Achieving Food Security through The Digital 5 Forces

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1. ABSTRACT

The dramatic onslaught of a rapidly increasing global population, shrinking percentage of arable land, reduced water availability and the influence of climate change has increased the vulnerability of the future of world agriculture and food security, thereby threatening the very existence of Life as we know it.

It is estimated that each degree Celsius temperature increase, on average reduces the yields of wheat by 6%, rice by 3% and maize by 7% and soybean by 3%. In a world where close to 800 million people are suffering from chronic undernourishment and malnutrition today, this is going to further exacerbate the situation. To address this problem, it is necessary that we rethink and reform the various practices traditionally followed in agriculture by harnessing the Digital Five Forces – Social Networks, Mobility, Analytics, Cloud and IoT – to create “Market Smart” and “Climate Smart” entities. These entities have been termed as PRIDE™s (Progressive Rural Integrated Digital Enterprises) by us. One of the key functions of PRIDE™s is to support Governments in their endeavor to achieve food security.

In this paper, we present the need for a suite of flexible multi-pronged technologies, for powering such progressive entities and transforming them into localized economic powerhouses that can withstand the various adverse global forces. This consists of the creation of personalized farm-specific protocols designed to optimize the usage of the land and resources belonging to the farmer, through an algorithmic approach based on statistical machine and deep learning techniques. Data ranging from macro remote sensing information down to micro, farm level IoT derived information is leveraged for this. Such data analysis has been proven to have had a transformative effect in the lives of small and marginal farmers moving them towards a future of economic prosperity and food security.
2. INTRODUCTION

Agriculture has always been central to increasing human wellbeing and national economic growth across the world. Its importance is in part due to its multi-functionality as livelihood provider and source of income and jobs for rural households. Agriculture has also played a central role in its contribution to rural communities’ cohesion, through the maintenance of ecosystem services (e.g. water supply and purification, pollination, pest and disease regulation and transformation of local economies.

Within the agricultural sector, small-scale farmers have remained central to agricultural development and continue to play important roles promoting an ecologically rational and socially just food system.

- Eighty percent of the farmland in sub-Saharan Africa and Asia is managed by small and marginal farmers (working on up to 10 hectares).
- Smallholders provide up to 80 percent of the food supply in Asian and sub-Saharan Africa. Their economic viability and contributions to the diversified landscape and culture is threatened by competitive pressure from globalization and integration into common economic areas; their fate is either to disappear and become purely self-subsistence producers, or to grow into larger units that can compete with large industrialized farms.
- The disadvantages which small holder farmers have in tackling the global economic and climatic forces, has drastically impacted the food security of

![Average size of agricultural holdings (ha)](image-url)
various regions.

• Food price shocks are likely to have a huge impact on the food supply of GCC countries in the near future. The region suffered immensely in 2007 and 2008, when prices in the global food market spiked, increasing by an average of 40%. The cost of food import in the GCC region rose from USD 8 billion to USD 20 billion during the fourth quarter of 2008.

3. Driving Rural Entrepreneurship & Innovation

Small and marginal farmers across the world are constantly plagued by myriad issues such as timely and reliable access to farm inputs, access to markets, access to reliable information at the right time and access to credit.

• Access to Technology: The farmer is not equipped with the latest technology nor trained to adopt it fast. Lack of new technology solutions keeps the farmer from gaining an equal footing globally.

• Market Linkages: There is a disconnect between what the farmer produces and what the consumer demands. The farmer is not connected to aggregators, food processors and retail chains to help shape the nature of his produce. As a result, produce remains the same annually, largely dependent on farmers and is often driven by the various governments’ subsidy programs.

There is an urgent need to organize small and marginal farmers into farming groups which will enable affordability to use modern technologies for sustainable agricultural development. New policy reforms have been introduced in countries such as India for re-organizing the production system in the form of corporate and contract farming. These production systems have been well adopted in farmer producer organizations/producer cooperatives and have overcome many issues.

Fig 2: Rural Integrated Digital Enterprises
Source: Tata Consultancy Services

While these Rural Enterprises have solved some of the issues associated with small and marginal farmers (such as fragmented land holding etc.), they still lack technology to facilitate the market driven production approach and to access the market data that
enables these enterprises transform into complete Rural Integrated Digital Enterprises.

These rural enterprises and all other associated stakeholders have to be empowered with an integrated system that would serve as a one stop knowledge base creation engine and delivery channel for distributing personalized cultivation practices to all the member farmers and optimize supply chain practices, thus bringing traceability of produce and transparency in transactions.

