, which will assist in creating and providing valuable information to aid new and relevant product creations.

Overview of related studies

A similar study conducted in the US used a qualitative research approach selecting and interviewing participants (Carolan, 2017). Additionally, a similar study conducted in the UK made use of a qualitative data collection method which included a detailed model to analyse and interpret the findings (Irani *et al.*, 2018). Finally, another research study conducted in the UK used a literature review based on a case study research design (Jagtap & Duong, 2019). Based on the literature review no study was conducted on factors affecting big data adoption in the food supply chain using quantitative content analysis with the TOE framework as the theoretical lens. On that note, this study will contribute to the body of work where there is a methodological gap.

Research methodology

The selected research design used to address the stated research question and its objectives for this study is a systematic literature review (SLR) with a quantitative content analysis design. Kitchenham *et al.* (2009:8) state that, “The aim of an SLR is not just to aggregate all existing evidence on a research question; it is also intended to support the development of evidence-based guidelines for practitioners.” Aromataris

& Pearson (2014) propose that the SLR intends to deliver an inclusive, impartial combination of several related studies in a single paper. Mouton's (2001) findings establish that a literature review is a study of a non-empirical nature that uses secondary data with the research question being descriptive, therefore positioning itself with the study's research question. Additionally, Mouton (2001) explains that an analysis of content design comprises a textual analysis of secondary data which is empirical. The method of conducting an SLR is as follows: research question selection, bibliographic or article data selection, selection of keywords, applying practical screening measures, the application of methodological screening measures, conducting the review, and producing the findings (Fink, 2014).

Unit/s of analysis

As Babbie & Mouton (2001) indicate, the unit of analysis refers to the object of a study and examines objects to conceptualise a summarised account of all such elements. For this research study, organisations within the food supply chain are the chosen unit of analysis. The study's research objective is to explore the factors affecting the adoption of big data in the food supply chain. The study intends to conceptualise the factors affecting the adoption of big data in the food supply chain and therefore presents suitable reasoning for the chosen unit of analysis.

Research instrument

A literature search was conducted using keywords such as "Food Supply Chain", "Transformation of Food Systems", "Emerging Technologies", "Big Data", "Big Data Adoption", "Food 4.0" and "TOE Framework." This search aided in providing all articles relevant to the research topic and study. Articles published within the period 2014 to 2022 were chosen as the study was conducted in 2022 and 50 applicable articles were selected. These articles were then subjected to a manual coding process and were categorised according to the mode, frequency, correlation and analysis of variance of TOE factors as given in Table 1.

Table 1: TOE factors that influence big data adoption

Technological Factors	*Organisational Factors*	*Environmental Factors*
Complexity	*Organisational Readiness*	*Competition*
Compatibility	*Resource Capacity*	*Vendor Capabilities*
Cost	*Firm Size*	*Maintenance & Support*
Perceived Usefulness	*Technical Skills*	*IT Policy & Regulations*
Relative Advantage	*Management Support*	*Market Structure*
Security	*Strategic Objectives*	*Government Pressure*

Data sources, sampling strategies and techniques

The study adopted convenience sampling to access and select relevant peer-reviewed articles from free accessible databases for research study due to budgetary constraints. Convenience sampling also known as non-probability or opportunity sampling, involves picking a sample or samples without a primary probability-based method of selection (Price, 2013). The sampling strategy and technique involved the search for keywords relevant to the research from articles published from 2014 to 2022 including "Food Supply Chain", "Transformation of Food Systems", "Emerging Technologies", "Big Data", "Food 4.0" and "TOE Framework".

Research methods

The systematic review method ensures that the data is collected, classified and categorised into a content analysis matrix according to the TOE framework (technological, organisational and environmental factors). Primarily, the data collection technique used is qualitative as the sampling method applied is convenience sampling. A search using selected keywords aided in the sampling of peer-reviewed articles explored on selected databases such as Taylor Francis Online, AIS eLibrary and Science Direct. Aromataris & Pearson (2014) indicate that a systematic review preferably intends to provide a response rather than presenting a general summary of the literature related to a specific subject. Additionally, Aromataris & Pearson (2014) emphasise that the purpose of a systematic review is to amalgamate and sum up current information and does not pursue the creation of new information. Therefore relevant literature on the specific subject must be available and accessible.

