Digital technologies and implications for Veterinary Services

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Summary

The pace of digital disruption over the past few years has been spectacular, transforming every sector of the economy, including animal production, health and welfare. This paper reviews some advanced digital technologies that may shape the future of Veterinary Services. These technologies are all data driven and are illustrated by three evocative examples that fall under the following categories: (a) wireless and mobile technologies for animal health monitoring, disease surveillance, reporting and information sharing; (b) advanced data processing technologies such as big data and data analytics used to uncover hidden patterns, predictions, correlation and other information; and (c) promising technologies such as blockchain applications used for effective and efficient management of various input supply chains.

Current challenges for increased application of these technologies in the animal health sector along with some implications for Veterinary Services are briefly discussed. Digital technologies will have a profound effect on how animal health services are delivered and how animal health systems are managed. It is therefore crucial for Veterinary Services to be proactive and adapt to the ongoing digital change. Investment in new technologies and preparing the current and future veterinary workforce with the necessary digital skills and knowledge to stay up to date and at the centre of digital innovation in animal health should be a priority for the years to come.

Keywords

Animal health – Big data – Blockchain – Digital technology – ICTs – Information and communication technologies – Mobile technology – Veterinary Services.

Introduction

By 2050, the world's population will be around 9.8 billion people (1), and food production will have to increase by 70% to cover the additional dietary needs (2). The livestock sector will be called upon to satisfy the increasing world consumption of animal-source food through sustainable animal production in ways that promote food security, poverty reduction, public health and food safety (3, 4). To address the new challenges an increasing population poses, and to achieve the United Nations Sustainable Development Goals (SDGs), technological advances and innovation will have to play a critical role in transforming the food and agriculture sector.

In the face of these challenges, Veterinary Services are more essential than ever to improve livestock health and productivity, ensure high food quality that meet safety standards, and to reduce animal diseases and public health risks across the human–animal–environment continuum. In addition, Veterinary Services are required to contribute solutions to global challenges related to food security, global health, antimicrobial resistance, climate change and shrinking natural resources.

Science and technological advances have been major drivers of change in the livestock farming and animal health industry over the last century. As they have become integrated into farming practices and animal husbandry, livestock technologies and processes, such as breed selection, feeding and milking automation as well as modern housing and environment management have led to the intensification of farming systems and production of more food for the growing population (5, 6). Advances in animal health biotechnologies such as vaccines, antimicrobials and diagnostic tools have been fundamental in supporting the intensification of farming systems and the growth of the livestock sector by reducing the burden of diseases and increasing the standards of animal health, welfare and product quality (7).

Today, the exponential growth is underpinned by rapidly advancing technologies and innovations in various forms including cutting-edge biotechnologies, nutritional technologies, digital technologies and more. Digital technology, one of the fastest evolving technologies, is heavily changing the way people live in the modern society and has gained intense attention in the recent years as part of the Fourth Industrial Revolution (Industry 4.0) (8). This revolution is driving disruptive digital technologies and innovations that are transforming almost every sector, and the food and agriculture sector is not exempt from this process (9). The technologies contributing to these developments include mobile applications, Internet of Things (IoT), cloud computing, big data analytics, artificial intelligence, blockchain and many other such advancements.

The deployment and use of these technologies in agriculture offer new ways and opportunities for better agricultural and livestock policies and practices leading to more sustainable and resilient food systems (10). As a subsector of agriculture, animal health plays a key role in this process and Veterinary Services have the responsibility not only to take part in this technological revolution but also to reassess the veterinary system organisation and ensure appropriate application of new digital technologies for policymaking, decision-making and planning. In line with its strategy to shape the global governance of animal health and guide the Veterinary Services towards better resilience, the World Organisation for Animal Health (OIE) conducted a survey on the external factors that have the potential to impact Veterinary Services over the next ten years and the adaptations required to contribute to sustainable development. Amongst the most relevant 17 external factors identified by experts and stakeholders, the use of big data analytics and other advanced technologies is likely to increase and therefore Veterinary Services should be prepared to respond to this trend (11).

