

Leveraging Animal Feed Supply Chain Capabilities through Big Data Analytics: A Qualitative Study

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Abstract

Purpose – Although big data analytics (BDA) has gained widespread interest in supply chain management (SCM) literature in recent years, our understanding of how it contributes to improved animal feed supply chains (SCs) is still underexplored. This study provides a greater understanding of the role of BDA in improving animal feed SC capabilities.

Design/methodology/approach – A qualitative approach was used in this study. Data were collected through 32 semi-structured interviews from several actors involved in the production and supply of animal feed concentrates.

Findings – This study provides rich in-description evidence of how BDA enhances performance in animal feed supply chain through improved logistics capabilities, quality control and information visibility. Our findings also suggest that organizational culture contributes to leveraging BDA capabilities in the feed processing SCs.

Practical implications – The research provides an in-depth qualitative investigation of implementing big data in the feed processing SCs. The study provides practical implications for SC managers in the agrifood sector.

Originality/value – The study contributes to the growing body of knowledge by providing field evidence of the relevance of BDA to animal feed SCs. This study adds to existing literature by providing an understanding of the role of internal culture of the organization in leveraging BDA capabilities in the SC.

Keywords: Animal feed supply chain; Big data analytics; Sustainable supply chain, Qualitative research, Logistics capabilities.

Paper type: Research paper.

1. Introduction

Agri-food supply chains (SCs) are central to all types of feed production systems and distribution systems (Bryden, 2012; Jum'a *et al.*, 2023). Although the agriculture sector contributes significantly to the livelihood of each nation, supply chain management (SCM) research has in general paid little attention to agrifood SCs (Kalaitzi and Tsolakis, 2022; Kumar *et al.*, 2017). As the global population continues to exponentially increase, it becomes increasingly important to meet the increased demand for animal products (Neethirajan and Kemp, 2021; Daniel *et al.*, 2022). The agri-animal feed industry is integral part of the agricultural SC, and it creates revenue and sustains the economy (Jum'a *et al.*, 2023). Animal feeds play a significant part in the global food chain, enabling the safe production of food with animal origins everywhere (Bryden, 2012). To address the issues of food scarcity brought on by population growth, livestock agriculture needs to adapt in order to provide more livestock products and to improve efficiency, while at the same time addressing concerns about animal welfare, environmental sustainability and public health (Neethirajan and Kemp, 2021).

In recent years, there have been increasing proliferation of innovation around technologies such as big data analytics (BDA), Internet of Things, 3D printing, Blockchain, as part of the “fourth industrial revolution” or what is known as “Industry 4.0” (Al-Masa'fah *et al.*, 2024; Onyeme, and Liyanage, 2024; Sahoo *et al.*, 2024; Younis *et al.*, 2025). In particular, BDA has created opportunities for massive data acquisition, visualization, analysis, forecast and decision making (Ansari *et al.*, 2023; Laskurain-Iturbe *et al.*, 2023). This study explores the growing importance of big data and its adoption in various sectors, driven by the need to increase competitiveness through innovations and technological tools (Brinch *et al.*, 2018; Kache and Seuring, 2017; Erevelles *et al.*, 2015; Wamba *et al.*, 2015). Big data is seen as a valuable resource, offering real-time insights into consumers, risks, returns, and efficiency through various data sources.

Despite the growing interest in big data, empirical evidence on its practical impact and challenges remains limited, creating a research gap (Jum'a *et al.*, 2023; Constantiou and Kallinikos, 2015; Wamba *et al.*, 2015). However, there remains a significant research gap in understanding how BDA can be effectively leveraged to enhance supply chain capabilities in the animal feed industry. The potential of BDA to address inefficiencies, improve decision-making, and enhance the overall performance of the animal feed supply chain is vast, yet

underexplored. This study aims to fill this critical gap by investigating the practical implications of BDA in the animal feed supply chain, providing valuable insights that are currently missing in the literature. The study also seeks to provide a practical perspective by developing a model to enhance feed processing SC capabilities through BDA.

Given that information plays a major role in the SC success, several studies have focused on the impact of BDA on SC performance. The literature reports many benefits of implementing BDA in SC settings, such as improving resilience and operational performance (Golan et al., 2020), enabling innovation (Jum'a *et al.*, 2023) and promoting sustainability (Zhu et al., 2018). However, despite these recorded benefits, there is a consensus among scholars that the implementation of BDA in the SCM field is still nascent (Bowers *et al.*, 2017; Tiwari *et al.*, 2018; Kalaitzi and Tsolakis, 2022). Hence, this study aims to explore the impact of BDA on SC capabilities. We focus on applying BDA to a unique sector, the agri-food industry, particularly animal feed. However, despite the potential benefits that BDA can promise to improve the agri-food SC (Neethirajan and Kemp, 2021; Yontar, 2023), there is a current paucity of studies investigating the impact of BDA on SCs (Jagtap and Duong, 2019) in the agri-food sector (Lezoche *et al.*, 2020).

This paper provides a detailed description of big data-enabled animal feed processing SCs, identifies opportunities and obstacles, and develops a model for improving SC capabilities. We provide evidence of how animal feed industry adopted big data, the necessary capabilities for successful implementation, and the impact of big data on various dimensions within the SC. This research seeks to contribute to the understanding of BDA practical applications in SCs, and how it can be integrated effectively in the animal feed SC.

The paper is structured as follows. First, we review relevant literature, providing a theoretical underpinning to the study. Second, we discuss the research design and data collection and analysis techniques adopted in the study. Next, we present the empirical findings, highlight the theoretical and managerial contributions, and offer further avenues for future research.

2. Literature review

2.1. BDA in the SC

Big data refers to extremely large or intricate data sets, with sizes up to Exabytes. It surpasses the technical capacity of a traditional system for processing, managing, interpreting, and

visualizing data (Kaisler *et al.*, 2013). The availability of large amounts of data creates new possibilities; therefore, many organizations have worked to improve their BDA capabilities to find and unlock their big data's hidden values. By improving its BDA capabilities, a company can create new products and services, improve customer service, increase sales and revenue, and enter a new market (Tiwari *et al.*, 2018). The main attributes of big data are now expanded into 6V framework involving, “volume” (high-volume data), “variety” (wide range of formats and sources), “velocity” (rapid growth in generation), “veracity” (quality, trust, and importance of data), “variability” (statistical variation in the data parameters), and “value” (huge economic benefits from low-data density (White, 2012, Mishra *et al.*, 2018).