Data analysis

The data analysis applied in the study consisted of categorising and tallying pre-defined settings which exist in the cluster of published articles. The 50 articles chosen were coded manually by the researcher constructed upon subjected clarification whereby the researcher acknowledged resemblances in the qualitative data and categorised this data into segments that share comparable content based upon factors that affect big data technology adoption. Reliability discusses the degree to which the outcome obtained by measurement and method can be repeated and replicated (Bolarinwa, 2015). Additionally, Bolarinwa (2015:198) states: "Reliability is an extent to which a questionnaire, test, observation or any measurement procedure produces the same results on repeated trials." O'Connor & Joffe (2020) explain that inter-coder reliability is a mathematical measure of the arrangement amongst diverse coders based on how equal data is coded. In the form of data analysis, the qualitative data was transformed and coded into quantitative data. This quantitative data was then analysed using a statistical analysis tool (SPSS) to produce frequency, Analysis of Variance (ANOVA) and correlation arithmetical results.

Research results – demographics

This section of the study presents the results of factors affecting the adoption of big data in the food supply chain based on the published articles between 2014 and 2022.

Figure 2 shows the frequency of articles published between 2014 and 2022 based on factors affecting the adoption of big data in the food supply chain. The results presented indicate that 42% of the related articles were published between 2014 and 2018 while 58% of the related articles were published between 2019 and 2022. These results propose that there had been a steady increase in research produced within the stated periods, despite a downward trough in 2018. Furthermore, 2014 and 2022 display the lowest research output at 2% each compared to 2021 which had the highest research output at 28%.

Figure 2: Articles published on big data in food supply chains by year

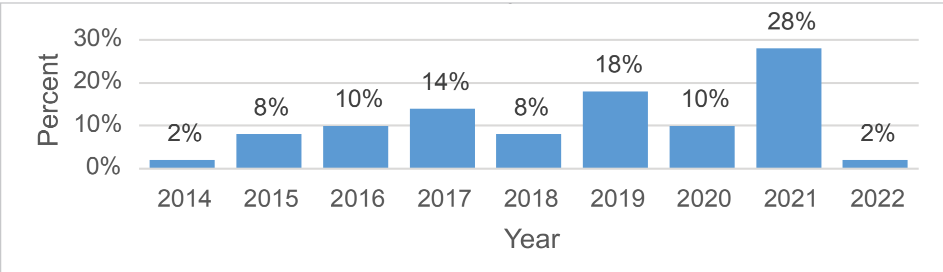


Figure 3 shows the frequency of articles published by region between 2014 and 2022 based on factors affecting the adoption of big data in the food supply chain. The results indicate that 42% of the related articles were published in Europe, 30% in Asia, 20% in America and 8% in Africa, the lowest research output region. The results show that Europe accounts for nearly half of the articles published on factors affecting the adoption of big data in the food supply chain between 2014 and 2022.