This paper does not aim to give a complete overview of digital technologies impacting animal health as this can be found elsewhere (12, 13, 14), but rather to look at some evocative examples of data driven technology trends of the moment that will most likely shape the future of Veterinary Services in the years to come. Current challenges toward increased application of digital technologies in the animal health sector along with some implications for Veterinary Services are discussed.

Digital technologies to transform Veterinary Services

At the heart of digital technology are new ways of data collection, management, use and exchange using existing and advanced information and communication technologies (ICTs) and innovations. These technologies are transforming modern economies and entire systems of production, management, and governance (15). For example, digital technology has already become an integral part of healthcare in human medicine as demonstrated by the increasing trend in national policies embracing digital health that covers what is known as electronic health (e-Health) (16). Similarly, the increased use of ICTs and innovations is driving e-Agriculture, which allows improved access to valuable information that can help stakeholders make the best possible decisions and use of available resources to deliver economic, social and environmental benefits through increased productivity, improved product quality and safety, and cost-effectiveness of services (17).

Although much of the digitalisation process has yet to take place, it is expected that the impact of digital technology on animal health and Veterinary Services can and will be profound in the years to come. Recent developments in ICTs and innovations have opened a wealth of new opportunities to improve veterinary practice (18, 19), and timeliness and accuracy of data collection and reporting for disease surveillance and animal health monitoring (13). The use of new ICTs also facilitate mapping and monitoring the spread of infectious diseases and their coordination across sectors, as well as tracking supplies of drugs and vaccines (16). These developments lead to better, more efficient, and timely decisions that will positively affect the performance and quality of Veterinary Services meeting standards of animal health and welfare practices (20).

The following section covers some digital technology trends that will undoubtedly drive the transformation of Veterinary Services. These technologies are all data driven and will be illustrated by three evocative examples that fall under the following categories: (a) mobile technologies and applications; (b) big data and big data analytics; (c) blockchain applications. Together, these technologies are part of the IoT which is based on the connectivity of machines and devices in collecting, sharing and analysing data. These technologies are amongst the nine disruptive technology categories identified by the World Economic Forum (8), in addition to crowdsourcing, 3-D printing and advanced biotechnology and genomics.

Mobile technologies and applications

Mobile technologies started with the use of simple delivery technologies, such as short message service (SMS) and voice-based systems. With the rapid growth of mobile devices such as smartphones, tablets and sensors together with the growth of crowdsourcing platforms, mobile technology is fast evolving and offers several opportunities to share real time field data for various purposes among large populations of ICT users, including those in developing countries (21).

With the popularity of smartphones and the widespread use of cloud and web-based technologies, there has been a proliferation of mobile phone-based platforms and applications (apps) in every sector of the society. In the human health sector, for instance, the use of mobile technologies and applications has rapidly expanded in the implementation of mHealth, as part of the broader e-Health, which is defined as medical and public health practices supported by mobile and wireless devices (22). Mobile technologies are also becoming more abundant in the agriculture sector, offering various agriculture-related m-services to stakeholders both in developed and developing countries (21, 23).

In animal health, mobile phones were initially used to collect data for animal diseases surveillance (24, 25). Mobile technology advances that followed have led to the increased use of mobile apps for collection, analysis and dissemination of real time animal health data (13). Specific examples of customised mobile applications used in resource-limited settings include the Event Mobile Application, a mobile app developed by the Food and Agriculture Organization of the United Nations (FAO) for enhancing national capacities in disease reporting, surveillance and early warning (26). Similar mobile applications have been introduced by the Southern African Centre for Infectious Disease Surveillance for One Health disease surveillance (27) and other pilot projects to improve disease surveillance, diagnosis and control (28, 29, 30, 31). In addition, mobile apps were used for the collection of data on animal-based welfare indicators to assess on-farm animal welfare (32).

While the above are only a few examples, most of which remain at the pilot level, the bulk of animal health mobile applications are being developed by national public organisations and local enterprises both in developing and developed countries, in addition to a wide variety of apps offered by mobile apps stores where large international companies are the main developers.