Large datasets are generated in SCs from a variety of sources, including sales, supplier collaboration, logistics service providers, blockchain, sensors, and enterprise resource planning (ERP) systems (Rai *et al.*, 2021, Jahani *et al.*, 2023; Abushaikha *et al.*, 2024). These types of data include unstructured, semi-structured, and structured data. BDA helps SC managers optimize and store data purposefully (Younis *et al.*, 2024). To support data-driven decision-making, BDA uses sophisticated analytics approaches to extract insightful knowledge from massive volumes of data (Tsai *et al.*, 2015). Indeed, BDA has recently been perceived as a game changer in the SCM setting (Dubey *et al.*, 2016). As global competition increases and customer needs and their buying patterns change constantly, SC actors are left with an abundance of data that needs processing and analysis. Hence, BDA enables businesses to prosper in a modern, dynamic, and fast-paced marketplace.

SCM has long utilized statistics and operation research to optimize supply and demand matching. Business analytics using information system support is closely linked to SC performance (Trkman *et al.*, 2010). However, the advancement of big data presents new opportunities to improve various SC activities. The widespread adoption of big data contributes to the advancement of smart manufacturing, achieving intelligence, and responsiveness in manufacturing processes (Laskurain-Iturbe *et al.*, 2023). Fisher *et al.* (2012) highlighted the role of BDA in improving decision-making across the SC by employing statistical methods and expanding the dataset beyond traditional internal data sources. Similarly, Hofmann and Rutschmann (2018) found that BDA can significantly enhance forecast accuracy. Furthermore, the adoption of big data has significantly reduced losses caused by production defects and quality issues, offering real-time monitoring and correction of quality problems (Laskurain-Iturbe *et al.*, 2023), which in turn positively impacts SC performance (Jum'a *et al.*, 2023).

Many scholars have explored the impact of BDA on various industries. For instance, Hofmann and Rutschmann found that integrating data sources can significantly enhance forecast accuracy. However, they acknowledge the need for a more comprehensive and varied study to generalize their findings. Similarly, Danielsen and Framnes (2017) correlated BDA with competitive performance but noted the need for more diversified survey categories to provide a broader perspective. In practice, the adoption of BDA is crucial for organizations, as it facilitates faster access to insights for strategic decision-making, but challenges arise from misunderstandings about big data resources and limited integration of BDA tools in the decision-making process, which can result in high failure rates (Duang-Ek-Anong, 2019). Big data's influence on SC performance is becoming increasingly evident, as manufacturers recognize its potential for real-time access to SC information (Zhong *et al.*, 2016). Through real-time monitoring and data analysis, issues can be swiftly identified, reducing inventory and capital requirements. Desai (2019) categorizes the potential advantages of big data in the manufacturing sector into four main areas: predictive maintenance and automation, productivity, and efficiency gains, SCM, and quality management.

2.2. Big data in food processing SCs

Although the agriculture sector contributes significantly to the livelihood of each nation, SCM research has in general paid little attention to agrifood SCs. (Kalaitzi and Tsolakis, 2022; Kumar *et al.*, 2017). The agri-animal feed industry is integral part of the agricultural SC, and it creates revenue and sustains the economy (Bryden, 2012). Animal feeds play a significant part in the global food chain, enabling the safe production of food with animal origins everywhere (Bryden, 2012). To address the issues of food scarcity brought on by population growth, livestock agriculture needs to adapt in order to provide more livestock products and to improve efficiency, while at the same time addressing concerns about animal welfare, environmental sustainability and public health (Neethirajan and Kemp, 2021). Thus, the animal feed SC is central to all types of feed production systems and distribution systems (Bryden, 2012; Jum'a *et al.*, 2023).

In this study, we define the animal feed SC as a group of interdependent individual or businesses who are engaged in the agricultural production and processing of animal food, including its production, processing, storage, trade, distribution, and consumption. Despite the paucity of research of empirical research describing the agri-feed SCs, there is some evidence

that suggests that these SC face great inefficiencies and uncertainty (Bryden, 2012, Neethirajan and Kemp, 2021). It was reported that monitoring the health and wellbeing of animals in livestock housing remains a significant challenge for farmers (Helwatkar *et al.*, 2014). Further, customers want more transparency from livestock farmers as their concerns about the sustainability and welfare of animal products grow (Neethirajan and Kemp, 2021). Hence, as global population continues to rise and the demand for animal products increases, seeking consistent improvements and solutions to make animal SCs efficient has become increasingly important (Wolfert *et al.*, 2017). Although previous studies have suggested that BDA present promising opportunities for agri-food SCs (e.g., Lezoche *et al.*, 2020; Yontar, 2023), there has been little research into the impact of BDA on the SC capabilities in the animal feed SCs.

Ensuring data quality is a fundamental aspect, often overlooked, in the effective use of big data. Gandomi and Haider (2015) highlight four key facets of big data quality, including the ability to use structured and unstructured data based on varying user requirements and reusing the same data for different outcomes. They also emphasize the importance of data integrity when migrating from one source to another, extending historical data lifetime through validation and data governance, and ensuring the authenticity and trustworthiness of data sources.

The question arises: can structured and unstructured data, especially from farms, impact the SC, and how can the reliability and accuracy of information throughout the chain be ensured? To address these inquiries, investment capacity, infrastructure availability, and high data quality are essential. Sanders *et al.* (2011) and Bwaliez and Abushaikha (2019) underscore the significance of data flow integration in the SC, relying on collaboration and synchronous decision-making facilitated by the bidirectional flow of rich information, especially in operations and planning. Nakandala *et al.* (2017) highlight the importance of information sharing in the agricultural sector, particularly in the time-sensitive fresh food segment, to enhance profitability, competitiveness, and sustainability. Quality is another paramount factor in the food SC, with the ability to replace damaged products promptly, implement preventive measures, and enhance product quality through monitoring and inspection. Many authors, such as Jagtap and Duong (2019) and Cappellesso *et al.* (2019), concur that the food SC revolves around quality and that big data plays a pivotal role in improving quality and monitoring the entire chain. Dong and Srivastava (2013) assert that realizing the promises of big data necessitates big data integration, highlighting its differences from traditional data integration in terms of data source diversity and structural heterogeneity.

Despite the growing interest in big data, its full potential remains underexplored (McAfee and Brynjolfsson, 2012). Previous research has predominantly addressed the technical aspects of big data, such as storage, security, and analysis of vast data volumes collected by companies. This literature review section reveals that there is limited understanding of how animal food SCs benefit from BDA.

