Developing a Framework for a Configuration of an Irrigation System for Small-scale Farmers

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Thesis presented in partial fulfilment of the requirements for the degree of Master of Engineering (Engineering Management) in the Faculty of Engineering at Stellenbosch University
This thesis has also been presented at Reutlingen Hochschule in terms of a double-degree agreement.

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December 2022

Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained herein is my own original work and that I am the sole author thereof (save to the extent explicitly otherwise stated). Reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and I have not previously submitted either in its entirety or in part, this thesis for obtaining any qualification.

Date: 12/2022

Abstract

Globalisation and an increased demand for goods and services has resulted in businesses being able to satisfy higher demands with increased efficiency and accuracy. This has resulted in industry streams employing practices that have paved the way for the new industrial revolution, namely Industry 4.0.

The agricultural industry is no exception; the emergence of precision farming technologies has increased the potential to meet high food demands and economic growth within the sector. Irrigation systems are part of precision farming technologies that enable farmers and businesses to reduce water usage, reduce labour and watering costs, control and monitor irrigation, and potentially increase yields. Small-scale farmers, however, experience barriers to applying irrigation systems. The main barriers are the investment costs of acquiring a system, not knowing the benefits related to specific systems and components, and not having or being unsure of the knowledge and skills required to operate the systems.

This thesis proposes a framework with a system configurator to support the small-scale farmer to overcome these barriers. A comprehensive framework for the configuration of an irrigation system addresses the main barriers to applying such a system through supporting small-scale farmers in selecting appropriate irrigation system configurations for site-specific applications. The framework is developed based on the Reference Architecture Model for Industry 4.0. The framework can be applied from three different perspectives; each perspective being used to overcome a specific barrier. The first perspective, namely the financial capability perspective is used to choose different technologies for each component to develop an irrigation system, or to select a market-ready irrigation system. The second perspective addresses the benefits of the system and its components. The third perspective, namely the knowledge and skills perspective, provides the knowledge and skills required to operate and understand each component and provides available study programmes and education levels or needed to acquire the relevant knowledge and skills. The configurator integrates the perspectives to configure the irrigation system.

A survey was performed on small-scale farmers to determine the usability and applicability of the framework, and it was found that the barriers identified in the literature were also present in practice, specifically the financial barrier. The framework succeeded in enabling the farmer to configure a system and communicating the requirements needed to operate the system. Feedback from the survey also indicated that the framework can be complex. A suggestion was therefore made to enlist the support of a consultant trained on the use of the framework, to guide the small-scale farmer into using the framework and implementing an irrigation system. It was also recommended that the framework be used as an educational tool by government and third-party organisations when setting up small-scale farmer programmes and schemes.

Opsomming

Globalisering en die verhoogde aanvraag na goedere en dienste het veroorsaak dat besighede aan hierdie hoër aanvraag moet voorsien met beter effektiwiteit en akkuraatheid. Dit het veroorsaak dat alle bedryfsektore van praktyke moet gebruik maak wat die grondslag neerlê vir die nuwe industriële revolusie, naamlik "Industry 4.0".

Die landboubedryf is nie ‘n uitsondering nie. Die ontstaan en verskyning van presisie-landboutegnologieë het die potensiaal verhoog om aan die hoër voedsel aanvraag te voldoen en om potensiële ekonomiese groei binne die sektor te verhoog. Besproeiingstelsels vorm deel van presisie-lanboutegnologieë wat boere en besighede in staat stel om waterverbruik te verminder, arbeid en water koste te verminder, besproeiing te beheer en monitor en om moontlik hul opbrengste te verhoog. Kleinskaal boere ervaar egter struikelblokke om besproeiingstelsels toe te pas. Die grootste struikelblokke is die beleggingskoste wat verband hou met die aankope van ‘n stelsel, om nie bewus te wees van die voordele van ‘n spesifieke stelsel en die komponente nie en laastens om nie die nodighede vaardighede en kennis te besit wat nodig is om die stelsel te bedryf nie.

In die tesis word ‘n raamwerk voorgestel wat ‘n stelselkonfigurator bevat om ondersteuning te bied aan die kleinskaal boer om die struikelblokke aan te spreek. Die omvattende raamwerk vir die konfigurasie van ‘n besproeiingstelsel spreek die hoof struikelblokke aan deur die kleinskaal boer in staat te stel om ‘n gepaste besproeiingstelsel te kies vir sy/haar spesifieke toepassing. Die raamwerk is ontwikkel op grond van die "Reference Architecture for Industrie 4.0" beginsels. Die raamwerk kan benader word vanuit drie verskillende perspektiewe waar elke perspektief een van die struikelblokke aanspreek. Die eerste perspektief, die finansiële vermoëperspektief, word gebruik om ‘n mark beskikbare sisteem te kies, of tussen verskillende tegnologieë vir elke komponent te kies om hul eie besproeiingstelsel te ontwikkel. Die tweede perspektief verskaf die voordele van die stelsel en die individuele komponente. Die derde perspektief, die kennis en vaardighede perspektief, spreek die kennis en vaardighede aan wat benodig is om elke komponent te verstaan en bedryf. Dit verskaf ook die studie programme en opvoedingsvlakke wat beskikbaar is om die kennis en vaardighede aan te skaf. Die konfigurator integreer die perspektiewe en word gebruik om die besproeiingstelsel to konfigureer.

‘n Opname was uitgevoer van kleinskaal boere om die bruikbaarheid en toepaslikheid van die raamwerk vas te stel. Resultate het getoon dat die struikelblokke in die literatuur, ook teenwoordig is in die praktyk, veral die finansiêle struikelblok. Die resultate het ook getoon die boer die raamwerk kon gebruik om ‘n sisteem te konfigureer en het die vereistes van die sisteem suksesvol gekommunikeer. Terugvoering het getoon dat die raamwerk kompleks kan word. Daarom word dit aanbeveel om ‘n konsultant in te span wat die raamwerk verstaan om die kleinskaal boer te lei om die raamwerk te gebruik.. Dit word ook aanbeveel dat die raamwerk gebruik word om as ‘n opvoedings middel wannneer regeringsorganisasies en derde partye skemas en programme skep.

Acknowledgements

Throughout the process of writing the dissertation I received a great amount of support, assistance, and guidance.

I would firstly like to thank God, as without Him I would not have been able to complete the work. I relied on Him to guide me through difficult times, and He enabled me to do what I could not have done on my own.

I would like to thank my supervisors, Mr Von Leipzig, and Professor Dr Hummel. Their expertise, patience, guidance, and support were invaluable in formulating my research and reaching my objectives. Their continuous insight and feedback elevated my performance and I learned valuable life lessons through our collaboration.

I would like to thank everyone who participated in my research, provided input, answered surveys, and gave valuable feedback during the entire process. My study is only as strong as those who help me, and I was fortunate enough to have willing and knowledgeable people providing a helping hand.

Lastly, I would like to thank my family, friends, and loved ones. This was a very challenging time for me and your love and support carried me through the process. I am forever grateful to have you in my life.

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Nomenclature

Abbreviation/Acronym	
ADC	Analog-to-Digital Converter
AS	Administration Shell
BSC	Balanced Scorecard
CDD	Common Data Dictionary
CDDS	Control Device Data Server
CEC	South African Crop Estimates Committee
CLI	Command Line Interface
CoAp	Constrained Application Protocol
CPS	Cyber Physical System
CRDP	Comprehensive Rural Development Programme
DGPS	Differential Global Positioning System
DLA	Department of Land Affairs
DMOM	Driver for Manufacturing Operation Manager
DRDLR	Department of Rural Development and Land Reform
DSL	Digital Subscriber Line
EC	Equipment Configuration
EDI	Electronic Data Interchange
EID	Equipment Identification
ELS	Equipment Location System
ERP	Enterprise Resource Planning
ESD	Extreme Studentised Deviation
ET	Evapotranspiration
FET	Field Impact Transistor
GBRT	Gradient Boosting with the Regression Tree
GDP	Gross Domestic Product
GIR	Geographical Information Retrieval
GIS	Geographical Information Systems
GNO	Get Next Operation
GPIO	General-Purpose Input/Output
GPS	Global Positioning Systems
GSM	Global Message System
GUI	Graphical User Interface
HAT	Hardware Attached on Top
HEN	Hierarchical Equipment Network
I4.0	Industry 4.0
ICT	Information Communication Technologies

ID	Identification
IDE	Integrated Development Environment
IDE	Integrated Development Environment
IIoT	Industrial Internet of Things
IMS	Irrigation Systems
IoT	Internet of Things
IPLRAD	Integrated Programme of Lan Redistribution and Agricultural Development
IRIs	International Resource Identifiers
IS	Irrigation Systems
ISE	Particle Specific Cathode
ISFET	Particle Field Impact Transistor
IT	Information Technology
LCD	Liquid Crystal Display
LR	Land Reform
LXDE	Lightweight X11 Desktop Environment
MES	Manufacturing Execution System
ML	Machine Learning
MQTT	MQ Telemetry Transport
MS	Manufacturing System
OEM	Original Equipment Manufacturer
OT	Operational Technology
PA	Precision Farming
PF	Precision Farming
PICES	Producer Independent Crop Estimates System
PID	Product Identification
PLM	Product Lifecycle Management
RAMI 4.0	Reference Architecture Model 4.0
RCG	Requirements, Constraints and Goals
RDF	Resource Description Framework
RGB	Red, Green and Blue
SCADA	Supervisory Control and Data Acquisition
SIMS	Smart Irrigation Management System
SIS	Smart Irrigation System
SNO	Set Next Operation
SOA	Service Oriented Architecture
SOC	System-on-Chip
SPD	Smart Product Development
SSM	Site-Specific Management
SWAMP	Smart Water Management Platform

VE	Virtual Entity
VRT	Variable Rate Technology
WANA	West Asia and North Africa
WS_MOM	Web Service for Manufacturing Operations Management
XML	Extensible Mark-up Language
YM	Yield Monitoring

Chapter 1 Introduction

Industry 4.0 is widely known for the disruption it causes in industries through technologies that enable or force businesses to create new business models and value offerings. The agricultural industry is no exception, as precision farming (PF) technologies have increased the potential for economic growth of participants in the sector. PF technologies includes all the agricultural production practices that use information technology either to tailor input to achieve desired outcomes, or to monitor these outcomes (Bongiovanni & Lowenberg-DeBoer, 2004). Irrigation systems (IS) use PF technologies such as sensors to enable farmers to monitor and control irrigation practices, and crops can be watered while adhering to their site-specific requirements (Ogidan, Onile and Adegboro, 2019).

1.1. Background Information

Agriculture is the foundation of developing economies. As one of these economies, South Africa needs to ensure a healthy agricultural industry that contributes to the country's gross domestic product (GDP), food security, social welfare, job creation and ecotourism while adding value to raw materials. The health of this sector depends on the sustainability of farming methods. Farming practices must therefore not only protect the long-term productivity of the land but also ensure profitable yields and the wellbeing of farmers and farm workers (Goldblatt, A, 2010).

It takes an enormous amount of water to produce food and if today's food production, consumption and environmental trends continue, we face a looming crisis. The challenges become even greater when we include emerging issues such as climate change and its implications for water availability and scarcity, the demand for biofuels, and competition for water from growing industries and domestic demands. Farming practices need to promote more sustainable water use if agriculture is to survive and flourish into the 21st century.

Recent droughts in the Southern and Eastern Cape have highlighted just how vulnerable South African farmers are to reduced rainfall. In November 2009 the Eden District in the Southern Cape was declared a disaster area and drought relief was granted to the region's livestock farmers in the form of feed vouchers. AgriSA predicted that countless farmers would face insolvency in 2010 because of drought. This may be a taste of things to come as water demand begins to exceed supply across South Africa in the context of a changing climate. Precision farming technologies enable farmers to use water more efficiently during irrigation practices (Manenzhe, T., Zwane, E. and van Niekerk, J., 2016).

The business of farmers is to farm. Effective farming needs someone involved in farming who possesses different skill sets. Manenzhe et al. (2016) asked farmers whether they are knowledgeable in farming. Most of the interviewed respondents (83 %) were had not previously been involved in farming as an occupation, and their farming skills were not as good as one would expect due to lack of training.

The role of formal education in the sustainability of projects cannot be dismissed, for example, Oni et al. (2005), reported that literate farmers are more likely to accept innovation than illiterate farmers. Formal education should not be regarded in isolation as capable of promoting sustainability but it can be argued that once more literate farmers apply technology it may enhance productivity and greater returns (Oladele and Oyewole, 2005).

Whether precision farming is feasible for small-scale farms is a leading concern for agricultural scientists. PF should provide improved farm management, which means that it should provide higher economic returns to the farmer at reduced environmental impacts. On a small farm with one variable crop, a farmer might have a good understanding of the site-specific requirements and would have sufficient skills and knowledge to manage the farm. If, however, there are a few dozen hectares and more variables, precision farming provides more control and monitoring ability.

In developing countries, which have a larger number of small-scale farms, several barriers or challenges exist in the application of PF technologies. Potential barriers include high implementation costs, i.e. not having enough funds and/or motivation to spend money on a high cost management system. Also, the knowledge and skill levels demanded to operate the system may be higher than what are currently available. Unavailability of services that include government support, electricity and resource supplies, and other farming related services, makes the implementation and use of an irrigation system difficult. This is essential in the developing world to accelerate change which is slow due to a lack of conventional support. An acceptable approach is for farmers to create their own local special data or precision farming technologies to their appropriate scale (Boyer et al., 2014).

A survey was conducted in 2014 by Boyer et al. in which cotton farmers across 14 states in the United States of America were asked what the primary barriers were to applying PF. More than 60% of the non-adopters sighted the high cost of PF as their main reason. The second most popular reason was the uncertainty of benefits, followed by the high complexity which can be translated into a demand for high knowledge and skills.

1.2.Rationale of the Research

The fragility of the agribusiness sector is prevalent in small-scale farmer dominant countries. The lack of PF applications in these countries discourages growth, damages existing ventures, discourages potential new ventures and underlines the risk of small-scale and subsidiary farmers being left behind in the value chain as bigger business are being enhanced through I4.0 technologies. These trends can be negated through the development of producer networks, addressing challenges the farmers face, and through good policies (Hollmann, McDermott and Naguib, 2013).

The aims of this research study was to negate this trend by providing a framework that can address the challenges that farmers face. The major challenges are identified and addressed as different perspectives in the framework. The framework aims to support the farmer to overcome each barrier and to configure an irrigation system that is suited to their site-specific requirements.

Bongiovanni and Lowenberg-DeBoer (2004) state that being economically sustainable is important for the success rate of farms, and that effective and efficient use of water through irrigation systems will contribute to the pursuit of economic sustainability. The financial limitations of small-scale farmers are well documented and were taken into consideration in developing the framework.

Chianu et al. (2009) found that the complexity of new irrigation systems is keeping small-scale farmers from applying them. There is a need to provide clarity on the use of the framework and what knowledge and skills are required to configure and operate the system. The framework is developed to fill this need and to support farmers in the process of developing their own systems. To ensure that the system they develop provides the desired benefits of a precision farming technology, RAMI 4.0 is used in the construction to ensure that the irrigation system qualifies as in Industry 4.0 product. This in return ensures that the benefits of such a system are actualised.

Jacobs et al. (2018) conducted a survey in which farmers found that the application of PF can be accelerated by making improvements in the training programmes for labourers and simplifying software thorough advice and farm specific benefit articulation. The framework aims to add value in supporting the farmers in addressing the irrigation problems they face and in return increasing the robustness of the agribusiness sector.

1.3.Problem Statement

The new industrial revolution, Industry 4.0, has enabled business to leverage new technologies and business models to fulfil the increased need for goods and services with accuracy and efficiency.

The agricultural industry has pivoted from traditional farming practices and has started to make use of precision farming technologies to meet increased demands for produce. The technologies, such as an irrigation system, have enabled farmers to reduce labour costs, reduce water usage, employ technologies that are customised to their requirements, increase yields from crops, and provide them with economic growth. These irrigation systems, are however not very accessible to small-scale farmers because of certain barriers.

Current research on small-scale farmers and I4.0, is centred on problem diagnosis. Studies aim at identifying the challenges and barriers which small-scale farmers experience in the 4th industrial revolution. The impact that new technologies have on the agricultural sector is clear; Rain and Thomas (2009) found that they enable increased farming resource utilisation and crop yield potential. Holmann, McDermott and Naguib (2013) state that the combination of the impact of the new technologies on the sector and the barriers that small-scale farmers face, negatively impact their ability to receive income.

Serote et al. (2021) state that there is an urgent need to provide small-scale farmers with extensive services, training, and other interventions that promote awareness of the new technologies and the potential they have on improving the rural livelihoods and promote farming longevity. In a study performed by Ngongo (2016), small-scale farmers indicated that their low access to resources keeps them from adopting precision farming technologies. Ngongo argues that better grant structuring and improved access to research resources should be implemented to increase the potential for adoption of new technologies.

Kendall et al. (2022) identified that barriers such as lack of awareness of the suitability of affordable irrigation systems, influence the level of the rate of adoption of PF technologies amongst small scale farmers. Kendall et al., argue that to improve the adoption rate of the technologies, the barriers towards adoption should be reduced, low-cost PF applications should be applied to small-scale farming requirements, and support mechanisms should be provided for the small-scale farmer. It is clear from the literature that the small-scale farming community is facing challenges in implementing precision farming and that there is a need to provide a solution or support to overcome the barriers.

1.4.Research Questions

Research questions are important guides in the literature review, the analysis of data and decisions based on the research design. The research questions posed aim to address the problem statement and guide the progression of the study (Bryman, 2014). In this thesis the research questions are focused on using the framework to address the barriers that small-scale farmers face in applying irrigation systems on their farms.

