The case for digital smart platform for agricultural value chains in Africa

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1. Introduction

Digital innovations can transform rural Africa as well as the agricultural sector while tackling other emerging challenges in Africa, from unemployment, especially the youth groups, food insecurity, and the need for further economic growth. In recent decades, Africa achieved some progress in addressing critical challenges to the sustained agricultural revolution, economic prosperity, and improved livelihoods. Nonetheless, the collective pressures of demographic changes, urbanisation, shifting diets, climate change, and protracted crises require a new set of innovative solutions. The growing use of digital technologies, tools, and services is extensively visible, including in the agricultural sector, and will play a vital role for African countries in meeting their targets on reducing poverty, and improving nutrition, and food security (IFPRI, 2020).

New digital technologies and services are already having a considerable impact on how food is being produced, processed, marketed, traded, and consumed across the continent. How African countries position themselves to harness and deploy digital technologies will determine the speed and nature of agricultural and economy-wide transformation in Africa. As pointed out by Kosec and Wantchekon (2020), any agriculture digitalisation strategy needs to be designed to fit local environments and meet the needs of all value chain actors, while creating new opportunities for Africa's youth and women. The benefits of digitalisation are evident across much of the agricultural value chain, from providing access to information and other services, including finance, all the way to improving links to markets. Technologies involved include Blockchain, Big Data Analytics, mobile data access, and the Internet of Things, as well as more low-tech, frugal innovations. Apps such as FarmCrowdy and FarmDrive in Kenya use Big Data to build credit scores for farmers and have since helped thousands gain access to loans. Tools such as Nigerian firm Zenvus' SmartFarm sensor and Ghana's Ignitia's weather forecast model provide farmers with soil and weather data, building their resilience to raise productivity and navigate shocks. Meanwhile, Hello Tractor technologies in Nigeria and Kenya and TROTRO Tractor apps in Ghana help farmers identify nearby tractors available for rent (Kosec and Wantchekon, 2020).

There are a set of conditions to be met to foster the development of digital platforms for agricultural development in Africa. Such an enabling environment must include (i) regulation for the use of digital technologies; (ii) fiscal incentives to encourage end-user adoption in which the private sector can leverage its innovation capacities; (iii) an emphasis on skills development to improve digital literacy; (iv) research and development; (v) reliable infrastructure to connect those in the most remote rural areas to ICT services; (vi) the creation of information and innovation hubs that stimulate the generation of new ideas and solutions for the use of ICT along the food value chain; and (vii) South-South cooperation (IFPRI, 2020).

Unlike previous years, the advent of multiple new vital technologies enable the ability to develop digital smart farms and distribution systems, and promise a significant change in transforming agriculture and food systems in food depleted countries, to create genuinely sustainable food ecosystems that meet the 2030 Sustainable Development Goals (Maru et al., 2018). A **Digital Smart Agriculture Platform** (**DSAP**) can be employed in cost-effective phased approaches where utilising currently available infrastructure can be leveraged for everyone in the value chain; farmers, processors, distributors, retailers, and government to work together to optimise the food supply ecosystem. Such an ecosystem can provide the ability to monitor, manage, respond, and report vital, actionable data essential to optimising crucial decisions.

Recent vital new technologies that can make a significant impact on the development of a digital smart agriculture ecosystem are:

- Cloud technology – The availability of technology services and serverless architectures enable rapid software application development at the lowest possible development and operational cost. In addition, these technologies enable rapid and automated expansion of computing power to meet the growth of an unlimited amount of data without any changes to the software application.

- Mobile Data Capture – Since mobile communication infrastructure is now ubiquitous and widely accepted, mobile applications can be tailored to gather, transfer, and provide analysis results to all participants in the agriculture value chain. Should there be a need to gather additional information, these mobile applications can be customised and redistributed in hours to recipients.
- New database types – There are new database architectures most recently available, explicitly designed for linking multiple entities in their relationships in a more efficient manner to enable a view of the entire ecosystem in a single "view." Now than ever before, these database archetypes are ideal for gathering, tracking, analysing, and reporting billions of data points and millions of connected parties without a significant impact on user experience.
- Artificial intelligence platforms – While artificial intelligence has been in existence for over 30 years, it required custom code to ensure high performance for significant data consumption and relevant outcome. Today's cloud computing enables the rapid development of artificial intelligence analytics without significant custom code development for rapid and low-cost development costs.
- API Integration – Application Program Interface (API) is how application programs ingest or distribute data between each other. In previous generations, each API had to be custom developed for each application, creating high barriers to develop an integrated system. New technologies exist which enable this to be performed rapidly or not at all, so that is convenient for multiple different manufacturing and distribution systems to contribute to a centralised agriculture database system.

These elements are crucial to the development of a base architecture for a **Digital Smart Agriculture Platform**. This base platform would easily be expandable to incorporate other new farming technologies when it makes economic sense to do so. These new technologies would include but not limited to:

- IoT Smart Farming – Internet of Things (IoT) is a system built for monitoring the crop field with the help of sensors (light, humidity, temperature, soil moisture, etc.) as input to a decision model generating an optimisation schedule for the automated irrigation system. The farmers can monitor the field conditions from a mobile device or internet-connected computer system anywhere in real-time and address issues as they occur to prevent future problems which drastically impact yield or quality. Highly sophisticated IoT-based Smart Farming can provide alerts and recommendations via analytics and is significantly more efficient when compared to current manual farming practices.

- Agriculture Drones - Today, agriculture is one of the major industries to incorporate drones. Drones provide an easy path to a top-down topological view without significant effort or start-up efforts. Use cases for drones include crop health assessment, disease analysis, moisture analysis, irrigation planning, crop monitoring, crop spraying, planting, and soil and field analysis. Drone services are readily available, enabling non-technical farmers a variety of options for analysis, including crop health imaging, and integrated GIS mapping, that can increase yields.

- Livestock tracking and monitoring - Large farm owners can utilise wireless IoT applications to collect data on the location, well-being, and health of their cattle. The latest innovations in livestock monitoring enable location and temperature monitoring without the need for a cellular network powered by solar technology, This reduces both acquisition and operational cost tremendously, extending the life of a tracking device to years so adoption can be accelerated. With this new technology, sick animals can be identified in real-time, and separated from the herd, thereby preventing the spread of the disease

- Greenhouse farming - is a methodology using sheltered structures that enhance the yield of vegetables, fruits, and crops, by reducing risks from weather and pest issues. Greenhouses control the environmental parameters through manual or automated processes to provide favourable growth conditions. In addition to protection against extreme weather conditions, greenhouse farming can extend or change growing seasons, enabling the ability to create alternate harvesting seasons, and providing food sourcing across the year. A smart greenhouse can be combined with the help of IoT smart farming, eliminating the need for manual intervention.

