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Design Science Information System Framework for Managing the Articulations of Digital Agroecosystems

Shastri L Nimmagadda[a]*, Amboge Samson[b], Neel Mani[c] and Torsten Reiners[d]

[a, b, d]*School of Management, Curtin University, Perth, WA, Australia*
[c]*Amity Institute of Information Technology, Amity University, Noida, New Delhi, India*

Abstract

Agriculture industries and their business ecosystems experience data and information overload because of complex network or interconnected domains linked to a variety of agro-based systems. Data search becomes tedious when specific queries are made to support crucial technical and financial decisions by agroecosystem service providers. Due to accumulated volumes of heterogeneous data and information in multiple primary sources, websites and company servers, the agriculture industry needs a robust and flexible digital agroecosystem development. To address the major challenges, a Design Science Research (DSR) approach is adopted, articulating systematic data mapping workflows and integrating their data structures in different knowledge domains. Purpose of the research is aimed at designing and developing an ontology-based data warehousing framework, with comprehensive multidimensional ontologies that motivated us to present various data modelling architectures in different knowledge-based domain applications. An emphasis is given to spatial-temporal dimensions in the modelling process that affect the structuring of data relationships in large geographic regions, which are typical in the agro-business environment.

Keywords: Design Science Research; Information System; Data Artefacts; Digital Agroecosystems

1. Introduction

The rice and wheat products are basic and essential commodities to 50 percent of the world population living in China, India and many 3rd world developing countries. Many countries that use mechanized farming practices are unable to cope up with increasing costs of farming and meet demands of agriculture production in particular in

*Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000 .
E-mail address: shastri.nimmagadda@curtin.edu.au

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populous countries. Multiple domains are involved in farming and production entities and activities. Inferior quality seeds and uneven distribution are other challenges of growth of crop production.

With the rise in population and urbanization, the demand for food production has increased quite substantially. With the result, an enormous growth of data sources has taken place in different domains. Large volumes and varieties of data sources do exist in multiple dimensions and domains of the agriculture industry and its related businesses. The data are in Big Data scale, weighing its gauge in latitude and longitude dimensions including with periodic attributes. Energy use in fertilizer industries, seeds supply and distribution, crop and food production, and improved yields in healthy soil are characteristic data attributes in diverse agro-based entities. The land topography, use and soil composition are additional dimensions of the agroecosystems. The entities and dimensions exhibit heterogeneity and multidimensionality in their habitat like any other ecosystem contexts.

The parametric-based agroecosystems and supply chain ecosystems constantly change their dimensions and it is challenging to search for information and share knowledge among multiple stakeholders and agro researchers. We use the secondary data sources, available in world data bank web sites [22] for empirical modelling and qualitative and quantitative analysis. A comprehensive and holistic methodological framework is necessary and we propose an ontology-based multidimensional warehouse repository, where unified metadata is made available to agroecosystem service providers. The metadata is a representative depository of data in new knowledge domains of agro - supply chain ecosystems**.**

The rest of the article is organized as follows. A literature review is done as discussed in Section 2, identifying the research gaps. In Section 3, issues and challenges of agroecosystems in relation to other associated energy, fertilizer and food ecosystems are described. Research questions and objectives are framed in Section 4. In Section 5, the significance, motivation and research contribution are described. The methodologies are discussed in Section 6 with analysis and discussions in Section 7. Artefact evaluations are discussed in Section 8 with conclusions and future outlook in Section 9.

2. Literature Review

The purpose of the literature review is identifying the research gaps. The issues and challenges are explored associated with seed industry and its growth in the Asian contexts [18]. Productivity based indicators have been described with linked policies on seed design and its monitoring and policy reform implementations. A systematic methodology on seed management is missing in terms of including data acquisition, documentation, storage and delivery of quality information. Kansiime and Mastenbroek [7] have made a social-ecological framework that needed seed systems and their integration with other formal systems linked with farmer seed enterprises and crop adaptation practices at farm scales in Ugandan contexts in East Africa. Though increased productivity and seed saving have been observed from the research, the data connectivity challenges between systems have not been addressed. Coomes et al. [3] identify common misapprehensions on farmer networks and their connectivity with seed systems. They suggest novel seed networks inform agriculture better and reflect the food policies in Africa, Europe and Latin American contexts. Arunyawat and Shresta [1] analyze land use ecosystem services and trade-offs to map and quantify set of ecosystem services such as sediment retention, water yield, carbon stock and habitat quality in northern Thailand to assess overall land use impact on ecosystem services using GIS. Kruize et al. [8] develop reference farm system architecture to map, assess design and implement farm software ecosystems. The key feature of the architecture is configuring and connecting ICT components from multiple vendors in feasible and coherent way to have seamless data exchange and active interoperability to make the architecture application work in a variety of farming challenges. The data integration, interoperability, use and reuse challenges of data architectures are unresolved. Barmpounakis et al. [2] explore eManagement and internet applications in agriculture domains including B to B collaborations and opportunities bringing business processes of multiple business entities together. Paraforos et al. [16] develop a Framing Management Information System (FMIS) using mobile devices focusing on financial transactions with the capability of profitability analysis. Lokers et al. [10] present a theoretical framework to structure and analyze data intensive case studies using Big Data tools and technologies addressing the heterogeneity of data, with an aim to build trust between data providers and data users using semantic technologies. Grady et al. [5] make farm development models and their implementation challenges in different agriculture domains. Wolfert et al. [21] have reviewed a number of case studies on articulations of Big Data tools in agriculture systems for smart farming for predictive interpretations in real-time operations, redesign business processes and models to meet demanding supply chain networks. Hira and Deshpande [6] have used multidimensional modelling approach with statistical mining of agriculture parameters. The authors have carried out association rule mining and business intelligence approaches to assimilate relationships among various agriculture-related data sources and their domains. In the current research, we adopt a new version of Design Science Information System for managing the articulations of the digital agroecosystems.