Figure 3: Articles published on big data in food supply chains by region

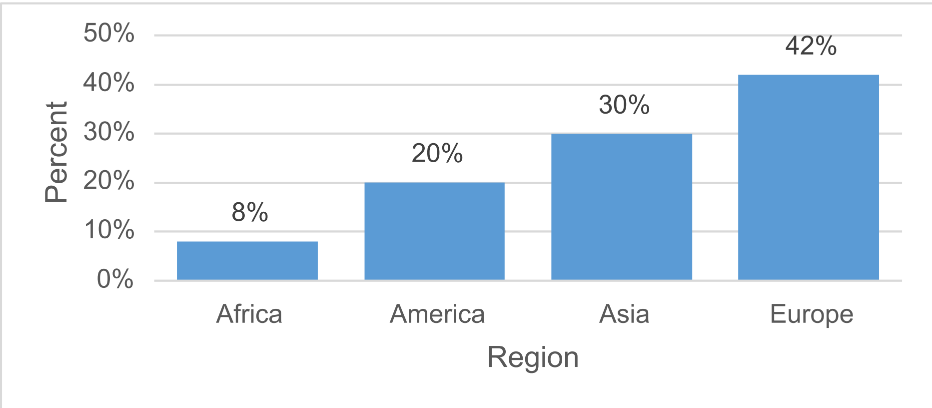
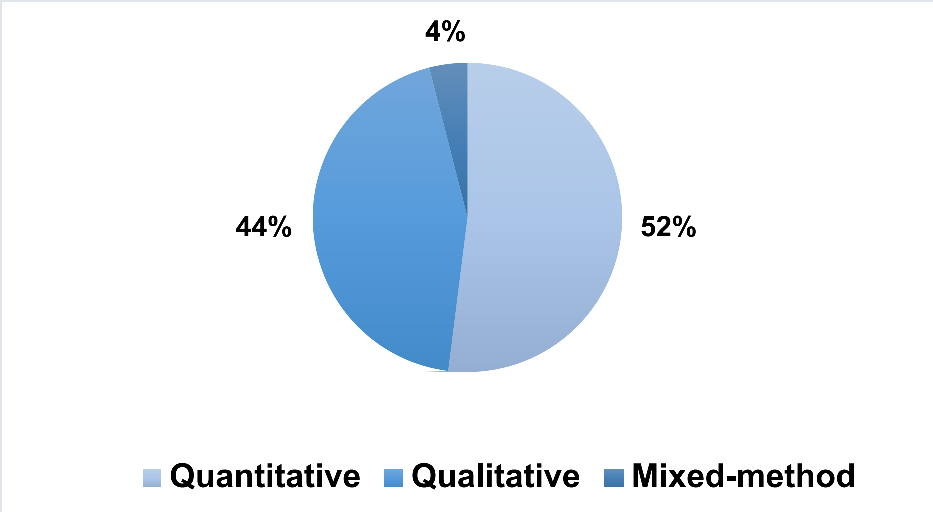


Figure 4 shows the frequency of articles published by research method between 2014 and 2022 based on factors affecting the adoption of big data in the food supply chain. The results show that most articles published conducted quantitative research at 52%, followed by qualitative research at 44%, and lastly, mixed-method research at 4%, the lowest research output by method. Additionally, the results propose that quantitative research was the most used research method when conducting studies on factors affecting the adoption of big data in the food supply chain between 2014 and 2022.

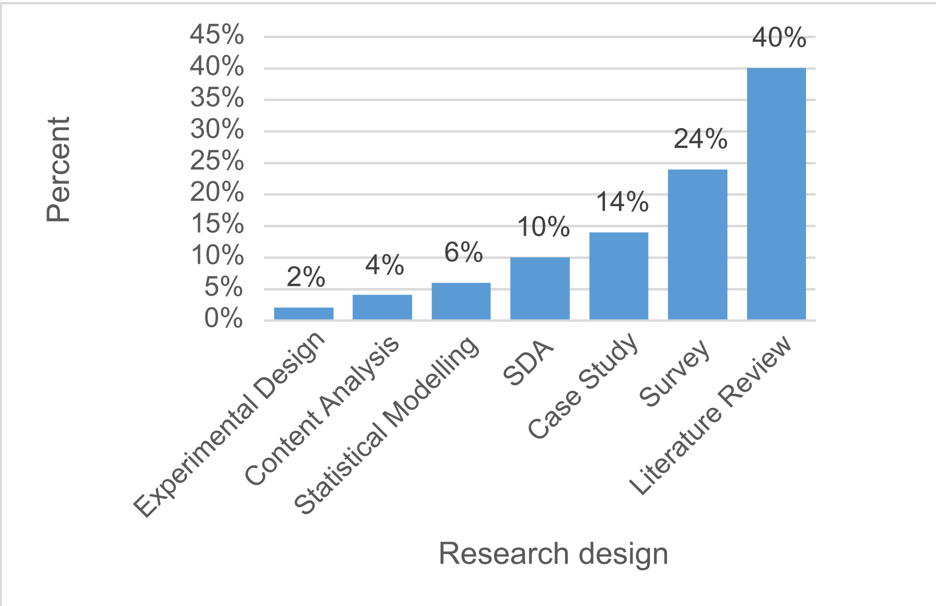
Figure 4: Articles published on big data in food supply chains by research method