3.1 Objectives of a Rural Integrated Digital Enterprise

• Leverage ICT to empower small-holder farmers by connecting them with partners and experts of various agriculture ecosystems and promoting scientific farming
• Leverage ICT to achieve economies of scale through aggregation of land-holdings, farm produce and agri-inputs demand
• Provide personalized, farmer specific bouquet of services like Agro Advisory, Best Practices, Crop Rotation and Planning, Alert Services, Procurement etc. on mobile in local language

3.2 Technology Innovation – Remote Sensing

Improving the practice of agriculture requires the supply of information that is accurate, timely, and spatially-available and at an acceptable resolution. Information that is required to optimize agricultural practices can be grouped into categories as shown in Figure 3. The fundamental source of data required in Cognitive Remote Sensing Services in Agriculture (CRSSA) is the imagery acquired by satellites. Many commercial and government satellites are available today for this purpose. The LANDSAT satellites formed the cornerstone of all of these efforts and triggered the possibilities of agricultural applications. LANDSAT data and its associated products are available for public consumption from Earth-explorer, GlobeVis, USGS, NASA, Amazon Web Services Public Data Library, and Google Earth Engine among others. Other satellites such as Sentinel, Planet Labs, RISAT, and ResourceSat have carried forward and improved on the strengths of LANDSAT. Currently, a constellation of satellites are available for agricultural applications and provide the core data on which CRSSA is built.

Fig 3. Data flow in services offered through cognitive remote sensing
Source: Tata Consultancy Services

This type of imagery plays a key role in
understanding the nature of the agricultural problem being addressed. The agricultural knowledge held by an image lies in the wavelength of the same. The choice of wavelength intended to be used to solve a specific agricultural problem needs to be closely related to the phenology of the crop of interest. For example, crop growth measures (such as Leaf Area Index, Stomatal Activity, Chlorophyll content) and soil health metrics (such as soil moisture, salinity, and pH) need to be correlated with the various wavelengths and the resulting knowledge acquired from this ground truthing upscaled for using satellite imagery. Indices such as NDVI use imagery from red, and near-infra red (NIR) wavelengths to identify crop health. While imagery using the visible, near-visible and radio wavelengths forms the basis of most of the current CRSSA, research is being conducted to take advantage of other spectrums.

In crop identification, specific crop growing practices are considered to use the satellite imagery. For example, identification of rice across large watersheds can take advantage of the ponded conditions under which most of the rice is grown. Crops such as Oil Palm can be identified by applying machine learning algorithms using their unique leafing pattern as a signature. A combination of spectrum choices and plant phenology-based markers can help in the development of newer CRSSA.

Disease and pest prediction provides insights on the vulnerability of a crop in the near future based on the location of the farm as well as the weather predicted for the upcoming weeks. Diseases (such as fungal, bacterial and viral) and pests require suitable temperature, humidity and wind conditions for emergence and propagation. The high dependence of their outbreak on weather can be forecast temporally through spatial weather forecasting models. Spatial aspects of farms along with forecasting from global climate models are utilized to provide farm-level predictions.

Using remote sensing, crop-based knowledge, weather forecasting as well as machine learning, we can now perform large-scale data analytics that has shown potential to optimally alter the agriculture value chain. Predictive analytics for various aspects of crop growth help improve precision and certainty in agriculture. These systems can provide actionable insights in a scale-agnostic approach for:

(a) Automatic estimation of crop acreage, Crop Yield and comparison with the previous years

(b) real time weather data and weather forecasts for (upto 21 days) & comparison
There are far-reaching impacts of this solution on various stakeholders as below.

- **Farmer:** Timely hyperlocal information of the farm will help him/her in taking informed proactive decisions and thus increase the overall productivity and profitability
- **Insurance Companies:** In case of a farm mishap, it takes a lot of time for the insurance companies to scrutinize and disburse the claim amount. Now with the farm level information being readily available it not only cuts down the time taken for the entire process but also increases reliability in the procedure
- **Government:** Provides necessary insights and reports that can be leveraged by various Government extension offices for policy decisions & allocate resources accordingly

### 3.3 Technology Innovation - Climate Change Adaptation

Climate change is expected to negatively impact food availability. Food production will drop and become more volatile as a result of extreme climatic events, changes in the suitability or availability of arable land and water, and the unavailability or lack of
access to crops, crop varieties and animal breeds that can be productive. It will also lead to changes in pest and disease occurrence.

Almost every month of 2016 was recorded to have been the hottest month in history. However, the trend continues and July 2017 tied with the warmest month on record and November 2017 became the third warmest November in 137 years of modern record-keeping since 1880. This is especially a concern as it occurred in the absence of El Niño, a natural climate cycle which helps heighten global average surface temperatures. This increase in temperature has far reaching impact on agriculture.