3. Issues and Challenges

We are not sure of any shortfalls manifested during energy creation, fertilizer production and in making agriculture products for mass populations. Helping farmers with forecasts of energy supplies and their management have not been the focus. Critical information regarding crop diseases, quality produce, and their open or shared historical data can provide useful information solutions related to energy, agriculture and food systems in such hierarchies [11, 12]. Using the existing open data sources in multiple domains and systems and bringing them in a unified digital ecosystem is challenging. The data usage and storage can bring diverse users or various agencies together aligning multiple domains in industrial sectors, minimizing interpretation of facts or instances of agro-based business systems. Data sharing among multiple users can increase the transparency with increasing accountability including successful implementations of artefacts and integrated workflows in agriculture domains. The users are typically agro researchers, project implementers, policymakers including farmers. Bringing domain experts into the agriculture business and typically aligning or integrating the businesses with new tools and technologies are needed. New data collection and data storage facilities are added motivations. Mostly, the farmers and farming communities are from an illiterate background, and they need to look beyond the tools and technologies with the accessibility of data and knowledge of interrelated domains and systems with cross-sector collaborations and scopes [15]. Disaggregation of volumes and varieties of data into categories or classifications in fine-grain data structuring contexts including denormalization of models can facilitate the digital agroecosystem developers to build smart constructs and models in a multidimensional integrated framework.

Accurate crop predictions and productions, data analytics may allow the farmers to harvest the crops in optimum time periods so as to produce maximum with minimum worry. Massive famine and risk of starvation areas may need new tools and technologies with chemically engineered quality seeds that may suit to soils are alternate healthy solutions. Automation in farming and precision agriculture, environment awareness need attention for which, the collaborations of manufacturing, energy and transport industries may not be underestimated. In recent years, the role of Big Data and analytics has been an increasing trend to pursue issues the challenges of digital agroecosystems [19].

4. Research Questions and Objectives

Based on the introduction, literature review and issues and challenges, research gaps have been identified and examined keeping in view the current contexts. A couple of research questions is designed: (1) what is the necessity of connecting multiple domains and systems through integrated methodologies; (2) how do we evaluate the integrated framework articulations in terms of data accessibility and information sharing. The objectives are: (1) build constructs and models for integration and align the agro business domains and systems (2) perform data and business analytics and evaluate the artefact articulations of the framework.

5. Motivation, Significance and Contribution

A concept of the digital ecosystem [15] is developed using an integrated workflow, considering system frameworks. An ontology-based data warehouse, as part of the framework is expected to provide a mechanism for delivering comprehensive, consistent and flexible agro data structures. Other objectives are to develop mining models, aimed at providing infrastructure for extracting vital information from warehouses within short periods of time and interpret the agro-knowledge in new domains. The proposed methodology, under the guidelines of Design Science Research (DSR) is expected to deliver agro-ecosystem bearing information solutions with data interpretation, knowledge discovery and operational decision-making, especially in integrated agribusiness environments.

The conceptualized and contextualized attribute articulations are needed for making the digital agro- based supply chain ecosystems [14]. Different artefacts articulated in an integrated framework can bring together the data sources of agro-industry. Data mining and visualization tools needed to interpret the metadata views in new knowledge domains have scopes in revealing new meta-knowledge management. A schematic view of the agro-ecosystem strategy is described in Fig.1, demonstrating various entities and dimensions and with characteristics of predictable connectivity challenges between agroecosystem and its linked supply chain ecosystems.