Many of these mobile applications may not be validated scientifically, but they still illustrate the substantial advantages to integrating mobile technology in various areas of the veterinary domain with the potential to improve the efficiency of collection, analysis and dissemination of field data to support planning, decision-making, and service provisions. However, in order for this technology to reach its full potential, some basic conditions must align to remove existing barriers to widespread adoption by stakeholders at every level especially in low resources countries. These conditions include, for example, infrastructure needs, including mobile network availability, the accuracy of information contained in the applications, and the economic viability of services they provide (33), in addition to interoperability and validation of available and new free web-based applications (34), as well as the optimisation for ease of their use.

Big data and big data analytics

The availability of vast amounts of high-throughput data, often referred to as ‘Big Data’ collected from different sources using advanced digital technologies, is a driver of the digital transformation of all sectors in the economy. While many definitions have been proposed according to interested parties, there is no unified definition of big data yet. The most common one describes big data with three characteristics referred as the ‘3 Vs’: volume, referring to the vast amounts of data available; variety, referring to the different kinds of data generated including structured and unstructured data; and velocity, referring to the speed at which the data are created and acted upon. Other definitions also include ‘veracity’, which refers to the variable quality and uncertainty of data. Additional characteristics used include 'value', which refers to the capacity to transform vast amounts of data into information to produce actionable insights, and other features such as volatility and validity (35).

Big data requires not only access to large data sets, but also the competence and infrastructure to process them in a timely manner, and the capacity to realise the valuable insights for the end users. The most commonly used techniques for big data analytics include modelling and simulation, statistical analysis, geographical information systems and data mining and machine learning. Machine learning technology, a subfield of artificial intelligence (Fig. 1), uses algorithms to build analytical models, helping computers to 'learn' from data (35). It is particularly used to process massive datasets by running various algorithm models to detect patterns, make predictions and provide a basis for decision-making.

The scope and application of big data falls under several industrial sectors. For instance, in human medicine big data offer a valuable aid in the development and implementation of health policies, for the optimisation of the healthcare system and the prediction and management of epidemics. The recent COVID-19 crisis, given the multidimensional and intersectoral nature of the impact it has engendered, has allowed the emergence of the use of big data and artificial intelligence as advanced, efficient and responsive tools to enlighten decision-making in a context of great uncertainty (36, 37).

In the livestock and animal health sector, big data applications are gaining momentum as digital technologies, such as wearable technologies and sensors, satellite data systems and mobile technologies, are generating large volumes of data to support data-driven farming and animal health monitoring (14, 38, 39). For example, big data applications are increasingly being used in veterinary care and large-scale livestock operations where digitalisation and automated systems excel in collating and processing large volume of data to monitor animal health, supporting early detection of animal disease, and preventing adverse health impacts (Table I). Big data analytics using artificial intelligence and machine learning models have been applied to mine a large dataset generated by sensors to predict infections and diseases in dairy farms (40, 41) and poultry operations (42), and monitor health in pig industry (43). Other examples include pilot initiatives deployed to capture and analyse large volumes of animal health data mostly from veterinary clinics for surveillance of diseases in companion animals (44, 45, 46, 47).

In veterinary epidemiology, big data analytics offer possibilities for spatial and temporal data analysis (48) as well as for better understanding animal diseases and health related risks (49, 50). Big data analytics also are excelling in the fields related to bioinformatics and high-throughput 'omics' data (genomics, transcriptomics, proteomics and metabolomics) which facilitate the understanding of host-pathogen interactions towards the development of new diagnostics, therapeutics and vaccines (51, 52).

While big data presents opportunities across many industries including animal health, the increasing availability and use of data to create value also represent important challenges and issues that need to be addressed before big data technology can become a widespread reality (51, 53, 54). This is essentially an issue of access to information, since big data generally belongs to private companies. Information ownership, data confidentiality and security are challenges that must be addressed, in addition to issues related to technical capabilities and adequate infrastructure particularly in developing countries. However, with the rapid development of efficient data mining techniques, big data technology is expected to grow in the coming years. This highlights the need for Veterinary Services to be prepared to use big data analysis and derive valuable knowledge from it to support planning, decision-making and field operations.