Climate change is expected to negatively impact food availability. Food production will drop and become more volatile as a result of extreme climatic events, changes in the suitability or availability of arable land and water, and the unavailability or lack of access to crops, crop varieties and animal breeds that can be productive. It will also lead to changes in pest and disease occurrence. Temperatures exposure above 30 °C in maize or rice kernels, damages cell division and amyloplast replication, which further reduces grain sink size and hence reduces the yield. It is estimated that each degree Celsius temperature increase, on average reduces the yields of wheat by 6%, rice by 3%, and maize by 7% and soybean by 3%. This is definitely bad news for the current world population of 7 billion, out of which almost 795 million people are already suffering from chronic undernourishment and starvation.

While agricultural research institutes are working on new cropping patterns, new heat and flood tolerant varieties and cultivation practices, there are still gaps in taking the research output from lab to land in a successful and expedited manner.

A targeted initiative was started at four climatically vulnerable districts in India - Mewat (Haryana) and Dhar (Madhya Pradesh), which are prone to frequent drought and Ganjam (Odisha) and Raigad (Maharashtra), which are susceptible to frequent flash floods.

It was found that the adoption of climate change technology by farmers is a 4 step process consisting of:

- Creating awareness amongst farmers about the impacts of climate change
- Enhancing knowledge of farmer through farm level testing, experimentation and validation
- Supporting internalization / farmer adoption of technology
- Supporting the farmer in terms of
embracing changes in farming practices and/or increasing productivity

While it is difficult to reverse the impact of the climate change, appropriate mitigation strategies can be developed to reduce the risks, especially for the vulnerable population.

These interventions have proven to be successful in tackling climate change:
• Knowledge Based farm Extension and advisory services
• Development of drought indices to facilitate Early Warning System (EWS) for Drought

Knowledge Based farm Extension and advisory services:

Due to inaccessibility to frontier technology, modern varieties and most importantly the timely and quality information, farmers are further more vulnerable to climatic risks. Agriculture nowadays has become more knowledge intensive. However, due to the lack of quick accessibility to need-based and quality information, not only the acquisition of agricultural inputs, application of right technology and attainment of higher production but also the profitable marketing of produce is severely affected. The resultant agrarian distress plagues the farmers even more. Early warning systems and speedy communication of contingency technological options are the keys for successful adaptation to climatic risks and vulnerability.

Initiatives have been taken for application of ICT based extension services to bridge the information and knowledge gaps under this project. Mobile based advisory services have demonstrated immense potential in speedy dissemination of information. Besides weather and climate information, farmers could be provided with technologies for production, protection and marketing of crops. The characterization of climate risks based on downscaled information, land topography, soil, and water, cropping system, livelihood systems and socio-economic base could be accomplished to develop suitable content for dissemination through mobile for appropriate adaptation during climatic risks events.

Development of drought indices to facilitate Early Warning System (EWS) for Drought:

One of the direct major impacts on agriculture due to climate change/variability is drought. It has been reported that the majority of the net sown area in various countries is vulnerable to drought conditions and about 50% of such vulnerable areas are classified as ‘severe’, where frequency of drought is almost regular. Unlike the other hazards, the impact of drought is non-structural making it difficult to measure the actual intensity of the hazard from societal aspect. Drought
has a multifaceted impact ranging from the environment of a region to its economy and the magnitude may vary with ecosystems. Frequent occurrence of drought affects human as well livestock population of an area keeping the growth of economy suppressed. The effect becomes more intensive over the underprivileged parts of the country where droughts emerge as a curse to the people dependent upon agriculture or livestock.

Based on the satellite images & remote sensing data, various indices have been developed. Standardized Precipitation Index (SPI) for Meteorological Drought monitoring has been derived from long term rainfall data. Standardized Water Level Index (SWI) for Hydrological Drought indicator monitoring has been derived from pre and post monsoon groundwater level data and Vegetation Condition Index (VCI) to monitor Agricultural Drought derived from long term Remote Sensing data.

Evapotranspiration (ET) is an important component of the hydrologic cycle and is the loss of water from the earth’s surface into the atmosphere by means of evaporation from the soil and transpiration from the plants. Accurate information on crop ET is very critical from water management and hydrologic modelling standpoint, to quantify water requirement at field scale/pixel scale, water stress and yield prediction. ET anomalies can also be used for drought monitoring/forecasting. Traditionally, ET can be estimated by observational methods, mass balance etc. which involves human intervention. Remote sensing is also one of the effective technology which uses surface energy balance approach for ET estimation.