There is a vast amount of precision agriculture technologies that achieve different goals. Manezhe et al. (2016) argue that farming practices need to promote more sustainable water use for the farming industry to survive and flourish in the 21st century. Food scarcity and the growing need for sustainable food production has accelerated the need for irrigation systems that are able to increase yields and economic growth for farmers. Ricciardi et al. (2018) implemented a study that determined the share of total food supply that small-scale farmers have, and found that they remarkably produce 32% of the world’s food supply even though they farm on 2 Ha or less of farmland; their farms only take up 24% of agricultural land. This means that they oversupply their share and are reliant on the global food demand. To satisfy the demand, crop yields need to be optimised, and to optimise yield the importance of effective irrigation cannot be understated. Irrigation is important to grow crops, maintain the landscape and soil and supply water to the crops during periods of low rainfall. Due to small-scale farmers’ role in food supply, the importance of irrigation and the need for sustainable food production, the research in this study was focused on irrigation systems.

The literature state the need for support provision, but current research lacks guides, support tools and the requirements needed to overcome the barriers that small-scale farmers face. Lack of support means that small-scale farmers are often required to bring about positive change or transform their farm by themselves. This research is therefore aimed towards enabling the small-scale farmer to overcome the barriers to applying irrigation systems. The lack of access to resources identified in that literature means that farmers might not have access to available irrigation systems, and need to configure their own irrigation systems. The research question addresses this lack. It is formulated as:

Research question:

Would providing a framework for the configuration of an irrigation system and addressing the key barriers to applying the system, support the small-scale farmer to select the appropriate configuration for his/her specific application?

Sub-questions:

SQ 1. What irrigation technologies are available in precision farming?
SQ 2. How would an Industry 4.0 product such as an irrigation system be developed?
SQ 3. What components are required to configure an irrigation system?
SQ 4. What are the requirements and benefits for the irrigation system components and technologies?
SQ 5. What barriers do small-scale farmers face in applying precision farming technologies such as irrigation systems?
SQ 6. How the framework would be deployed to the site-specific requirements, constraints and goals (RCGs) of a small -scale farmer?
SQ 7. Would a small-scale farmer be able to use the framework to configure an irrigation system for his/her site-specific requirements?

The framework in this thesis is expected to provide a configured irrigation system with selected components that address the barriers that small-scale farmers face. The requirements for each component are provided as support to the farmer if he/she decides to implement the system.

1.5. Research Objectives

The objective of this study aims to answer the following research question to:

Provide a comprehensive framework for the configuration of an irrigation system that addresses the key barriers that small scale farmers face in implementation.

The objective stated above is created with the aim to provide a configured irrigation system plus knowledge and skills, and to articulate the benefits and financial requirements of the configured system. The objective is broken down into the following steps:

SO 1. Research precision farming technologies and expand on irrigation technologies and techniques
SO 2. Review and select an appropriate reference architecture to support the development of an irrigation system
SO 3. Research irrigation system components and select components that enable it to function as an Industry 4.0 product
SO 4. Identify the current available irrigation systems and components and determine the requirements and benefits thereof
SO 5. Research and analyse the barriers to applying precision farming technologies
SO 6. Deploy the framework to configure an irrigation system based on RCGs

SO 7. Establish the usability and applicability of the framework for small-scale farmers.

1.6. Research Limitations

Limitations are factors that are largely out of the researcher's control and can affect the outcome of a study. Limitations are the results of the methodology used and design choices made within the study. The limitations provide certain parameters within which a study can be conducted. Simon and Gees (2013) identify the following:

I. A limited time frame in which it can be conducted.
II. Financial limitations which need to be considered when designing the framework.
III. Limited access to farmlands and data due to availability and permission.
IV. Crop yields and irrigation opportunities which rely on natural processes such as rain, climate, and soil properties.
V. The ability of the farmer to use the framework.
VI. Case studies are scarce.
VII. The COVID-19 Pandemic and the resulting ramifications impact the progress of research.
VIII. Survey and interview feedback and results are limited to response rate, amount, and respondent knowledge.

1.7. Research Methodology

The study follows a mixed method research methodology through a facilitation approach to satisfy the objectives. This mixed method approach is used when one form of research is employed to support another form of research. It thus combines both qualitative and quantitative research. This approach enables the strengths of qualitative research to be capitalised on whilst offsetting the weaknesses of quantitative research and vice versa. The facilitation requires using qualitative research to interpret the relationships between variables (Bryman and Bell, 2018).

The approach is represented in the following figure:

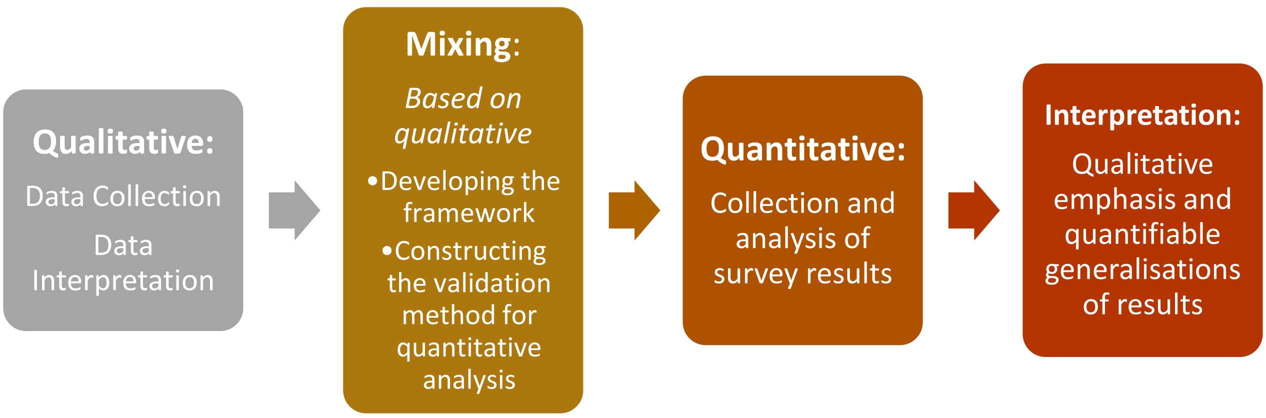


Figure 1: Research Methodology

Qualitative research is performed to collect and interpret data to fill the gap in literature and the requirements needed to fill the gap. A framework is developed based on the data collection and interpretation. It is followed by a survey used as a method to add quantitative analysis to the qualitative data gathered in the initial research data and framework development. General emphasis is placed on the qualitative data that is collected from feedback. Also, through analysing the data, generalisations can be made. Both these aspects of interpretation enable a thorough conclusion to be constructed.

1.8. Research Design

In this study a comprehensive framework is developed for the configuration of an irrigation system which addresses key barriers to applying the system. It will support small-scale farmers to select appropriate configuration for specific applications and to overcome the barriers faced in applying precision farming technologies. The study can be divided into the following steps:

Figure 2: Study Design

I. Identifying the research problem and gaps in the literature and formulating objectives to address the problem identified.
II. Collecting and interpreting data to aid the development and deployment of the framework.
III. Breaking the framework development t down into a three-step process.
IV. Deploying the outlines and output of the framework.
V. Validating the framework through a non-probability sampling survey of small-scale farmers.

The study design aimed to provide the researcher with the necessary sequential steps to follow in order to complete the study. The steps were executed with the aid of the research methodology.

Table 1: Research Steps and Methods

Research Step	Research Methods
Problem identification and formulation	Literature review
Data collection and interpretation	Literature review Pareto analysis
Framework development	System configuration design Thematic analysis
Framework deployment	Theoretical implementation
Validation	Non-probability based sampling survey

Building on this, the link between the research question, sub-questions, objectives and research methods are shown in the table above. Orange indicates that it is part of the literature review, blue is the framework development and deployment, and green indicates the survey.

Table 2: Research Methods

Research Question	Research Sub Question	Research Objective	Research Methods
Would providing a framework for the configuration of an irrigation system and addressing the key barriers to applying the system, support the small-scale farmer to select the appropriate configuration for his/her specific application?	What irrigation technologies are available in precision farming?	Research precision farming technologies and expand on irrigation technologies and techniques	Literature review
	How would an Industry 4.0 product such as an irrigation system be developed?	Review and select an appropriate reference architecture to support the development of an irrigation system	Literature review
	What components are required to configure an irrigation system?	Research irrigation system components and select components that enable it to function as an Industry 4.0 product	System configuration design on RAMI 4.0 –
	What are the requirements and benefits for the irrigation system components and technologies?	Identify the current available irrigation systems and components and determine the requirements and benefits thereof.	Thematic analysis Literature review
	What barriers do small-scale farmers face in applying precision farming technologies such as irrigation systems?	Research and analyse the barriers to applying precision farming technologies	Literature review, thematic analysis and Pareto analysis
	How would the framework be deployed to the site-specific requirements, constraints and goals of a small -scale farmer?	Deploy the framework to configure an irrigation system based on RCGs.	Theoretical implementation
	Would a small-scale farmer be able to use the framework to configure an irrigation system for his/her site-specific requirements?	Establish the usability and applicability of the framework for small-scale farmers.	Non-probability sampling based survey

This chapter explores the design of the research and elaborates on the questions, objectives and methodology of the research. A mix of qualitative and quantitative data allows the researcher to gain a broad and in-depth understanding of the research areas. In this chapter each of the parts are elaborated on to explain the methodologies used and their contribution to the study.

1.8.1. Problem Identification and Objective Formulation

Background research was performed on the impact of Industry 4.0 on small-scale famers in the agricultural sector. Current literature was analysed to identify the problems that small-scale farmers face. After it was established that the problems exists across various literature studies, a gap was identified to provide a solution to the problems. Objectives were formulated based on this to ensure that the solution allowed for the intended contribution.

1.8.2. Data Collection and Interpretation

A qualitative approach was used to compare current research with conference proceedings and papers, journal articles and online articles. The research was done on precision farming, Industry 4.0 and the barriers to applying precision farming. A narrative review was used to gain an initial broad understanding on the topics of precision farming and Industry 4.0, and was used to determine the current state of the literature and to identify potential gaps where a contribution can be made. A semi-systematic approach to review the barriers to applying precision farming in literature was used. Qualitative collection methods were used to determine the barriers and the Pareto analysis was employed to quantitatively analyse the barriers.

1.8.2.1. Precision Farming and Industry 4.0

In the literature review precision farming technologies were explored. The reasons for employing precision farming technologies are evaluated as they could contribute towards motivating farmers to implement them. As mentioned in 1.3, a focus was placed on irrigation systems and their design was investigated to determine which components are required for the system to function and what their contribution is. This section concerns qualitative data and system design.

Qualitative research was conducted on Industry 4.0 to further understand the revolution and its impact. This section identifies the enabling technologies that ensure a product is an I4.0 product. The framework in this study aims to enable farmers to configure irrigation systems that can function in an I4.0 capacity. Reference architectures for developing an I4.0 product are explored. Reference Architecture Model for Industry 4.0, RAMI 4.0, is used to focus on product development at various stages in its life cycle (Löwen, 2017).

1.8.2.2. Barriers to Applying Precision Farming

A Pareto analysis is performed in 2.3.2., to determine the barriers that small-scale farmers face around precision farming technologies. The Pareto principle states that the bottom 80% of consequences are results of the top 20 % of causes. There is not an equal balance of input and output. Rooney (2002) quotes Microsoft's CEO at the time, stating that fixing the top 20% of bugs reported, 80% of the remaining errors would be eliminated. The Pareto analysis in this study enabled the researcher to determine the top 20 % of the barriers that small-scale farmer face with regards to precision farming. By addressing these 20 % of barriers, the remaining 80% of barriers are subsequently addressed. The Pareto analysis was designed with the following inclusion criteria, further described in 2.3.1, to ensure that the analysis is accurate:

I. Type of publication: Only include relevant sources
II. Date: A year was chosen which excludes any sources that are older than the year specified.
III. No restriction was placed on the participants in the data source.
IV. Studies that use variations on the following key words were used:
    a. precision Farming

b. barriers
c. small-scale Farmers/Farming

The Pareto analysis made use of qualitative data collection from different sources. When consulting different sources, different definitions for the same barrier were found. For example, in one source "lack of financial resources" barrier was identified. In another source, it may be communicated as "Not enough money". Both imply that the system is too expensive. A thematic analysis was then used to group barriers that refer to the same problem. In 2.3.1 they are grouped by definition as follows:

I. Too Risky
II. Lack of Trust
III. Not Profitable
IV. Time Consuming
V. Continuously Evolving Technology
VI. Benefits Uncertain
VII. Too Expensive
VIII. Access to Technology and Support
IX. Ethical Consideration
X. Too Complex

After extracting data from 426 different sources that fall within the inclusion criteria, the main barriers were identified by looking at the Pareto chart. There is a clear breakpoint in the cumulative percentage in the graph after the third most frequent barrier. This indicates that these barriers should be addressed.

1.8.3. Framework Development

The framework was developed in a three-step process. Each part aims to fulfil the objectives that they are paired to in the table linking the framework development to the research objectives and questions. The three-part process is shown in the figure below.

Figure 3: Framework Development Process

The first part requires the researcher to identify pre-conditions for the perspectives of the framework. The perspectives in the framework each aim to address one of the main barriers. The perspectives set the entry level requirements and aims to eliminate large-scale and complex systems.

1.8.3.1. Developing Perspective Preconditions

The framework can be used from three different perspectives. Each perspective was used to address one of the main barriers to applying precision farming, as identified in the Pareto analysis. They are: too expensive (financial capability perspective), too complex (knowledge and skills capability perspective) and unclear benefits (benefit articulation perspective).

The financial capability perspective’s pre-condition was determined through an analysis of the current financial resources available to small-scale farmers, and total farming budget literature. The literature around farming budget provided a quantitative measure of what percentage the small-scale farmer can allocate towards irrigation. The financial resources of small-scale farmers differ substantially, and their financial capabilities are expressed through a quantitative representation of the grants and loans they can receive.

The knowledge and skills perspective’s pre-conditions were difficult to determine due to the lack of theoretical data on what exactly those skills are. A survey was performed by Clay in 2018 that determines the academic knowledge and skill requirements of different stakeholders in the precision farming domain. A thematic analysis was done on the definitions of small-scale farmers and the stakeholders defined by Clay (2018), and it was found that the small-scale farmer’s definition was closest to that of an equipment operator and equipment technician. Their knowledge and skills are therefore included in the perspective. Academic requirements were also added.
The benefit articulation perspective identifies the main components of an irrigation system. They were identified through the literature study and during the framework development, and later changed to include the components identified in the construction of the system configurator on RAMI 4.0.

1.8.3.2. Identification of Existing Technologies

The second part of the framework identifies the existing technologies and the benefits, costs and requirements of the technologies and their components. They were identified through a thematic analysis of the current research and available data. As stated, the identification of necessary components through RAMI 4.0 changed which components were added into the framework perspectives. The identification of these technologies was thus revisited.

The financial requirements, knowledge and skills requirements, and benefit articulations for 5 different technologies for each component is provided. A search strategy was employed to limit the variations to 5 due to considerable informational load and potential decision fatigue. The perspectives include available irrigation systems as an alternative to the configured irrigation system.

1.8.3.3. System Configurator Development

The third part develops pathways via a system configurator for the farmer to develop an irrigation system or choose an applicable system for site-specific requirements. The system configurator was developed and designed according to the principles of RAMI 4.0. The hierarchy levels and architecture layers were used to guide the researcher in developing a configurator that would include components which enable the irrigation system to perform the required tasks of a precision farming technology. This was done so that the configured irrigation system can provide the farmer with the benefit of precision farming and I4.0 whilst adhering to the limitations and requirements they have.

1.8.4. Framework Deployment

The deployment of the framework outlines the use of the framework and states the output thereof. Following the steps in the deployment ensures that aspects were included that best enable small-scale farmers to develop irrigation systems.

1.8.4.1. Defining RCGs

The deployment starts by farmers defining their site-specific requirements, constraints and goals (RCG). The RCG are identified in literature and ensured to be applicable to at least one of the perspectives. These are stated at the start of implementing the framework in a quantitative or qualitative manner, depending on the small-scale farmer's ability to do so. Thereafter the perspectives are used to select components and available systems within the framework that adhere to the small-scale farmer's RCGs.

1.8.4.2. RCG and Framework Perspectives Integration

The farmer has now integrated the perspectives of the framework to satisfy the RCGs identified. He/she has the access to the different technologies in each component and the available irrigation systems in the integrated table that can satisfy his/her RCGs. The system configurator is then used to select the components that will satisfy their requirements.

The farmer is firstly equipped with the configured irrigation system and/or available irrigation system chosen and then with the financial requirements, benefit articulation, and knowledge and skills required to implement the system. The system can function as an I4.0 product to provide them with the benefits of precision farming technologies. The output of the framework provides the impetus necessary for the small-scale farmer to implement an irrigation system on their farm, which successfully addresses the barriers that they face in doing so.

1.8.5. Framework Validation

In this study three different validation methods were considered. An experimental case study was considered due to its ability to present findings in practice that are not yet seen in the literature. A non-experimental survey was considered due to it being able to describe the characteristics of a population and the ability to establish a relationship between the population and variables. A non-experimental focus group was considered as it allows the researcher to interact with participants, explain the use of the framework in detail, and gather more qualitative feedback.

A survey was chosen as the validation method used in the study because it provides the opportunity to provide larger sample sizes and enables the researcher to make generalisations from respondent feedback. The survey provided an opportunity to determine whether the framework would be applicable and be used by the small-scale farmer. The survey method was also chosen because when the validation of the study was to commence, the COVID-19 pandemic and subsequent lockdown regulations severely limited the possibility of physical workshops, focus groups and field studies.