To meet the high standards of tracking from source to the consumer, a new technology designed specifically for recording, defining, searching, and visualising each contributing agricultural entity in the value chain is required. Such a system must:

- *Focus*. The application is designed on the specific needs of the more simplistic approach of DRC farmers. Provide tools tailored for them to perform planning. What to produce, when to produce, where to produce, for whom to produce. These needs both imported data from outside the farm (e.g., weather data, market data, crop, and animal growth models) as well as localised data from the farm (e.g., soil).
- *Comprehensive*. Be comprehensive, but yet a simple, intuitive user interface that will encourage high adoption rates.
- *Continual monitoring and assessment*. This would provide farmers to track growth versus expected outcomes and determine the next steps for any unexpected results.
- *Pro-active government oversight*. Data from the farm can be combined with other locally similar farmers to determine an aggregated analysis of the overall farming progress to goals for the government, to enable intervention when required significantly in advance before it is too late to change course.
- *Automation*. Samples of automation include leveraging sensor data; switching on water pumps to irrigate fields when soil humidity falls below a target amount; opening or closing windows in glasshouses; or auto feeding animals at different times of the day can be performed rather than following a rigid schedule due to lack of actual data.
- *Forecasting*. By leveraging analytics built into the platform, a forecast can be generated for yield, revenue, and profit. This requires a combination of localised and imported data as well as prediction models: the more data the farmer (or the farmer's adviser) has, the more accurate the forecast is.
- *Extensible and Expandable*. Be optimised for creating relationships between entities and understand the value chain relationships between all entities. New types of entities or organisations can easily be added to the overall ecosystem map.
- *Unlimited data*. Enable unlimited amount of data to be collected with each contributor to the value chain.
- *Link Analysis*. Link chart and mapping visualisations so that detailed node analysis from farm to table can be performed. This linkage analysis will allow government oversight to rapidly respond to disease outbreaks such as hoof and mouth, salmonella and e. Coli with AI analysis to determine the source of an outbreak.
- *Visual data analysis*. Enable field data and photo capture using mobile or drone technology for on-line and off-line modes with the flexibility to add or modify data fields and distribute changes in minutes.
- *Flexibility*. To add unforeseen new entity types and their associated relationship without significant modifications to the underlying software infrastructure and database structure. Be flexible to accommodate the wide variety of stakeholders with the desire to be presented with their own unique set of data of interest.
- *Rapid change*. Quickly adapt to new requirements that may occur with new compliance regulations.
- *Secure*. Encompass the highest level of security with detailed user/group control access to specific data or data categories.
- *Rapid report development*. Provide the ability to develop reports, dashboards rapidly, and analyse trends for multiple different requirements by crop type of animal type.
- *Ease of integration*. Easily integrate with other outside systems through APIs and other means of data exchange to enable a comprehensive data repository. This capability is crucial to the market adoption and tracking of food supply and where inefficiencies lie. These inputs provide invaluable results to the overall food supply planning to benefit the entire nation to determine action specific action plans to an overall strategic plan. Making integration with other players in the value chain is essential to market adoption.

- Leverage cloud technology. Build specifically to take advantage of the latest cloud technology for high availability computing, enterprise reliability, and low operational overhead.

This paper presents the key features of a typical Digital Smart Agriculture Platform (DSAP) for value chain development partially developed by RippleNami[1] .

2. A brief review of the digital revolution

The mobile phone revolution is an example of how significant advancements in technology can enable African nations to quickly devour and accelerate their progress to be closer in capabilities to more developed nations. Indeed, mobile phone technology was first introduced in the mid-80s, leveraging two major new underlying technology shifts to gain market adoption; the invention of miniaturised lower power integrated circuits and the advent of lithium batteries to use for primary power storage. During the period of this new method of communication, the landline infrastructure coverage for Africa was at 7% in the early 2000s with no cellular service. Mobile phone technology enabled African countries to bypass significant investments in developing extensive landline infrastructure and immediately move to create less expensive cellular networks ideally suited for the African physical landscape and the limited landline infrastructure. Today, mobile phone technology adoption ranges from 75% to 93% adoption across African countries, and the adoption rate near that of developed nations. Even more astonishing, there is nowhere else in the world that moves more money on mobile phones than Sub-Saharan Africa. The region is currently responsible for an astonishing 45.6% of mobile money activity in the world—an estimate of at least $26.8 billion in transaction value in 2018 alone.

The same type of revolution is open to the African agriculture ecosystem. Indeed, advances in sensors, computational power, and networks massively increase our ability to access, analyse, and recombine big data sets. At the same time, the opening up of social media liberates the rapid exchange of information and experience. Recent developments in blockchain and big data will shorten supply chains and quality assurance systems to bring benefits directly to all stakeholders involved in all stages of agricultural value chains. Also, cell phone technology offers widespread access to data and applications. The great majority of smallholder farmers now have access to cell phones, and youth are particularly well placed to capitalise on the technology. Data-driven agriculture is "the thoughtful use of big data to supplement on-farm precision agriculture. It means having the right farm data, at the right time, to make better decisions throughout the whole agricultural value chain."

The introduction of Information & Communication Technologies (ICTs) in agriculture is a pivotal step in increasing agricultural productivity. Advances in different technologies have led to the concept of precision agriculture (PA (see Swinton and Lowenberg-DeBoer 1998; Lowenberg-DeBoer 2018; Lowenberg and Erickson, 2019). It requires the use of new technologies, such as geo-positioning systems, sensors, satellite or aerial images, and information management tools to assess and understand variations. Collected information may be used more precisely to evaluate optimum sowing density, estimate fertilisers and other inputs needed, and to predict crop yields accurately. It seeks to avoid applying inflexible practices to a crop, regardless of local soil or climatic conditions, and this may help to assess local situations for disease control better. Despite a lot of research undertaken in precision agriculture, this information benefits only large-scale commercial farmers. The majority of the rural farmers are not able to benefit from these efforts due to the existing extension models that cannot reach every farmer. Yet, simple communication technologies such as mobile phones can reach remote areas and provide farmers with an alternative access route to information.

Smart Farming is the application of information and data technologies for optimising complex farming systems. The focus of Smart Farming is not on precise measurement or determining differences within the field or between

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[1] RippleNami is a global software development company specialising in data traceability and transparency including collecting, organising and visualising data. RippleNami enables stakeholders to track and visualise assets, resources, events, and personnel. The results enable the stakeholder to make informed real-time decisions. Most recently, RippleNami developed and continues to be the technology provider for Kenya's **Livestock Identification and Traceability System** (**LITS**).

individual animals. The focus is instead on access to data and the application of these data – how the collected information can be used smartly. Smart Farming involves not just individual machines but all farm operations. Farmers can use mobile devices such as smartphones and tablets to access real-time data about the condition of soil and plants, terrain, climate, weather, resource usage, workforce, funding, etc. As a result, farmers have the information needed to make informed decisions based on factual data, rather than their intuition.

The real goal, though, toward accelerating the Africa agriculture industry is Digital Farming. The essence of Digital Farming lies in **creating value from data**. Digital Farming means to go beyond the mere presence and availability of data and create actionable intelligence and meaningful added value from such data. Digital Farming is **integrating both concepts - precision agriculture and Smart Farming**. According to a paper on Digital Agriculture by DLG (German Agricultural Society), Digital Farming is understood to mean "consistent application of the methods of precision agriculture and smart farming, internal and external networking of the farm and use of web-based data platforms together with Big Data analyses."