2.3. Gap in literature

Managing animal feed supply chains present unique challenges due to its distinctive characteristics. Actors in the animal feed SC use a common set of performance indicators divided into key performance indicators to evaluate their performance. Feed quality, particularly safety and health, sensory properties, shelf-life, product reliability, and convenience, plays a pivotal role due to the sensitivity and risks associated with food products. Ensuring quality and safety is crucial to avoid costly incidents such as product recalls and market withdrawals, impacting the entire SC performance from producers to retailers. The distribution system, especially for refrigerated products, and efficient logistics systems that minimize food losses and waste, are vital elements in the food SC, as noted by Hochfelder (2017) and Zhong *et al.* (2017).

Accurate demand planning and forecasting are key to reducing feed waste and efficiently managing inventory, which positively impacts SC performance. Customer satisfaction is linked to demand, and the more satisfied customers are, the better the SC performs. Responsiveness, product availability, and customer complaints are crucial sub-measurements within customer satisfaction, influencing the overall SC performance. BDA offers the potential to enhance food SCs by improving decision-making accuracy and speed, enhancing data sharing, ensuring food quality and safety, supporting mass customization, and identifying new opportunities and product requirements, as suggested by Anica-popa (2012), Tien (2012), and Ji and Tan (2017). This study explores the growing importance of big data animal feed supply chain, driven by the need to increase competitiveness through innovations and technological tools. The study contributes to literature by concentrating on the animal feed industry, a sector that has been relatively overlooked in SCM and BDA research. By examining the distinct challenges and opportunities related to BDA adoption in this industry, the research offers valuable insights that can be extended to other sectors with similar characteristics, such as the food and agricultural industries. Despite the growing interest in big data, field evidence on its practical

impact and challenges in this industry remains limited, creating a research gap. This study aims to address this gap by investigating how big data contributes to leveraging the animal feed SC capabilities.

3. Methodology

3.1. Grounded theory research

Grounded theory seeks to develop theory directly from data instead of testing hypotheses to validate existing theories (Glaser and Strauss, 1967; Miles and Huberman, 1994). Additionally, grounded theory strives to uncover new insights into the patterns of relationships between individuals and how these interactions contribute to constructing truth (Glaser and Strauss, 1967). Given that the research topic concerning the role of big data and its impact on animal feed supply chains hasn't been extensively covered in existing literature, grounded theory approach using qualitative methods are invaluable for gaining in-depth insights (Baxter and Jack, 2008; Towers *et al.*, 2020). Such approaches are well-suited for exploring multifaceted phenomena, allowing for a comprehensive investigation (Baxter and Jack, 2008; Melhem *et al.*, 2024; Alnadi *et al.*, 2024). This qualitative research is consistent with the study's grounded theory approach and enables a flexible examination of various elements related to the research objectives.

3.2 Data collection

Qualitative data were collected through 32 semi-structured interviews with companies involved in animal feed supply chains. The interviewees were professionals with significant experience in big data-related projects within and outside the animal feed industry, making them suitable for the study. The research team engaged in communication with experts in big data and employees within various SCs, gaining insights into the practical application of big data in animal nutrition and the companies experiences with their key SC actors. Consistent with the grounded theory approach, the semi-structured interviews with key informants working in different SC departments were conducted to gather valuable insights. Table 1 provides an overview of interviews.

[Take in Table 1]

Interviewees were selected based on their involvement in the animal feed supply chain, ensuring representation from various positions and functions within the supply chain (Towers

et al., 2020), as clarified in Table 1. This approach provided a comprehensive perspective on the topic under investigation. Additionally, we employed a snowball sampling technique to identify later interviewees (Alnadi *et al.*, 2024), allowing us to reach key informants who might not have been initially accessible but played crucial roles within the supply chain. In qualitative research, snowball sampling is particularly useful for accessing hard-to-reach or specialised participants, as initial interviewees can refer others with relevant expertise or experience, thereby enriching the data collection process.

3.3. Research quality

It is crucial to address various quality-related issues in the coding process. This included considerations of generalizability, validity and reliability. Generalizability, which pertains to the extent to which findings can be applied beyond the specific case under investigation, is a complex issue in qualitative research. Scholars argue that the limited sample size of the investigated business hinder generalizability, while others contend that it is possible under certain conditions. In qualitative research, there is no universally accepted standard for sample size, and the number of participants interviewed is typically influenced by factors such as information power (Eisenhardt, 1989; Glaser and Strauss, 1967), the availability of suitable informants, and the attainment of theoretical saturation (Eisenhardt, 1989). Theoretical saturation occurs when additional data no longer contribute new insights (Eisenhardt, 1989). In this study, the recurrence of common themes and categories was reached after 32 interviews. Therefore, no further interviews were deemed necessary, as additional data were unlikely to yield new insights (Glaser and Strauss, 1967).

The interview questions were designed specifically for this study, grounded in the research objectives and theoretical framework. They were carefully developed to explore key themes relevant to the study and were refined through expert review, feedback from the author team, and a pilot study to ensure clarity and relevance. For data analysis, we employed a structured coding process, beginning with open coding to break down the data into meaningful units and assign labels to each segment. This was followed by first-order coding, where related codes were grouped into categories, and selective second-order coding, where core themes and concepts were identified (Melhem *et al.*, 2024). To maintain consistency with the grounded theory approach, coding decisions were regularly discussed and compared among the author team, strengthening the reliability of our analysis (Glaser & Strauss, 1967; Miles & Huberman, 1994).

4. Analysis and findings

In this study, data analysis employed thematic analysis principles following Broun and Clarke (2013). NVivo software package was used to organise data and support the data reduction and coding process. The analysis aligns with the conceptual framework and research questions and are organized according to major and minor dimensions, which will be detailed in the subsequent sections.

4.1. Logistics Capabilities

Table 2 shows the findings of the role of BDA on the logistics based on the data analysis. Logistics capabilities is presented in terms of the role of BDA in improving distribution capabilities, forecast accuracy, and delivery reliability.