- Mapping Evapotranspiration at High Resolution with Internalized Calibration (METRIC) algorithm has been done for ET estimation. Through the adapted algorithm, ET is estimated throughout the crop season using METRIC and is used for crop stress detection and as an input to the soil water balance to estimate the real time irrigation requirement. Pixel level ET anomalies are also used as one of the components for drought monitoring.
- Long term NDVI data and VCI based on real time satellite data could be used for short term drought prediction for early warning. This can further be improved with other parameters like soil moisture and rainfall for developing composite drought index for more reliable drought prediction irrespective of the ecoregions.

Using the above information, scientists and
researchers have been able to leverage the developed advisory platform to provide valuable information such as delayed monsoons, drought predictions etc. to the farmers.

The impact on the farmers was noticed to be significant with some of the benefits being:

- Fertilizer Usage Reduction
- Pesticide Usage Reduction
- Averting disaster due to access to timely advisory
- Better access to markets
- Better crop planning taking into account the vagaries of Nature

3.4 Technology Innovation – Internet of Things (IoT)
Agriculture, in general, encompasses three essential elements of a connected ecosystem – cultivation of crops, livestock management, and fisheries.

Cultivation of a given crop requires a specific set of ambient conditions to be available. Since conditions vary widely in regions across the world, a system of agro-climatic zones suited to the growth of specific crops has evolved. From highly fertile river beds to harsh deserts, the diversity and associated challenges need to be overcome through different farming modalities to ensure that land is used to its full potential. Livestock management, similarly, has various facets. Milk from a small group of cows is often an augmented source of livelihood for cultivators given the uncertain weather, for example, that can lead to crop failures. For organized dairies that thrive on milk collection, processing and distribution, effective livestock management to maximize yield is, of course, an integral requirement. Likewise, to get best yields from pisciculture, health and growth of fish has to be maximized which requires continuous monitoring of water temperature and pH levels. In short, a strategic technical intervention at the process level is essential if one has to bring significant gains in agricultural produce whether for crops, milk or fish.

Accurately sensing parameters pertinent to a given agricultural context is critical in our march towards having a robust food security system for the future. Due to miniaturization of sensors and advances in storage and communication systems, today we can have interconnected sensing and instrumentation systems that can coordinate with each other to achieve specific high-level objectives. Such systems come under the realm of IoT.

Micro-climate monitoring with sensors is immensely useful for a variety of precision agriculture services in open and closed farming scenarios for agriculture, livestock and fisheries. In open farms, when used in conjunction with remote sensing, IoT can provide valuable additional ground data to improve the quality of precision agriculture services such as pest and disease prediction and in calculation of evapotranspiration.
which is useful for irrigation scheduling. There are many situations however that requires frequent, instantaneous or invasive sensing for which an IoT-based intervention becomes necessary. This also extends to closed farming setups where one is able to do little with satellite imagery or with GPS. Cognitive end-to-end IoT solutions that address many such challenges and improve the quality of offerings are in the offing.

**Fig 10:** IoT for Open Farms  
Source: Tata Consultancy Services

Taking an example of IoT for open farms, temperature and humidity sensors placed in the canopy of vineyards can be very useful to predict risk of diseases such as Powdery Mildew in advance while giving an estimate of the ripeness of grapes for harvest. Knowing the instantaneous value of a parameter such as soil moisture of a field is helpful for just-in-time irrigation, especially when water is scarce. Some precision monitoring scenarios may require soil moisture to be measured at varying depths. Similarly, measuring the instantaneous pH value of a pond can help in timely interventions for aquaculture. Here, by continuous monitoring of pH one can get some estimates on the quality of fish. All such applications require IoT. High-value crops like grapes, which often have a camouflage, need precise monitoring of micro-climatic parameters such as temperature, humidity and others to know specific conditions like ripening of the fruit (which affects quality) in addition to precise forecasts for specific diseases which saves crop and maximizes yield. The promise of yield improvements or enhanced crop protection justifies the installation of equipment in the vineyard. Armed with long-range radio technologies such as LoRa, the geographical spread of the monitoring setup could be much wider today. A portable mobile-based soil moisture sensing setup which can be very useful in irrigation planning activities while maintaining the complete digital trail of measurements has also been developed.