According to Maru et al. (2018), farmers typically use (access or share) three streams of data and information in their Farming. The fourth stream of off-farm data also exists but has little use for farmers.

The first stream (localised data) is data generated and collated on the farm for use only on the farm. This includes soil data (soil form, soil depth, nutrient composition), seed and fertiliser use, date of sowing, production practices, water use, etc. that farmers have about their immediate location. This data can be generated and managed by the farmer or by an agent acting for the farmer.

The second stream is data generated and collated off the farm, for use on the farm. Examples are climatic data and market prices that have been interpreted and customised for on-farm use. This is called 'imported' data.

The third stream is data generated and collated on the farm for use off the farm. This is usually processed, aggregated, or combined with other data and information generated elsewhere and is used by various actors and stakeholders, such as governments or private companies. Governments may use this data to establish ownership, revenue, and subsidies or to target services – that can all directly benefit farmers. Other users include market intermediaries, farm input, and service providers, including banks, insurance agencies, farm advisory services, scientists, other farmers, and their associations, etc.

The fourth stream is data generated and collated (on and) off the farm, mainly for use. A large proportion of 'agricultural' data is generated through disparate data sources such as government statistical and research data. Even though such data has little direct on-farm application – it can, through policy changes perhaps, have indirect on-farm influence. This is called 'ancillary' data.

The figure below provides a good summary of all four streams of data.

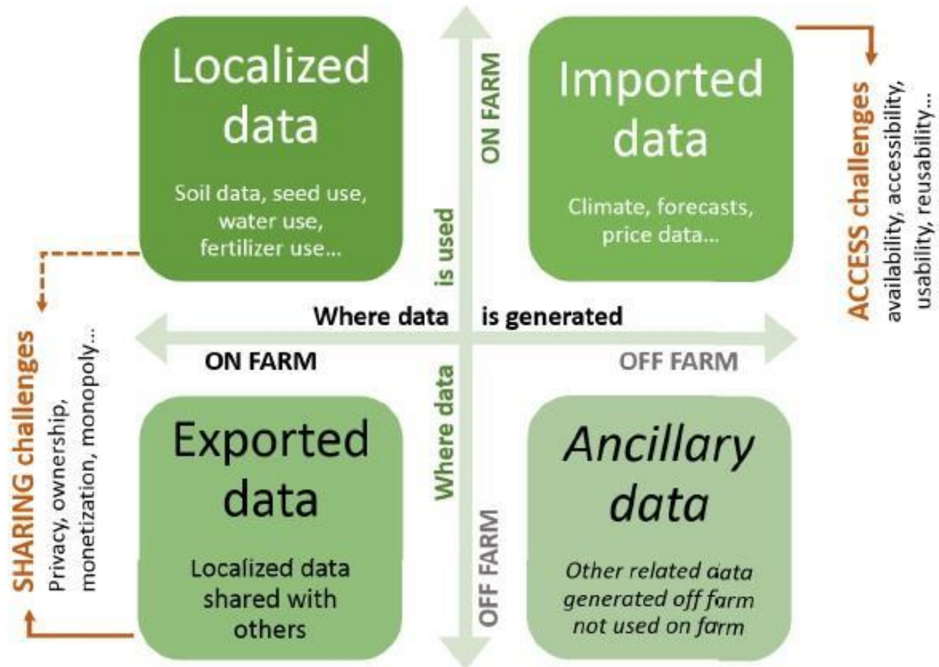

Figure 1: Streams of Data (*Source: Maru et al. 2018)*

Not all data is the same, and the development of a Digital Smart Agriculture Platform must accommodate the different use cases from the initial architectural design so that it can easily be expanded to be used for different purposes in agri-food systems. Data use cases include but not limited to:

- *Planning*: what to produce, when to produce, where to produce? For whom to produce? What operations to do when and where on the farm? These needs both imported data from outside the farm (e.g., weather data, market data, crop, and animal growth models) as well as localised data from the farm (e.g., soil).

- *Monitoring and assessment*: How are the products growing? What is the status of natural agricultural resources? This requires mainly localised data from the farm (e.g., monitoring data from sensors). This is also one of the areas where data from the farm has an 'export' value for other actors (e.g., for monitoring the use of land and natural resources or for national maps of land capability).

- *Event management and intervention:* Which action should be taken and when? This requires mainly localised data from the farm (e.g., soil data from sensors) but can benefit from external data like weather forecasts, growth models, or market conditions.

- *Autonomous action through ICTs*: For example, switching on water pumps to irrigate fields when soil humidity falls below a target amount, opening or closing windows in glasshouses, or auto feeding animals at different times of the day. This requires similar data as event management above.

- *Optimisation*: What will be the economic, environmental, or social return/effect on the investment/action? This depends entirely on imported data, like market data, consumption statistics, land and water use, potential payment schemes for environmental services.

- *Forecasting*: How much will be the crop or animal yield? How much profit? This requires a combination of localised and imported data as well as prediction models: the more data the farmer (or the farmer's adviser) has, the more accurate the forecast is.

- *Tracking and tracing*: Where is the product, item, resource, or material? What is its source, and where will it go next? This is a crucial area where a lot of external tracking data benefits the farmer; the data shared from the farm can also become essential for the comprehensive tracking data flows (e.g., farm identification, farming practices, agricultural input used).

- *Negotiating and market access*: Where are the consumers? What do they want? Who else is selling the same product? Which market is surplus, and which glut? Which service providers are around me? Localised data on-farm operations and products, and input needs, can be combined with imported data by farmers (or their representing organisations) to negotiate better prices, discounts, and the like. Localised 'metadata' on farmers and their farms can be powerfully aggregated by farmer organisations using joint actions to negotiate better deals for their members.

3. **Digital Smart Agriculture Platform**

The proposed **DSAP** includes four modules, namely **rCAPTURE®, rTRACE™, rWAVES®,** and **rANALYZE™.** **rCAPTURE** enables electronic data collection in the field in both off-line and on-line modes using mobile devices. Data fields within **rCAPTURE** can quickly be modified, with new user workflows to be distributed within hours instead of days or weeks. **rCAPTURE** not only enables farmers in the field to collect and process results but will also be used for collecting inspection and compliance data for government agencies. With little access to cell or Internet service, the off-line and remote data collection is essential for farmers to adopt and utilise this tool.
rWAVES is an intuitive data visualisation mapping application, designed so users can see a geographical representation of the data across any number of categories such as the location of all crop-producing assets, underperforming farms, and diseased regions. With **rWAVES**, users can now seamlessly aggregate data in a real-time, searchable visualisation platform that enables better decision making. **rWAVES** makes it easy to compare multiple different groups or categories in a geographical visualisation.

Analytic reports will be available through the **rANALYZE** artificial intelligence web application module providing instant access forecasting tools and management reports displaying trends and production results in an intuitive graphical or tabular format. **rANALYZE** will also enable users to generate their reports with ad-hoc report generation, providing a breadth of information at the user's fingertips. Results of **rANALYZE** would be provided in both the mobile phone and over a consolidated Web Interface for power users.