[Take in Table 2]

The above table shows the role of BDA in improving logistics capabilities. Overall, the qualitative evidence suggests that BDA contributed to predicting freight rates for the future, making the right decisions, reducing costs, increasing distribution system efficiency, and ensuring business continuity by managing the raw material sourcing process. The analysis shows that the use of big data in distribution and transportation resulted in improved prediction of freight rates as stated by Interviewee 21, *“We deal with the third party, so we use that data to predict what the estimated Lane rates could be in a new fiscal year.”* One Regional SC Manager adds: *“big data enhances the management of sourcing RM and the animal feed concentrates...It helps in better tracking for the consumption volume, so we can be more efficient in preparing the deliveries.”*

4.1.1. Delivery reliability

Interviewee 11 explained: *“We are working on a project called ‘Branded Feed’ which focused primarily on improving logistics efficiency. The problem was how to deliver. How to optimize transportation from our plants and distribution centres to our customers that business is very particular because the customer is it. We manage the inventory for our customers, so the customers do not even need to call us to put an order. We always monitor their inventory, and then when they are low on inventory, it generates a signal, and that signal has to go back to our production facilities, but then they have to integrate and coordinate how to deliver that particular load to our customers.”* All this led to improve the delivery reliability.

Interviewee 32 explained that *“BDA cannot predict unexpected events, for example what happened recently in Suez Cannel with Evergreen vessel.”* She also added that there is another constraint: *“The government regulations as well is one of the challenges that impact the BDA to enhance logistics. So, see the Brexit right in the UK and how it impacts the on-time delivery as well so.”* Interviewee 04 added: *“BDA helps our port operation, manage their terminals more efficiently. This helps us to minimize the occupancy rate of the berth average queue of the merged occupancy rate of the berth average queue of the vessels and vessel turnaround time at the port... all this improves our logistics operations.”*

4.1.2. Forecast accuracy

Interviewee 10 who built many models related to the forecast worldwide commented on the benefit of BDA in improving the forecast accuracy: *“predictive analytics provides a deeper understanding of why a consumer buys a product. Gaining an intimate understanding of customer preferences gives us an advantage over their competitors, and it gives insights into sales, inventory, customer satisfaction, markets, etc.”*

4.1.3. Inventory management

Interviewee 09 expressed her view: *“You can also use all kinds of statistical or mathematical optimization techniques to determine what are your optimal reorder points or things like that or what is your minimum safety stock level, so you can use all of that information to determine what the best safety stock level is.”* Interviewees' perceptions of the benefits and role of big data were identified as critical determinants of the impact of this technology on inventory management that will have the same effect on SC performance.

Interviewee 31 who believes that the most important benefit his company gained from implementing BDA in managing the inventory is to mitigate the risk: *“Lead time, sourcing, stock availability is very important to managing inventory and any issue in these three carrying risk on the company. BDA will mitigate the risk if it is implemented in a correct way.”*

4.2. SC Visibility

Table 3 presents the findings of the role of BDA in the aspect of SC visibility.

[Take in Table 3]

4.2.1. Responsiveness

The advantage of big data, wherever it is applied, is that it provides “future insights,” whether in the short or long term. Most interviewees emphasized have indicated the potential of big data to collect behavioural data of animals enhance responsiveness to the feed SC. Through big data, control and monitoring of truck waiting times at plants can be optimized, leading to improved response times and overall logistics network performance. Interviewee 13 commented based on her experience: *“Big data improves the optimization by increasing the end-to-end SC visibility.”*

Overall, according to participant insights, big data improves the company’s customer response by streamlining internal processes and leveraging data and analysis tools to enhance efficiency and speed. Interviewee 03 explained: *“our company has developed a sophisticated model for real-time alerts, hinging on big data, machine learning, and artificial intelligence to pinpoint products requiring periodic production”*. This model also monitors consumer demand and, upon reaching a specific threshold, issues alert to production for replenishment. It additionally identifies outdated components, such as those near expiry or expired, providing decision-makers with the ability to make timely choices, including disposal or repurposing in other product blends. These alert models, among others, have effectively rectified numerous inventory issues, obviating the need for manual shelf audits and showcasing the transformative impact of science and data on bolstering on-shelf availability.

The Principal Operations Research Engineer emphasized how BDA plays a significant role through “improving service level agreement (SLA)” by ensuring high on-time delivery percentages, which are tracked by BDA models. Additionally, predictive models aid in forecasting order delivery reliability, and “safety stock optimization” ensures accurate customer demand fulfillment. In his view, enhancing “delivery reliability” and visibility of inventory significantly contributes to improved customer satisfaction.

4.2.2. Information integration

The integration of IT systems facilitates data access, enabling the company to collect data from diverse sources allowing the company to offer a broad range of nutritional solutions and recommend optimal feed products. In the context of big data, data from various sources must be accessed and shared through channels and information systems. Interviewees highlighted

two key aspects, emphasizing the need for seamless connections between data generated within a processing system and data visualization, as well as the importance of linking different sensors in a plant to a common data source. It was emphasized that data should be consolidated in a unified repository, and integration is a crucial prerequisite at this stage. In summary, the efficiency and accuracy of BDA are significantly enhanced when data from diverse sources is centralized in one location, and the imperative of integration is underscored, especially when dealing with various information systems.

4.3. *Quality Control*

An emerging theme of this study is related to the role of big data in improving the quality of products and their management. Table 4 presents all the answers and the results derived from them according to each sub-category.

[Take in Table 4]

4.3.1. *Quality assurance system*

A significant portion of the data generated through smart technology and sensors often remains confined within information silos within the factory. The involved companies recognized the potential of contextual data and took steps to break down these silos, leveraging big data and artificial intelligence services in the cloud to ensure that the right data arrives at the right place at the right time. Most interviewed confirmed that their companies employed these capabilities to “manage, monitor, and improve quality through BDA. Interviewee 28 explained the role of *“Big Data and specialized algorithms” in early detection of deviations from product or raw material specifications. This early warning system allows corrective actions to be taken well before reaching the final product stage, reducing the chances of rejection, discount sales, rework, or waste*”. Interviewee 15 expanded on big data’s role in enhancing quality management, emphasizing its contribution to *“improving the quality of products”* by controlling ingredient mixes, reducing errors in formulation, analyzing laboratory results, and tracking customers who ceased purchasing products due to historical quality issues. In essence, big data has been instrumental in enhancing quality control by providing early indicators for deviations from specifications and minimizing errors in product formulation.

4.3.2. *Product safety and health*

Human food and animal feed are intricately connected, with “safe animal feed” being essential for the health of animals, the environment, and for the safety of foods of animal origin. This connection underscores the importance of ensuring the safety of both. Interviewee 02 pointed out that *“models can incorporate parameters related to safety, including specifications and tolerance factors to produce products within safety standards, thereby improving quality and consistency of the animal feed mixes.”*

Interviewee 13 added another perspective, highlighting how *“big data helps through algorithms to maintain specific levels of vitamins and moisture to ensure product health and safety... The focus on raw materials is crucial because issues with them can propagate to the final product. BDA help us provide accurate formulas, reduce mistakes and errors, identify quality issues before shipping or packaging, and predict interactions between raw materials when mixing them.”*

This means that big data offers both preventive and reactive solutions for feed safety, as well as the ability to predict interactions between raw materials and products that can impact product safety significantly.