The results of a survey can determine how a framework is applied. Due to the inaccessibility of technologies and resources, relevant stakeholders and small-scale farmer organisations can determine the required support they need to provide to a small-scale farmer to successfully use the framework and implement an irrigation system on their farm. Third party stakeholders can provide support in using the framework by addressing the results from the survey. If the survey results indicate that improvements are needed or additional guidance is required by a small-scale farmer, these stakeholders can use it to develop the requisite support.

The survey objectives are first stated to determine the criteria for the participants and to provide a reference for designing the survey. The survey was used as a qualitative collection method and analysed in a qualitative manner by exploring themes and trends in the results. It was also analysed in a quantitative manner by interpreting the results through a statistical and descriptive approach. The qualitative results facilitated the quantitative analysis.

1.8.6. Conclusion

A research design enables a study to be conducted within clear guidelines. The guidelines enable a structured approach to the methodologies and research that enable the objectives of the study to be reached. It is clear that small-scale farmers face barriers to applying irrigation systems and there is current lack for support and guidance to overcome these barriers. The research design provides the necessary structure and methodologies to fill this need.

The research question, sub-questions and objectives are each paired with a research methodology to enable the questions to be answered and objectives to be reached. If the design is followed, the framework for the configuration of an irrigation system that addresses the main barriers small-scale farmers face, can be developed.

1.9.Scope of the Study

The scope of the study refers to the capacity of a study, in other words, what will be included and what determines what will be included in the study.

I. This study only aims to address small-scale farmers

The concept of a small-scale farmer can be approached from various perspectives, depending on the objective of the analysis. Small-scale farmers are widely agreed upon as operating under structural constraints such as access to sub-optimal types of technology, resources, and markets. This appears in most definitions about other farmers in the sector. Another definition offered by Brooks et al. (2009), is “farm households struggle to be competitive, either because their endowments of assets compare unfavourably with those of more efficient producers in the economy or because they confront missing or under-developed markets.” The World Bank Rural Development Strategy defines small-scale farms as farms “with a low asset base and operating in less than 2 hectares of cropland” (Ergin et al., 2017).

Logical order can be followed to determine the definition of a small-scale farm:

I. First, the criteria for categorisation should be chosen. This criterion can be land, labour, market orientation etc.
II. Second, assessing the data availability for the implementation of the criteria.
III. Third, the decision should be made on if the criteria should be considered on an absolute or relative basis.
IV. Finally, a threshold should be established to differentiate the small-scale/subsidiary farmer from other farms/farmers.

To define it fully, the concept should be agreed upon on what a farm or farmer is. FAO defines an agricultural holding as “an economic unit of agricultural production under single management comprising all livestock kept and all land used wholly or partly for agricultural production purposes, without regard to title, legal form or size”.

The characteristics of small-scale farmers can be unpacked based on several variables. Several characteristics are variable such as household size, income, type of crop or produce, market access and capital limits among others. Subsidiary farmers and small-scale farmers share similar characteristics and are distinguished by the purpose of their farming practice where the latter aims to produce for income instead of living purposes. Joel et al. (2016) offer several general characteristics from a literature study conducted. They are:

I. Small-scale farmers are generally categorised by having limited education levels, limited information access, limited management skills and operation time.
II. Building on that, small-scale farmers are individuals who generally have spent limited time in school and fall within the 45 to 54-year-old range. This age range, according to literature, is less likely to apply precision farming.
III. Farming decisions are mostly made to satisfy household welfare before profit is considered.
IV. The objective of the household mainly dictates farming activities.
V. Lower yields are synonymous with small-scale farmers as they use outdated farming practices.
VI. They have limited electricity and clean water access.
VII. They can be categorised by external inputs and expenditure patterns.
VIII. They can also be categorised by the size of the land which their farm occupies.

Limited access to land is a common in defining a small-scale farm. A typical upper limit of 2 hectares is typically identified on the land area as is the number of livestock operated or owned by individual farmers and their families. In a statistical analysis by Grain, (2014), 77 countries used land size thresholds to define small-scale farms. It is worth noting than in considering the size of a farm, the reference is often made to operating land, which refers to the land effectively used by a farm or a household under different arrangements. This excludes the land owned definition, which includes land rented out and land rented by the farmer. Land size definitions are limited to the fact that it relays information which is biased towards highly heterogeneous economic and social conditions, so that the area of land may not fully categorise the small-scale, but for the purposes of this paper it is enough. Grain (2014), calculates the statistical average farm size as 3.564 *Ha*. The USDA refers to a small-scale farms as one that produces or sells less than $ 250 000 per year. It gives a representation of the economic situation of the holding and its risk of incurring poverty. Grain (2014) uses the economic representation of the small-scale farmer to compute the average farm size according to the USDA as 1.2 *Ha*. This corresponds with the World Bank Rural Development Strategy's definition of the farming capacity to be below 2 *Ha*,

II. The system configuration should represent a low-cost irrigation system

In other words, the system should be affordable to implement, design and operate. This means that only low-cost components should be considered; there are a vast number of components available on the market but only certain components are affordable. Low-cost choices aim to address the financial limitations that small-scale farmers experience. The farmer's financial capability as stipulated in 3.1.1., would determine the value of a low-cost system.

III. The framework is subject to literature availability

The framework is enabled by the knowledge gathered in the literature and the application thereof. Certain aspects of the framework are limited due to a lack of available information, and other parts are enhanced due to vast amounts of information available.

Stand-alone irrigation system components do not have benefits and specifications communicated in farming specific terms but rather in technical terms. The technical aspects might not be useful to small-scale farmers and could therefore require alternative communication techniques such as reference to market available products.

Definitions

Small-Scale Farmer: A farmer who produces a low yield of crops and/or livestock on a small piece of land, generally around 2 hectares, without using advanced or expensive technologies. Farmers rely on intensive labour and supply to local or surrounding markets. Farmers produce for their household and generate income from selling the rest of the produce.

Low-cost system: The cost of the irrigation system should not exceed the amount available for the small-scale farmer to allocate to irrigation practices. Depending on the capital capability of the farmer, which is further discussed in 3.1.1, the system will be accepted as a low-cost system either:

I. ***< $ 91***
II. ***< $ 364***
III. ***< $ 1820***

Chapter 2 Theory and Literature Analysis

In this section the literature which covers the background of the research problem is analysed and reviewed. Topics discussed are precision farming (PF), irrigation systems, Industry 4.0 and barriers to applying PF. The literature review enabled the researcher to find studies related to the research problem and to identify opportunities and gaps in the literature. In this chapter the current technologies available in precision farming is explored to gain an understanding of what would be required in the configuration an irrigation system. Industry 4.0 is researched to understand the impact it has on the farming sector, and the barriers to implementation of precision farming and irrigation are identified.

2.1. Precision Farming

Bernard Meyerson, the Chief Innovation Officer at IBM Corporation states that: *"Technology has the potential to answer some of our biggest questions and help us understand the world better around us. We must therefore work together to ensure that the food and agriculture sector is not left behind and that these efforts contribute towards global food systems that benefit farmers, consumers, and the planet."* (Cullum, 2019).

Precision farming (PF) has come to fruition in recent years along with Industry 4.0 as a tool that obtains more accurate data from increased utilisation of resources to potentially increased profits (Rains and Thomas, 2009). PF, as a management practice, first found widespread acceptance in the Midwest of the United States of America. It was applied in the Corn Belt to increase yields of corn, wheat, and soybeans and to reduce production costs at the same time. PF management principles and technologies can be applied to almost any agricultural commodity (Rains and Thomas, 2009).

The practical definition of precision farming refers to the accumulation and consolidation of data at applicable levels, then interpreting and analysing the data to develop management strategies that can be implemented for specific times and scales. Precision farming therefore improves productivity and maintains sustainability. Farmers who practise precision farming indicate that it improves their economic viability and productivity, lowers environmental degradation and production risks, and is socially acceptable towards labourers (Jacobs et al., 2018).

Certain steps should be taken to determine if precision farming would be feasible for specific agricultural areas. Getting an aerial photograph of the area can help determine if locally available practices can be useful. From aerial photographs, field characteristics such as sandy areas, fence positions, poor drainage and other relevant characteristics can be identified. Keeping manual records of the characteristics and crops is the next step. Yield monitors can be used to do this. (Rains and Thomas, 2009).

To meet higher food demands and security challenges, producers must ramp up their production efforts and make optimum use of the available resources through using precision farming practices whilst striving to uphold sustainable practices (Jacobs et al., 2018).

In this section current precision farming technologies are explored, and the irrigation system's design and components are unpacked to understand what it requires to implement such a system.

2.1.1. Sustainability and Precision Farming

There is little question that the concepts of sustainability and precision farming are impossible to separate. Ever since the first global positioning system was used in an agricultural context, the economic and environmental benefits were obvious (Bongiovanni and Lowenberg-DeBoer, 2004).

Sustainability originally referred to industrial and agricultural technological applications that reduce and prevent degradation of the environment. The technologies are often associated with economic activity that led to the betterment of the environment or reduced degradation, especially since the definition of sustainability is also a popular topic of debate. In 1972, the United Nations defined its aim as: "…meet[ing] the needs of the present without compromising the ability of future generations to meet their own needs" (Bongiovanni and Lowenberg-DeBoer, 2004, p. 360).

Hartwick and Solow (1995) define sustainability in an economical context as the ability to uphold constant productivity or consumption by substituting between natural resources and manmade capital. Manmade capital in this context refers to anything developed through physical and intellectual capital. Pearce and Atkinson (1993, 1995) state that capital and natural resources are complementary during the production process and due to natural resources being the limited factor in the process, it should therefore be reserved. Sustainability can be described as the intersection between ecology, economics and sociology (Bongiovanni and Lowenberg-DeBoer, 2004).

Site-specific management (SSM) is an age-old agricultural practice which is the idea to do the right thing at the right time. SSM is defined by Lowenberg-DeBoer (2004, p. 361) as: "The electronic monitoring and control that is applied to the information processing, data collection and decision support for the spatial and temporal allocation of inputs for crop production."

The mechanisation of agricultural practice in the 20th century has resulted in economic pressure to handle large fields with uniform agronomic practices. PF uses information technology through various agricultural practices to achieve and monitor desired outcomes. While the sustainability of the environment is promoted, ethical considerations should be made to preserve the sustainability of the workforce (Bongiovanni and Lowenberg-DeBoer, 2004).

2.1.2. Ethical Debate

Farmers and companies must use practices that are profitable and socially acceptable to be sustainable. Utilitarian concerns such as climate change, excessive erosion, water pollution and the over usage of pesticides are driving forces of sustainability practices. Philosophical and religious driving forces are also notable. Preserving the land for future generations who will inherit the land

and thinking of land as a responsibility to humans, are examples of these driving forces (Bongiovanni and Lowenberg-DeBoer, 2004).

2.1.3. Challenges

Variation is one of the major stumbling blocks in the application of PF. These include:

I. Soil, biological, and soil process variations.
II. Random variations such as rainfall.
III. Manageable variations such as fertiliser and seed applications.

The interaction of the three different variations results in offsite impacts. Larson and Pierce (1991) define soil quality as the capacity of soil to function in a sustained and productive manner while improving and maintaining resource base, environment, and plant, human and animal health. PF is important in controlling soil erosion and compaction. It contributes to environmental protection from pesticides to soil nutrients (Bongiovanni and Lowenberg-DeBoer, 2004)

IoT systems generate vast amounts of data though real-time monitoring integration with big data. Irrigation systems therefore need to use sustainable and effective mechanisms to manage and analyse data. Blockchain, solar powered IoT devices, data sorting and clustering to reduce data volume, time-efficient algorithms and sustainable components should be evaluated when developing systems. Equally important is the analysis of the data generated by PF technologies to optimise IoT systems according to crop and weather conditions.

2.1.4. Precision Farming Technologies

Most solutions for irrigation systems comprise low-cost sensors and controllers that increase the benefit scope of utilizing these smart systems. The main elements of the architectures used to develop these systems are devices, communications, services, management, applications, and security. IoT systems are enabled through devices located in environments to perform detection, monitor control and action activities. The devices should have interfaces that allow for connection with other devices to transfer information. The data needs to be processed so that actions can be taken on it. Communication protocols are used to transmit data to perform tasks. Services are also needed to enable systems to perform device discovery and device control and to analyse and collect data. Applications allow the user and the system to interact (Gracia et al., 2020).

PF practices are applied to commodities to aid in decision making on planting dates, depths and populations, application rates and time for fertilisers and pesticides, selection of cultivars, and tillage practices. They are enabled by five major components. These are yield monitoring (YM), variable rate technology (VRT), sensors, global positioning systems (GPS) and geographical information systems (GIS) (Rains and Thomas, 2009).

2.1.4.1. Geographical Information Systems (GIS)

GIS consists of computer software that provides users with data storage, retrieval, and transformation of spatial data. GIS technologies can obtain data from different field locations regarding soil type, nutrient contents, and other data (Rains and Thomas, 2009). GIS generates maps that indicate variability of nutrient levels, topography, yield, pest incidence and soil characteristics. The software used to generate such maps can be of three types. Firstly, software that generates maps automatically given a specific data set. Secondly, software that delivers flexibility to change map parameters and create multiple attribute maps. The third type is front-end added GIS software that can be applied to agricultural mapping (Rains and Thomas, 2009).

2.1.4.2. Variable Rate Technology (VRT)

VRT consist of controllers that vary the emission and output of pesticides, fertilisers, and lime. VRT relies on GIS and GPS to locate field positions and controls applicable hardware to change application rates. Figure 4 shows how different components of PF fit together to produce a functional VRT system. In this system the GPS communicates the tractor's field location to the operator.

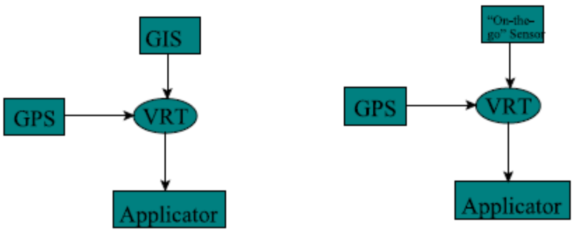


Figure 4: VRT Components [Rains and Thomas, 2009]

The GPS links with GIS software which indicates the field characteristics of a specific location. The yield goal specification determines the number of fertilisers to apply to the location. VRT relies on large amounts of manual field scouting to generate maps (Rains and Thomas, 2009).

2.1.4.3. Yield Monitoring (YM)

YM is used to assess field production and determine better management of the production process. As yield is measured and the data is stored on a computer along with the GPS coordinates where the yield data was measured. The software creates a yield map that provides yield variability and production. Yield variability is illustrated on a map by different colours representing different yields. Red shows low yields, while green represents high yields. Yield production is calculated across the yield of an entire field (Rains and Thomas, 2009). Certain sources of yield variability should be considered when yield monitoring is done:

I. Lack of nutrients for plant production.

II. Water stress
III. *pH* imbalances for poor release of available nutrients.
IV. Disease among crops.
V. Insect and pest presence.
VI. Poor drainage.
VII. Weed presence competing with resources.

The yield can be reduced through certain operator and equipment errors:

I. Faulty equipment such as broken pesticide distributors can leave certain plants vulnerable.
II. Planting problems.
III. Lime spreader that affects the pH balance.

To combat yield variability and reduction, precision management practices should enlist the aid of advisors, agents, and specialists. YM can also be used to generate profit maps which is done by using crop yield, sales data, and the records of field inputs. Profit maps are used to determine which areas of the crop or field are making or losing money. Profit can be calculated as:

1. Farming Profit Calculation

$$P = GI - I$$

$$\boldsymbol{P = profit\left(\frac{R}{ha}\right); GI = Gross\ Income\left(\frac{R}{ha}\right); I = costs\ (\frac{R}{ha})}$$

(Rains and Thomas, 2000).

2.1.4.4. Sensors

Sensors are used to determine the characteristics of various soil properties, crop stress, pest incidence, temperatures, light exposure, rainfall, and more. Sensors can identify these characteristics while resources are active, such as a tractor or scout moving across a field and when airplanes and satellites are flying over and taking photos. Yield monitors are currently the leading on-the-go sensing systems. Remote sensors is the term used to describe satellites and aerial sensors that can provide instant field characteristics maps (Rains and Thomas, 2009).

Light and temperature sensors are the least accurate sensors at around 40 % while combining them with soil moisture sensors will improve their accuracy to 62-81 %. The soil moisture sensor is considered most important for irrigation (Gracia et al., 2020).

2.1.4.5. Global Positioning Systems (GPS)

A GPS is used to pin-point objects on the face of the earth. It consists of a set of 24 satellites that orbit around the earth at a high altitude. Radio signals are transmitted between these satellites and receivers on earth. The receiver relies on an additional signal from a reference position to provide an accurate position. The reference position can be provided by another satellite or a land-based object. The satellite providing the reference signal is known as a differential global positioning system (DGPS). The main reason for the use of GPS is its ability to return to a given location, again and again (Rains and Thomas, 2009).

2.1.4.6. Conclusion

Based on the research done on the available technologies in precision farming, only the technologies contributing to irrigation will be considered. These are technologies that enable the functionalities of an irrigation system.

2.1.5. Irrigation Technologies

Modern irrigation which is normally accompanied by drip and sprinkler irrigation is commonly used in desert land with sandy soil. Traditional or flood irrigation is used in old land areas with common clay soil. Modern irrigation is synonymous with pressurised methods as it requires pumping water through a pipe network. Flood and gravity irrigation on the other hand, makes use of natural mechanisms (Ismail, 2003).