The heart of the system, **rTRACE**, is designed around graph database technology, a unique database characterised by nodes or entities. An example of a node includes a farmer, a processing plant, a secondary processor, the distributor, and a retailer. Due to the in-built relationships in graph databases, creating corresponding data between everyone in the value chain is much straightforward than in relational databases, which require complex queries which result in slow performance and frustrating user experience for large amounts of data. Graph databases are ideally suited for complex relationship applications with advantages of high performance, scalability, and easy expansion. They can accommodate an unlimited number of nodes and linkages for any network scenario versus traditional relational databases. With graph systems, single queries that track linkage data for analysis purposes can run in seconds to get a visual representation in the form of nodes and linkages with results showing the yield and output flowing through different stages of a given value chain.

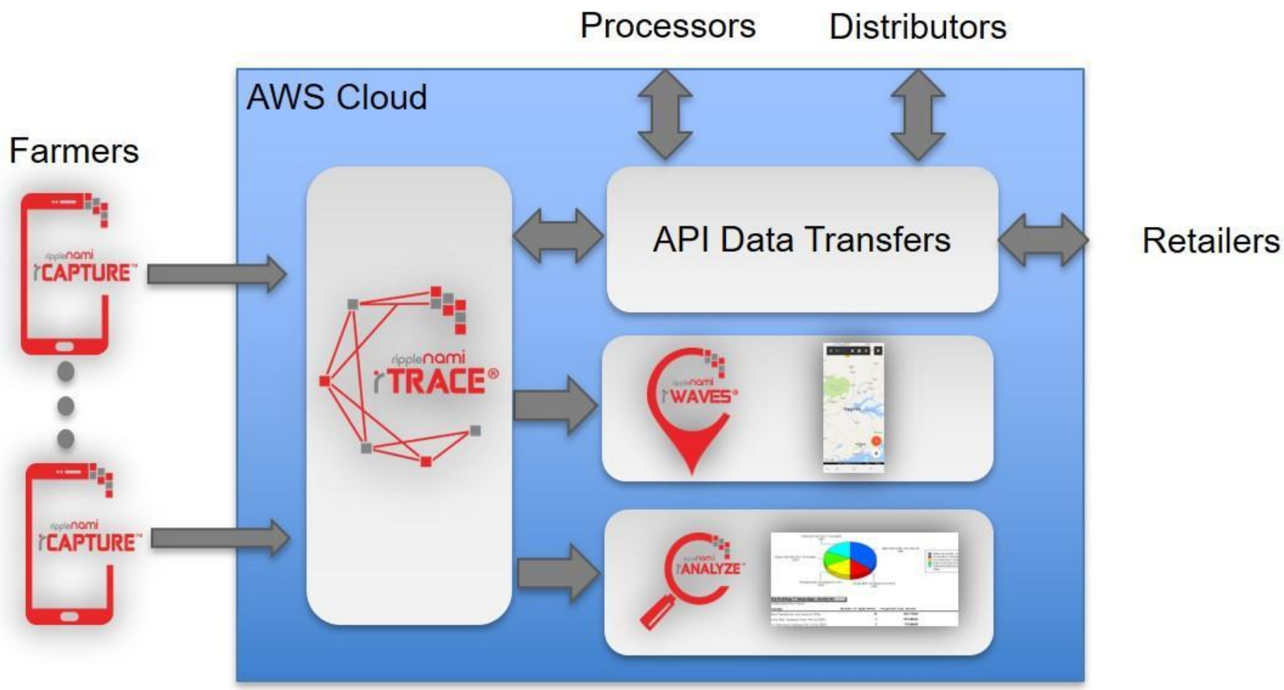

Figure 2: Digital Smart Agriculture Platform for Agricultural Value Chains

The **DSAP** is developed with the latest in cloud technology, leveraging the billion-dollar investments in tools, infrastructure, and platforms from Amazon Web Services (AWS), bypassing the legacy and bulky burdensome costs of older software technology. By using the AWS cloud, **DSAP** takes advantage of readily available AWS services for rapid product development coupled with the lowest possible operational costs. Built around a modern architecture of microservices, new features and capabilities can quickly be added as another service to the base architecture without significant engineering re-architecture. Each microservice is an independent service, enabling rapid and efficient engineering development.

5. Agriculture value chain and data requirement

Typical **Agriculture Value Chain** encompasses numerous, varying assets, each with unique properties, origins, derivatives, owners, and custodians. The relationships between the assets, their owners, and custodians change over time. This history of changes forms the basis for capturing and performing traceability in the system. The progression of assets, their derivates, and associations with other assets within the **Agriculture Value Chain** may be described as follows.

Assets

Assets at the beginning stage involve components necessary for the production of new assets (crops, livestock) during the Production stage. Assets in this stage include a farmer, crop type, its location, machinery equipment, fertiliser, soil type, pesticides, virtually all items required for farming production. For instance, the seed source registered within the traceability system may also be considered a **Sourcing** asset as it is a critical input to farming success. Even at the **Sourcing** stage, each asset has an owner and a custodian.

Production

Assets of the **Production** stage focus on farmers, activities performed within the farm such as inspections, diagnoses, pesticide treatment, water sources, labour, planting, watering, fertiliser and harvesting schedule, crop yield, and derivative assets. At this stage, the custodian is the farmer, and all assets remain in the custody of the farmer until they are formally transferred to another party, such as a processing centre, distributor, or retailer (farmers market).

Processing
The primary assets of the **Processing** stage are the bulking and processing centres equipment, the containers of incoming crops or derivative assets, and any extracted samples for laboratory testing. If desired, equipment associated with processors or other parties can be tracked added to the information inventory to determine productivity efficiency. At this stage, processors are the custodians of assets until they are formally transferred to another party, such as the distributor or laboratory. These assets include farm products in its various forms, including but not limited to canned, pureed, frozen, raw, or combined with other assets (a combination of other farm products), bound for delivery to the distributors or a retailer.

Distribution
Assets at the **Distribution** stage represent completed assets destined for the markets (Retailers, wholesalers, exports, etc.). They remain in the custody of the distributor until such time that it is formally shipped to a new party. Distributors will carry and track inventory in large containers with bulk information of the asset in its final form.

Retailers
Assets at the **Retailers** represent completed items destined for the end consumer and remain in their custody until the end of consumer purchase. Farmers who sell directly to end consumers would be considered as a retailer, with operations consistent with the direct farm to table connection. Market price trends based on geographic location are captured and available for all retailers to utilise for maximum profit.

Export
Assets at the **Export** stage represent completed assets ready for export and all associated export documentation. Assets at this stage remain in the custody of the Export Agency until they are formally released.

Import
Assets at the **Import** stage originate outside the value chain system. Once such assets are registered into the traceability system, they may be tracked like any other asset whose sourcing occurred within the system.

Arrows in Figure 3 illustrate many of the points in the value chain where **rCAPTURE** will record data and establish traceability.