4.3.3. Product reliability and convenience

Interviewee 16 expressed his point of view: *“One opportunity right is that we can automate. These processes for how we assess a measure and assign. Quality to our goods. Through you know technologies, including if you think of like heat sensors, hey, what the temperature on this meat stuffs like that.”* Based on that, big data enhance the company to produce more reliable and convince products as it makes the company more proactive in taking the actions when an issue occurred. Interviewee 25 commented on this: *“So let's say you know the vegetable oil on your shelf at the supermarket it has to pass different SQR or quality specs and before you know the insulin-making that oil, or even blending that oil, you can go out of spec for many reasons, so BDA helps us in predicting if we're going to go out of specifications”*

4.4 Organizational Culture

A SC Manager observed that the culture was open to change but emphasized that farmers prioritized “cost and benefits” and advocated for gradual cultural shifts with the involvement of state organizations and associations. Interviewees emphasized the need for tailored approaches, as *“the same exact data can be used in a different way”* in various regions,

highlighting the cultural diversity his company encountered as a multinational corporation. This included the importance of aligning big data with the local culture's perceptions, where its success depended on factors such as labour reduction or enhanced safety and efficiency. Table 5 provides a summary of how qualitative data related to cultural dimensions were induced.

[Take in Table 5]

The SC Manager of a global feed processing company, Interviewee 28, explained that their company has successfully involved employees in decision making and implemented big data initiatives including “...*chicken flock health monitoring, which utilizes computer vision technology to detect well-being problems in chickens at an early stage, enabling timely interventions by farm operators. An optimization algorithm for farm visit scheduling and a predictive model for body weight prediction was developed, benefiting both customers and [our company] by reducing unnecessary trips and providing more accurate weight estimates. This new product category generates additional revenue for us*”. Similarly, Interviewee 22 clarified that “...*in the future, our big data scientists aim to use data analytics to shorten broiler chicken life cycles and increase laying hen production, as well as to explore genetic history and future predictions for various cattle breeds*”. This comes in line with the recent changes in the organizational approach of focusing on data-driven decision making, which evolved in the past few years.

5. Discussion

5.1. Discussion of findings

Big data was found to help identify and address gaps within the SC, ultimately improving its performance. The adoption of big data was also seen as crucial for companies lacking strong technological infrastructure. The study emphasized the importance of employee readiness for adopting big data and the need for cultural change to accommodate this technological shift. The integration of IT and the establishment of data-driven decision-making cultures were also highlighted as essential elements in the successful implementation of big data within the SC (Frisk and Bannister, 2017).

The research identified that big data improved forecasting accuracy, leading to better inventory management and efficient transportation systems (Mahalik and Kim, 2016; Salhieh *et al.*,

2018). Additionally, big data positively impacted product quality control, benefiting the feed manufacturing sector, and contributed to the automation of warehouse management (Nantee and Sureeyatanapas, 2021).

The findings indicated that big data played a crucial role in improving SC visibility and customer satisfaction through responsive SCM (Wang and Yue, 2017). Furthermore, the study highlighted the role of IT in facilitating data acquisition and its subsequent use as big data, stressing the importance of data integration and multiple data sources (Duang-Ek-Anong, 2019). It also introduced the dimension of culture, both within the organization and externally, as a critical factor influencing the acceptance and adoption of big data. The researchers found that the adoption of big data must be preceded by a process to prepare employees internally to accept this technology, especially as it will contribute to changing many processes and will change the way of work in general. In addition, many employees will have some concerns in the form of losing their work, whether inside warehouses, truck drivers, or even those who work in the planning department, as big data provides the required information, and its application requires greater reliance on technology systems, automation, and digitization more than relying on human resources (Frisk and Bannister, 2017).

The first part, external culture: as for the external culture, the culture of each country plays an important role in accepting this technology or not, and therefore will the company benefit and maximize its use of big data or not? There are industrially advanced countries that accept, and there are countries such as developing countries, it is more likely that they will not accept the lack of capabilities such as knowledge and capital (Closs and Mollenkopf, 2004). Therefore, it is complicated because we are talking about different cultures, not only across countries but also within the country itself. Therefore, there must be cooperation between governments and multinational companies in creating the infrastructure first to apply this technology, such as electricity and the internet, and cooperation with farms by providing the necessary funding to use this technology, especially for medium-sized farms or owned by individuals. Multinational companies should also provide feed production experts and data scientists to educate farmers and respective companies about the importance and benefits of big data and provide training to deal with technological devices.

In Turkey, for example, which is a developed and productive country, the researchers, with the help of the logistics manager of Beta Company, asked a number of medium and large farmers

who were reluctant to use some sensors to obtain more data from their farms, and the answer was that they did not mind using technology, but they had many questions about the costs and profits that will accrue to them if they use this technology.

There are farmers who tend to use traditional methods and refuse to change to more modern methods. Therefore, the application of big data requires a great effort from all parties, and this dimension needs many studies to understand it more deeply. There is no doubt that any impact on any part of logistics, whether inventory management, warehouses, or delivery, will affect the performance of the SC. Improving inventory levels, raising forecast accuracy, increasing delivery reliability, all these initiatives are positively reflected on the SC. Thus, adopting BDA in logistics activities will improve many aspects, as explained earlier. The same applies to the quality of the products, which have a significant role in improving the performance of the SC, and BDA have made quality management more efficient and proactive in discovering and addressing any problem (Waller and Fawcett, 2013).

All this increases customer satisfaction and raises the level of service provided, making the SC more flexible and responsive to the customer increases its performance as well. BDA has made the SC more responsive by giving it more accurate insights into the customer's desires, how they will change in the future and what is the market direction. Therefore, SC performance, in general, will differ significantly, especially if the application of big data in different departments and activities in the business (Wang and Yue, 2017).

Based on all the results reached by the researchers regarding each of the four dimensions that were addressed in the previous studies and literature, in addition to the fifth dimension, "culture," which still needs further investigation in future research, the findings affirm that BDA have a positive impact on improving the performance of SC, taking into account the conditions that must be met to ensure the success of the function of these analyses for the purpose for which they were found.

