PEER REVIEWED

Precision Livestock Farming Ecosystems: A Synthesis of Technology, Process and Culture

"The proof of a system's value is its existence."

Alan Perlis[1]

Business Ecosystems: A Context

Each precision livestock farming (PLF) technology generally has value potential in its own right for any given farm site, and thus can be evaluated to a degree in a similar manner as other products/services have always been, and continue to be today. However, the greatest value of each PLF technology is not realised one technology at a time in isolation. Even though the technologies themselves are designed, built and operate as individually intended, their greatest value will come from the broad adoption of the ecosystem that they are each a part of – an ecosystem made up of multiple technologies synthesised into a cohesive, interconnected whole.

Sir Arthur Tansley, a British botanist, introduced the term 'ecosystem' in 1935 to describe what he referred to as 'the basic units of nature' – a community of organisms interacting with each other and their mutual environments.[2] In a 1993 Harvard Business Review article,[3] James F. Moore, an organisational researcher at Harvard University, adapted the biological ecosystem model to a business context – coining the term 'business ecosystem', and defining it as:

"An economic community supported by a foundation of interacting organisations and individuals—the organisms of the business world. The economic community produces goods and services of value to customers, who are themselves members of the ecosystem. The member organisms also include suppliers, lead producers, competitors, and other stakeholders. Over time, they coevolve their capabilities and roles, and tend to align themselves with the directions set by one or more central companies. Those companies holding leadership roles may change over time, but the function of ecosystem leader is valued by the community because it enables members to move toward shared visions to align their investments, and to find mutually supportive roles."[3]

A business ecosystem has also been defined as:

"An adaptive network of interdependent entities that grows by developing and maintaining innovative solutions and technologies through collaboration and coordination."[4]

In 1996, Moore further outlined his business ecosystem thesis and its impact on the structure of the value chain – in particular the importance of an interdependent community of collaborative partnerships and deeper customer engagement.[5] Within market spaces where business ecosystems operate, the nature of innovation and the nature of competition change in profound ways.[3,4,5,6]

Whether we are engaged with agriculture and crop/livestock production or not, business ecosystems we are familiar with and live our personal and professional lives within are (to name a few) Apple, Amazon, eBay, Facebook, Google, Intel, Microsoft, Netflix, Samsung, Uber and Wal-Mart. We engage these ecosystems every time we pick up our phones, turn on our computers, sit in front of our televisions, enter our homes and walk out of our front doors. These business ecosystems have been created and have been continuously evolving for at least the past two decades.

More recently within agriculture, a pioneer in the pursuit of precision farming and the development of an agribusiness ecosystem is the farm equipment manufacturer, John Deere.[7,8,9,10,11,12,13] In contrast, for livestock and protein production there are now a growing number of available PLF technologies and digital platforms and many more are on the way, but there are yet to emerge substantive PLF ecosystems within which these many technologies operate.

This is about to change, as current PLF technologies and digital platforms connect and integrate – moving from simple monolithic systems towards integration and formation of a more complex system of systems. It is from this "primordial systems soup" that we will see the emergence of the first PLF ecosystems. Many PLF technologies and a number of PLF ecosystems will spring to life – some will fail, others will become viable but remain limited in their reach, and yet others will grow and expand – such is the nature of all ecosystems within any environment, be they biological, mechanical, digital or a combination.

The "Brave New World" for Livestock and Protein Production

There are three primary elements to a strategic framework for all ecosystems that integrate and connect cyber-physical systems within any business environment:

- Technology
- Process
- Culture

For all businesses and commercial operations that operate within each business environment, people are the drivers, technologies are the vehicles and processes are the roadways.

The strategic framework for PLF ecosystems in livestock and protein production is no different – the same three primary elements and strategic framework for all PLF ecosystems integrating and connecting PLF technologies within a livestock and protein production environment apply.

Technology

Analogising technologies as vehicles – there are many different kinds of vehicles designed and built to serve many different functions: some are faster than others, some are stronger than others, some are more expensive than others, some are safer than others, some are better built and longer-lasting than others... but all are tools that have particular purposes and use cases that they support.