Blockchain applications

Blockchain is an emerging and promising digital technology that has gained significant attention among diverse business sectors in recent years (55). In the simplest terms, a blockchain consists of a linked chain to gather, store, share and track information through a network of public or private computers called nodes. Data is kept in the form of encrypted dataset bases distributed among all participants of the network without the need for a centralised control (56). The blockchain allows data to be recorded with real-time updates across the network in a way that is designed to be transparent, efficient, unalterable and secure.

In agriculture, blockchain-based applications are being piloted in various agri-food value chains (56, 57, 58).

In the case of livestock and veterinary sectors, blockchain adoption is still in its infancy. However, blockchain-based systems can be potentially applied for traceability of livestock (56), and animal product supply chains (59, 60), as well as for efficient management of various input supply chains such as animal feed, veterinary drugs, diagnostic kits and vaccines, especially those that require a cold chain (61). Table II shows an example of an integrated animal product supply chain that can be managed through a blockchain application (56).

The blockchain technology also has the potential to improve the implementation and monitoring by Veterinary Services of technical requirements under trade agreements and to verify and enforce compliance with international animal health standards (58), as well as to scale up the use and implementation of electronic veterinary certification systems. All these applications offer tremendous opportunities for use of blockchain technology in the animal health sector. However, wide adoption by Veterinary Services particularly in developing countries may not happen in the near future.

Implications of digital technologies for Veterinary Services

In the era of digitalisation of agriculture and the advent of related concepts such as e-agriculture and precision agriculture (17) as well as livestock precision farming (62), it would be appropriate to surmise that data-driven technologies and services have the potential to improve the efficiency of animal source food production and quality throughout the entire food chain. In addition, digital technology may be part of the solution to overcome the impact of global trends such as population growth, changing land use and climate change on global food systems, interactions among humans, wildlife and domestic animals, and global health threats (9).

The use of data-driven technologies is going to continue to change production sectors and industries and the animal health sector is no exception. The potential benefits of integrating new digital technologies in animal health are convincing and will likely unlock new models that make national Veterinary Services more efficacious and efficient for meeting the required standards for animal welfare and health practices. The question remains whether Veterinary Services will be able to capture the opportunities and adapt to the rapid digital change.

Achieving the full potential benefits and desired outcomes of the digital transformation is challenging in all sectors. There are hurdles to overcome along the way before digital technologies can be widely adopted by animal health actors especially in the developing world. These challenges have been extensively reviewed from different perspectives and range from infrastructure requirements, interoperability of digital systems, policies and regulations, to digital skills and competencies and the digital divide (63, 64). As such, the ongoing digital transformation and its challenges will have important implications for the Veterinary Services, which must be considered from the perspectives of technology users, policy-makers, regulators, partners and other stakeholders (13, 19, 53, 65). The following are some of these implications.

Developing a legal and policy enabling digital environment

Governments and policy-makers play a primary role in creating the enabling environment needed to support the development and appropriate use of digital technologies. In the agriculture sector, developed countries are advancing and already incorporating digital agriculture in some existing policy instruments or developing full-fledged digital agriculture strategies. In developing countries, initiatives and projects for the use ICTs in the agriculture and associated sectors are growing, but have not yet been adopted in a comprehensive national strategy to develop efficiency gains from the digital transformation (66). Many countries still require institutional support for the development and consolidation of national sectoral digital strategies and their effective implementation, which usually requires more resources and capabilities. Governments and policy-makers need to assess the enabling environment and identify the necessary policies, regulations, incentive frameworks and capacity development to establishing a conducive environment for both supply and demand of digital technologies and facilitate technology uptake by stakeholders across the sector. The national Veterinary Services will have to actively engage in this process to ensure they are not left behind in the digital transformation.