5.2. Emerging model

Based on all the results that have been reached, the researchers have reconfigured the basic model that was built based on what was mentioned in the literature by reversing the results and adding them to the initial model, as shown in the Figure 1.

Companies must possess the financial capability to invest in this technology. Big data applications require substantial capital to establish and expand the necessary infrastructure, including the development of new systems and the enhancement of existing ones. Furthermore, the company must have the ability to secure competent human resources, such as data scientists, engineers, and software developers, to effectively harness the potential of big data.

[Take in Figure 1]

Another critical capability is the presence of a robust IT infrastructure to support the adoption of big data. Robust infrastructure is essential for maximizing the benefits of big data, including the use of global systems like ERP across the different functions, which can greatly facilitate the big data mission. Furthermore, the company should collaborate with SC partners to ensure infrastructure compatibility, data sharing, and to enhance big data operations.

It is crucial to underscore that the desire and the capacity, whether financial, human, or informational, must be derived from a fundamental business need. The company must identify its needs and pinpoint the gaps that big data adoption can address. Once all these capacities are in place, the company can consider the fundamental requirements for adopting and utilizing big data, such as data quality, availability, accessibility, central data collection, and data integration. Experts can then proceed to build algorithms and models to extract valuable insights from the amassed data.

The study has shed light on the impact of big data and its analyses on four dimensions influencing SC capabilities: logistics, product quality, and customer satisfaction. These dimensions are widely acknowledged in the existing literature as pivotal factors influencing SC capabilities. Notably, the fourth dimension, emerged as a significant influence, a dimension not extensively explored in prior research.

Culture plays a pivotal role in the implementation of big data, and its significance varies across countries and regions within the same geographical area. The government's support in terms of infrastructure, such as ensuring uninterrupted internet access and a consistent supply of electricity, significantly eases the adoption of big data by companies, ensuring a continuous flow of high-quality data that positively impacts SC capabilities.

6. Conclusions and implications

6.1. Theoretical contribution

This study makes significant contributions. The study addresses a gap in the existing literature by enriching the discourse on the role of big data in animal feed supply chains, and introduces an adapted model derived from the field evidence. The model enriches our understanding of the intricate impact of BDA on various dimensions of the supply chain, spanning logistics capabilities, quality control, and supply chain visibility. Our model also introduces an innovative dimension often overlooked by prior research – organisational culture. The findings suggest that the internal culture of the organization contributes significantly to leveraging BDA benefits in the SC. Thus, this study adds to existing literature by providing an understanding of the role of organizational culture in this context. This contribution is particularly valuable for multinational corporations that operate across diverse cultural environments, as it underscores the need for a culturally sensitive approach to BDA implementation.

The study contributes to literature by emphasising certain prerequisites which are essential for the successful implementation of BDA in animal feed supply chains. These include high data quality, robust systems and sensors, seamless integration of systems, and maintaining data quality, and collaborative data-sharing practices both among the company's internal functions and across the supply chain

Prior research has largely focused on the operational aspects of SCM, often emphasizing efficiency, cost reduction, and logistical optimization. This study, however, introduces BDA as a transformative tool that can significantly enhance supply chain capabilities, such as forecasting accuracy, inventory management, and product quality control. By demonstrating how BDA can provide more accurate insights and improve decision-making processes, this research contributes to the theoretical understanding of SCM in the era of digital transformation. The study expands the theoretical framework of SCM by incorporating data-driven decision-making as a critical component of modern supply chain strategies.

The study contributes to literature by concentrating on the animal feed industry, a sector that has been relatively overlooked in SCM and BDA research. By examining the distinct challenges and opportunities related to BDA adoption in this industry, the research offers valuable insights that can be extended to other sectors with similar characteristics, such as the

food and agricultural industries. This focus not only enhances the relevance of SCM and BDA theories but also lays the groundwork for future research in lesser-explored sectors, thereby aiding in the development of industry-specific SCM theories.

In conclusion, this study makes substantial theoretical contributions by extending SCM theory to incorporate BDA, bridging gaps between BDA and SCM literature, introducing cultural dimensions into the discourse on technology adoption, providing a contextual focus on the animal feed industry, and offering methodological innovations. These contributions collectively advance the understanding of how BDA can be effectively integrated into supply chain management, paving the way for future research that continues to explore the intersection of technology, culture, and supply chain performance.

6.2. Practical implications

This study both enhances theoretical understanding of the subject and offers practical insights for businesses in the animal feed sector, guiding them toward more informed and adaptable supply chain strategies. Key recommendations include setting clear objectives for BDA initiatives, addressing skill gaps through targeted training and learning experiences, and recognizing the importance of cultural change in the adoption of BDA. The adoption and implementation of BDA require a comprehensive approach that involves data scientists, engineers, and artificial intelligence experts. The study emphasizes that data quality, seamless integration, and investment in IT systems and sensors are critical for the successful implementation of BDA, particularly in the feed manufacturing sector, where accurate data on animal behaviour is essential before developing final models or algorithms.

The study provides a detailed account of how BDA can be effectively applied in animal feed supply chains. It presents field evidence demonstrating how the implementation of various BDA-supportive technologies and systems, such as Near-Infrared Reflectance, can enhance the nutrient analysis of feed products like forage, premixes, and concentrates. The combined use of certain BDA programs offers numerous benefits to farmers, including optimized nutrition and feeding strategies, a stronger and healthier herd, and ultimately increased milk production. The study also offers practical guidance on how farmers can collaborate with animal feed supply chain partners to maximize the utilization of BDA capabilities.

6.4. Limitations and future research directions

There are several limitations for this study, which opens avenues for future research. One limitation concerns the generalisability of qualitative research. While this study offers a detailed examination of animal feed supply chains, the ability to generalize the findings could be enhanced by conducting survey-based research. Future researchers could also conduct further studies in different cultural settings and national contexts. Another limitation of this study is that the developed model depended on specific factors related to the SC as they emerged from this specific context. Future studies are encouraged to consider other factors to improve the comprehensiveness of the model. For example, the need for future research on the influence of organisational culture on big data applications within SCs seem to be an interesting area for future research. Finally, it is recommended that future studies collect data from other actors in the SC which may also include governments, third-party logistics providers and retailers.