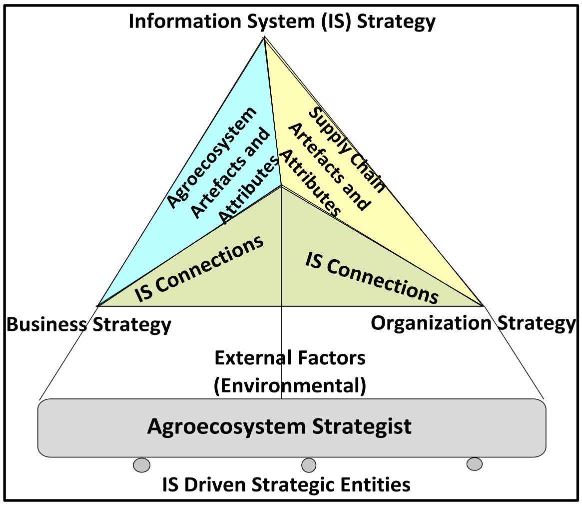

Fig. 1. IS/IT guided agroecosystem strategies

6. Methodology

To establish the connectivity, we take the help of various artefacts associated with multiple supply chains, which are geographically located and periodically identified. Where the distribution of seeds matters in the agroecosystem, the connectivity can be explored using Big Data sources and through description of their ontologies as illustrated in a schematic view in Fig. 2. They are corroborated with the dimensions of elements and processes of supply chain systems. The connectivity is explored between multiple attribute dimensions of supply chain systems with the other agroecosystems, such as GM crops and foods, soil testing, fertilizer usage, and investments and finance. Weed control, grain qualities, harvesting and pest control, are other challenges may be incorporated while addressing the design considerations of articulations in diverse agroecosystem scenarios.

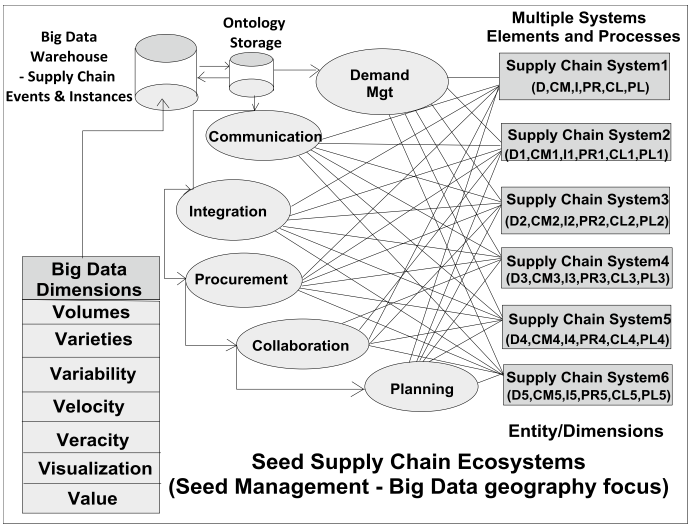

Fig. 2. Establishing connectivity between agro product suppliers through supply chain ecosystems

The entity relationship, multidimensional data relationship and object-oriented data models, are constructed as sets of artefacts or constructs, representing the semantics of agriculture data. Similar constructs are used to build and evaluate models in multiple domain applications within the agro-based seed industry. As a follow-up of guidelines of design science information systems research, an integrated framework is generalized for its implementation in multiple domain applications [14, 15]. These innovations define the designs, practices, technical capabilities and products through which the analysis, implementation and use of Information Systems (IS) can effectively be accomplished. As identified in [17], the design processes and artefacts are evaluated analysing the IS challenges and solutions. We aim at a research framework as described in Fig. 3, focusing on research activities and research outcomes in the agroecosystem contexts.

Different data sources are presented in multidimensional data models that may characterise in new knowledge domains. A model is a set of propositions or statements expressing relationships among constructs [20]. In design activities, models represent situations as problem and solution statements. The ER, EER, MR and MMR are set of constructs of data modelling formalism (Fig. 3). A model is merely viewed as description and or graphical representation of how entities, objects and dimensions are presented and related each other in the modelling process. The semantic-based data models are useful for designing information systems. Entities, objects and dimensions ensure their usefulness in the modelling process while representing and communicating with information system requirements.