When it comes to all global livestock industries, we need far better tools and methods (*i.e.*, vehicles) to enable:

- faster, better informed local farm decision-making for business operations
- better informed overall business decision-making for business management and leadership
- faster, more seamless multi-business data and information-sharing for industry-scale decision-making

Technology holds the potential to become these better vehicles. Technology is, in effect, the virtual lens though which we can see what is happening within our operational environment – simultaneously serving as both a microscope and telescope, enabling us to more clearly see the granular detail and the big picture. Technology is the means by which we complement and contrast our own observational capabilities – what we see, hear, touch, smell, taste and intuitively sense. Technology serves a role as a virtual advisory board – looking at our environment in different (broader, deeper, more continuous) ways than we can as sensing individuals, and giving us an improved perspective (either confirmation of our thinking or a needed reality check) upon which to base decisions and confident action.

In the process of leveraging technology vehicles/tools, data is the raw material, information is the product, knowledge is the currency and decisions are the value.

Process

To effectively utilise our available vehicles, we must have a system of navigable highways and roadways. Processes are the highway/roadway system upon which we drive our technology. Some roads are better than others – be they paths or trails, unmaintained dirt roads, low maintenance gravel roads, two-lane or four-lane highways, or highly maintained interstate systems. In business, processes serve the critical purpose of guiding where personnel are going, defining what technologies they need to get there and providing a clear and efficient route along the way. Processes vary widely in terms of their quality and clarity – some are rudimentary and difficult to follow, others can be followed but marginally so, yet others are well-marked and readily navigable.

Processes within business ecosystems provide the roadmap – a model, if you will – with which to navigate both the physical and digital waypoints and destinations of business operations. The processes of PLF ecosystems in livestock and protein production operations are no different – aggregated and interconnected within the structure of an overall model.

PLF Ecosystems: A Basic Model

A broad and robust PLF ecosystem will be comprised of five fundamental elements:

- Genetics (inherent genetic potential and phenotypic expression)
- Nutrition (nutrient quality, diet formulation and diet handling)
- Environment (internal environment quality and external environment influence)
- Management (processes, protocols and personnel)
- Health – disease (inherent virulence and nature of exposure)

For livestock and protein production industries, these five elements cover the entirety of what drives all live production operational models – effectively, there is nothing that occurs in live operations that does not fit into one or more of these five fundamental elements. Each element is inextricably connected to and integrated with the others – genetics influences the response to nutrition, environment influences the expression of genetics, management influences the level of health (impact of disease), and disease affects nutritional requirements.

To be optimally comprehensive and robust, a PLF ecosystem must ultimately encompass all of these same five elements into its structure and account for the synthesis of every combination within and between each livestock species (Figure 1).

Within live operations is a continuously cycling process of measurement (diagnose and monitor), analysis (analyse and predict) and intervention (preemptive prevention