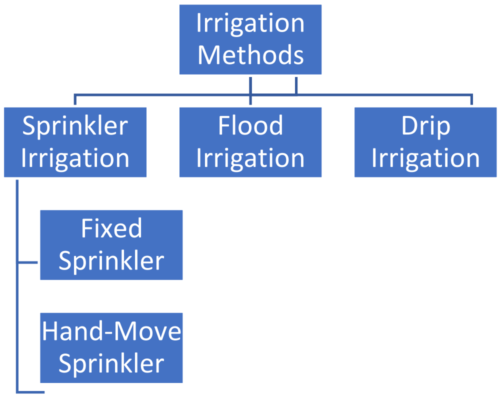


Figure 5: Irrigation Methods (Ismail, 2003)

The most important use of modern irrigation techniques is to improve crop productivity. The applicability of irrigation techniques and drainage systems is evaluated through the minimum flow of irrigation water and maximising the yield. The balance of these two aspect can be achieved by creating an on-farm water saving system through using efficient equipment and modern technologies. To choose the best equipped irrigation techniques should be carried out in stages. Firstly, identify the technical acceptability of the specific irrigation technology. Secondly, choose the most economically applicable method for the area taking into account the crop being irrigated (DWMM, 2015).

Technical applicability depends on various environmental-economic factors and climate conditions such as soil, relief, hydro-geological and economic conditions, and number of qualified irrigators. Soil factors include deficit of evaporation and wind speed. Relief considers the absorption rate in the first hour and depth of soil thickness. Hydro-geological considerations are the slope and volume of work. The depth of occurrence of saline and fresh groundwater is also considered. Irrigation methods can be categorised by how water is applied to the crop. In other words, by direct or indirect methods (DWMM, 2015).

2.1.5.1. Direct and Indirect Irrigation Technologies

Irrigation water should be conveyed uniformly to all parts of a field to yield reliable crop production. The topography of the land can influence the flow of water through the crops. The type of crop, which varies in irrigation requirements, also influences how water is distributed to the irrigation area. Irrigation methods aim to apply water that ensures minimum water wastage for economic and sustainability reasons. The availability of water and soil types along with the above-mentioned factors dictate the choice of the irrigation methods used (Radwan, 2008).

2.1.5.2. Direct Irrigation Methods

In this method water is moved from rivers into a canal by constructing a structure that lead water into the canal. The water flows through a gated structure when water levels are high enough to flow because of gravity. It is thus heavily reliant on rainfall. Figure 6 shows how a direct irrigation scheme using river water would be constructed (Radwan, 2008).

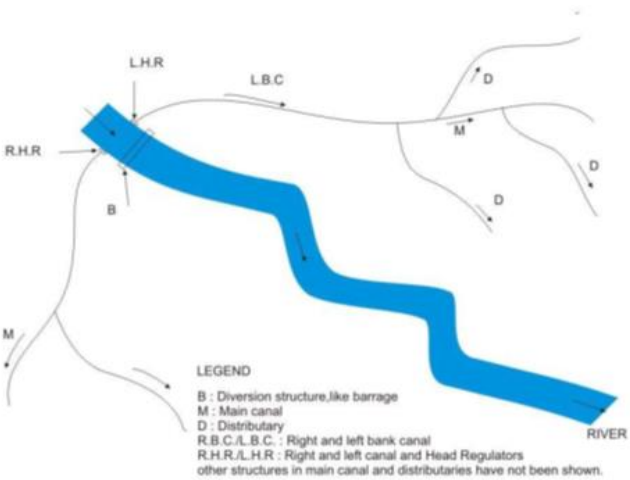


Figure 6: Direct Irrigation Methods (Radwan, 2008)

The diversion structure raises the water level and forces the water to travel down the channel. The river water flows out into canals at the L.H.R and R.H.R sections. It then flows towards the main canal and is distributed to other fields requiring irrigation (Radwan, 2008).

2.1.5.3. Indirect Irrigation Methods

In this type of irrigation method, excess water from rivers is stored in a reservoir or tank at an upstream location at a dam constructed across the river. The method is usually practised in non-deltaic areas. Figure 7 offers a general layout of a storage irrigation scheme (Radwan, 2008).

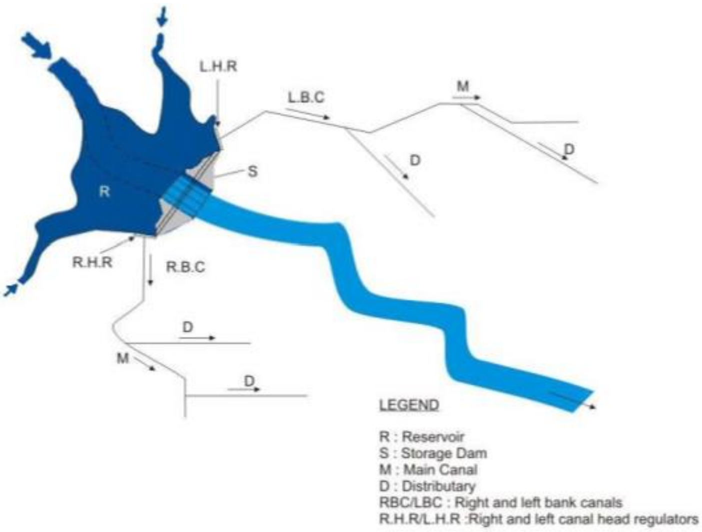


Figure 7: Storage Irrigation Methods (Radwan, 2008)

The storage dam at point S is usually constructed with an outlet, spillway, or log chutes, and the capacity of the reservoir is usually determined by the irrigation needs of the field combined with statistics of annual rainfall. Depending on the topography, the surface area of the dam is large compared to the direct irrigation storage water area (Radwan 2008).

2.1.5.4. Surface Irrigation Technologies

This method transfers water directly from a channel located in the upper areas of the field to the soil. The water covers the surface area of the field as a continuous sheet of water that raises the soil moisture up to the field capacity. The distribution of the water is unequal and not very efficient and it can lead to soil erosion. Radwan (2008) suggests that this can be applied through two methods:

I. Border Irrigation
II. Basin Irrigation

In these methods the water floods the land. It is ineffective applied to crops that perform better when water is applied to the root zone of the crop (Radwan, 2008). In surface irrigation water is supplied through gravity to flow over soil from canals, pipes, or ditches into the field. In some applications water needs to be pumped from a certain source to a crop location at a higher elevation. Examples of surface irrigation are: furrow, basin, and border irrigation. Surface irrigation is suitable for field crops, orchards, and pastures.

The efficiency of surface irrigation systems varies due to it being reliant on soil type, field uniformity, specific crop types, and management structures. Surface irrigated systems rely on the soil to transport the water which makes it reliant on natural factors. Proper surface irrigation and conditions can lead to systems approaching 90 % efficiency (Bjorneberg, 2013).

2.1.5.4.1. Border Irrigation

Borders are usually long graded land are separated by rock fills. The main feature of this method is the uniform surface over which water can flow down the slopes and over the field. Each strip is watered independently through a stream of water from the upper end of the field as shown below (Radwan, 2008).

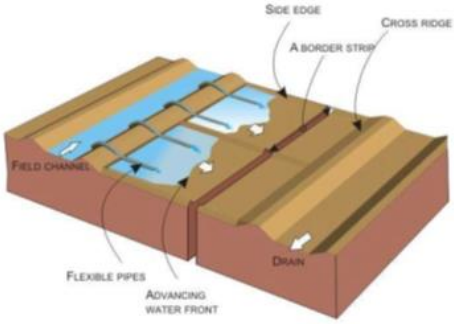


Figure 8: Border Irrigation (Radwan 2008)

Water spreads and flows down a strip at the border ridge, and as the water advances and reaches the lower end of the border the water supply is cut off. This method is however not well suited to small-scale farms reliant on manual and animal powered labour and cultivation (Radwan, 2008).

2.1.5.4.2. Basin Irrigation

Basins are flat areas of land surrounded by low bunds. These bunds prevent water flowing to adjacent fields. The basins are filled to desired levels and kept until water infiltrates the soil. The method can be divided into check basin and ring basin methods.

The size of the levelled land depends on the stability of the soil and the required water levels. Water is diverted through the check basins by a supply channel system and ditches. The basin size is determined by the criteria below (Radwan, 2008):

Table 3: Basin Size Criteria (Radwan, 2008)

Basin Size	Criteria
Large	Steep slope of land High sand profile in the soil. Small stream size into basin Small depth requirement for irrigation application Manual labour for field preparation.
Small	Flat slope of land Clay-like Soil Large stream size into basin Large depth requirement for irrigation application Field preparation is mechanized.

Basin irrigation is a method suitable for various field crops, and ring basin irrigation is suitable for tree growth (Radwan, 2008).

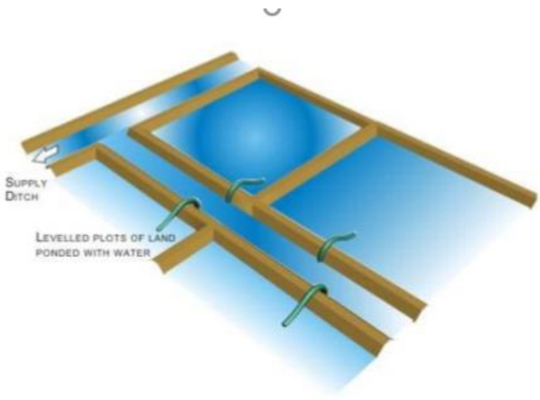


Figure 9: Basin Irrigation (Radwan, 2008)

The major difference between border and basin irrigation is that in basin irrigation water is applied to a nearly level field where water can dam or pond for extended periods of time, and border irrigation uses dykes, which divide a sloping field, to let water flow into rectangular strips of divided field and drains at the end. The dykes contain water and do not rely on ponding as in basin irrigation. Basins are small and have inflow rates of about >100 *Ls^-1*. The size of a basin is determined by the balance of the slope, water supply, and soil infiltration rate. Efficient basin irrigation requires level fields where the water depth reaches between 5 and 20 *cm*. This ensures that higher elevation fields receive the same amounts of water (Bjorneberg, 2013).

Drain back level basin irrigation consists of a series of parallel basins that receive water from a 5-10m shallow ditch. After a basin is filled, a gate is opened so that the adjacent basin can be filled. The process is repeated until each basin is filled. This improves uniformity by reducing the amount of water at the inflow zone and subsequently increases the advance rate between basins. Where there are slopes in fields, border irrigation is more applicable than basin irrigation. Areas between dykes can be 3 to 30 *m* wide and up to 400 *m* long. The field slopes between diked should, however, be close to level to ensure that water flows uniformly down the field. Water can be supplied from open ditches with gates, breaches, or siphon tubes. Basin and border irrigation are less labour intensive since water is supplied to larger areas from fewer outlets (Bjorneberg, 2013).

2.1.5.4.3. Furrow Irrigation

Furrows consist of small channels that carry water down land slopes that flow between crops rows. As water moves down the slopes it infiltrates the soil of the crops. This method is suitable for all crops and crops that cannot stand water for long periods of time. Water is supplied to the channels through a dedicated supply channel that contain breaches at the embankment where the furrow channel starts. The method is applicable to all soil types except of sandy soil, which would provide inefficient lateral distribution of water between furrows. Furrow irrigation for earlier cultivation of crops and occupies less surface area (Radwan, 2008).

In furrow irrigation systems, water flows in periods from 12 to 24 hours. The length of irrigation time depends on furrow length, water management practices, and soil properties. The inflow rate into furrows can range from 10 to 100 *L min^-1* due to the same type of consideration. In an ideal system, 25 % of the total irrigation time should be used for water to advance across the crop field to uniformly irrigate the field. Flow rates should be carefully managed on fields with slopes steeper than 1 % to avoid soil erosion. Soil with a low infiltration rate should receive longer durations of low inflow rates of water to ensure that the desired amount of water is applied to the soil. Higher infiltration rates are required for crop fields with low slopes and/or high soil infiltration rates. Siphon tubes, gated pipes or ditches can be used to relay water to furrows. Furrow irrigation requires lower capital investment, less technical knowledge, and higher labour resources than other irrigation methods. It is not well-suited to automation because the water flow rates must be adjusted for each furrow in the irrigation system (Bjorneberg, 2013).

2.1.5.5. Subsurface Irrigation Technologies

The methods below explain the technologies that supply water directly to crop roots below the surface area. This method reduces surface evaporation losses and enables less hindrance to cultivation which takes place on the surface. The two different methods to provide water below the surface, are described below (Radwan, 2008):

2.1.5.5.1. Natural Subsurface Irrigation Method

Under favourable conditions of topography and soil, the water table could be close enough to the root zone for water to reach it through the upward capillary movement in the water table. The natural flow of water may not provide the required amount throughout the crop growing season, and can be supplemented by constructing deep channels in the fields filled with water to preserve water table levels at the desired elevation above root zone depths. The method is favourable to the following conditions:

I. Permeable soil in the root zone.
II. Presence of an impermeable substratum below the water table that prevents deep percolation of water.
III. An abundant supply of salt free water. If there is too much salt it can move upwards along with moisture and lead to salt incrustations on the surface.
(IIT Kharagpur, 2008).

2.1.5.5.2. Artificial Subsurface Irrigation Method

Maintaining the desired water table below the root zones is accomplished by providing perforated pipes laid in a network pattern below the soil surface at a desired depth. This method is only applicable if the soil in the root zones has a high horizontal permeability to provide free lateral movement of the water and low vertical permeability to prevent deep percolation of the water. The pipes are very closely spaced when uniform water distribution is needed. To avoid interference and the hindrance of pipes, they should be buried at no less than 0.4 *m* below the surface. This method is known for being expensive, having unsuitable distributions of subsurface moisture, and having the possibility of clogging the perforation of the pipes (Radwan, 2008).

2.1.5.6. Sprinkler Irrigation Technologies

This method simulates natural rainfall but distributes water uniformly to the field surface at a rate less than the infiltration rate of the soil to avoid surface runoff. Water is supplied through a system of pipes that pumps water through sprinkler holes into the crop field. The method is suitable for undulating lands with poor water accessibility, sandy or shallow soils, or where uniform water distribution is required. There is no land levelling required as with surface irrigation methods. The water running through the pipes should be free of suspended sediments and is therefore not suitable for crust-forming soils where it would block the sprinkler nozzles. A sprinkler irrigation system normally consists of a pump unit, laterals, sprinklers, and mainline or sub-mainlines. The layout of this system is shown in Figure 10 (Radwan, 2008).

Sprinkler irrigation is suited for most row, field and tree crops and can be applied under or over the canopy. Large sprinklers are not applicable to sensitive crops such as lettuce since water drops can damage the lettuce. Sprinkler irrigation has a relative high efficiency which is dependent on climate. It has a 60 % efficiency in warm climate, 70 % in moderate climate, and an 80 % in humid or cool climates (Radwan, 2008).

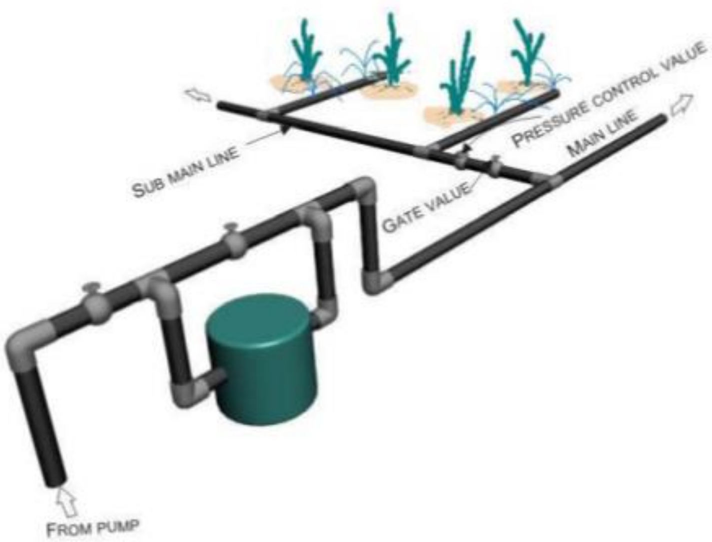


Figure 10: Sprinkler Irrigation System (Radwan, 2008)

The pump, usually a centrifugal pump, takes water from a source and provides the desired pressure to deliver water into the pipe system. Mainline and sub-mainline pipes provide water to the laterals. These pipelines can be laid on the surface or placed underneath the soil surface. The pipelines can be constructed with cement, aluminium, or plastic. Radwan (2008) recommends the following when operating sprinkler irrigation systems:

I. Avoid irrigation during high winds.
II. Avoid applying more water than what crops need.
III. Apply consistency of irrigation equipment along the entire system.
IV. Use properly sized risers to prevent crop interference.

V. Make use of consistent maintenance techniques.

VI. Keep sprinklers kept steady and in a vertical position.

VII. Maintain pump pressure of at least 4.5 *bar* by keeping the suction sump clean (Ismail, 2003).

Laterals are the medium that delivers water from the pipelines to the sprinklers. They are portable more often than permanent, and can be made from aluminium or plastic.
The types of sprinklers used most in agricultural practices are:

I. Perforated pipe systems: Holes are perforated in lateral irrigation pipes at certain locations in a desired pattern to distribute water uniformly. The water sprays both ways and each pipe can cover areas from 6 *m* to 15 *m* wide (Radwan, 2008).

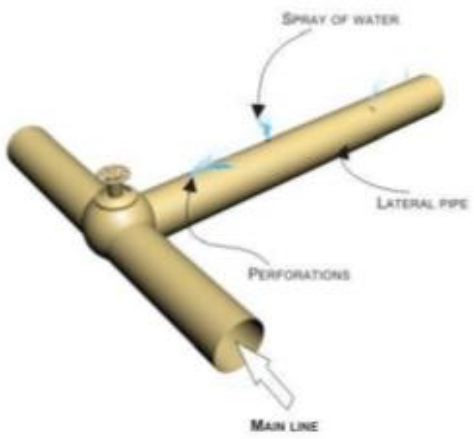


Figure 11: Perforated Pipe System (Radwan 2008)

II. Rotating head system: Small nozzles are placed on riser pipes placed at uniform lateral intervals. These lateral pipes are usually laid on the ground surface. The sprinkle nozzle rotates through a mechanical arrangement powered by the thrusting of the water (Radwan, 2008).