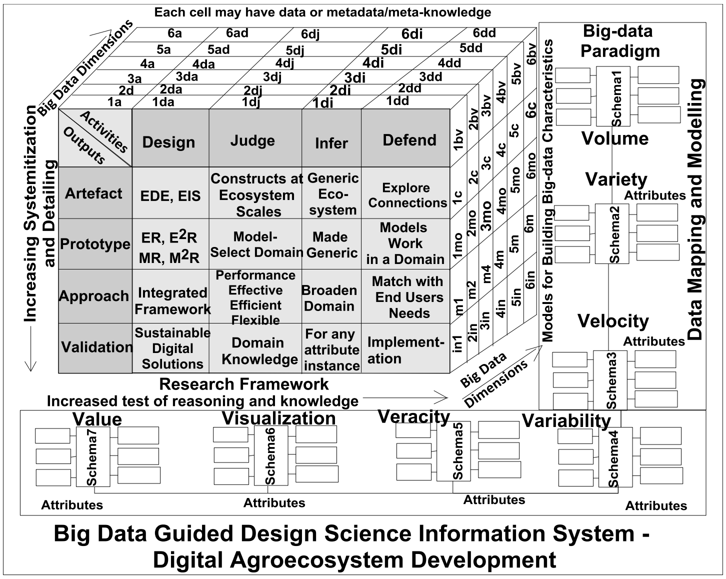

Fig. 3. Big data guided Design Science articulations of Agroecosystem

A method is a set of steps (an algorithm or guideline) used to perform a task. Techniques are based on a set of underlying constructs (language) and a representation (model) of the solution space [9, 13]. Although they may not be explicitly articulated, descriptions of tasks and results are intrinsic to methods. Methods can be tied to particular models in that the steps take parts of the model as input. Further, methods are often used to translate from one model or representation to another in the course of solving a problem. Data structures are stored, consolidating the image of computer memory with algorithms and retrieving data for processing and data mining. The problem statement specifies the existing stored data and the data to be stored or retrieved. The method (algorithm) transforms this into a new specification of stored data (storage) or returns the requested data (retrieval). Many algorithms use tree-structured constructs to model the problem and its solution.

System development methods [9] facilitate the construction of a representation of user needs (expressed, for example, as problems, decisions, critical success factors, and socio-technical and implementation factors). They further facilitate the transformation of user needs into system requirements (expressed in semantic data models, behaviour models, process flow models) and then into system specifications (expressed in database schemas, software modules), and finally into an implementation (shown in physical data structures, programming language statements). These are further transformed into machine language instructions and bits stored on disks. Design science creates the methodological tools that natural scientists use. Research methodologies prescribe appropriate ways to gather and analyse evidence to support (or refute) a posited theory [9, 13].

Validation is the realization of an artefact in an environment, substantiating its viability in the application domain. Based on secondary data the models are tested and implemented in commercial organizations. IT research instantiates both specific information systems and tools that address various aspects of designing information systems. Instantiations operationalize constructs, models, and methods. However, an instantiation precedes the complete articulation of its underlying constructs, models, and methods. That is, an IT system may be instantiated out of necessity, using intuition and experience. Only as it is studied and used, are we able to formalize the constructs, models, and methods, based on which they are designed?

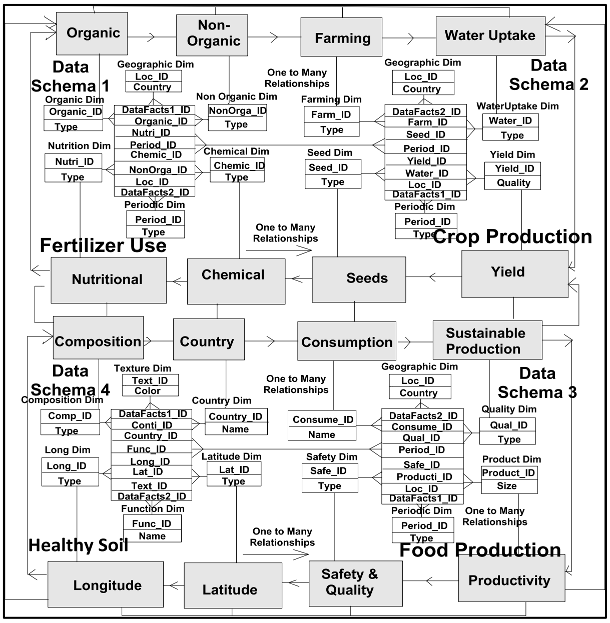

Fig. 4. Schema design, making connections between various entities

Different data schemas are constructed for different entities of the agro-industry. As shown in Fig. 4, four schemas are designed for different entities. At physical data modelling stage, several dimension and fact tables are created with attributes and instances for exploring connectivity between multiple entities. The connectivity between domains and systems can be established between "Healthy Soil", "Food Production", "Crop Production" and "Fertiliser Use" entities or dimensions. Building ontology-based data warehouse, resolving the semantics, schematic, syntactic and system heterogeneities attributed by both agroecosystem and supply chain ecosystem entities and dimensions, classifying and interpreting them in several application domains are framework development objectives.

7. Analysis and Discussions

We discuss the contributions made in the research article. The constructs and models used in making the integrated framework, are evaluable in terms of their performance in multiple applications. In addition, we assess the feasibility and applicability of the methodology, implementing the framework in multiple domains of agro-industries.