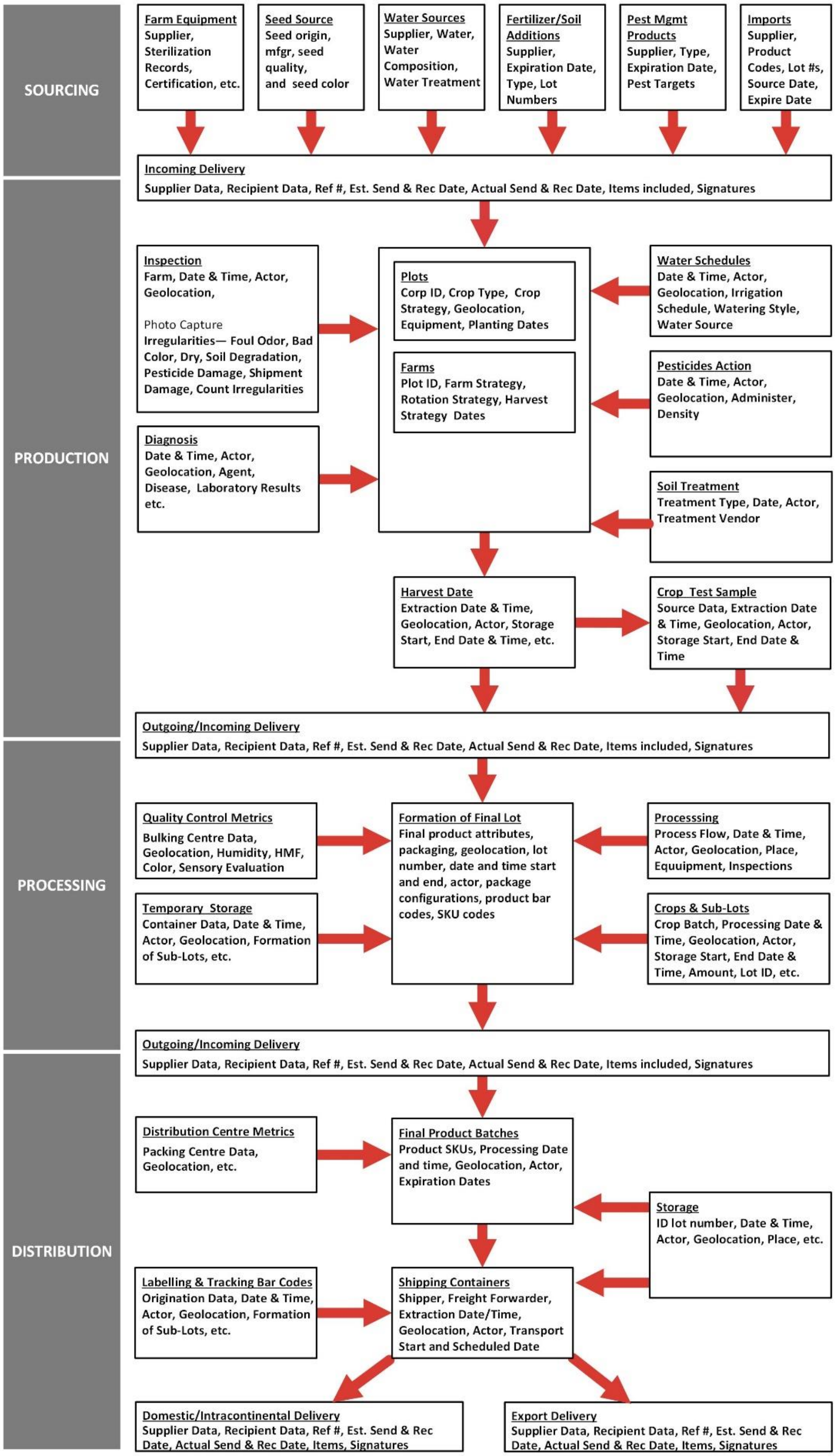

Figure 3: Agriculture Value Chain Network (Source: RippleNami 2020)

6. Need for traceability – in Agricultural Value Chains

Comprehensive databases creating linkages between multiple assets, events, owners, and attributes must be developed to ensure efficiency and competitiveness throughout the entire agricultural value chain networks.

An accurate representation of what transpires throughout the history of an asset requires all recorded business events to be attributed to the appropriate stakeholder. For example, activities such as inspections and certifications may be associated with a crop or a piece of equipment. Or a transfer of crops from a farmer to a food processor. Such capability is covered within **rTRACE** using the following two design patterns.

The **Custody pattern** requires that every asset is in the custody of a given party until such time that the party relinquishes custody to another party through a Transfer. All observations and actions for an asset are linked to the party with custody of the asset at the time.

Every asset is linked to a party such as a farm or Processing Center. Every activity, e.g., inspection or treatment, is formally linked to both the asset and the party with custody. All inspections and treatment relative to the asset (e.g., crop) are associated and linked to the asset. See below an example.

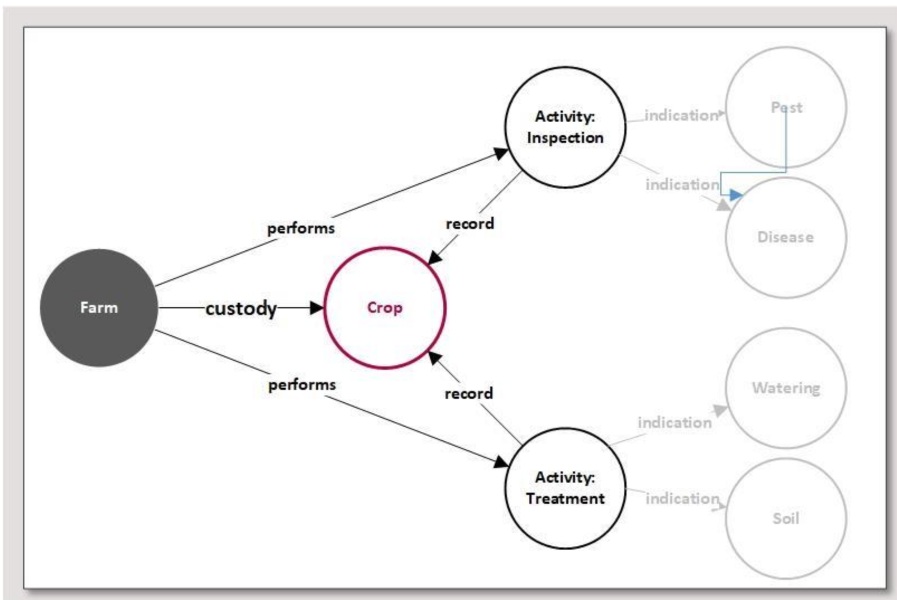

Figure 4: Custody pattern (source: RippleNami 2020)

The **Transfer pattern** requires the recording of a formal change-of-custody when an asset's custody transitions from one party to another. A transfer is recorded in the form of a 'Transfer Manifest' that formalises source and destination party information along with what assets are itemised in the manifest. Upon receipt of the transfer manifest and the items referenced within it, the custody association between the previous holders is closed, albeit not deleted, and a new custody association is created to the receiving party.