The three main categories associated with sprinkler irrigation are: solid-set, moving and set-move. Sprinkler irrigation can be applied to a wide variety of field crops, orchards, vegetables, pastures, and turf. It is also applied to frost protection, dust control in animal operations, and waste water. Solid-set sprinklers are set for single operations, and set-move systems are mechanically or manually moved to other parts in a field when a set operation is completed. The moving systems continuously applies water through the field as it moves.

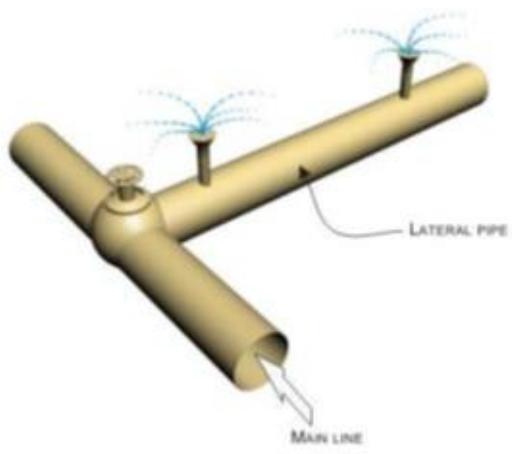


Figure 12: Rotating Pipe System (Radwan, 2008)

Sprinkler irrigation is more efficient than surface irrigation since the water application is controlled. In hotter and high wind areas sprinkler irrigation loses its significance since evaporation and wind drift cause water losses. An important part of sprinkler irrigation is system maintenance since worn-out nozzles and pipe leaks reduce water applicability and system efficiency (Bjorneberg, 2013).

2.1.5.6.1. Solid-set Sprinkler Irrigation

This system is typically designed to deliver small amounts of water at frequent intervals to meet crop needs every 1 to 5 days. The application rates for field crops range from 4 to 6 *mm h^-1* and 5 to 30 *mm h^-1* for turf applications. Fixed costs for solid sets are the most for any sprinkler system since the whole irrigated area is equipped with sprinklers and pipes. Due to the set state of the sprinklers, labour costs are reduced and plants are less stressed since water can be applied at any given time. Solid-set sprinklers are reliable and uniform and good with high value annual crops that have a low tolerance to water stress (Bjorneberg, 2013).

2.1.5.6.2. Set-move Sprinkler Systems

Set-move sprinklers apply water at a slow rate from 4 to 6 *mm h^-1* between intervals from 8 to 24 hours. After the completion of an operation, the system is moved to an adjacent area for the next operation. Moving cycles can last between 7 to 10 days, and can be divided between hand-move and side-roll systems. The first system can comprise one single sprinkler or a system of line arranged sprinklers. A line of sprinklers is typically made up of 9 to 12 *m* long pieces of 75 to 100 *mm* diameter aluminium pipes with a sprinkler mounted on one of the ends or in the centre of the pipe. Individual pipes are connected from an irrigation line, which has a length of around 400 m after an operation is completed; the line is then disconnected and manual labour is required to connect each piece 10 to 20 *m* to the next set (Bjorneberg, 2013).

Side-roll systems, also known as wheel lines, are a similar concept having a large diameter from 1.5 to 3 *m* diameter and is mounted in the centre or on the end of each aluminium pipe that elevates the sprinkler. After the operation is completed, the pipe is drained and is moved via an engine to the next area (Bjorneberg, 2013).

2.1.5.6.3. Moving Sprinkler Systems

This system is made up of centre pivot, travelling guns, and linear move systems. The travelling gun consists of a large capacity sprinkler mounted on a cart that is pulled across the field by either a cable or the water supply hose. The irrigated area stretches 50 to 100 *m* wide and 400 *m* long. There are centre pivot and linear move systems, which consist of one or more spans of sprinkler pipe elevated by A-frame towers. The towers are hydraulic or electric-powered motors and elevate the sprinkler to around 4 m above the ground. The centre pivot serves as a stationary point and the towers move in a circle. Water is supplied to the system from the pivot point. A typical centre pivot system has eight spans, a length of around 400 *m*, and irrigates areas from 40 to 60 *ha*. Centre pivot systems are widely applied due to their ability to irrigate large areas uniformly with little labour. After an area is irrigated the centre pivot is moved. In the United States 45 % of irrigated fields make use of this technique (Bjorneberg, 2013).

The overall cost of an irrigated area is reduced by increasing the total length of the centre point; the irrigated area per unit length is thus increased in distance from the pivot point. The water application rate increases with more distance from the pivot point because each of the spans have to irrigate a larger area for each revolution. A 50 *m* span from the pivot point irrigates 0.8 *ha* while a 350 *m* span from the pivot point irrigates 12 *ha*. The application rates of these systems often exceed the infiltration rate of the soil around the pivot point. Linear move systems have a control unit at one end or in the centre to irrigate square fields. Drive units, the power source, can be equipped with a pump so that the water can be supplied from an open ditch flowing parallel to the direction of travel. Increasing the distance systems travel reduces the system cost per irrigated area. Modern systems have low pressure sprinklers; 70 to 200 *KPa*, mounted on tubes extended below the irrigation pipe, so the height of the sprinklers varies from 1 to 3 meter above the soil and the wetted diameter ranges from 3 to 20 *m*. The sprinklers can be manufactured to have fixed or rotatory spray plates that can be adjusted for their application rates and water droplet sizes to meet field conditions and operator preferences. A common preference is to have sprinkler pressure regulators that maintain constant nozzle pressures and a system that can be moved around the field at varied heights. These sprinklers have minimised drift and have 100 *KPa* nozzle pressures. Technology applications change continuously for the centre pivot operation, and can be developed to communicate with irrigation machines through cell phones, satellite radios and internet systems. Speed and zone controls can be applied through technology (Bjorneberg, 2013).

2.1.5.6.4. Drip Irrigation Technologies

This method involves dripping water onto the soil of the crop area at very low rates, varying from between 2 to 20 litres per hour. The water drips from a system of small diameter plastic pipes with outlets known as emitters or drippers. Water is dripped close to the plant so that the soil in which the root grows is wetted and not the whole soil profile. Water is applied more frequently and provides a favourable high moisture level on the crop soil. Figure 13 gives a standard layout of a drip irrigation system.

Drip irrigation is characterised by meticulous and frequent application of low volumes of water through cavities spaced along polyethylene tubing or pipes. This technology was first adopted by growers of high value crops such as tomatoes, strawberries, peppers, and melons (Bevacqua, 2001).

Radwan (2008) recommends the following steps:

I. After the system is installed, flush the system the rid it of soil sediments.
II. Clean the filters should regularly.
III. Clean or replace emitters when they are plugged.
IV. Inspect hoses regularly for cracks and leaks.
V. Inject phosphoric or nitric acid towards the end of the irrigation cycle to prohibit the growth of bacteria and chemical precipitation, and keep the acids in the system until the start of the next cycle.
VI. Pair only soluble fertilisers with drip irrigation; the nitric acid can be used to facilitate water solubility of potassium sulphate at a rate of 0.1 litre in 200 litres of water.
VII. Use fertilisers in the middle region of the irrigation cycle (Ismail, 2003).

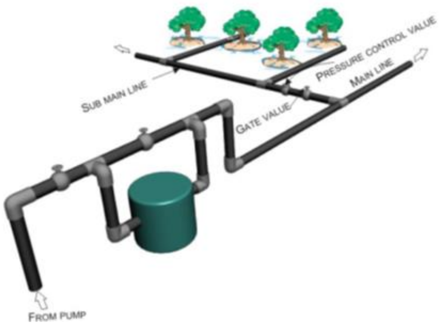


Figure 13: Drip Irrigation Systems (Radwan, 2008)

This system consists of laterals, emitters, control head, pump unit, and main and sub-lines. The system is suited to areas with marginal water quality and steep sloping land where water or labour is expensive or where there are high value crops that require frequent water application. It is more economical for orchard than for other crops due to orchard crops being well spaced which allows for maximised water saving. Drip irrigation has an excellent ability to adapt to saline water. Due to constant moisture content salt levels are kept below the critical point. Drip irrigation systems therefore have high efficiency (Radwan, 2008).

Micro irrigation is a system that minimises water loss through applying water at low rates and pressure onto focussed areas to reach root zones. The system is typically automated and makes use of drip emitters along the pipe. The system is compatible with irrigated trees, vineyards, orchards and shrubs. Water is applied at a constant rate to obtain optimal soil water content near plant roots. Optimal filtration is needed for micro irrigation as sediment and algae can plug emitter openings, micro sprays, and bubblers. Chemical treatment is sometimes needed to combat the plugging of emitters. The system consists of polyethylene pipe with pre-installed emitters at regular intervals which are attached at desired locations. Flow rates vary from 2 to 7.5 *L/h*, and *a* pressure varying emitter maintains flow rates while varying the pressure from 70 to 200 *kPa*. This is a common application in vineyards (Bjorneberg, 2013).

2.1.5.6.5. Comparing Irrigation Technologies

The introduction of efficient irrigation methods is an important factor in modern agriculture. The development of automation in the agricultural sector increases the efficiency of irrigation water and allows for saving up to 15 to 20 % of irrigation rates (DWMM, 2015).

Drip irrigation has been more efficient with water saving compared to other irrigation technologies and has resulted in:

I. A saving 20 – 24% of water for vineyard irrigation and a yield increase of 48 %.
II. A saving up to 50% of water for tomato irrigation and a yield increase of 29 %.
III. A saving up to 27% of water for cotton irrigation and a yield increase of 53 %.

A drip irrigation system consists of a water source, valves, pressure regulator, filter, pump, injector, backflow preventer and a distribution system of tubes and pipes. The system is automated by adding solenoid valves and a controller. The conversion from furrow irrigation to drip irrigation has proven to be challenging as it requires many changes in production practices. Some of these changes are crop rotations, the management of soluble salts, soil borne pathogens, minimum tillage and fertiliser and soil amendments. The conversion has also brought about important economic consequences. A study in 2000 conducted in southern New Mexico highlighted these consequences, and Table 4 below illustrates the changes experienced (Bevacqua, 2001).

Table 4: Changes Experienced When Converting from Furrow Irrigation to Drip Irrigation [Adapted from Bevacqua, 2001]

Changes experienced when converting from furrow irrigation to drip irrigation		
Change	Increase/Decrease	Percentage
Crop production	Increase	25 %
Chemical cost	Decrease	18 %
Fertilizer cost	Decrease	26 %
Capital cost	Increase	47 %
Fixed cost	Increase	19 %
Seed cost	Decrease	20 %
Net operating profit	Increase	12 %

We can compare the effectiveness of irrigation methods, and Table 5 offers a summary of theoretical efficiencies. It is evident that sprinkler and drip irrigation systems are more efficient than other surface irrigation methods. These efficiency ranges account for application variances from farmer to farmer.

Table 5: Irrigation Efficiency of Irrigation Systems (Bjorneberg, 2013)

System Type	Application Efficiency
Surface irrigation	
Furrow	50-70 %
Border	60-80 %
Level basin	60-75 %
Sprinkler irrigation	
Solid get	60-85 %
Set -move	60-75 %
Moving	75-95 %
Travelling gun	55-65 %
Drip irrigation	80-95 %
Sub irrigation	50-80 %

In a study conducted by the International Journal of Interdisciplinary Research in Arts and Humanities in the Bijapur district of Karnataka where a group of 165 respondents were surveyed, it was found that 83 % of the respondents make use of drip irrigation and the rest use sprinkler irrigation. The main reason for the selected method is the benefit of reducing water waste. The farmers also indicated that the use of modern irrigation systems enable improved control over water usage and a reduction in water wastage. The study found that there is a clear correlation between the type of irrigation and the satisfaction level of the farmer (Indhumathi et al., 2017).

Suggestions from the study were firstly, that the government should provide specialised loans and sanctions for modern irrigation technique users. Awareness programmes and training on modern irrigation techniques should be offered, and soil testing is required to determine the soil type that best fits the irrigation system technique. The following diagram (Indhumathi et al., 2017) captures the main requirements for irrigation systems:

Item	Flood irrigation	Sprinkler irrigation		Drip irrigation
		Hand-move	Fixed	
Soil type	Heavy clay to medium	Light sandy to medium	Light sandy to medium	Light sandy to heavy clay
Suitable location	Valley and Delta	Desert land	Desert land	Desert, valley, and Delta land
Land leveling	Required	Not required	Not required	Not required
System costs	Low	Medium	Above medium	Above medium
High wind	Not affected	Affected with possible spacing control	Affected	Not affected
Labor & effort	High	medium	Low	Low
Irrigation efficiency	Low 50%	Medium 65%	Above medium 75%	High 85%
Suitable crops	Most crops	Except long crops and trees	Except trees	Trees, vegetables, and row crops
Irrigation water salinity	Up to 1100 ppm	Up to 800 ppm	Up to 800 ppm	Up to 1750 ppm
Required pressure	None	3-4 bar	3 – 4 bar	1 – 2 bar
Maintenance	Low	Medium	Below medium	Above medium
Fertilizers injection	Not used	Possible	Possible	preferable

Figure 14: Requirements of Irrigation Systems (Indhumathi et al., 2017)

Irrigation efficiency can be calculated as the ratio between the surpluses of moisture at the root zone to the irrigation rate. The irrigation rate is calculated in consideration of the increase of moisture in the root zone, evaporation, runoff, infiltration into the depth of soil, and water loss in the pipelines of the irrigation area. The following tables compare the current irrigation techniques and capture the advantages and disadvantages of various irrigation methods (DWMM, 2015).

Table 6: Sprinkler Irrigation Advantages and Disadvantages

Sprinkler Irrigation	
Advantages	*Disadvantages*
Solid set sprinkler irrigation	
Good water control	High capital costs.
Automation and high irrigation frequency	System may interfere with field operations.
Fits various field shapes	
Set-move sprinkler irrigation	
Lowest capital cost of sprinkler systems	Highest capital cost for sprinkler systems.
	Poor performance in high winds.
Moving sprinkler irrigation	
High sprinkler uniformity	High capital and maintenance cost.
Lower labour intensity	Loss of suitability in fields without uniformity.
	Potential of wind and evaporation losses.

Sprinkler irrigation in general	
Suitable for irrigation of most crops	Irrigation with saline water adversely affects the foliage cover.
High irrigation efficiency	Problems of topsoil compaction associated with formation of the crust on the soil surface and increased runoff.
Provides extensive mechanization of all farming operations and their implementation in a short time	Complicates agricultural works.
Accurate water flow measurement	Water loss of the border of irrigation area.
Ease of application of fertilizers	Crops can get damaged by changing sprinkler system over and over.

For drip irrigation the advantages and disadvantages are:

Table 7: Drip Irrigation Advantages and Disadvantages

Drip Irrigation	
Advantages	*Disadvantages*
Increased yields with irrigation rates as water consumption per unit decreases.	Not suitable for anti-frost irrigation.
Wind has less effects on irrigation performance and uniformity	Adding additional technologies creates complex issues.
Reduces irrigation complexity and prevents water runoff	Loss of applicability in areas with sandy soils and strong winds.
Other farming practices can continue while irrigation takes place.	Difficult trade-off between increased yields and water savings with high investment costs.
Fertilizers can be applied directly to root zone.	Expensive.
No peripheral water losses.	In heavy soils, creates flow problems and water blockages.
Less weed formation	Requires frequent water treatment and filtration.
Possibility of smaller irrigation rates and shorter irrigation intervals.	
Less wet loss due to evaporation	
Less planning intensity when implementing	
High application frequency	

Surface irrigation measures compare as follows:

Table 8: Surface Irrigation Advantages and Disadvantages

Surface Irrigation	
Advantages	*Disadvantages*
Low capital investment	Low irrigation efficiency with high water losses.
Low energy/overhead and operation costs	Less control of water allows for diseases to spread amongst crops.
Possibility to apply irrigation when there are high wind speeds.	Systems are not applicable to sloping fields.
Suitability with crops susceptible to leaf diseases	

Border and basin irrigation technologies both lower labour intensities, and the other advantages are:

Table 9: Border and Basin Irrigation Advantages and Disadvantages

Border Irrigation		**Basin Irrigation**	
Advantages	*Disadvantages*	*Advantages*	*Disadvantages*
Lower labour intensity	Water flows over the entire soil surface.	Lower labour intensity.	Water flow backlog and levelling required for sloping fields.
Less runoff water possibility than furrow irrigation		High efficiency when paired with good design.	
Easier to manage infiltration depth			

Lastly, furrow irrigation technologies have the following advantages and disadvantages.

Table 10: Furrow Irrigation Advantages and Disadvantages

Furrow Irrigation	
Advantages	*Disadvantages*
Low capital and maintenance cost	Labour intensive.
Small channels for water flow	Possibility for soil erosion.
	Less control over water flow.
	Percolation losses and possible water runoff.

It is clear that irrigation technologies can benefit or limit farmers. Successful irrigation systems use technologies to save water, improve yields and increase the ability to control and monitor irrigation operations.