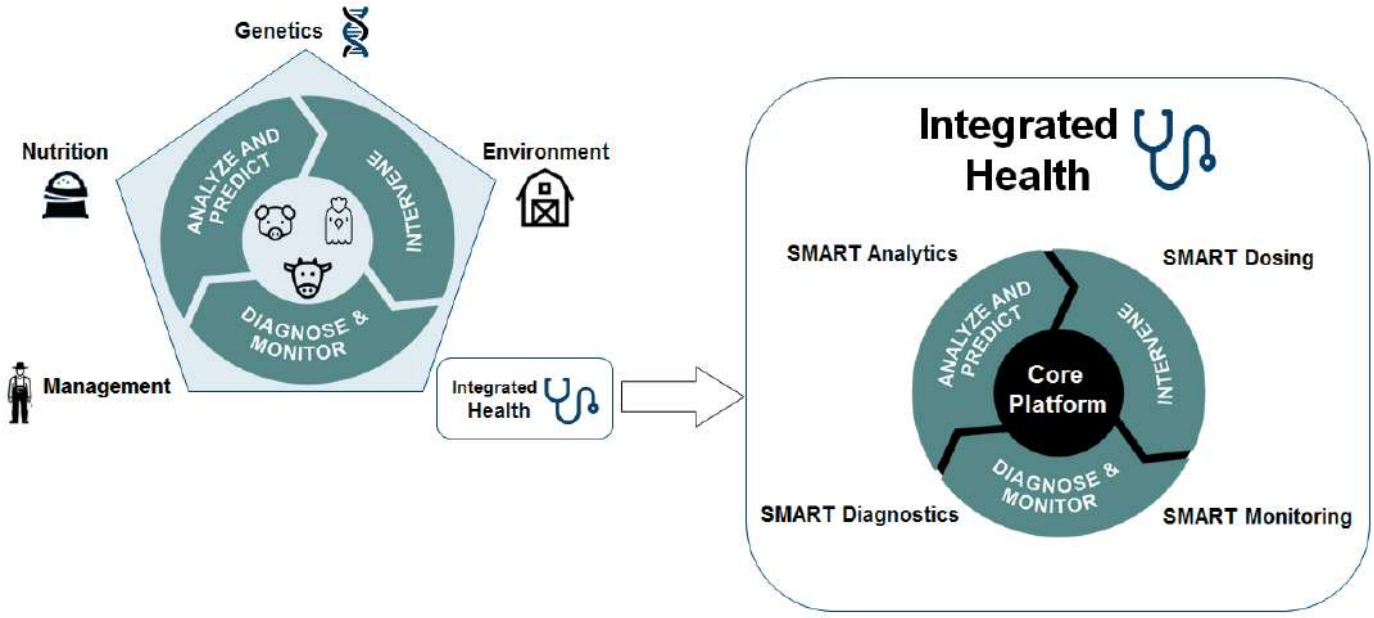

Figure 1: The five fundamental elements of a PLF ecosystem for livestock production live operations, and basic construct of an integrated health sub-system.

and contingent treatment). A robust PLF ecosystem will incorporate technologies that can measure all of the key operational drivers, analyse the optimal aggregate of measures, deliver decision-ready information to decision-makers and provide effective intervention delivery.

PLF Ecosystems: The Role of Technology

A robust PLF ecosystem must be composed of technologies fitting into seven fundamental categories, all connected to and interconnected through a core digital platform (Figure 2).

Figure 2: The seven fundamental PLF ecosystem technology categories.

Smart identification and tracking include technologies to:

- Identify and record movements of individual animals and cohorts of animals – within farms, buildings, rooms and pens; as well as between farms and operational sites (e.g., trailer loads of weaned animals, replacement animals or market animals)
- Define physical locations/zones (e.g., pens, rooms, barns, sites)
- Identify and capture movement of physical assets (e.g., feed carts, processing carts, power washers, semen coolers, trucks, livestock trailers, feed trucks)
- Identify and record movements of personnel (e.g., animal care personnel, truck drivers, maintenance personnel, management staff)

Smart sensing, detection and measurement include technologies to record data on:

- Internal environmental conditions and quality (e.g., temperature, humidity, light, barometric pressure, air movement, airborne particulates, volatile organic compounds)
- Feed and water usage (disappearance, waste, consumption)
- Personnel observations (mortality counts, treatment counts, clinical disease symptoms, images, video, audio, notable events)
- Animal behaviour and clinical symptoms (feeding, drinking, activity, movement, aggression, lethargy, coughing)
- Asset locations and usage
- Personnel locations and activity
- Equipment operation and performance
- Animal, feed, water, surface and airborne organism diagnostic detection, quantification and characterisation

Smart dosing includes technologies to:

- Deliver doses (e.g., vaccines, medications) automatically or with user-operated powered devices
- Identify animal(s) receiving doses
- Identify dosed material being delivered
- Record dosed material characteristics (temperature, pH, optical density)
- Record dose delivery events, volumes and administration route accuracy
- Enable real-time input inventory management

Communication and connection include technologies to:

- Ensure reliable internet connectivity and sufficient capacity at an acceptable cost for all physical locations, mobile assets and personnel
- Support continuous, real-time transmission of all sensor data
- Facilitate remote communication among personnel within sites, throughout production systems and across advisory and support networks
- Enable real-time streaming of audio, image and video to better leverage specialised personnel (e.g., veterinarians, nutritionists, engineers, production supervisors, senior management and leadership)

Human resources and culture technologies to:

- Increase personnel efficiency and effectiveness
- Improve teamwork and collaboration
- Support positive and desirable behaviours
- Enable improved recruiting and retention

Data management and analysis platforms designed to:

- Simply and conveniently capture, process, move and store data
- Provide alerts and notifications to enable focus and timely action
- Provide intelligent dashboards and visualisations to support informed decision-making

Analytics and intelligent decision support for:

- A data structure that facilitates synthesis of all relevant data streams
- An ongoing cycle of algorithm development and improvement
- Continuously generating decision-ready actionable information in real time

All technologies that make up a PLF ecosystem have one overriding purpose: to support and optimise decision-making at all operational levels – department, farm site, flow, business, region and network. It is through improved (faster, more confident, less costly, more profitable, more responsible) decision-making that better business results are obtained and better living can be enjoyed – better decisions, better business, better lives.

Towards Industry Transformation: The Requisite Culture

"Innovation is hard because 'solving problems people didn't know they had' and 'building something no one needs' look identical at first."