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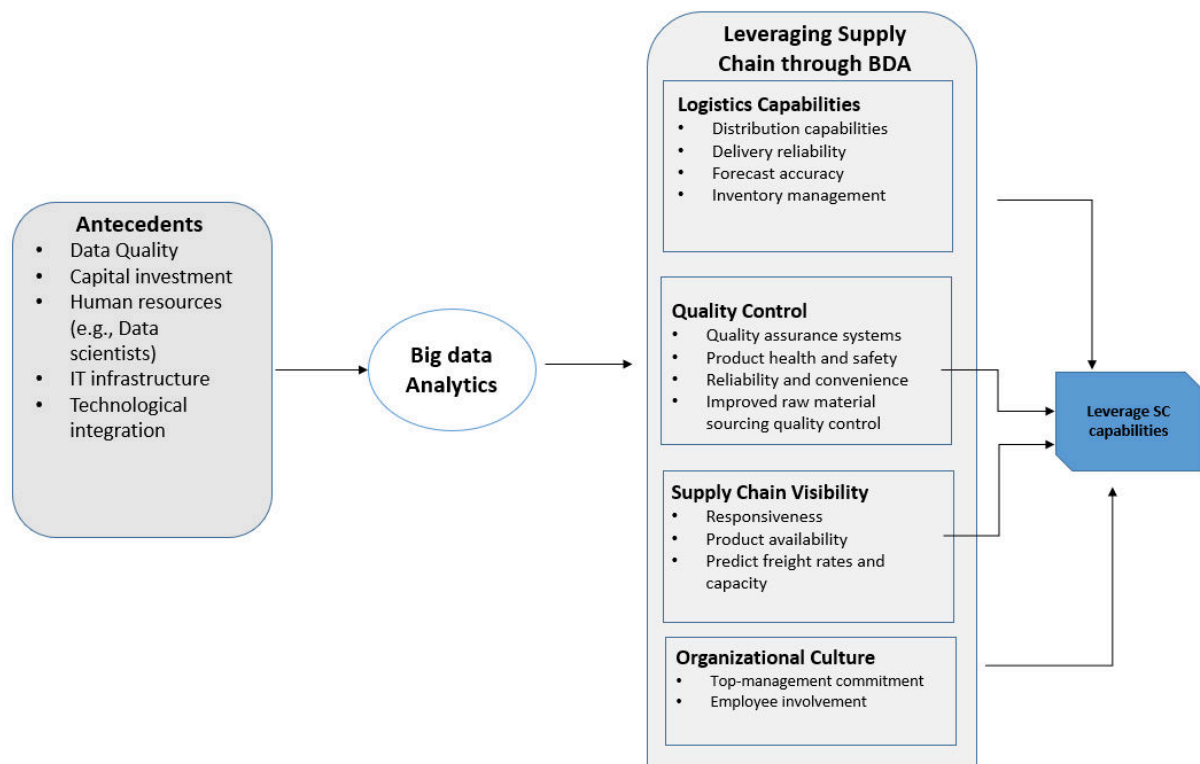


Figure 1: Emerging model of the study. Source: Authors own work

Table 1: Overview of interviews. Source: Authors own work

Interviewee Reference	Interviewee Position	Years of experience	Interview language	Length of interview
Interviewee 01	Data Scientist	30	English	45
Interviewee 02	Senior Data Scientist	4	English	50
Interviewee 03	Principal Data Scientist	9	English	65
Interviewee 04	Principal Operations Research Engineer	5	English	99
Interviewee 05	Lead Optimization Scientist-Supply Chain	7	English	63
Interviewee 06	Lead Data Scientist	3	English	55
Interviewee 07	Lead Data Scientist	8	Arabic	45
Interviewee 08	Senior Data Scientist	5	English	30
Interviewee 09	Senior Data Scientist	12	English	41
Interviewee 10	Product Owner (Data and Analytics)	23	English	40
Interviewee 11	Regional Supply Chain Manager	3	English	46
Interviewee 12	Senior Research Process Controls Engineer	3	English	57
Interviewee 13	Data Experience Lead	5	English	47
Interviewee 14	Regional Transportation and Logistics Manager	9	English	43
Interviewee 15	Information Analyst	15	English	45
Interviewee 16	Supply Chain Lead	3	English	50
Interviewee 17	Business Transportation Lead	7	English	46

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Interviewee 18	Continuous Improvement Lead	9	English	51
Interviewee 19	Global Data and Analytics Lead Transportation and Logistics	12	English	69
Interviewee 20	Continuous Improvement Lead	7	English	40
Interviewee 21	Supply Chain Officer	27	English	45
Interviewee 22	Supply Chain Director	7	Arabic	35
Interviewee 23	Data Scientist	6	Arabic	40
Interviewee 24	Data Scientist	9	Arabic	40
Interviewee 25	Factory Manager	9	Arabic	45
Interviewee 26	Regional Manager	11	Arabic	55
Interviewee 27	Commercial Manager	3	Arabic	42
Interviewee 28	Regional Supply Chain Manager	7	Arabic	41
Interviewee 29	Research Process Control Engineer	4	Arabic	45
Interviewee 30	Data Experience Lead	5	English	40
Interviewee 31	Regional Transportation Manager	4	Arabic	45
Interviewee 32	Sourcing Manager	7	Arabic	45

Table 2: The impact of BDA on logistics capabilities. Source: Authors own work

Representative quotes	First-order codes	Second-order codes	Theoretical dimension
“We use that data to predict what the estimated freight rates could be in a new fiscal year which helps us adjust our prices and communicate the implications of this to our supply chain partners” (Interviewee 22)	BDA predicts freight rates	<ul style="list-style-type: none"> Distribution capabilities Forecast accuracy and inventory management Delivery reliability 	Logistics capabilities
“Big data will facilitate the operation of the logistics network. So, a lot of the projects we work on are related to better operating, our transportation lines are also our warehousing sites” (Interviewee 05)	BDA improves the efficiency of distribution network		
“One of the observations was related to a tender for Yemen. The Yemeni’s customer placed an order for the coming 12 months and we offer him the price and a model has used to predict the prices for the coming months considering different factors, like freight rates” (Interviewee 16)	Predicts freight rates		
“It helps us optimize our consolidation in case of multiple consignments from several origins” (Interviewee 31)	BDA improves transport efficiency		
“BDA helps us minimize the occupancy rate of the berth average queue of the vessels and vessel turnaround time at the port” (Interviewee 14)	BDA improves turnaround time of the vessels		
“BDA improves our on-time delivery performance, but the government regulations as well is one of the challenges that impact the BDA outcomes. So, see the Brexit right now in UK and how it impacts the on-time delivery as well. So, yeah, you can have the best models in the world but if there are	There is no model can predict forecast with unexpected events like COVID-19		