2.1.6. Irrigation Systems

Irrigation systems present commercial and subsidiary farmers an opportunity to manage water irrigation in places where water scarcity is a challenge. In many areas in Africa, irrigation is a manual practice. An irrigation system can automatically start/stop pumps on the irrigation area based on the soil moisture content acquired from a moisture content sensor in the soil of the irrigation area and using a temperature sensor in the water reservoir. The measured values acquired from a sensor is sent to a programmed microcontroller that configures a control algorithm. An irrigation system can prioritise certain irrigation requirements such as determining the number of pumps to be operated and which area of the irrigation site should be watered. Crops can therefore be watered based on their specific irrigation requirements (Ogidan, Onile and Adegboro, 2019).

2.1.6.1. Traditional Irrigation Systems

Traditional irrigation systems refer to the application of the abovementioned irrigation technologies to various crops and irrigable land. Traditional irrigation systems date back to Mesopotamia and Egypt 6000 BC. Farmers benefited from the free-flowing Nile River and used a combination of pulley and wheel-power systems to harvest water for crop production.

Current traditional irrigation technologies such as drip and sprinkler systems are used in stand-alone irrigation systems by connecting the system to a water resource and relying on manual human labour to operate, implement, and manage the system. Traditional irrigation systems are still a popular choice in small-scale farming communities, which means there is an opportunity to provide solutions that will enable small scale farmers to move into the next evolution of irrigation provided by Industry 4.0.

Besides upgrades and the modernisation of irrigation systems, improved irrigation systems and technical support are required for sustainable implementations and effective management. This is a major limitation in improving the economic value of farms. Irrigation scheduling, allocation of strategies, and other management of irrigated resources need to be intensified to improve water sustainability. Management strategies vary in objectives, which range from maximising economic return from crop yields to the level of crop variation. Another objective is the high priority of improving sustainability and water availability (Farahani et al., 2006).

2.1.6.2. Modern Irrigation Systems

Experts agree that irrigation systems and controllers compared to traditional irrigation controllers conserve more water across a variety of scenarios. Several controlled research studies indicate substantial water savings anywhere from 30% to 50 %. Tests by the Irrigation Association (IA) and International Centre for Water Technology at the California State University in Fresno have shown irrigation controllers to save up to 20% more water than traditional irrigation controllers (Hydropoint, 2017).

Ogidan et al. (2019) developed an Arduino-based drip irrigation system using the Internet of Things (IoT) that allows for efficient irrigation based on temperature, soil humidity and pH values sent to the Arduino microcontroller. This drives a solenoid valve through a driver circuit transistor, while sensor measurements are updated on the web and sent to the Android mobile device. The required fertiliser for the crops is suggested by the system based on the sensor measurements of temperature, pH, and soil humidity for the farmer to act upon.

Ogidan et al. (2019) also found that a Raspberry Pi processor with Linux can be developed to create web-based irrigation systems. The systems comprise a Raspberry Pi, DC Motor, temperature sensor, soil moisture sensor and humidity sensor. The DC motor can regulate the direction of water flow through the tubes. The sensor readings are compared with stipulated predetermined values and the system regulates itself around the values. The working of the system is sent to the user in real time. Systems can be designed to combat water scarcity by designing it to bypass irrigation sites that have enough moisture and can irrigate dry sites. This can be done using a soil moisture content sensor. Water management is a focal point when designing an irrigation system, but sustainability and water scarcity solutions have not been a focal point in the literature. There is thus a need to have an irrigation system that addresses economic sustainability (Ogidan, Onile and Adegboro, 2019).

Another study tested a prototype controller/receiver system consisting of a traditional irrigation controller modified to receive a signal broadcast via satellite. Outdoor water savings were calculated based on 2-years of pre-installation usage and were adjusted for weather conditions. The reported average outdoor savings was 16%, and it was also reported that this represents 85% of the potential savings based on reference ET. A water efficient irrigation study of the Saving Water Partnership, a coalition of 24 water purveyors, was conducted in Washington State’s Puget Sound. The water savings were calculated based on historical consumption, and adjustments were made for weather conditions. The reported water savings were 20,735 gallons per year per site for sites with rain sensors controllers and 10,071 gallons per year per site for sites using traditional controllers (Hydropoint, 2017).

2.1.6.2.1. Irrigation Systems and Industry 4.0

The agricultural sector has seen an increase in potential of yields and productivity and a decrease in environmental strain with the emergence of precision farming in Industry 4.0 technologies through system performance and decision-making technologies, real-time monitoring, and system control. . To design and implement a reliable, site-specific, cost-effective irrigation system, a deep understanding of emerging technologies, reference architectures, and specific capabilities are required. There is a wide spectrum of irrigation systems in the precision farming space, which makes it difficult to determine which system would fit which specific requirement. A reference architecture for developing irrigation systems is therefore needed. Information regarding market-ready and industrial technology integration is required to outline control specific elements for the system (Febriani, 2020).

Transforming an irrigation system to the I4.0 domain means it can perform process analysis, generate data, and communicate. Big Data, the Internet of Things, cloud technology and the horizontal and vertical integration of systems enable irrigation systems to perform in an Industry 4.0 capacity (Alabi, 2009).

Table 11: I4.0 Enabling Technologies in Irrigation Systems

Industry 4.0 Enabling Technologies	Description
Cloud technology	Assists in the irrigation practice to increase productivity, collaboration, decision-making support, predictive maintenance, and remote monitoring. • Sharing irrigation parameters to reduce water waste. • Real-time communication for operating the irrigation process. • A cloud model that stores, manages, and processes irrigation data.
Internet of Things (IoT)	IoT supports small-scale farmers to manage water usage and supply of water efficiently using smart devices. • Monitoring the irrigation process in real time • Ability to connect the hardware and software for the irrigation device. • Detect changes.
Big data	Big data availability enables strategic decision-making based on analysing and interpreting data. • Improves the performance of irrigation systems. • Collects data such as soil, moisture content and weather patterns. • Ensures the irrigation process performs according to data analysis.
Horizontal and vertical integration	The irrigation system integrates the stakeholders and components. • Allows for the different components of the irrigation system to be connected. • Passes on and communicates data between various systems.

Farming supply chains differ from traditional industry applications where information, product flow and knowledge are shared amongst producers and customers at every stage in the chain. Agriculture uses heuristic methods based on experience which results in environmental exposure and stochastic events contributing to higher supply chain uncertainty and a lack of predictability in rural farming communities. Precision farming enables agricultural management practices to turn their challenges into opportunities. Sufficient infrastructure, training, legislative environment, and willingness to adopt new technologies play a large part in digital transformation (Zambon, 2019).

For Agriculture 4.0 to succeed, modern telecommunication infrastructures and other technological advancements are of paramount importance in the transformation. Agricultural technology started with Agriculture 1.0 with the use of animal power, the combustion engine in Agriculture 2.0, and guidance systems and precision farming in Agriculture 3.0. In the current iteration, Agriculture 4.0, systems are connected the cloud. This occurs in parallel with Industry 4.0, which represents a combination of internal and external farming operations, providing real-time data at all farming sectors and processes. It offers an opportunity to address all uncertainties in the agri-chain. A 'smart' farm can adapt autonomously and in real-time to increase efficiency. It is achieved through constant communication between markets and production and within the system itself (Zambon, 2019).

The choice of the best irrigation systems depends on the information and data provided by the monitored field. Users can provide the system with features of soils, crops, and irrigation systems as well as analog measurements. Automatic weather stations can provide public weather data through the Internet. The sensors in the field use IoT technologies to provide users and algorithms with real-time data. To benefit management, the data must be readable and reprocessed to the same temporal windows. Data fusion is therefore required to improve soil data quality when there are several sources providing the same data types from the field. This fusion informs the decision algorithm on when to start irrigation. Industry 4.0 has enabled irrigation systems to perform the functions described below.

Data Gathering

Most sensor nodes which provide data on soil and weather are used on open low-cost platforms such as Zigbee, WIFI, LORA, ARDUINO, RASPBERRY PI, GSM and GPRS. These platforms are predominantly wireless. CoAP and MQTT are protocols for sending and storing data for irrigation systems. When the relevant devices are not turned into sensor nodes, data can be added manually through a mobile application. Weather station data provided from an automatic weather station near the field is carried to the system through HTTP (Campos, 2020).

Data Reprocessing

Several approaches exist for reprocessing soil data. Some detect soil data outliers and process these using noise filtration techniques. A pattern recognition of water consumption by a crop radicular system detects outliers based on a time-series analysis of soil moisture gathered at several depths during, before, and after irrigation. A framework provided by Campos (2020), allows farmers to define criteria for weather and soil data outlier removals. Algorithms such as Z-score, Chauvenet, Modified Z-Score and generalised ESD (Extreme Studentised Deviation) are used to achieve these removals (Campos, 2020).

Irrigation Management

Algorithms allow automatic irrigation by analysing gathered data from a wireless sensor node. Decision trees can determine the irrigation time and water need. Crops rules compare threshold values with soil moisture data and decide whether to turn the irrigation on or not. Matric potential and water balance decisions support platforms for the execution of irrigation management which enables farmers to manage IoT components for field monitoring. Soil data and captured images are used to determine the irrigation needs of these platforms. Web systems move beyond the visualisation of soil moisture and weather data from wireless sensor nodes by using crisp rules for data analysis, and send message to farmers to identify irrigation times or to irrigate automatically. Real-time weather and soil moisture data can be used stand-alone or the data can be combined to determine irrigation management practices. The SCADA (Supervisory Control and Data Acquisition) system can automatically carry out data gathering, planning, and the execution of water balance management (Campos, 2020).

Soil Moisture Prediction

Decision trees, linear regression, random forest, and gradient boosting with regression tree (GBRT) machine learning (ML) techniques are used to predict the most suitable irrigation plans based on soil and weather sensor data. GBRT is incorporated as a decision support service module in the system. Another prediction module uses support vector regression (SVR) and k-means machine learning on data, and forecasts soil irrigation requirements. A drought forecasting integrated system can use a matric potential at the depth of the crop root, water balance model, depletion indices, and crop stress measurements, to estimate soil moisture needs.

In Campos (2020), weather data, crop information, and irrigation water numbers are inserted in a computational model to estimate the daily matric potential of the most superficial soil layer, which signals when the crop needs irrigation. The predicted value is inserted into a Van Genutchen model to determine the soil moisture in fields without sensors. Local and global prediction models are used. The local model uses prediction for each monitoring field, and the global approach creates a single model that can be applied to any monitoring point. GBRT provides the best results when compared to linear regression, M5 Model trees and rules, RepTree, decision stump, random forest, and random tree approaches.

Soil Image Processing

When a soil image is captured, the image is a mixture of red, green and blue (RGB) colours. The image is converted to grayscale through the following equation:

2. Solar Image Processing

$$\boldsymbol{Global\ Illumination = 0.2989 * Red + 0.5870 * Green + 0.1140 * Blue.}$$

This histogram is constructed by determining the number of pixels at a certain pixel intensity of the processed grayscale image plus the values can lie between 0 and 255. Initially wet and dry pixel values are close to each other and can be offset by capturing a pure white background with the same illumination and then subtracting it from the grayscale image. The categories for soil moisture percentages are given as:

I. No wet content - completely dry soil
II. 15 % wet content- dry soil
III. 30 % wet content- conditionally wet soil
IV. 60 % wet content- moderate wet soil

V. 95 % wet content- wet soil

VI. 100 % wet content- completely wet soil.

This application was developed on Eclipse SDK 2.6.2 compiler and converted to an android application using an .apk file. The user determines a time interval where the camera module captures images of the soil. The application converts RGB into grayscale and then determines the soil moisture content. The values are transmitted to the GSM module along other data and stored in the memory of the smartphone (Barkunan, 2019).

IoT Platforms for Precision Farming

The SWAMP (smart water management platform) consists of components that allow for the implementation of various IoT applications for irrigation systems. Users can customise services for data gathering (MQTT or LoRa), processing, and the synchronisation of data with different crops, weather, and geographical locations. SWAMP is therefore very flexible. Agro-IoT provides the farmer with real-time data gathering, aggregation, and analysis in the context of smart farming. It enables the management of devices and event detection from data analysis. It does however not contain the modules for data synchronisation and outlier removal or for soil moisture prediction. For fields without soil moisture sensors, a water balance module is used without soil moisture data or a water balance module with soil moisture data generated by the predictive module. For fields with soil moisture sensors, a matric potential or water balance module with soil moisture data is used (Campos, 2020).

2.1.6.2.2. Benefits of Irrigation Systems

Within recent technological developments, there have been innovative systems developed for irrigation without farmers interfering in the irrigation process. Modern irrigation systems are employed to solve lack of water, reduce water waste, minimise labour requirements, and regulate the irrigation of crops. The fielding operation evolution has required high accuracy in the process to optimise output and crop quality plus limited production costs which are satisfied through such irrigation systems. With the increasing world population there is increased reliance on higher farming yields. Efficiencies have become important to deal with the declining abilities of farmers in the agricultural field, which has been a result of companies attracting workers away from farming practices in countries such as, for instance, Japan (Dell, 2018).

From the literature, the main benefits of using irrigation systems have been identified as follows:

Table 12: Benefits of Irrigation Systems

Benefits of irrigation systems	
Optimising water levels	Maintenance and Monitoring easy.
Determining irrigation needs based on soil moisture and weather data.	Platform for further applications.
Increased water usage efficiency	Time saving through atomization.
Increased profitability	Increased crop yields.
Less water waste (environmental and profit savings)	Specialized irrigation systems direct water specifically to each plant's roots. Because irrigation systems do not just sprinkle water like your typical rainstorm, surrounding weeds cannot and will not germinate. As a result, you will have less weeding to do.
Maximizing irrigation capabilities	It preserves soil structure and nutrient.
Minimising costs	Better quality crops.
Controlling crop production	

The economy of many countries relies on agriculture and it is therefore important to optimise their irrigation of crops. An irrigation system aids small-scale farmers to meet irrigation standards. Irrigation systems aim to reduce agriculture labour, control and save water, increase production while minimising water usage, and minimise manual labour through intervening in watering operations. The design of an irrigation system determines the benefits it provides (Dell, 2018).

2.1.6.3. Design of an Irrigation System

An irrigation system is designed to deliver water to the soil to provide plants and crops with water requirements. If the water applied exceeds the water requirements of the crops, the excess water infiltrates below the root zone and causes leaching in fertilisers, groundwater contamination, and a rise in the water table (Ismail, 2003).

Irrigation practices have had the biggest impact on the sustainability of the environment as they are the largest consumer of limited freshwater resources. In dry areas over 75% of available water is allocated to agriculture. In regions such as West Asia and North Africa (WANA), where there is extensive freshwater poverty, less and less water is allocated to agriculture. In this region, the per capita water supply is below the water poverty line of 1000 m^3/capita. This scarcity of water results in the overexploitation of groundwater and can cause quality degradation. Having access to water in dry regions is the biggest constraint in agriculture; in areas with water scarcity, there is still inefficient water usage. Although making use of irrigation produces more food, water productivity is still low, and soil and water quality is on the decline. This is due to poor water management practices on farms. In most countries in the WANA region, authorities have not provided successful policies for water allocation and incentives for water saving, which has led to overuse of water on crops. Sustainable water productivity can be ensured by applying appropriate measures such as the adoption of improved technologies, continuous policy improvements, and better water allocations. Water saving during agricultural practices can be divided into two parts:

I. Improve irrigation and network delivery efficiencies to reduce water losses.
II. Increase the productivity of crop water through the improvement of water, soil, and crop management practices.
(Farahani et al., 2006).

Applying water to fields enhances the quality, productivity, magnitude, and reliability of crop production. The Food and Agriculture Organization of the United Nations states that irrigation practices contribute to 40 % of the world's food production on about 20 % of the world's crop production lands (Bjorneberg, 2013).

Irrigation plays a pivotal role in food production. The expansion of production relies on the development of irrigation and water management systems under increasing changes in the environment. Modern irrigation systems are becoming more applicable as they are more effective and efficient. The techniques increase crop yields along with the help of fertilisers. Large scale modern irrigation techniques are also cost effective (Indhumathi et al., 2017).

2.1.6.4. Irrigation System Capacity

It is important to differentiate between the types of irrigation projects. The types are captured in Table 13:

Table 13: Project Types for Irrigation Systems

Project Type	Description
Major project	Projects that manage large water surfaces, namely irrigation areas over 10000 hectares.
Medium project.	Projects consists of medium storage size surface water and division structures and has irrigation areas between 10000 and 2000 hectares.
Minor project.	The projects are normally for irrigation areas under 2000 hectares. Irrigation normally uses water from ground water, tubes, wells, and water tanks.

This can help to determine whether implementing an irrigation system is worthwhile. It is also a consideration during budgeting for the launch of a system.

2.1.6.5. Selection of Irrigation System Components

Several questions can be asked to determine which irrigation method is available to the farmer. The following questions apply to small-scale farmers and irrigation selection.

Table 14: Key Irrigation Selection Questions

Key Questions for Irrigation Selection	Description
Is water available for irrigation?	Determining if the environment provides readily available water resources for irrigation development. The information used to determine this are the distance of the water source, weather data, available surface and groundwater resources, and water resource variability.
Which areas can be irrigated with the available water resources?	The delineation of the irrigable area that considers the landscape (field layout), distance and level of water resources with respect to the field, quantity and water availability, suitable soil, land to be irrigated, and field fertility.
Which irrigation techniques are relevant?	Matching irrigation techniques to environmental conditions and farming context, which includes operating costs, water resources (quality, quantity, and fluctuations), complexity and cost of the installation, and technical equipment and support services that are locally available.
What kind of crops can we irrigate?	Assessing the potential, traditional knowledge, and market for crops. Determining the percentage of crops to sell, seasonal irrigation decisions, and what crops would suit the environment.
What is the social and economic context?	Determining which irrigation techniques the farmer can master, what access and skills the farmer requires, and if additional training and resources are required.
What support services are available?	Assessing which public and private services and agencies are available to the farmers to educate, train or support them. These can be in the form of government agencies, online material, and NGOs.