There is need to consider cohesive actions by FAO and the OIE and global partners in collaboration with specialised institutions to support countries in establishing and implementing digital technologies in the agri-food system including the animal health sector. For example, the recent global initiative, the international platform for digital food and agriculture coordinated by FAO will provide a policy forum for governments to support the digitalisation in the food and agriculture sector with the potential to play an increasingly important role in achieving global food security and improving livelihoods, especially in rural areas (67). In addition, FAO is already developing mechanisms to support and facilitate discussion on the adoption and use of new ICTs and share knowledge on innovation and technology, skills and capacity in agriculture and livestock through a variety of digital approaches and solutions such as the e-Agriculture Community of Practice (68). This initiative focuses on the exchange of knowledge and resources related to the use of ICTs for sustainable agriculture, between United Nations agencies, governments, universities, research organisations, non-governmental organisations, farmers' organisations, the private sector and the wider community.

Developing the digital skills of the veterinary workforce

In a world of rapidly evolving technologies and options, the Veterinary Services need to keep up with technological advancements to be able to provide the necessary policy advice and technical expertise to the beneficiaries. As such, the demand for digital skills is expected to rise in the future within all stakeholder groups of the animal health sector. Introduction of ICTs in formal veterinary education is becoming reality, not only in developed but also in developing countries. This trend should be reinforced and sustained with the introduction of specific technology related skills in the curriculum to ensure a minimum understanding of how new and advanced digital technologies work, along with soft skills such as teamwork, problem-solving critical thinking which are also integral to the uptake and implementation of disruptive technologies in the workplace (19).

The veterinary workforce already lives in a connected world and will have ever greater access to digital technologies in both the public and private spheres. Developing the digital skills of this workforce is critical for wide adoption of the technology. The Veterinary Services will have to develop sustainable continuing education programmes to increase access to training in the use of digital technologies and opportunities for attaining the necessary digital skills. Failure to ensure this skill development can end up marginalising the veterinary workforce in an increasingly digitally driven world. Specialised training and education programmes portraying the advantages of digital technology and its ease of use will be required to ensure that the workforce can use it proficiently in all aspects of the veterinary domain whether in field operations or in animal health planning and management. Specifically, there is need for more education and training in data science, including statistics and computer science to develop the necessary knowledge and skills, for example, to mine big data and engage in big data analytics (48, 50). In addition, Veterinary Services will have to adapt their technical competence as well as optimise resources and services through institutionalisation of interprofessional and multidisciplinary collaboration to formulate, validate and scale up relevant technologies and promote their adoption across the sector.

National Veterinary Services in developing countries with support of specialised organisations will have to develop models of digital skills training aimed at veterinarians and animal health stakeholders so they can learn to assess and implement the best practices and technologies in their work. Assessment of the workforce should also consider the implications for the animal health labour market of introducing digital technologies and their management. Providing veterinary workforce with knowledge resources and facilitating education and training through digital tools such as e-learning, knowledge sharing and networks will improve and reinforce skills and competencies in the use of digital technologies.

Fostering public–private partnerships

Digital technologies are being mainly developed and disseminated by the private sector for commercial purposes. The importance of partnerships in veterinary digital solutions has grown over recent years in developed countries, with several initiatives involving the veterinary practice, large corporations and digital products and systems innovators. However, realising the full potential of this digital transformation and extending the benefits to all stakeholders of the animal health sector will require a policy framework with guidelines to tap into private sector investment and innovations. It is therefore fundamental to establish collaboration and strategic partnerships involving the national Veterinary Services, the private sector, ICT corporations and digital technology innovators, as well as data providers with clearly defined roles of each actor on how to exploit the opportunities of digital animal health at all levels. Public–private partnerships (PPP) in the digital space will become the new norm for the creation of sustainable business models that provide viable digital solutions and support the rapid deployment of digital technologies in veterinary domains. These models should integrate the needs of all stakeholders and the requirements for the development of the necessary infrastructure and processes to support the digital transformation of the Veterinary Services. In this regard, the recently developed OIE PPP guidelines (69) could facilitate collaborations and strategic partnerships to expand Veterinary Services' capacity in digital transformation.