Data Mining, Visualization and Interpretation: Classifying the clustered data, mining of association rules and construction of decision trees are various techniques that can support the knowledge building process in the current research contexts [6, 14]. The 2D and 3D data visualization cross plots, map views, histograms, bubble plots, scalar plots, scatterograms and plots representing statistical multi-variates and regression analysis are characteristic metadata views. The bubble plots are better ways of presenting associations between dependent or independent variables in different scalar narratives. In bubble plots, the diameter of each bubble varies in size, providing pathways to present additional dimensions in the agro-business data. The explored metadata can graphically uncover properties of the data quickly and detect any patterns and or deviations from expected results. They contribute to digital agro-ecosystems and their new knowledge interpretations in different application domains. As described in Fig. 5a, a cuboid structure enlightens the metadata linked to supply chain life cycle in which various domains and systems are brought together from multiple industries. Hierarchical ontologies is an added concept connecting diverse industrial contexts, such as energy, manufacturing, transport, fertilizers and agriculture including its associated food industry entities. The Gross Domestic Product (GDP) is an added dimension to the supply chain system, providing an economic gauge to its management. Fig. 5b is an illustration of metadata representation with a data view extracted from the cubes and they are presented in "year" and "million tonnes" attribute instances. Our research objective is to interpret several data views that can reveal new knowledge in multiple domains and systems of diverse agro-based industries.

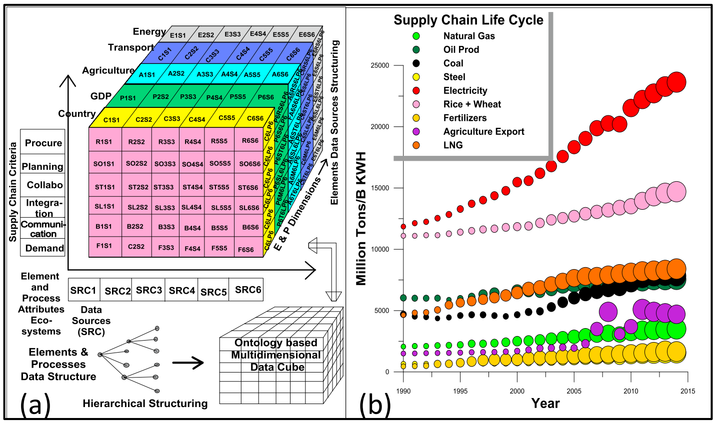

Fig. 5. Representation of data views (a) the cuboid data structure and (b) a metadata view

We further analyse the strategic ideas, such as Enabling the Business of Agriculture (EBA) and Delivering Together Facility (DTF) using multiple dimensions that led us evaluating business values from quality seeds, agriculture development and food production. Various metadata views are extracted as shown in Fig. 6. As presented in Fig. 6a, the bubble plots associated with oilseeds, seeds associated with cereals, wheat and rice, their production and distribution attributes, are made in different periodic dimensions. The plot views are drawn for different countries as exhibited in Figs. 6a and 6b.

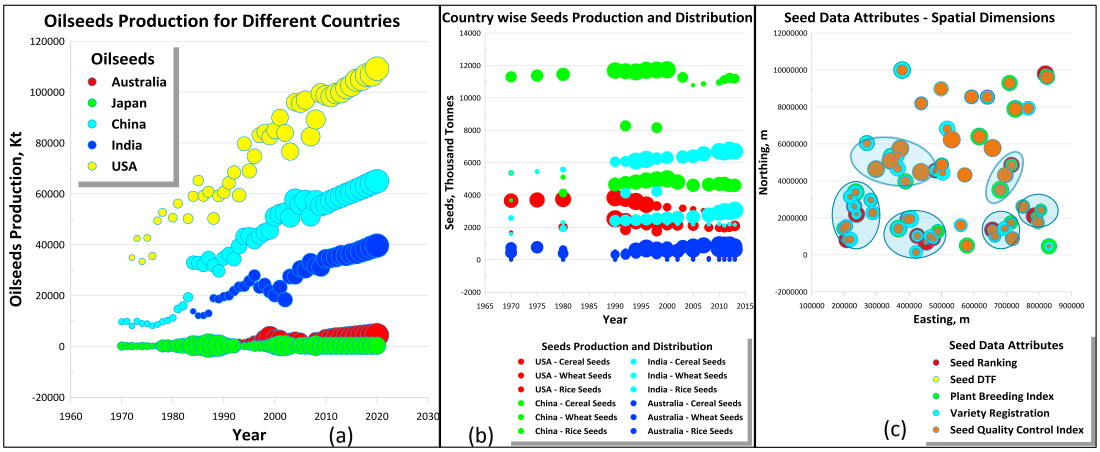

Fig. 6. Attribute data views drawn from metadata for interpretation (a) oilseeds production (b) country-wise seeds production (c) seed data attributes in spatial dimensions

As shown in Fig. 6b, we have plotted bubble plot views of fertilizers produced and consumed in various countries. The most populated and industrially developed countries, where production and consumption are more chosen in the analysis. The seed data attributes how they are distributed and connected spatially are shown in Fig. 6c. As shown in Fig. 6c, the seed ranking, seed DTF and a couple of indices linked with plant breeding and seed quality control attributes and their instances are plotted for different counties using their spatial coordinates, easting and northing dimensions. It is interesting to visualize and interpret the bubbles are either closely connected or far away disconnected as encircled in Fig. 6c that suggest the seed attribute values show similar properties in the countries, implying they geographically associated, with dissimilar properties meaning thereby attributes are far-away disconnected. We have done a similar analysis between energy use, fertiliser consumption and crop production attributes at different periodic attribute instances as shown in Fig. 7. In populous countries like China and India, with meagre energy use, there is steady growth in fertiliser and agriculture production.