Farmers need to consider several factors when adopting new technologies. Firstly, technical considerations. For an irrigation system to be implemented, certain technologies need to be available depending on the configuration of the system. Farmers should consider water supply availability and scheduling based on climate conditions, type of crop and soil, and the irrigation method coupled with the system. If farmers adopt a technology, they need to be knowledgeable to fully exploit the benefits of the system.

To ensure the implemented system will yield good crops and optimal yields, attention needs to be given to the type of crops, their variants, the cropping and irrigation calendar, agricultural practices, and the condition under which the crop is grown. To achieve this, farmers need to ensure they have access to resources to enable the benefits. The resources include seeds, fertilisers, pesticides, tools, and credit. Suitable crop selection considers crops that will do well in the market, crops that are used for self-sustainability, new crops enabled through using an irrigation system, the cropping calendar, and farmer knowledge. Economic considerations should be of high importance to the farmer. These range from investment costs to operation and maintenance costs (labour and energy), access to credit resources, and market access.

Social and cultural considerations are also of importance to the small-scale farmer. Breaking away from traditional farming practices can be intimidating at first. Ensuring farm labourers are accepting of the technology will ensure increased potential of success. It is therefore important to determine whether operators will be able to operate and maintain the system. Climate and environmental considerations influence the type of irrigation system used. Farmers can be exposed to extreme weather conditions, rainfall variability, and seasonal pests. These factors have an impact on crop yield and a suitable irrigation system needs to provide relief to the farmer with increased efficiency.

Restuccia defines an irrigation system based on the ability of the system to perform the following:

I. Adjusting watering times based on weather or soil moisture data on a daily basis.
II. Allowing the farmer to view and conduct changes to the controller from a computer, tablet, or smart phone.
III. Using sensors to monitor flow to perform real time water use analysis.
IV. Stopping the system from running when high flow is detected.
V. Generating reports that provide the user the ability to analyse data and perform water management decision making.

(Restuccia, 2016).

A selection of the most appropriate irrigation strategies must consider specific constraints as well as the more evident water saving advantages. The inter-connection between the appropriate irrigation methods, productivity, and crop economic success, is evident (Battilani, 2014).

Irrigation selection criteria differ from source to source. Battilani (2014) found that the operational boundaries which the farmer works under should be included in the selection criteria. These limitations include financial, weather, soil and knowledge requirements. FAO (1997) states that irrigation technology and methods should be considered as selection criteria, and that the criteria should consider the goals which the farmer wants the system to achieve. The criteria depend on various economical and geographical factors which should be included when selecting a system that best fits the farmer’s profile, crop, initial costs, labour requirements, water source, size and shape of crop land, fuel cost, and availability. Other factors to consider are whether the farmer owns the land or is leasing it. Also important is what equipment you use and whether you own it or are adapting leased equipment to use in your system (Tyson, 2015).

Table 15: Factors for Irrigation Selection (Tyson, 2015)

Factors for Irrigation Selection: (Tneutron, 2020)	Description
The depth of irrigation water supplied.	The amount of water stored at the root zone of the plants. At the time given for the purpose of irrigation water to sustain plant growth is to remain normal. It is influenced by type of crop, crop growth, type of soil, and whether there is a shallow water table or a barrier to the water.
Maximum allowable flow velocity (*Vmax*)	The flow rate of water that does not cause erosion. *Vmax* values are generally dependent on the type of soil, application per area and other soil factors.
Manning roughness coefficient (n).	This is a parameter in the Manning n value equation. It is used to measure the effect of the channel resistance when water moves down the drain, wall, or basin.
Flow Rate (F).	It is necessary to know the channel bottom slope or wall to estimate the flow rate. The flow cross-sectional area or depth of flow at each part of the channel as given by using the Manning equation.
Rate of Infiltration (I).	This metric is very important for the evaluation, design or management or surface irrigation systems. The infiltration rate is determined before designing the irrigation canal.

Netafilm (2020) states that:

"Precision irrigation requires an irrigation system that is designed and installed with all resources and production goals in mind, with the aim of ensuring optimal production"

This serves as the basis for the factors that influence irrigation system component selection as captured in the following table.

Table 16: Factors That Influence the Type of Irrigation System Chosen

Factors that influence the type of irrigation system chosen: (Netaflim, 2020)	Variables to consider when making decisions on irrigation systems:	From these variables' decisions are made on:
Landscape beds on separate zones from grass	Climate.	Crops and/or cultivar.
Sprinkler pressure	Soil type (physical and chemical attributes).	Soil preparation actions.
Sprinkler placement	Water composition and availability.	Fertiliser requirements.
Sprinkler nozzle selection	Topography.	Row direction, block design, roads.
Condition of the components	Availability of electricity.	Plant spacing, row lengths, block sizes etc.
Soil type, condition, and slope	Diseases and pests.	
Plant requirements		

Therefore, for an irrigation system, the small-scale farmer should consider site-specific requirements, farming and irrigation goals and under what limitations they are working. The irrigation system market also has readily available systems that can be used to satisfy various considerations.

2.1.6.6. Available Irrigation Systems

The irrigation market is divided into segments based on components, irrigation control, application, and geography (Allied Market Research, 2020).

I. Components: sensors, flow meter, smart detection/network elements
II. Irrigation controller: weather-based and sensor-based
III. Application: greenhouse, open field, residential, golf courses, turf and landscape and more
IV. Geography

The market leaders are Rain Bird Corporation, The Toro Company, Hunter Industries, Netafilm, HydroPoint Data Systems, Baseline Inc., Calsense, Rachio, California Sensor Corp and Weathermatic (Allied Market Research, 2020).

2.1.6.6.1. Types of Irrigation Systems

Irrigation systems can be subdivided into 4 levels of autonomy. In increasing level of autonomy they are: manual, semi-automated, automated, and smart. Irrigation systems use regional weather, site, or soil moisture data as a basis for determining appropriate watering schedules. Irrigation technology is rapidly increasing and improving to meet the needs of sustainable farming crops (GardenSoft, 2020).

The various types of controllers available for irrigation are classified based on their components and functions:

I. Weather-based controllers
II. Flow sensors –are used in conjunction with weather-based systems to detect problems such as broken sprinkler heads or risers, and provide a platform from which a controller can shut down the zone and flag it as a high flow condition. The water valve is continuously opened and closed.
III. Rain/freeze sensors –keep the irrigation system from irrigating when there is rain or under certain environmental temperatures.
IV. Sensor-based controllers

V. Pressure regulation – at certain pressures, the water distribution is most uniform over a target area, which allows for shorter run times on areas requiring less water and also eliminates the added risk which high pressures have on sprinkler damage.

VI. Drip irrigation

VII. Low precipitation rates – used to offer improved water distribution uniformity, which is important to reduce water run times
(Calsense, 2020).

2.1.6.6.2. Criteria for Available Irrigation Systems

Certain criteria are applicable to determine whether a product is considered a smart product or a product that can provide a digital service. To categorise the availability of irrigation systems controllers, certain criteria are established. These criteria are defined in Appendix B. The criteria given are necessary to develop the system configuration to articulate the benefits that an irrigation system will provide for the farmer. The criteria range from sensor type, to automation level, to capacity and price.

The inclusion of each of the criteria was determined by cross-examining the literature and information on available irrigation. The categorisation of each criterion was determined by examining the full range of criteria. The most suitable categories were determined and are given in Appendix B.

2.1.6.6.3. Categorising Available Irrigation Systems

Table 49 in Appendix A: *Criteria and Categories for Available Irrigation Systems* categorises current irrigation systems available in the market. These need to be evaluated to determine the need for developing your own. There was no geographical filter added to the procurement of the products, which means they could be developed in any country if they were available for purchase or to order. Consumer-ready products were found in the literature, project reports, internet websites and company pages. The products were categorised according to a logical process applied in the previous tables. In instances where the product qualified to be in more than one category, for example Hydrawise products, which are smart and connected through a browser and smart assistant application, are each a different category in the smart connectivity criteria. In these cases, the highest level in that category is given to the product.

2.1.6.6.4. Component Integration towards a Comprehensive Irrigation System

Ogidan et al. designed an irrigation system that addresses the water scarcity problem, as shown in Figure 15. The sensors comprise two parts; one is a moisture content sensor and the second an ultrasonic sensor. The first detects the amount of water present in the soil, converting it into an electronic signal and sends it to a microcontroller. The ultrasonic sensor, which is placed in a reservoir, detects the water depth below the surface of the sensor, converts it to an electronic signal and sends it to the microcontroller. Both signals are received as analog signals (Ogidan, Onile and Adegboro, 2019).

The second part of the design is the control. The Atmega 382 microcontroller on Arduino Uno works to coordinate the functionality of the SIS. The microcontroller receives analog signals from the sensors and converts them digitally. From the converted values the appropriate irrigation action is determined. An output signal is sent to the pump through relays. A liquid crystal display (LCD) connected to the microcontroller displays the soil moisture content, water level, and the active pumps for irrigation; these values are known as the state of the system. The system is powered by a 12 V DC source, and the algorithm was developed on Arduino with Arduino Integrated Development Environment (IDE) programming script and uploaded to the microcontroller (Ogidan, Onile and Adegboro, 2019).

The third part of the design stipulated by Ogidan et al. is water optimisation. This is applied by the microcontroller when it decides when and which pumps should be deployed for irrigation at a given time. The entire system is shown in block diagram form in Figure 15 where the components of the water optimisation are shown. They consist of sprinklers, pumps and relays that provide the water to the irrigation locations. In this system, Pump 1 to 3 delivers the water to the sprinklers that irrigates the three farms. The fourth pump acts as a feedback section where excess water from the farm is recycled back into the system to ensure that water is not wasted. This promotes continuous availability of water in times of water scarcity (Ogidan, Onile and Adegboro, 2019).

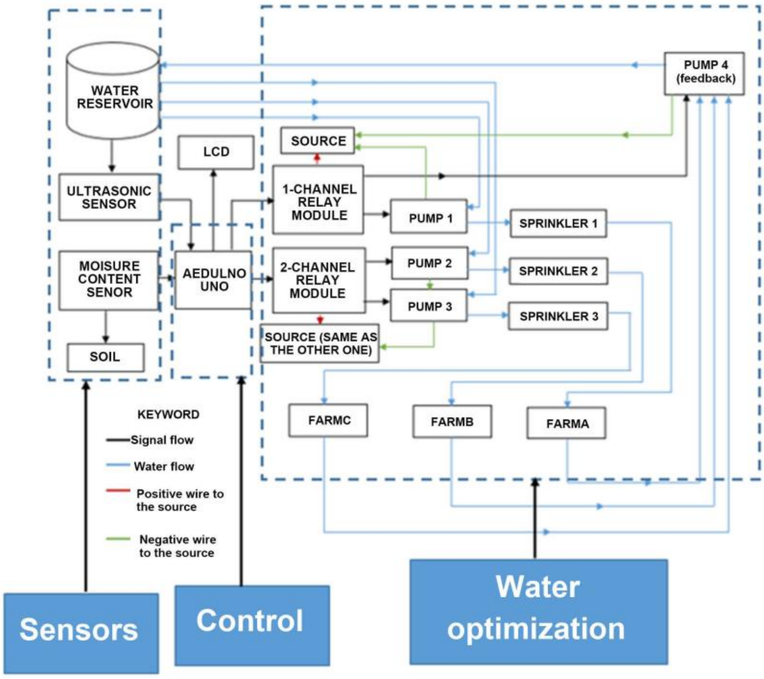


Figure 15: Irrigation System Block Diagram [Adapted from Ogidan et al. 2019]

This system was designed as a laboratory-scale architectural model and tested on different soil samples. The samples are dry, 6 % moisture content, and moist (84%) and wet (96%). The system consists of sensors, reservoir, farmhouse, pumps, and a control unit. The control unit algorithm is shown in Figure 16. The decision values and values in the diamond blocks indicate the different water levels in the reservoir. The control algorithm tests determine the soil moisture content and determines if it is dry, moist or wet. When it is dry, the algorithm moves on and determines the water level in the reservoir. When the level is detected, the appropriate pumps are turned on. If the water level is very low, no pumps are switched on (Ogidan, Onile and Adegboro, 2019).

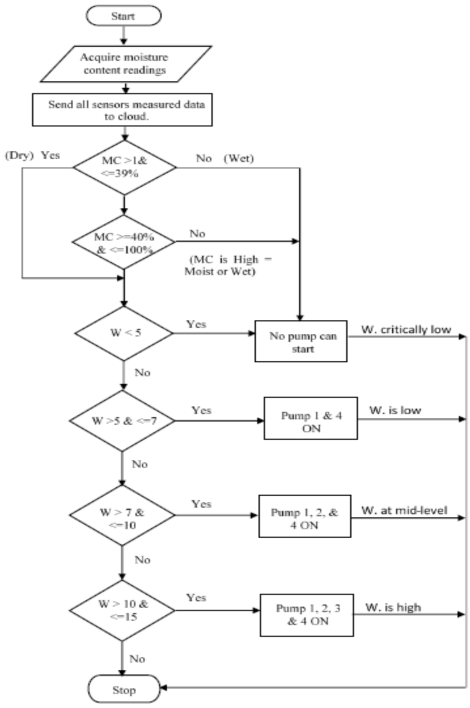


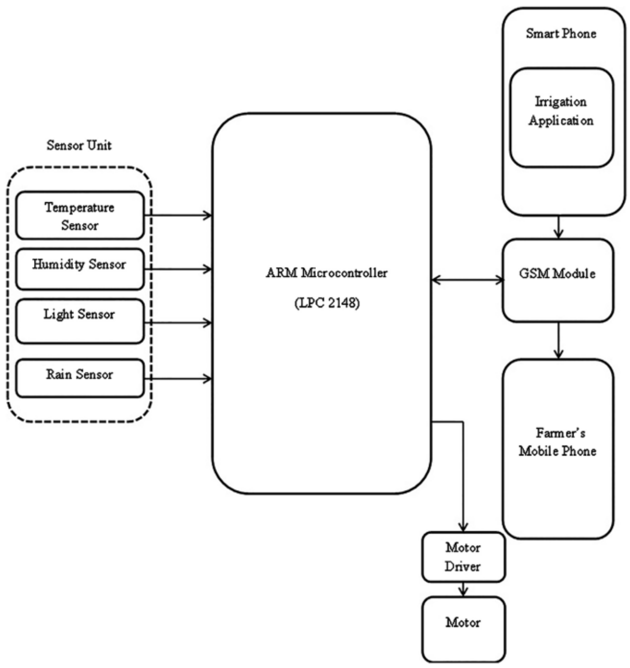
Figure 16: Program Logical for Irrigation Systems [Adapted from Ogidan et al., 2019]

This system would also promote longevity of the irrigation pumps as it switches off in times of water scarcity. It minimises waste and promotes sustainability by recycling water back into the system (Ogidan, Onile and Adegboro, 2019).

2.1.6.6.5. Irrigation System Architectures

Barkunan (2019) proposed an integrated site-specific irrigation controller using infield data feedback to assist in decision-making and real time monitoring. It can measure soil, temperature, and moisture. A PIC16F88 microcontroller is used to monitor crops and collect data. The germination of diseases can be detected by continuously monitoring the weather conditions. The system allows for real-time irrigation analysis from the physical parameter field values. A wireless information unit can be used to transmit the data to the user.

The sensor unit in the system collects physical data regarding temperature, humidity, light intensity, and rainfall from the irrigable field. The application is used to determine soil moisture content which is displayed on a smart phone. A global message system (GSM) is used to send and receive messages between the smartphone and the microcontroller. Based on sensor values, the ARM controller manages irrigation by controlling the motor unit that drives the irrigation rate and periodically updates information for the farmer to analyse (Barkunan, 2019).



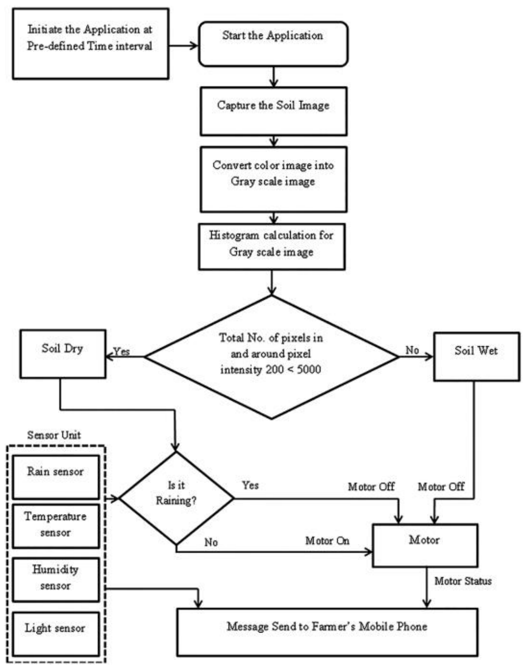


Figure 17: Irrigation Systems Conceptual Framework
Figure 18: Irrigation Systems Logic Flow

This application integrates with the soil image that is captured. It converts the image to grayscale and determines the histogram values from the grayscale images. From these values, soil moisture is determined and from the given parameters the system decides whether to irrigate or not. If the reading exceeds the threshold (5000 at 200-pixel intensity) the soil is wet enough, and no irrigation is needed. If it is below, the soil is dry and the sensor values are evaluated to determine the motor operating rate. Three instances exist based on moisture content and sensor values. The first is wet soil, and the motor needs to be turned off. In the second the soil is dry but rainfall is expected, and the motor is kept off. In the third, the soil is dry but no rainfall is expected, and the motor is therefore kept running (Barkunan, 2019).