Articles by research design

Figure 5 shows the frequency of articles published by research design between 2014 and 2022 based on factors affecting the adoption of big data in the food supply chain. The results propose that most articles published conducted a systematic literature review at 40%, followed by surveys at 24% and case studies at 14%. Additionally, the results propose that experimental designs were the least preferred research design at 2%, closely followed by content analysis at 4%.

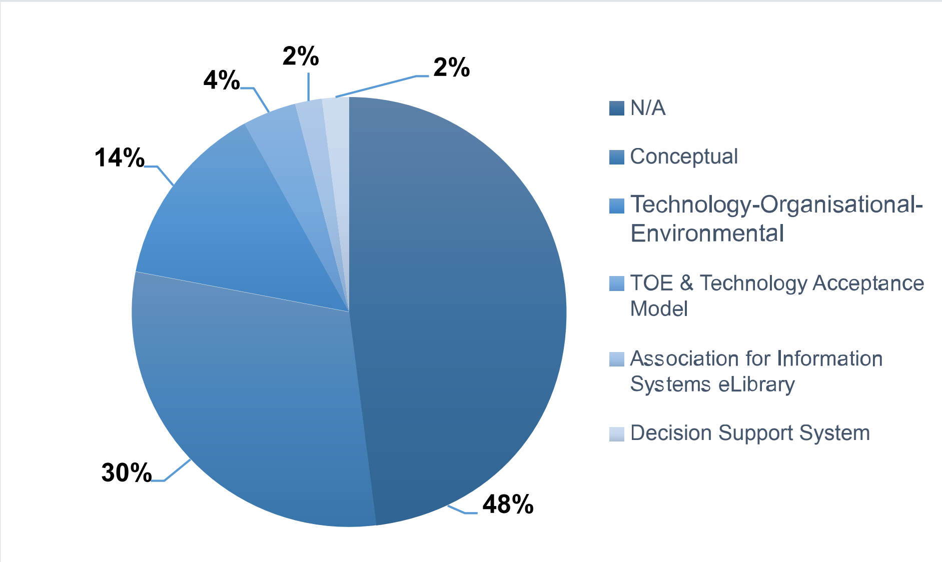
Figure 5: Articles published on big data in food supply chains by research design



Articles by the framework

Figure 6 shows the frequency of articles published by research frameworks between 2014 and 2022 based on factors affecting the adoption of big data in the food supply chain. The frameworks range from the Technology Acceptance Model (TAM), the TOE framework, the Decision Support System (DSS) framework and numerous conceptual frameworks. The results propose that most articles, at 48%, did not use a framework (N/A), whereas 30% of the articles applied conceptual frameworks. Additionally, the results propose that the TOE framework was applied within 14% of the articles, and 4% made use of a combined approach using the TOE and TAM frameworks. Lastly, the results propose that the DSS and Association for Information Systems (AIS) eLibrary frameworks were the least preferred research frameworks at 2%.