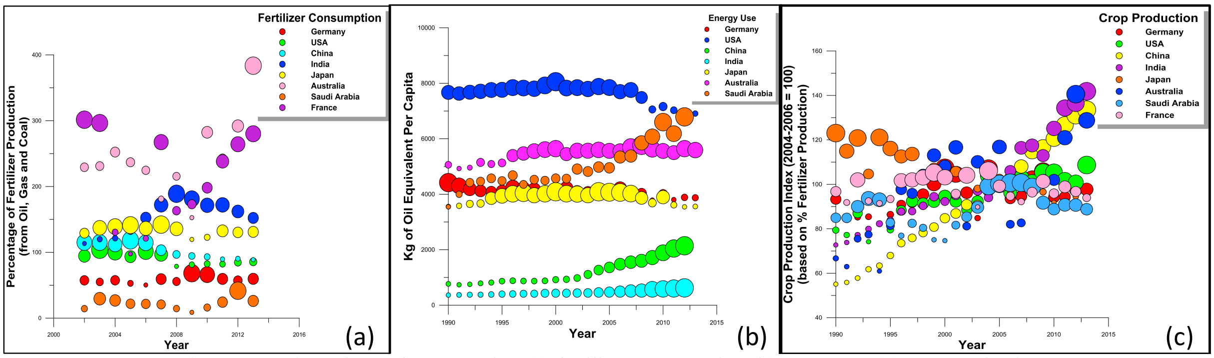

Fig. 7. Data views drawn from metadata (a) fertilizer consumption (b) energy use (c) crop production

The energy created from different oil and gas resources including coal is stable at different periods as shown in Fig. 7b. In industrial countries, such as USA, Germany, France and Japan, a substantial part of the energy is used in generating fertilizers that could boost the growth of agriculture products. Bubble plot views are plotted for crop production for different periods and countries. Crops produced in different countries are shown in Fig. 7c. Many industries in these countries use automation and new farming techniques to improve productivity with sustainable agriculture growth. Although the production instance values are steady for various historical periodic occurrences; the recent data suggest a substantial increase in crop production in many countries.

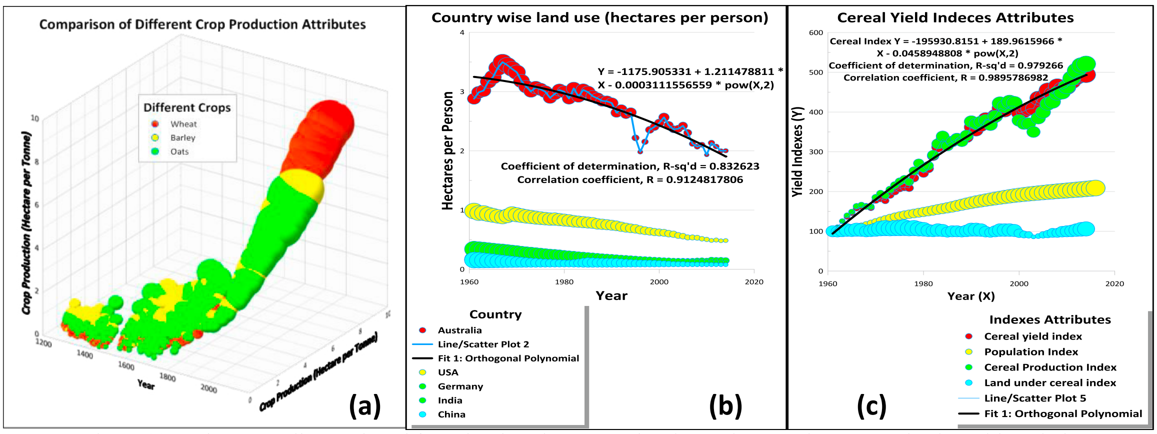

Fig. 8. (a) Cash crop attributes plotted for a developed country, showing an increase in crop production with period; Statistical mining and regression analysis done for (b) land use and (c) cereal yield attribute dimensions

A 3D Bubble plot view is extracted from metadata and it is plotted in Fig. 8a to interpret the gauge of cash crop production for a developed country at different periodic attribute instances. These bubble plots attributed to production instances are comparable with different wheat, barley and oat crops as given in [4]. As described in Figs. 8b and 8c, regression analysis is done for land use and cereal production attributes. The regression plot of land use, in terms of hectares per person, suggests more scope of farming and land use in Australian contexts. For populous and industrially developed countries the farming land is getting diminished with increase in period (Fig. 8b). We plot various indices of yield, land and population and as shown in Fig. 8c, there is substantial growth in cereal production with the period and a moderate increase in population. In both cases the correlation coefficient and coefficient of determination are strong. The results are corroborated as discussed in [18]. Interestingly, the land use attribute instance falls with the periodic attribute value. Lower land use is observed in USA, Germany and lowest in China and India, because of the increase in urbanization and deforestation. In addition to the land use, cereal yield and production indexes are analysed with their respective population indices as shown in Fig. 8c.