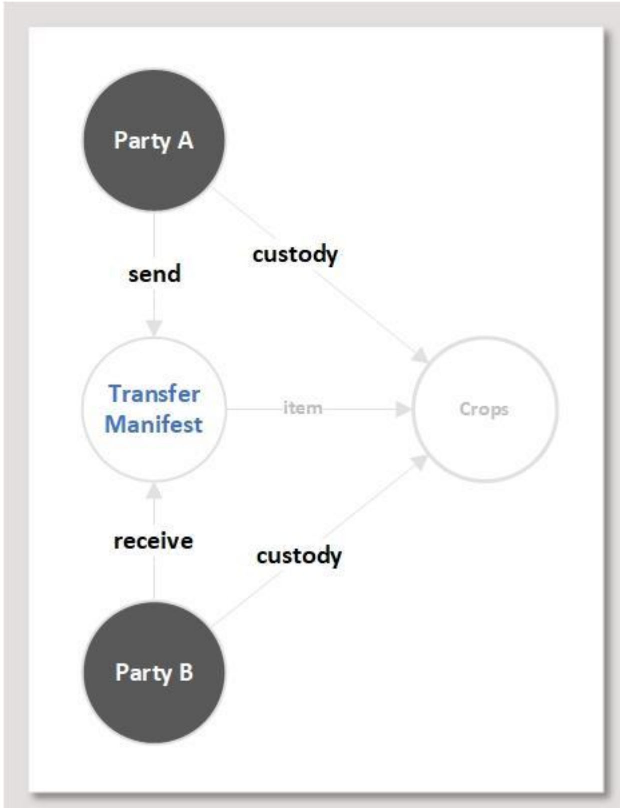

Figure 5: Transfer Pattern (source: RippleNami 2020)

The **rTRACE** traceability engine is responsible for capturing and maintaining a complete lineage of an asset. While the traceability of an asset, such as farmer's crop, or canned vegetables, references every historical observation or action, traceability within the engine is implemented through a small set of design patterns. The fundamental patterns include Source, Copy, Split, and Combination.

The **Source pattern** drives traceability between assets within the system. It requires all derivative or downstream assets to be stored as unique assets, each with permanent links to its predecessor. A 'source' association is created between two assets when one is a derivation or descendant of the other. The assets may be of the same type as in the case of agriculture being repackaged. The assets may also be of different types, as in the case of agriculture that is extracted from a colony. Given this pattern, all activities throughout each stage of the **Agriculture Value Chain** may be retrieved by traversing the 'source' associations of an asset from any point in time to its origin.

The **Copy pattern** addresses the need to replace or relabel an existing asset. Common business cases may be the transfer of asset contents from one container to another or assigning a new label to an item. The new asset is created with properties copied from the original and a new 'source' association to the original. Any activities events recorded against the original asset are not transferred to the new asset.

The **Split pattern** addresses the business case where an asset is divided into separate derivative assets. An example of this may be the division of a single bulk container of crop into smaller individual jars or containers. Each derivative asset is itself a new asset in the system with a unique identifier and similar data differing in quantity or amount. The new asset retains a custody association with the original asset's custodian party and a new 'source' association to the original asset.

The **Combine pattern** addresses the business case where multiple assets may be combined into a new asset. An example of this may be the pouring of multiple smaller containers of agriculture into a larger pool of agriculture to be stored or pasteurised. In such a case, the new asset, i.e., the vat of pasteurised or stored agriculture's lineage, is the union of all lineages for each joined asset.

The derived asset is itself new in the system with a unique identifier and similar data differing in quantity or amount. The new asset retains a custody association with the original asset's custodian party and individual new 'source' association to each of the original assets.

An example of traceability in the **Agriculture Value Chain** is presented in the following illustration.

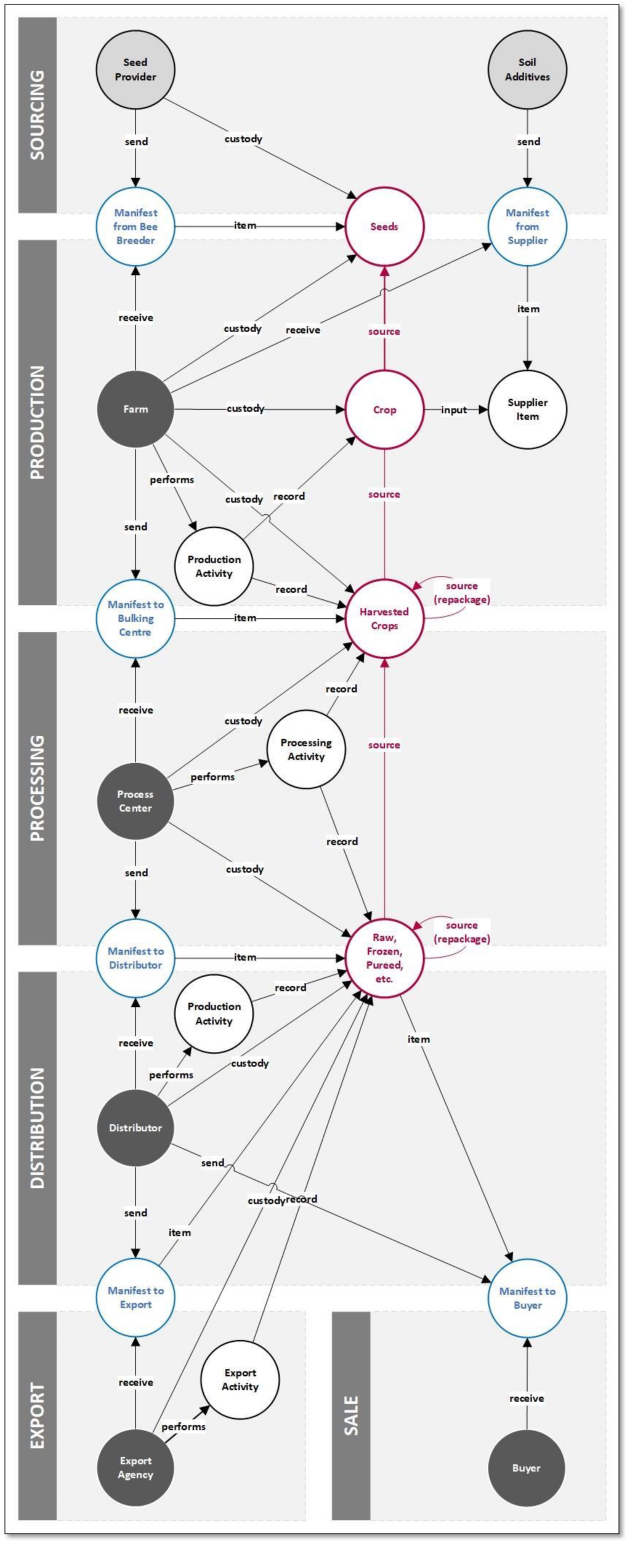

Figure 6: Agriculture Value Chain (source: RippleNami 2020)

The **rTRACE** solution architecture is designed to accommodate all of the patterns cited above; the **Source** pattern, **Copy** pattern, **Split** pattern, and **Combination** pattern. Built on a serverless, modern, cloud-service architecture,

rTRACE is a force-multiplier concerning the available processing power, storage, security, scalability, and reliability that would otherwise be unattainable at the cost and schedule to implement from scratch.

rTRACE is composed of four major components:

1. API Gateway. The gateway for ingesting and responding to API calls from rCAPTURE, IoT Systems other related systems.
2. Security services. These services provide Identity and Access Management. These services also manage encryption and key management functionality for both symmetric and asymmetric encryption algorithms that might be used in the transfer of data from external data sources.
3. Application microservices. Application microservices include but are not limited to an asset, alert, role-based access control, track ingestion, transfer, data quality, error resolution, tag, and owner services.
4. System microservices. System-level microservices across all the application microservices, which include but are not limited to search, database, storage, ledger, email, and notification services.