Building national and global robust system for data management and governance

The digital transformation, fuelled by massive quantities of data being generated by various data-driven technologies, has been impacting data management for the last few years (13). This change offers great opportunities but will also bring challenges including who owns, controls, and manages the data being collected and also who will have access to it. These concerns call for creating robust, secure and scalable data management systems that can meet the increasing demands of master data management, data quality and data governance in this new era of digital transformation.

In animal health, data management is changing in many countries with a shift to digital data collection systems using various ICTs. Consequently, higher quality and more accurate data will be available in a timelier manner for decision-making, planning and management. Data will become central to veterinary systems, whether specific and small-scale data customised for routine disease reporting or big data from various sources for identification of risk factors and trends in disease patterns. It is therefore fundamental for Veterinary Services to strengthen their capabilities and infrastructures for improving data use and accessibility through interoperability, harmonisation and optimisation of data distribution to stakeholders (70). It is equally important to develop collaborative models and tools for information sharing beyond the animal health sector through exchange of data across sectors and value chain for various purposes (71), and ensuring interoperability of data systems which must 'talk' to each other (34). Furthermore, translating data into smart and effective actions will be essential, requiring constant dialogue between data collectors, analysers and policy-makers.

At the global level, the OIE is promoting digital transformation of animal health particularly for the management of animal disease data using the new platform of the World Animal Health Information System (OIE-WAHIS). The new interface will allow for data to be viewed, analysed and extracted more rapidly in a variety of analytic programmes. In addition, the new OIE-WAHIS platform will provide straightforward and standardised ways to interconnect with other international or regional information systems and integrate other valuable data sources, so that users can share and mutually enrich data in collaboration with the OIE. Similarly, FAO is in the process of upgrading its EMPRES Global Animal Disease Information System (EMPRES-i) to support Veterinary Services by facilitating the organisation and access to national, regional and global level disease data and information under the overarching FAO's Hand-in-Hand Geospatial Platform (https://data.apps.fao.org/). These global platforms along with relevant regional platforms will play a critical role in the governance, management and use of animal health data at global and regional levels, to accompany the digital transformation of Veterinary Services.

Conclusions

The world is changing at a fast pace with the emergence of an array of cutting-edge digital technologies, offering great potential to improve food production to feed the growing population, promote more environmentally sustainable agricultural practices, and maintain high-quality sanitary standards. Digital technologies are transforming the agriculture and livestock sector including animal health and welfare. And this transformation is expected to continue in the years to come with far-reaching impacts on the veterinary sector both in developed and developing countries. Preparing the current and future veterinary workforce to stay up to date and at the centre of digital innovation in animal health should be a driving force for the future of Veterinary Services.

Résumé français: titre

Résumé

Mots-clés

Resumen español: título

Resumen

Palabras clave

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Table I

Examples of big data applications in animal health reported in primary studies

Application	Reference	Analytic approach	Type of data	Source of data
Surveillance and forecasting of diseases in companion animals	Guernier *et al*., 2016 (45)	Internet-based surveillance for collection of data and their integration using Statistical analysis	– Google search data – Notifications from passive surveillance	– Internet search engine – Disease surveillance system
	McGreevy *et al*., 2017 (46)	Analysis of real-time, clinical veterinary records using natural language processing (NLP) technology	– Veterinary clinical records	– Veterinary schools – primary care veterinary clinics
	Self *et al*., 2019 (47)	Analysis of disease prevalence data using Machine learning algorithm: Bayesian spatio-temporal Poisson regression model	– Disease prevalence data including: – Laboratory data – Spatial and temporal data	– Laboratories – Veterinary care community
	Muellner *et al*., 2017 (44)	Practice based surveillance using coded and customized data entry interface	– Veterinary clinical data (electronic veterinary medical records	– Primary Veterinary care clinics
Monitoring of pig production and health industry	Faverjon *et al*., 2019 (43)	Transdisciplinary data collection and integration in a central data repository that are automatically processed and transformed into a homogeneous interoperable format	– Health and laboratory data – Reproduction data and fattening performance – Transport data – Meat inspection and meat quality data – Feed data – Climate data	– Veterinary Services and private veterinarians – Producers and marketers – Transport logistics – Slaughterhouses – Feed mills – Climate sources
Detection of mastitis in dairy farms	Ebrahimi *et al*., 2019 (40)	Automatic collection and analysis of milking data using different machine learning models	– Milking parameters generated by automatic milking sensors and systems	– Dairy farms
Detection of poultry diseases	Borgonovo *et al*., 2020 (42)	Analysis of sensor generated data using data driven Machine learning algorithms	– Data on the concentration of volatile organic compounds in the air in poultry farms	– Poultry farms