8. Evaluation of Framework Articulations

Several data schemas designed for the integrated business environment are flexible and adaptable in multiple domains and varying attribute scenarios. For example, as per domain knowledge of the agro-industry, the models are modifiable, considering the semantics, business rules and schematically derived attribute dimensions. Having done the design and development of data warehouse, the application is tested for research outcomes and their analysis:

- Integrated data warehouse and data mining articulations are implementable in agro-industries.
- Standardisation of artefacts and their linked data warehousing and data mining technologies can help the interoperability, saving enormous resources in the agro-based industries.
- Consistency, reliability, integrity, and quality of agro-data and information are paramount.
- The models and methods can facilitate in decision support systems for forecasting resources.

Domain ontologies in the form of constructs and models are compatible in the warehouse environment and integrate them in multiple domains to arrive at unified metadata. The data views selected for interpretation are successfully used for extracting new domain knowledge in agro-industries. The DSR articulations used in managing the digital agroecosystems, establish their feasibility and applicability. Performance of artefacts is analysed with the data size and type of structuring. In addition, the heterogeneity and multidimensionality challenges are critical in the integration process and the criticality depends on the performance of design science articulations. Interpreted data views provide useful knowledge on digital agroecosystems. Initial data gathering, design and mapping, data loading, building and testing artefacts including data warehousing are different stages of the application through which the project is successfully completed. Rollout and feedback from end users remain to be carried out, though quite good reception is expected from research communities.

9. Conclusions and Future Outlook

The issues and challenges of agro-based business information systems have been identified. In pursuance of resolving the major challenges, such as data heterogeneity, multidimensionality, their connectivity and interoperability, we have designed and developed various data artefacts to explore connections in between diverse domains and their linked agro-ecosystems. The constructs and models accommodated within the integrated framework with design science information articulations motivate us resolving data complexities. The connectivity is successfully explored using knowledge-based domain ontologies associated with large size datasets of agro-ecosystems. We have computed metadata and evaluated the integrated framework by using data mining, visualization and interpretation artefacts. Using various data analytic and graphic visualizations, we have successfully interpreted metadata views in new knowledge domains.

The constructs and models accommodated in the methodological framework continue to evolve in the agro-based ecosystems. The models deduced in various contexts relevant to crop production, fertilizer and land use, agriculture growth attributes are useful for researchers. The seed development and distribution are added dimensions in these models. The design science information system articulations could improve the efficacy of artefacts that manage the energy use, fertilizer consumption and agriculture growth with the motivation of precision agriculture. The data modelling methods, which are holistic can facilitate the outdoor applications including plant-specific direct applications (PSDA) including EBA and DTF submissions. In addition, data and agro-business analytic models demonstrate the evaluable artefacts of framework. The land use attribute and its variation is significant in bubble plot views for different countries. Our results show although significant land use adopted in many populated and developed countries, the hectare per person attribute is momentous in the case of Australia. However, yearly hectares per person have shown a strong coefficient of correlation suggesting an optimum use of agriculture land in many countries.