The API Gateway manages access and routes HTTPS requests from an API client such as rCAPTURE, a Mobile application, a Web Application, or a third-party application to the RESTful APIs of the microservices. The RESTful APIs establish a well-defined contract for each service in the form of a Swagger or OpenAPI Specification. This industry-standard specification is used by API clients to execute service logic such as create, read, update, or delete functions, to name a few.

The APIs and definitions are segregated into two sections: Internal and Published. The Internal APIs reflect intra-system communications, either from a first-party mobile or web single-page application or from composite service calls within the system itself. The Published APIs are those available to authenticated and authorised third-party applications such as processing centres, distribution centres, wholesalers, exporters, and retailers.

Below is a typical flow of an API call using the **rTRACE** Rest Services for adding or modifying an asset in **rTRACE**.

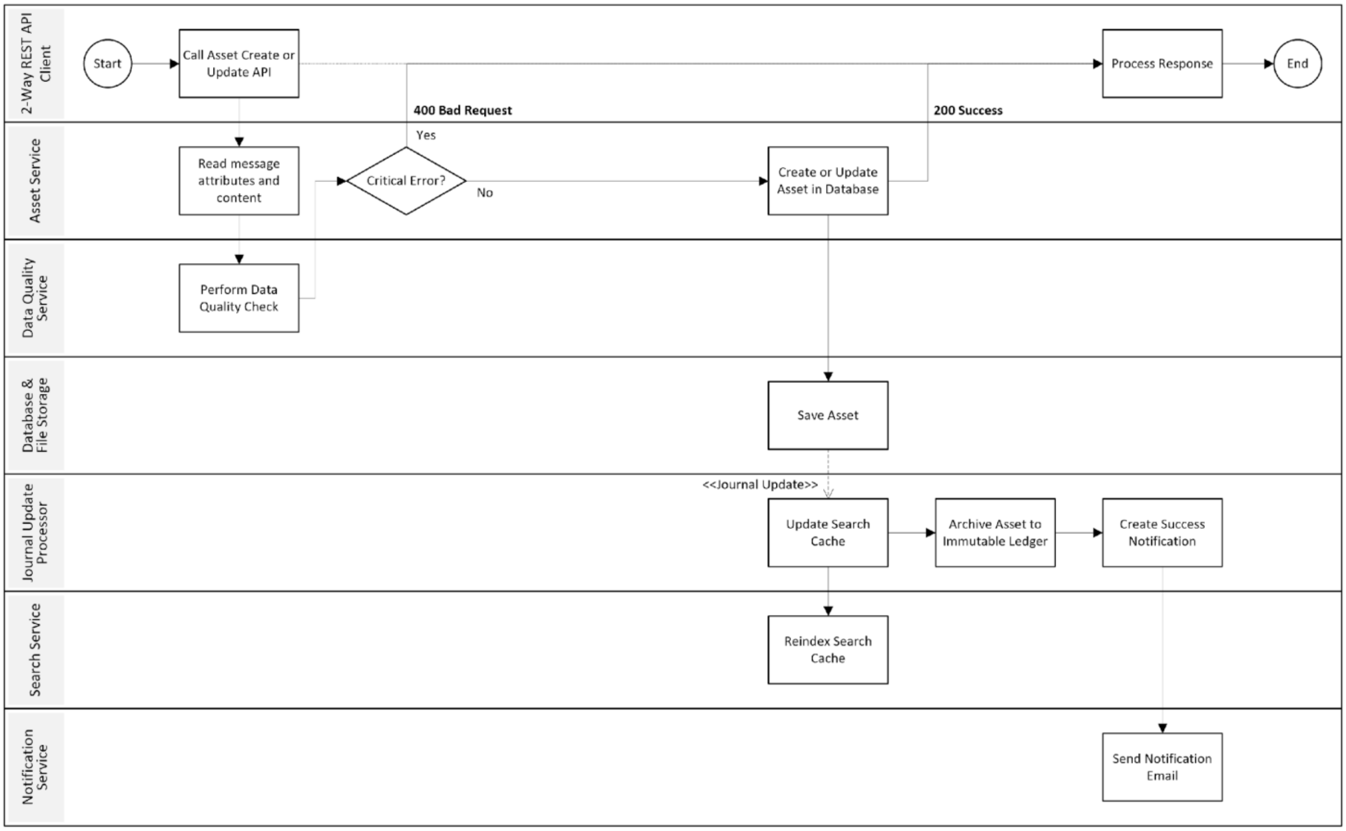

Figure 7: Typical Data Flow (source: RippleNami 2020)

7. THIRD-PARTY DATA INTEGRATION

A vital part of this program is the integration and exchange of data to 3rd party data sources. Although DSAP will be able to collect data from rCAPTURE and IoT devices from the farm source, other organisations that contribute to the agriculture value chain will need to submit their data into DSAP quickly and seamlessly. Also, they may request data from DSAP for their tracking purposes.

DSAP is designed with integration to 3rd party data sources in mind. It is made to be flexible while also providing public-facing Web Services APIs to enable the exchange of data to 3rd party data sources. The DSAP Web Services API will enable 3rd party organisations to perform data exchanges without significant engineering effort efficiently. In addition, depending on the software used by 3rd parties, one can design special software to develop connectors to other software APIs to facilitate proper data exchanges. In addition to APIs, data exchanges may also require the use of EDI (Electronic Data Interchange), an older standard for the exchange of invoices and purchase order data.

A crucial part of DSAP is to assist with local and international public health inspection compliance analysis and enforcement. Integration with 3rd party APIs with existing systems from government agencies can be developed. Other government agencies involved with transport and custom control are expected to occur.

For import and export data, the plan is for DSAP to perform data exchanges with TMS (Transportation Management Systems) software applications. TMS is a subset of supply chain management concerning transportation operations. A TMS usually "sits" between an ERP (Enterprise Resource Planning) or legacy order processing and the warehouse or distribution module. Various TMS sellers include large enterprise software development organisations such as Oracle, SAP, JDA Software, and CH Robinson, as well as smaller providers such as e2Open, Kuebix, and BlueJay. Specific API integrations with TMS will depend on the discovery of the software and APIs used by organisations that contribute to the agriculture value chain.

Likewise, wholesalers, distributors, and retailers both within and outside of a country that participates in the country's agricultural value chain will need to contribute their data to DSAP. It is expected that the ability to instantly correlate issues with specific crops or perform recalls with minimal effort to identify the proper lots would be an incentive for these organisations to contribute their data via their system APIs to DSAP. With Role-Based Access Control and richly detailed control of data ownership, DSAP will provide a portal for all contributors to see "their" data and all the associated links to their data.