Aaron Levie[14]

Beyond the structural needs, an even greater challenge lies with the behavioural/cultural changes necessary for squeezing the greatest value out of emerging PLF technologies.

A New Industry Cultural Mindset

Livestock producers and veterinarians are very used to a model of product/service assimilation where research and development as well as hypothesis testing are done elsewhere, inside of the organisational black boxes of their product and technology providers, then the products/services or learnings are brought to them generally "fully baked" and ready to plug into an existing operational structure. Yes, producers and veterinarians participate in field trials and projects to evaluate under their particular conditions the performance of new (and new to them) products/services, but all of this is done within a legacy operational structure and cultural environment where the capabilities of these new products/services are already relatively determined inside of the provider's black box.

Livestock production businesses are much less (or not at all) used to being participants in the earlier development phases of technologies – even more so the case for technologies whose value is not realised until there is relatively broad spatial and operational network adoption. One of the shifts in behavioural/cultural mindset needed to get the most sustainable value out of PLF technologies and a PLF ecosystem it operates within is a transformation into a willingness (if not even an eagerness) to engage PLF companies and their developing technologies early – in the development phase.

A New Business Cultural Mindset

Business operational decision-making is a dynamic and often uneasy combination of objectivity and subjectivity, of data and feeling, of science and intuition. The relationship between science and business is all too often a rocky one, but that is changing.[15] It is clear that high-quality science can support better decision-making:

- through developing better ways to measure
- by developing better ways to analyse
- by providing more confidence in interpretation

However, for science to be most valuable in a business operations context we need to expand our view of the scope of science.

Let's consider two complementary forms of science:

- Institutional-rooted science
- Industrial-scale science

Institutional-rooted science is science that utilises classic methods of design, data acquisition and statistical analysis. Institutional science has and continues to make very valuable contributions to its business and professional constituencies, but institutional science has limitations. Institutional science can tell businesses:

- What *has* happened (retrospective, observational)
- What *may* happen, given a specific and defined condition set (experimental)

But for businesses running production operations every minute of every day, that is not enough to be most effective and maximise sustainable potential in the long run.

We need to complement institutional (static) science with industrial (dynamic) science – science that can tell us what *does* happen, every time it happens, when it happens, that helps us understand why it happens, and what we can do about it. We need industrial science that projects/predicts what is *probable* to happen if we continue operating the same way we have been, and help us dynamically identify what to change (for the better) in what we're doing, and tell us what that is actually worth to our business.

The technologies of precision livestock farming, particularly when interconnected and synthesised into an ecosystem structure, are precisely what will help deliver the kind of industrial science that businesses and entire industries need and will find valuable on a sustainably continuous basis.

To Conclude…

"The future has already arrived. It's just not evenly distributed."

William Gibson[16]

The potential of precision livestock farming technologies is clear. The PLF global market in 2015 was estimated to be approximately $600m USD but is expected to grow to $2.16 billion by 2020… a dramatic growth over five years.[17] To continue to chase that potential and beyond, many existing as well as new start-up companies will enter the PLF marketplace to supply PLF technologies to livestock producers. The challenges to all of these companies will be offering a clear value proposition for producers, providing technologies and integrating them into ecosystems that enable positive user experiences for all users, do so at a cost that enables clearly improved profitability to producer businesses and delivers to the protein-consuming public a sustainable supply of affordable high-quality protein.

The potential of PLF ecosystems is also clear – one only has to look at the success of business ecosystems that we all live within every day of our personal and professional lives. Success is, of course, not ultimately judged in the short term.

When it comes to business ecosystems, sustainability equates to success, and to be sustainable the successful ecosystem must possess three critical traits:

- It must be (relatively) inexpensive to implement and execute
- It must be simple and easy for users to operate
- It must deliver ongoing value to all participants

The same sustainability traits will apply to all successful PLF ecosystems.

PLF ecosystems and their integrated technologies hold tremendous potential to revolutionise livestock production, health and welfare. For that potential to be realised, both the current infrastructural and behavioural/cultural constraints must be resolved. As active participants in various aspects of the global livestock and protein production industries, we – every one of us at every level – are directly responsible for meeting the protein needs of a growing global population. To do so we must embrace that responsibility and the innovations that will help us deliver on that responsibility – and PLF technologies and ecosystems are precisely those kinds of innovations.

"Don't have good ideas if you aren't willing to be responsible for them."

Alan Perlis[1]

"Where is the life we have lost in living? Where is the wisdom we have lost in knowledge? Where is the knowledge we have lost in information?"

Choruses from the Rock, T.S. Eliot[18]

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