Figure 6: Articles published on big data in food supply chains by framework



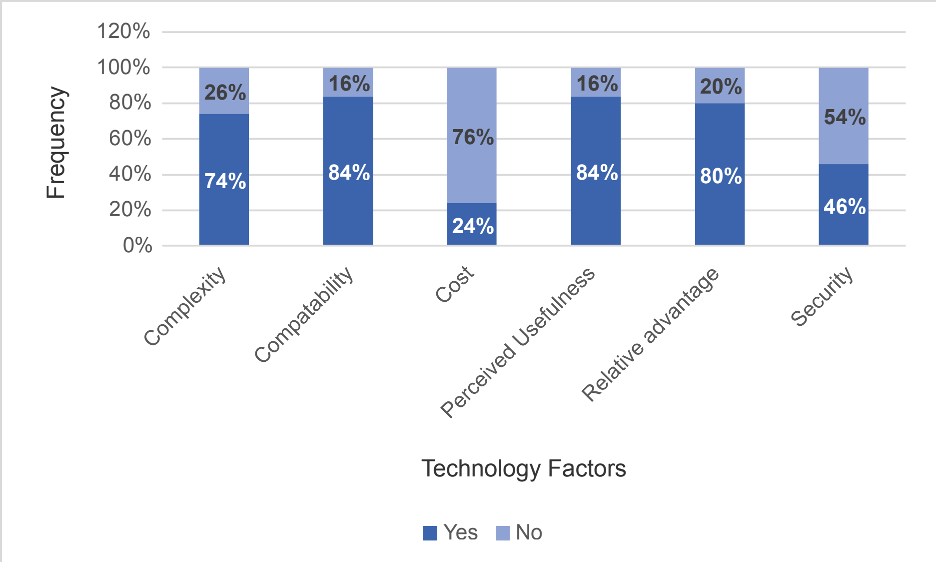
Frequency results of TOE factors

This section provides results from the study of the technological, organisational and environmental factors that affect the adoption of big data in the food supply chain.

Technological factors

The study analysed and measured six technological factors that affect the adoption of big data in the food supply chain: complexity, compatibility, cost, perceived usefulness, relative advantage and security. Figure 7 shows the frequency of technological factors that affect the adoption of big data in the food supply chain based on 50 published peer-reviewed articles. The results propose that compatibility and perceived usefulness were the most important technological factors to affect the adoption of big data in the food supply chain, at 84% each, followed by relative advantage at 80% and complexity at 74%. Only 46% of the articles covered the factor of security, with the least discussed factor being cost at 24%. The results, therefore, illustrate that organisations should consider compatibility and perceived usefulness as the most influential factors that affect the adoption of big data in the food supply chain.

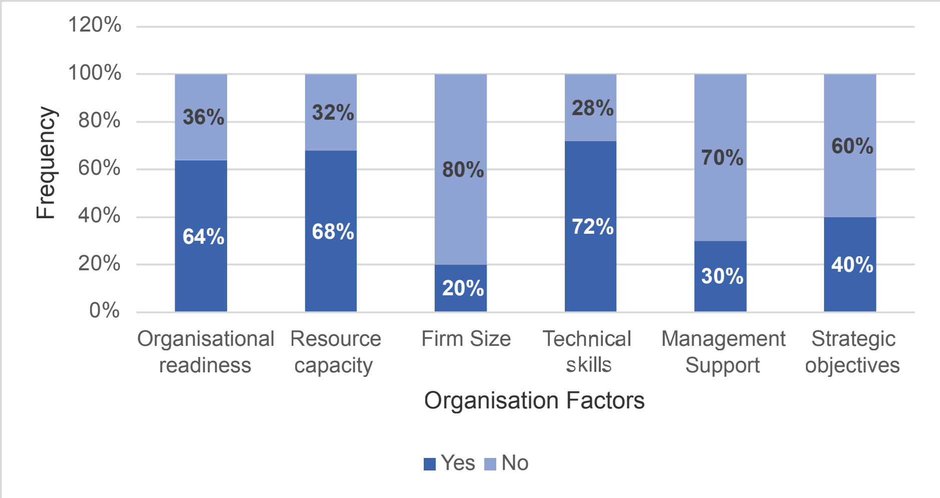
Figure 7: Frequency of technological factors