With complete crop lineage within DSAP, processors and manufacturers will have the ability to offer more information to the end consumer concerning quality and prove the organic nature of the source. Such information would enable the bottler to develop a consumer marketing program via a unique label that can be scanned to provide the lineage data directly to the consumer, either through a website or a mobile application. Although the scan would be directed for consumer consumption, other government agencies would have access to the same information through the same scanning mechanism. Since the labelling and scanning requirements are unknown at the time of the proposal, this capability is out of scope for the initial phase of DSAP development.

FUNCTION-AS-A-SERVICE

Business logic is implemented as a suite of distinct, often single-purpose business functions running in Serverless computing. Doing so allows all developers to focus on delivering business features while the provisioning of servers or containers, fault tolerance, and scalability are available out-of-the-box. Functional components are automatically scaled to meet any given usage demand and allows for a constant service response time, whether there are one or thousands of clients. This solution is ideal given the potential for large numbers of service clients—mobile applications, web applications, third-party clients, and devices.

DATABASE AND STORAGE

At the heart of **rTRACE** is a revolutionary database, a Graph-structure database, which is used for storing business owners and their associated relationships. In an ideal world, supply chains for any product are linear: whereby a single agriculture lot yields a single processed unit throughout the life cycle of an agriculture jar, a relational database would be an easy-to-understand progression to the final finished product. But with the complexity of multiple farms contributing to a single processing lot, and sub-lots being created and processed differently from a mother lot, this creates a complex, interconnected network.

New technology is required to manage complexity. As opposed to relational databases, a standard data model that stores rigidly structured data into predetermined rows and columns, graph databases assemble nodes, and the relationships between them into connected structures. Graph databases are used for many popular applications, whereby there are linkages between multiple entities. The most popular applications using graph databases are social networks such as Facebook and LinkedIn, which are defined by their ability to connect any defined node (person) to any other person without significant impacts on the network structure.

Graph databases are characterised by nodes, properties, and edges, with nodes being entities, properties are characteristics of a node, and edges representing relationships between nodes. An example of a node is a farm, seed producer, the processor, and the distributor. There are three significant advantages of using a graph database over a traditional database in a traceability application. These are:

1. **Fast**. The relationships allow data in the store to be linked together directly and, in many cases, retrieved with one operation. Querying relationships within a graph database is fast because they are perpetually stored within the database itself. Relationships can be intuitively visualised using graph databases, making them useful for heavily interconnected data. Graph databases, by design, allow fast and straightforward retrieval of complex hierarchical structures that are difficult to model in relational systems.

2. **Complex Yet Simple.** Because graph databases are based on interconnections between nodes, they can store data in a variety of complex network configurations with no two network configurations being alike. If an agriculture lot is subdivided into multiple lots, or with multiple lots merged into a single bottle operation, graph databases can easily handle this data relationship. However, the process of creating new nodes, such as splitting a lot into multiple lots, is quite simple and straightforward.

3. **Scalable**. A single network is not limited by any number of nodes within any network. There is a complete set of nodes that link to each other, with no impact on capability or performance. Nodes can be added at will, enabling the straightforward depiction of a change in the relationship without reconstruction of the database design.

A unique property of Graph databases is the ability to subdivide or merge multiple assets without impacting the underlying database structure. Whether the network consists of 2 nodes or 1000 nodes, the retrieval of the network configuration is a single I/O operation to the database, resulting in incredibly fast response times to queries for analysing traceability across the lineage of multiple entities/nodes. The addition of another interconnected entity can be performed without the need to create another data table as would be required in a traditional relational database.

Complex relationships such as multiple suppliers to a processing plant and the split or combining of lots at a processor plant, inspections of a crop, the bulk-centre data, manifests, storage facilities, shipping providers, export companies, export facilities, distributors, and laboratory results can be represented in a single network configuration. Each crop with each farmer will have its unique network configuration, all within the same database, without compromising the depth of data within each node.

The proposed approach will use the advent of cloud computing, and significant advances in database technology enable the utilisation of advanced graph databases while enabling developers to create rapid business intelligence reports using standard SQL (Standard Query Language) programming, eliminating any need to learn new languages.

8. Concluding remarks

In the past five years, digitisation transformed "African economies in four major ways: retail payments systems, financial inclusion, sustainable business models, and revenue administration.[2]" "Agriculture in Africa has a massive social and economic footprint. More than 60 percent of the population of sub-Saharan Africa is smallholder farmers, and about 23 percent of sub-Saharan Africa's GDP comes from agriculture[3]." A business as usual approach will result in further expansion of food insecurity, as Africa is projected lead the world with the most considerable population growth according to Pew Research. The advent of COVID-19, in addition to the invasion by locusts, is threatening to exacerbate the issue of food insecurity, mainly since the second wave of locusts are occurring during the beginning of the planting season. Expanding digital innovations into the agricultural sector will transform rural Africa while tackling other emerging challenges in Africa, from unemployment, especially the youth groups, and the need for further economic growth.

[2] Brookings, 2018, New Frontiers in Africa's digital potential, Chapter 5
[3] McKinsey & Company, February 15, 2019 Winning in Africa's agricultural market.

References

International Food Policy Research Institute. 2020. 2020 Global Food Policy Report: Building Inclusive Food Systems. Washington, DC: International Food Policy Research Institute. https://doi.org/10.2499/9780896293670

Kosec, K., and L. Wantchekon. 2020. "Can Information Improve Rural Governance and Service Delivery?" World Development 125

Atalay, E., A. Hortacsu, J. Roberts, and C. Syverson. 2011. "Network Structure of Production." Proceedings of the National Academy of Sciences, 201015564.

Banerjee, A., A. G. Chandrasekhar, E. Duflo, and M. O. Jackson. 2014. "Gossip: Identifying Central Individuals in a Social Network." National Bureau of Economic Research.

Bonacich, P., 1972. "Factoring and Weighting Approaches to Status Scores and Clique Identification." Journal of Mathematical Sociology 2 (1): 113–20.

———. 1987. "Power and Centrality: A Family of Measures." American Journal of Sociology 92 (5): 1170–82.

Gould, P. R., 1967. "On the Geographical Interpretation of Eigenvalues." Transactions of the Institute of British Geographers, 53–86.

Katz, L., 1953. "A New Status Index Derived from Sociometric Analysis." Psychometrika 18 (1): 39–43.

de Paula, A., 2016. Econometrics of network models, No CWP06/16, CeMMAP working papers, Centre for Microdata Methods and Practice, Institute for Fiscal Studies.

Trendov, N.M., Varas, S. and M. Zeng. 2018. Digital Technologies In Agriculture And Rural Areas. Briefing Paper. Rome: FAO.

Swinton, S.M. and J. Lowenberg-DeBoer. 1998. Evaluating the profitability of site-specific Farming. J. Prod. Agric. 11(4): 439-46.

Lowenberg-DeBoer, J. and B. Erickson. 2019. Setting the Record Straight on Precision Agriculture Adoption. Agron. J. 111:1552-1569.

Lowenberg-DeBoer, J. and B. Erickson. 2019. Setting the Record Straight on Precision Agriculture Adoption. Agronomy Journal, 111(4): 1552-1569.