Table and Figures

government or trade restrictions then this would still be a challenge” (Interviewee 17)			
“An important insight here right is context, COVID-19 has completely changed demand throughout the world, that's an event that totally changed demand patterns, and therefore, we learnt that we cannot even rely on the historical data from before” (Interviewee 12)	Integration between systems enhances the data used in the model		
“Systems integration with customers' warehouses that shows product consumption help the data scientists to have the right models and hence accurate analytics results” (Interviewee 24)			
“The BDA optimization model help us plan better safety stock policies and understand better where your cycle stock” (Interviewee 19)	Data availability and quality impacts the inventory model		

Table 3: The impact of BDA on the SC visibility dimension. Source: Authors own work

Representative quotes	First-order codes	Second-order codes	Theoretical dimension
“These systems enable us to build algorithms that analyse the behaviour of customers and then suggests items based on their preferences. Thus, with the help of big data technologies, we can do a predictive analysis of customers’ interests and offer them products they are likely to purchase” (Interviewee 09)	BDA predicts the customer behaviour and hence make the supply chain more pro-active	<ul style="list-style-type: none"> • Responsiveness • Information integration • System integration 	Supply chain visibility
“Our CIBI system, which provides BDA capabilities, gathers, and uses cow-related data, and environmental factors to predict growth from birth to calving, and this shared with the different parties. This improves the visibility in our supply chain” (Interviewee 27)	Analysis of animal data and share it with the different members		
“...such analytics enabled us to offer a wide range of nutritional solutions and recommend optimal feed products for dairy farmers” (Interviewee 13)	BDA helps decrease inventory cost and improve visibility in the supply chain		
“To participate in the CGPS programs, farmers simply need to grant our company access to their cow data, which will then be fed into the CGPS system for mining and analysis” (Interviewee 06)	Accessibility to real-time data for improved responsiveness		
“We have a data analytics system for nutrition. with this a dairy farmer can either submit a set of required information pertaining to his dairy farm, cows raised (e. g. type and age of cows), location and feed used into the ANS online portal, and then obtain a customized nutrient analysis report supplemented with recommended feed products from the Alpha ended.	Big data will allow it to provide better insight into how we produce animal nutrition. Automated equipment		

Table and Figures

Alternatively, Alpha dairy solution experts can visit a farm, take inputs from cows directly on-site, and then return to the CNS portal to obtain recommended nutrients and feed products” (Interviewee 09)			
“Key metrics modelled by the CGPS include (1) feed costs and usage, (2) estimated cow growth compared to optimal growth (based on the animal age at first calving), and (3) the overall financial impact to farmers. The program then suggests ways of improving these outcomes... gathers and uses cow data, information on rations fed, as well as local environmental factors to predict growth from birth to calving” (Interviewee 18)	System integration Improved visibility		
“The integration of our two systems of CNS and CGPS programs yields many benefits to farmers, amongst which optimized nutrition and feeding strategy, a stronger and healthier herd and ultimately higher milk production of better quality in the long run” (Interviewee 25)	System integration improves BDA capabilities which result in improved benefits for farmers		
“One primary source of data assets come from the innumerable sample tests the company has run on its feed products (e.g., forage, premixes, and concentrates). By using its patented Near-Infra-Red Reflectance (NIR) technology” (Interviewee 20)	Integration is mandatory when we have different information systems		

Table 4: The impact of BDA on the quality dimension. Source: Authors own work

Representative quotes	First-order codes	Second-order codes	Theoretical dimension
“Big Data analytics tools and the specialized algorithms which develop will inform us when the product or RM is out of specifications. Big Data enables a more, let's say, more comprehensive approach to quality control. BDA reduce the cost of waste and defects as it provides early warning signals” (Interviewee 01)	BDA gives indicators when RM or final product is out of specifications BDA provides ways for you to become more proactive in terms of quality issues	<ul style="list-style-type: none"> Quality assurance system Reliability and convenience Health and safety control 	Quality control
“BDA would support us through controlling the mixes and reduce the errors by the formulation of animal feed” (Interviewee 13)	Quality assurance and product safety		
“So now big data help in improving the quality of the products by controlling the mixes and reduce the errors by the formulation. It gives info about the interactions between ingredients and its analysis of the lab results as well” (Interviewee 25)	Reliability and convenience of animal feed products through BDA		
“BDA helps us maintain specific levels of moisture and gives an indication of the best levels that guarantee health and safety in the product. Any change in any parameter without considering the safety and health standards can give damage to the animal’s legs or ruminants, for example” (Interviewee 32)	Quality assurance, health and safety of animal feed products		

Table and Figures

<p>“So, let’s say you know the vegetable oil on your shelf at the supermarket it must pass different SQR or quality specs, and before you know the insulin-making that oil, or even blending that oil, you can go out of spec for many reasons. Big data help in taking corrective actions quickly and proactively” (Interviewee 10)</p>	<p>Big data can help us in predicting if we're going to go out of spec</p>		
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Table 5: The impact of BDA on the organizational culture dimension. Source: Authors own work

Representative quotes	First-order codes	Second-order codes	Theoretical dimension
<p>“In the past, the company was not open to the idea of changing how we take decisions, but things seemed to have changes in recent years...we started to pay attention to the power of data around us...this is key to enable analytics and integrate with our partners” (Interviewee 15)</p>	<p>Changing the way things are performed, and the focus on data-driven decisions</p>	<ul style="list-style-type: none"> • Top management commitment and data-driven decisions • Employee involvement 	<p>Organisational culture</p>
<p>“The small farmers are not having the technology available in some other developed countries that just might be farther along on adapting this technology”(Interviewee 16)</p>	<p>Some farmers in emerging economies have concerns about privacy and security</p>		
<p>“When they talk about smart manufacturing or any sort of big data in manufacturing or in companies. We talk about people, processes, and technology in those three areas, and so this big data does overlap all three” (Interviewee 28)</p>	<p>The willingness to invest in big data is lower in emerging economies</p>		
<p>“You cannot use big data the same way in Europe or the US as you do in the Middle East, cultures are definitely different...there is less employee involvement and less tendency to make data-driven decisions. But at our company this has improved significantly in the past few years, we started to benefit from big data techniques, we learnt a lot from our counterparts in Europe and the US” (Interviewee 27)</p>	<p>BDA might help to reduce labour, so people inside the society have fears to lose their jobs.</p>		



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