Table II

Blockchain chain application for management and traceability of animal product supply chain from farmer to consumer. Implication for Veterinary Services as a participating node (adapted from [58])

<table>
<tr><th>Participating nodes of the network</th><th>Data uploading at each node level</th><th>Implications for Veterinary Services as participating node</th></tr>
<tr><td>Producer</td><td>Data on feed, breeding, housing condition and sanitation, biosecurity measures, vaccines and treatments, veterinary certificates and others</td><td rowspan="5">– Uploading data on animal health situation
– Timely release of electronic animal health reports
– Efficient tracking and monitoring of noncompliance with international standards
– Improved ability to monitor and control animal diseases in order to maintain disease free status
– Efficient tracking of contaminated animal food products
– Issuance of electronic veterinary certificates (veterinary inspection, health certificate, etc.)
– Issuance of electronic veterinary certifications in case of international trade
– Possible automatic certification based on information associated with the product available in the blockchain network</td></tr>
<tr><td>Processor</td><td>Data on storage and slaughter conditions, food safety compliance, lot number, veterinary inspection certificate and other certifications</td></tr>
<tr><td>Distributor</td><td>Data on shipment and delivery details, storage and transport conditions, and warehouse and vehicle food safety and sanitation measures</td></tr>
<tr><td>Retailer</td><td>Data on delivery details, inventory metrics and sanitation measures, veterinary inspection certificates and others</td></tr>
<tr><td>Consumer</td><td>Gets full information on the product such as where and where and how it was produced, processed, transported and inspected</td></tr>
</table>

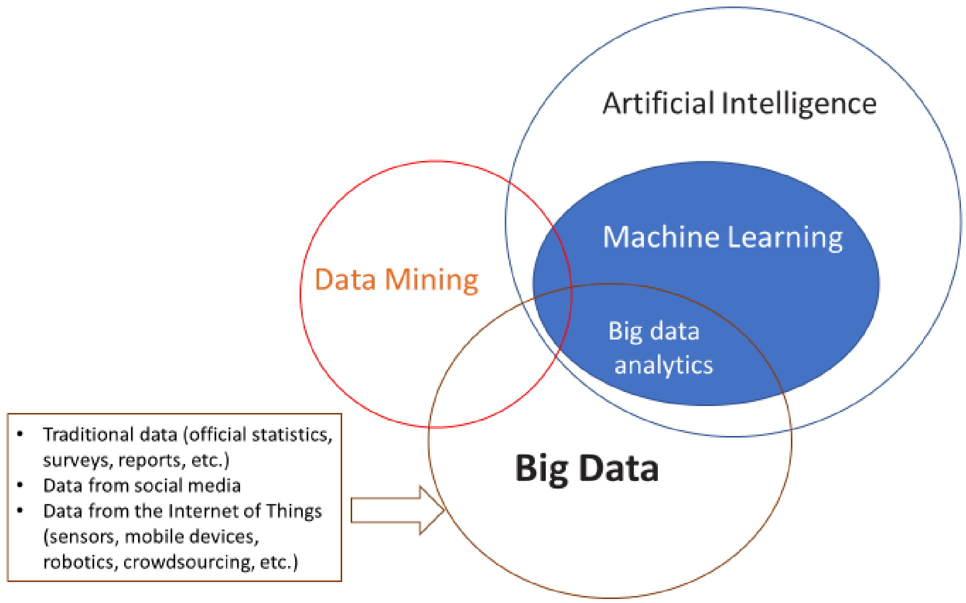

Fig. 1

Big data ecosystem and linkage with artificial intelligence, machine learning and data mining (adapted with permission from [35])