Organisational factors

This research study analysed and measured six organisational factors that affect the adoption of big data in the food supply chain: organisational readiness, resource capacity, firm size, technical skills, management support and strategic objectives. Figure 8 shows the frequency of organisational factors that affect the adoption of big data in the food supply chain based on 50 published peer-reviewed articles. The results propose that technical skills were the most important organisational factor, at 72%, followed by resource capacity at 68% and organisational readiness at 64%. Only 40% of the articles covered the factor of strategic objectives, followed by management support at 30%. Lastly, the least discussed factor was firm size at 20%. The results, therefore, illustrate that organisations should consider technical skills and resource capacity as the most influential factors that affect the adoption of big data in the food supply chain.

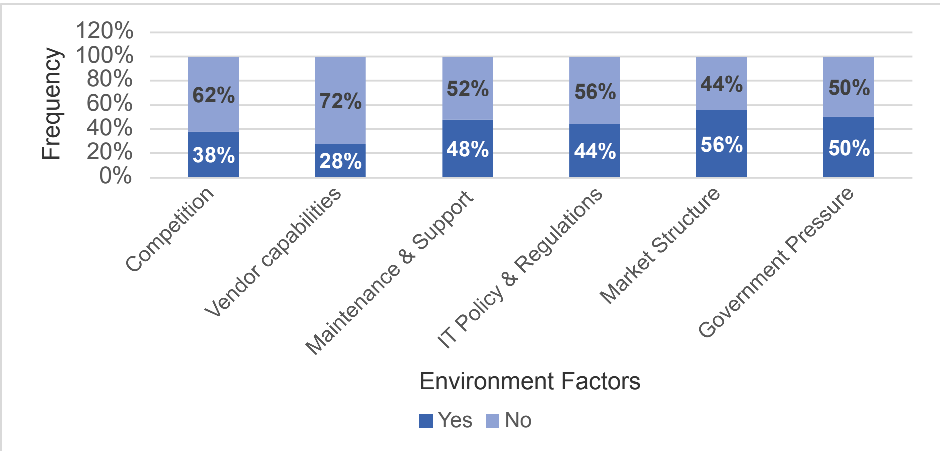
Figure 8: Frequency of organisational factors



Environmental factors

This research study analysed and measured six environmental factors that affect the adoption of big data in the food supply chain: competition, vendor capabilities, maintenance and support, IT policy and regulations, market structure and government pressure. Figure 9 shows the frequency of environmental factors. The results propose that market structure was the most important environmental factor, at 56%, followed by government pressure at 50% and maintenance and support at 48%. Only 44% of the articles discussed the topic of IT policy and regulations, followed by competition at 38%. Lastly, the least discussed factor was vendor capabilities at 28%. The results, therefore, illustrate that organisations should consider the market structure and government pressure as the most influential factors that affect the adoption of big data in the food supply chain.

Figure 9: Frequency of environmental factors



Discussion and conclusion

The research study conducted an SLR on factors that affect the adoption of big data in the food supply chain, focusing on articles published between 2014 and 2022. The study reviewed 50 articles and found that compatibility, perceived usefulness and relative advantage are the key technological factors that affect the adoption of big data in the food supply chain. The study results indicate that technical skills, resource capacity and organisational readiness are the key organisational factors that affect the adoption of big data in the food supply chain. The results also show market structure and government pressure are the key environmental factors that affect the adoption of big data in the food supply chain.

In conclusion, the study results suggest that there has been an increase in research output on the factors that affect the adoption of big data in the food supply chain which contributed to the upward research output in the regions. Furthermore, study results suggest that technology factors (compatibility, perceived usefulness and relative advantage), organisational factors (technical skills, resource capacity and organisational readiness) and environmental factors (market structure and government pressure) affect the adoption of big data in the food supply chain. The study contributes to the body of knowledge on factors affecting the adoption of big data in the food supply chain and may catalyse further studies on factors affecting the adoption of big data in the African food systems. NA94

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