**Fig 11:** Soil Moisture Sensors  
Source: Tata Consultancy Services

In regions where open farms are not possible either due to space limitations or unsuitable...
soil and weather conditions, indoor farms start taking prominence. IoT has an even bigger role here as a lot more parameters now need to be monitored from growth medium to light intensity levels in order to ensure optimum growing conditions for the crop. Closed farming setups from greenhouses to crop-processing units and indoor soil-less cultivation from hydroponics to aeroponics benefit immensely from IoT for precision control and monitoring. To get a glimpse of this, a process like withering of leaves on the factory floor (which still uses non-digital heuristic methods) requires temperature and other parameters to be closely monitored. Digital intervention with IoT can help precisely regulate the usage of machinery used for the process and save on electricity.

Low-cost affordable IoT solution frameworks that are being used for indoor monitoring of plants with a number of sensors have been developed. The insights are being leveraged for effectively managing the plants. Today, we are barely scratching the surface of the extent of possibilities and advantages that IoT can bring to agriculture and ensure enough to feed the world for years to come.

**Improving disease prediction using ground sensors:**

Potato is major crop in many countries worldwide and certain diseases like Phytophthora Infestans (Late Blight) are known to cause widespread damage to the crop across the world.

For improved prediction of this disease in one of the major potato growing belts of the world, deployment consisted of a set of wireless nodes that are connected to a central gateway on the field through the ZigBee protocol. The gateway aggregates and streams sensor data to the cloud. Key micro-climatic parameters including temperature, humidity and leaf wetness are monitored in order to validate the Jhulsacast disease prediction model developed for the region. In conjunction with the field scouting application to report pest and disease incidents, model was successfully validated and demonstrated its improved prediction performance over other models proposed earlier.

![Fig 13: Potato Jhulsacast model validation with sensor network on ground and human participatory sensing](source: Tata Consultancy Services)

**Understanding farm worker behavior to improve quality of Yield:**

In crops such as tea, yield is dependent on the quality of leaves that get processed. It requires picking of two young leaves and a bud which is largely a skillful manual process undertaken by workers. Through a pilot intervention with wearable technology, it has been shown to be possible to characterize the tea picking behavior. This data is useful to impart training to workers and optimize their picking patterns by reducing variability and helping improve quality of yield.
In order to address the varied IoT application requirements in agriculture, a comprehensive solution stack that extends from cloud to silicon on the field is required. A flexible IoT adaptor is deployed on the cloud, as part of the precision agriculture solution that can acquire data from a variety of sensing sources. On the edge, a configurable gateway middleware that runs on COTS embedded boards is deployed to collect and process data locally from sensor clusters and receive commands from the cloud for actuation. The gateway talks to devices on the local network through various protocols such as ZigBee, WiFi, and others. The gateway layer also includes the smart-phone which acts as a mobile gateway for low-cost portable sensing solutions at scale. As evident from the applications discussed earlier, a lot of contextual aspects come into the picture when we bring an IoT intervention to meet a given challenge in agriculture. These analytical solutions are translated into cognitive elements that empower the IoT stack both on the cloud and the edge to improve the quality of the agriculture offerings.

Fig 14: Characterizing tea-picking behavior with wearables
Source: Tata Consultancy Services

4. Putting it all together – the 4A Model

The above technologies need to be integrated and employed to develop an application for managing large-scale farms. The goal of the application will be to define a Decision Support System (DSS) for the whole farm with the objective of optimizing field-level management and resources while taking into account farmer-level constraints. The platform should support aggregation of structured or unstructured data and should have a complete data management module complemented with predictive/big data analytics module, besides smart push notifications and support for intelligent information gateways. The application should provide the following key services:

1. **Acquisition:** Based on IoT, UAVs (Drones), Remote Sensing, Images, Voice
2. **Analysis:** Machine learning algorithms, data analytics and real time data processing
3. **Advisory:** Direct on-field or supply chain operations based on intelligence gathered through data analytics
4. **Actuation:** Actuating various on-field machinery based on data analytics intelligence.

InteGra from TCS has been an effort to realize this.
5. Conclusion

The technology elements are focused on empowering the rural digital enterprises and translating them into technology powered avatars of Mahatma Gandhi’s “Gram Swarajya” vision. The scalability of the innovation spans various fronts. In terms of technology, the architecture has been designed to handle millions of transactions. Active research is on-going to make the system, including the infrastructure, even more robust so that the response time can be further reduced. In addition, intelligent knowledge bases and retrieval systems are being designed so that responses can be answered in real time and automatically. Various innovative business models are being looked at so that radical concepts like “farming as a service” and “uberization” of farming can be enabled.

Thus, the intersection of technology and business innovations can revolutionize the rural landscape of the world and help convert the villages into localized economic strongholds with far-reaching implications for food security across the globe.
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