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References

[1] Arunyawat, S. and Shrestha, P. R. (2016) "Assessing Land Use Change and Its Impact on Ecosystem Services in Northern Thailand", Sustainability 2016, 8, 768; doi:10.3390/su8080768.
[2] Barmpounakis, S. and Kaloxylos, A., Aggelos Groumas, Lampros Katsikas, Vasileios Sarris, Konstantina Dimtsa, Fabiana Fournier, Eleni Antoniou, Nancy Alonistioti, Sjaak Wolfert, (2015) "Management and control applications in Agriculture domain via a Future Internet Businessto- Business platform Information Processing in Agriculture 2 (2015) 51–63.
[3] Coomes, O. T., Shawn J. McGuire, Eric Garine, Sophie Caillon, Doyle McKey, Elise Demeulenaere, Devra Jarvis, Guntra Aistara, Adeline Barnaud, Clouvel, P. Laure Emperaire, Sélim Louafim, Pierre Martin, François Massol, Marco Pautasso, Chloé Violon, Jean Wencélius, (2015) "Farmer seed networks make a limited contribution to agriculture? Four common misconceptions," Food Policy, Food Policy 56 (2015) 41–50.
[4] Diekotter, T., Wamser, S., Wolters, V. and Birkhofer, K. (2010) "Landscape and management effects on structure and function of soil arthropod communities in winter wheat," Agriculture, Ecosystems & Environment, 137(1), pp.108-112.
[5] Grady, M. J.O. and O'Hare, G. M. P. (2017) "Modelling the smart farm," Information Processing in Agriculture 4 (2017), 179–187.
[6] Hira, S. and Deshpande, P. S. (2015) "Data Analysis using Multidimensional Modelling", Statistical Analysis and Data Mining on Agriculture Parameters, Eleventh International Multi-Conference on Information Processing-2015 (IMCIP-2015), Procedia Computer Science 54 (2015) 431 – 439.
[7] Kansiime, M. K. and Mastenbroek, A. (2016) "Enhancing resilience of farmer seed system to climate-induced stresses: Insights from a case study in West Nile region, Uganda," Journal of Rural Studies, 47 (2016) 220-230, Elsevier, USA.
[8] Kruize, J. W., Wolfert, J., Scholten, H., Verdouw, C. N., Kassahun, A. and Beulens, A. J. M. (2016) "A reference architecture for Farm Software Ecosystems," Computers and Electronics in Agriculture, Computers and Electronics in Agriculture 125 (2016) 12–28.
[9] Kuechler, W. and Vaishnavi, V. K. (2008) "The emergence of design research in information systems in North America," J of Design Research, 7(1):1--16 · January 2008, DOI: 10.1504/JDR.2008.019897.
[10] Lokers, R., Knapen, R., Janssen, S., Randen, Y. V. (2016) "Jacques Jansen Analysis of Big Data technologies for use in agro-environmental science," Environmental Modelling & Software, Environmental Modelling & Software 84 (2016) 494-504.
[11] Mader V, Birkhofer K, Fiedler D, Thorn S, Wolters V, Diehl E. (2016) "Land use at different spatial scales alters the functional role of web-building spiders in arthropod food webs," Agriculture, Ecosystems and Environment 219: 152-162.
[12] Mansoor, D.K.L. Marty, D.M. Eric, C.C. Lanier, L.N. (2013) "Quantifying and mapping multiple ecosystem services change in West Africa.," Agric. Ecosyst. Environ. 2013, 165, 6–18.
[13] Neuman, W. L. (2000) "Social research methods qualitative and quantitative approaches", 4th Edition, Allyn & Bacon, Needham Heights.
[14] Nimmagadda, S.L., Mani, N. and Reiners, T. (2018) On Knowledge-Based Design Science Information System (DSIS) for Managing the Unconventional Digital Petroleum Ecosystems, *KES IDT International*, Gold Coast, Australia.
[15] Nimmagadda, S.L. (2015) "Data Warehousing for Mining of Heterogeneous and Multidimensional Data Sources," Verlag Publisher, Scholar Press, OmniScriptum GMBH & CO. KG, p. 1-657, Germany.
[16] Paraforos, D. S., Vangelis Vassiliadis, Dietrich Kortenbruck, Kostas Stamkopoulos, Vasileios Ziogas, Athanasios A. Sapounas, Hans W. Griepentrog, (2016) "A Farm Management Information System using Future Internet Technologies", IFAC-Papers On Line 49-16 (2016) 324–329, Seattle, WA, USA.
[17] Ploesser, K. (2012) "A Design Theory For Context-Aware Information Systems Improving IS Design Science Outcomes Through Theory-Driven Design", Thesis Doctor Philosophy, Queensland University of Technology, Australia.
[18] Roser, M. and Ritchie, H. (2019) "Yields and Land Use in Agriculture". *Published online at OurWorldInData.org*. Retrieved from: 'https://ourworldindata.org/yields-and-land-use-in-agriculture' [Online Resource].
[19] Spielman, D. J. and Kennedy, A. (2016) "Towards better metrics and policymaking for seed system development: Insights from Asia's seed industry", Agricultural Systems 147 (2016) 111–122, Elsevier and Science Direct, USA.
[20] Venable, J., Pries-Heje, J., Baskerville, R. (2016) "FEDS: a Framework for Evaluation in Design Science Research", Eur. J Inf. Syst. 2016. 25: 77, https://doi.org/10.1057/ejis.2014.36.
[21] Wolfert, S., Lan Ge, Verdouwa, C., Bogaardt, M. J. (2017) "Big Data in Smart Farming – A review, Agricultural Systems", Agricultural Systems 153 (2017) 69–80.
[22] Websites consulted for data sources:
1. https://www.worldseed.org/resources/seed-statistics/
2. https://data.worldbank.org/indicator/
3. https://data.worldbank.org/indicator/TX.VAL.MMTL.ZS.UN?view=chart
4. https://data.worldbank.org/topic/infrastructure
5. https://ourworldindata.org/fertilizer-and-pesticides