The system can stop/start water pumps based on soil moisture data from a sensor while taking into an account data from an ultrasonic sensor in the reservoir that measures the water level. The Arduino microcontroller controls the values and configures the control algorithm. The system allows for irrigation operations by determining the number of pumps to be operated, plus their locations. It can therefore water crops depending on their requirements. Irrigation systems allow the reuse of water during irrigation and through that the health of the irrigation pumps is preserved (Ogidan, 2019).

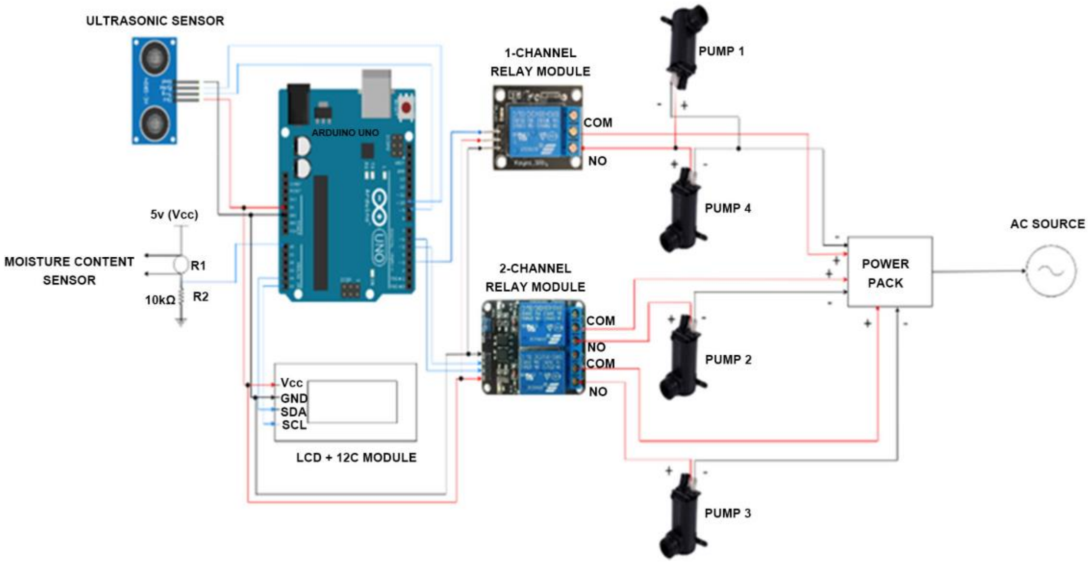


Figure 19: Visual Mapping of an Irrigation System (Ogidan, 2019)

In this system the soil moisture is measured and converted into a digital signal at the microcontroller. The ultrasonic sensor is used to measure water depth and sends an electrical signal to the microcontroller. An Atmega 283 microcontroller on Arduino Uno coordinates all the activities of the irrigation system, and sends digital control signals through relays to the pumps. An LCD connects to the microcontroller and displays moisture content, water level, and pump statuses. The controller derives its power from a 12 Volt DC source. The Arduino integrated development environment (IDE) is suited to develop the control algorithm (Ogidan, 2019).

Kakade (2014) provides a system using a soil moisture sensor which senses each field direction and sends data to the Raspberry Pi through a wireless network device. The microcontroller compares the value to the required parameter for soil moisture. When it is below the required value, the controller node switches on the irrigation motor. MQTT communication is used to communicate between the controller and the farmer's device.

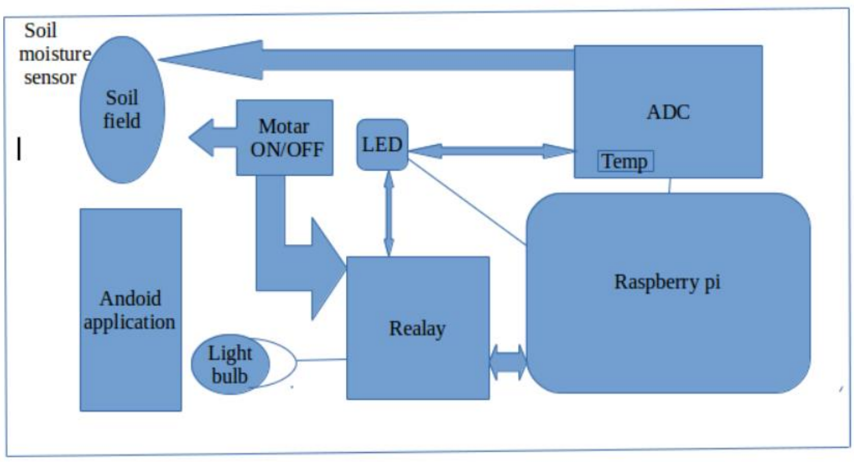


Figure 20: Irrigation Systems Control Architecture (Kakade, 2014)

Farmers periodically visit fields to check soil moisture content and therefor base their requirements for water supply on these measurements. They must travel to switch off motors and allow for sufficient water flow, which is very labour intensive since farmers need to irrigate multiple agricultural fields in various geographical fields. Automation of this process relieves some of these stressors, and the presence of the farmer is not needed in the field when sensors are used. The Raspberry Pi microcontroller sends messages to and from the field and the farmer through sensor nodes and a wireless networking device. When the soil moisture content is not at the desired level, the irrigation motor is switched on to irrigate the field. A block diagram for the microcontroller is given below:

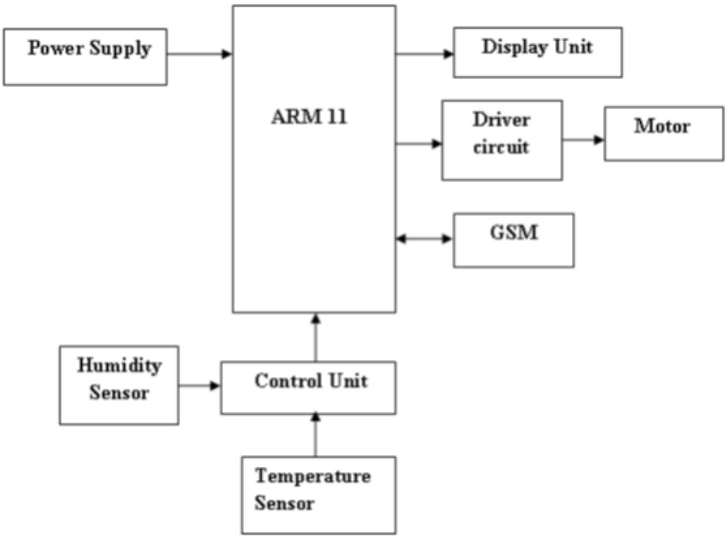


Figure 21: Irrigation System Architecture Template (Prasanna, 2016)

Roy (2014) proposes an autonomous irrigation system that uses climate criteria to adapt daily irrigation depths to the plant's needs. PLCs can measure temperature, radiation and wind which adapts the irrigation schedule to the observed conditions, which leads to improved irrigation practices that are cost effective and can adapt to climate changes.

2.1.6.7. Components and Functions

Akubattin et al. (2016) describe an irrigation system where pump control is processed when soil moisture thresholds are exceeded. Green House Monitoring and Controlling is a complete designed system that monitors greenhouse soil moisture and temperatures. It operates on a smartphone connected via Wi-Fi to a Raspberry Pi which connects to a soil moisture and temperature sensor. A schematic representation of the system is given by:

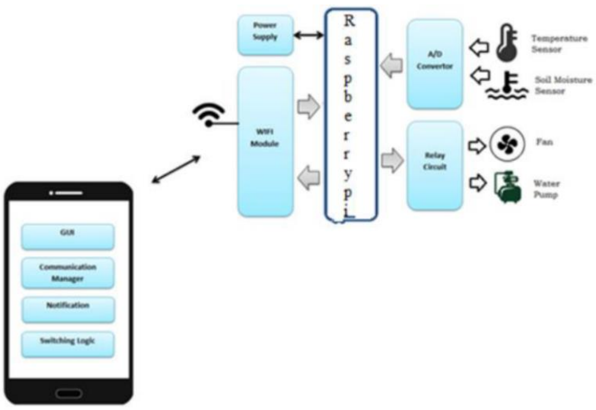


Figure 22: Communication Logic (Akubattin, 2016)

The Raspberry Pi connects the smartphone and sensors. The values from the sensors are compared with the threshold values provided by the farmer. The soil moisture sensor senses the volumetric water content in the soil. It consists of a soil level detection module where the user can provide a reference value. A temperature sensor allows the system to reduce irrigation in cooler temperature ranges to save irrigation requirements. The Android application serves as the client and receives inputs from the user. The GUI develops in the XML and receives inputs from his GUI. A breakdown of the structure is given in the following configuration:

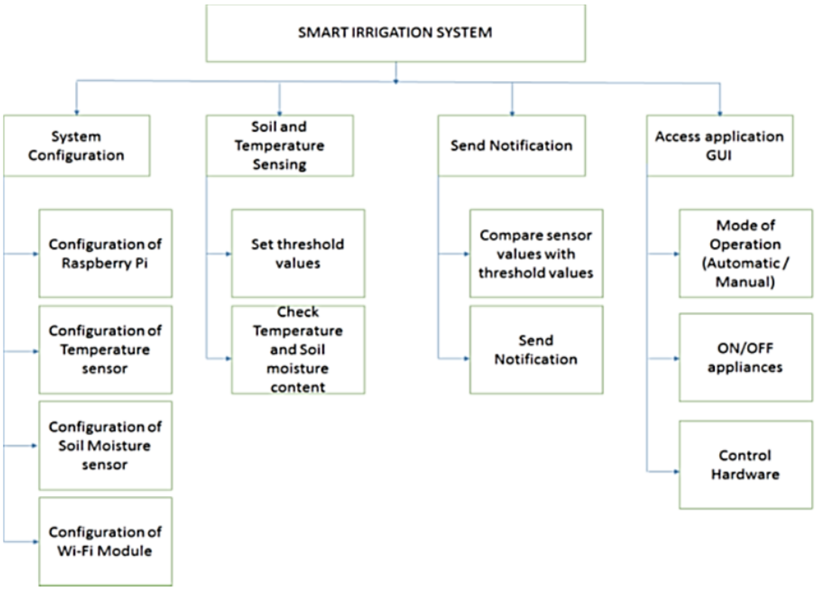


Figure 23: Smart Irrigation System Configuration (Akubattin, 2014)

The system configures all the hardware devices. The soil moisture sensor, temperature sensor and the Wi-Fi module are all connected through the Raspberry Pi. A Raspbian operating system is related to raspberry gpio connections with the soil moisture sensor and temperature sensor. The farmer receives a message when threshold values are exceeded, and can open the application and choose information from the control hardware, system on/off, automatic systems on/off functions and sensor values (Akubattin et al., 2016).

An automated irrigation system uses humidity sensors to find soil humidity, and based on this data, the microcontroller manages the solenoid valve. Java platforms are used to receive information through serial communication from the microcontroller. The system can determine fertilisers required for crops, and the best crops to cultivate for the climatic and soil conditions are updated to the server by monitoring soil PH level, temperature level, and other values. The crop is continuously monitored, and values (PH, temperature, and moisture content) are displayed on the LCD. The system improves cultivation methods and leads to better productivity. This leads to increased flexibility in monitoring the irrigation system anywhere through the internet.

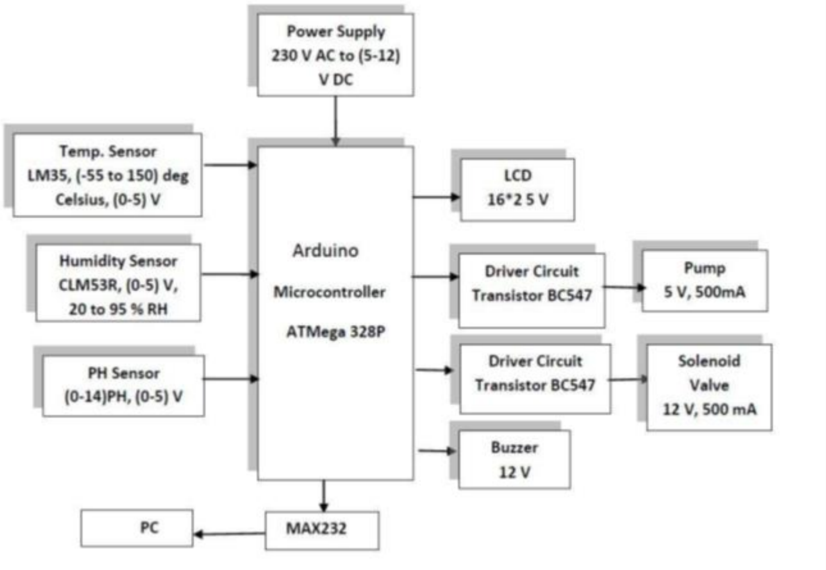


Figure 24: Irrigation System Component Architecture (Parameswaran, 2016)

Kakade (2014) and Barkunan (2019) provide outlines of the various components of irrigation systems and what their functions are. The main components of such systems are captured in the table below.

Table 17: Components of a Standard Irrigation Systems (Kakade, 2014) & (Barkunan, 2019)

Components	Description
Relay	Detects abnormal conditions in electrical circuits. They open or close load contacts in response to one or more electrical quantities like voltage and current.
ADC	Converts analog signals to digital code in binary. The analog output pin is connected to the input analog to digital converter in the ARM microcontroller.
Soil moisture sensor	Soil moisture sensors detect dielectric percentages in the soil. The HR 202 humidity sensor senses water vapour in the air. The range is between 20 % - 60 % humidity at a temperature of 0-60 *°C*. It operates in a range of 3.3 V to 5V and can produce analog or digital outputs.
Temperature sensor	Detects changes in temperature in the environment. The temperature sensor, LM 35 SZ temperature sensors, can sense temperature between −55 to 150 *°C*. It operates between 4-30 V and produces an output voltage of 10 *mV* per centigrade of temperature change.
Rainfall sensor	The rainfall sensor has two modules that detects rain and the other is a control module. The sensor has two separate PCB tracks that acts as a variable resistor which changes values according to the waterfall on the board. The module PRD80 operates between 3.3 *V* to 5 *V* and requires a current up to 20 *mA*.
Light resistor	The light dependent resistor (LD) converts light energy into electrical energy. In the system an ORP12 cadmium sulphide photoconductive cell is used. The cell resistance can be increased to 10 M ampere for a dark area.
Microcontrollers	Microcontroller that pulls power directly from the Raspberry Pi 2. Ground is used to ground the device and all nodes can be used at the same time as they are on the same line. UART is used to communicate with other devices, I2C allows the user to connect and communicate with hardware modules that support I2C protocols. SPIs enable communication to hardware modules that support SPI protocols. The LCP2148 microcontroller is a cost-effective reliable controller which has an operating voltage of around 3.3 *V*.
MQTT	Microcontroller that pulls power directly from the Raspberry Pi 2. Ground is used to ground the device and all nodes can be used at the same time as they are on the same line. UART is used to communicate with other devices, I2C allows the user to connect and communicate with hardware modules that support I2C protocols. SPIs enable communication to hardware modules that support SPI protocols.

Farmers are starting to use various monitoring and control systems to improve farming operations through automation based on parameters such as moisture, carbon content, light detection, soil pH which are monitored and analysed to increase yields. For a system to qualify as an irrigation system, functional and non-functional requirements should be met (Parameswaran, 2016).

2.1.6.7.1. Functional Requirements

When developing such a system, various functional requirements need to be considered. The requirements are listed below.

I. If the moister sensor is dry in the line (its location), the system will be checked by the rain sensor; if there is rain the system will not work because there is no need to irrigate, otherwise the system will check the temperature sensor with the light sensor and if the temperature is high and the percentage of light is high as well, the system will not work because the water will easily evaporate.

II. If the temperature is low, the light is low, there is no rain, and the moisture sensor is dry, a signal will be sent to the controller to open the valve(s) and pump.

III. If water level is low in the tank the system will shut down automatically and send an SMS to the user, by using the water level sensor.

IV. Flow meters should be able to indicate that there is a leak in a pipe in the irrigation system.

2.1.6.7.2. Non-Functional Requirements

Non-functional requirements refer to considerations that the system developer evaluates to determine which components to include, the level of performance the system needs to uphold, and under which limitations the system operates. Examples of non-functional requirements are:

I. Easy to implement: The materials required for the project must be easy to install for implementation of a successful project. The materials should also be easy to connect with each other to build the project and be more effective. The materials must be easy to replace in case of damage.

II. Open source: The controller open source for this project, so the hardware is reasonably priced and has free development software.

III. Strength: The tools needed for the project must be strong to operate for a long period of time to achieve the desired success. Another important goals is to save money.

IV. Quality: The tools required to build the project must be of excellent quality to operate for a long time. This avoids wasting money, technical problems, and disturbances in the process. Excellent quality is required for desired success.

V. Modifiability: The components should be chosen based on its ease of modifiability, so that it can be used across various system designs.

VI. Communication: The system should be able to communicate with the end user.

VII. Accuracy: The reading of all data should be detailed because it will be saved in an SD card for analysis and research.

VIII. Performance: The system must work in real-time.

IX. Operational: The system should operate automatically.

X. Cost: The cost of this system must be reasonable because we aim to decrease labour cost.

XI. It is also important to identify the system's stakeholders, users, and clients.

The requirements provide a pathway to knowing how to implement the system to perform the tasks and adhere to the requirements for irrigation.

2.1.7. Implementation and Operating the Irrigation System

As digital technologies such as automation and AI are becoming empowered by IoT and become part of all industries, everyone in the workplace needs to "skill up" to operate the technologies and add value to their businesses (Sulecki, 2020). In the agricultural sector, there has been growth in high-tech production techniques to increase the efficiency and effectiveness of farming operations. Along with technologies, knowledge thereof, knowledge to use the technologies, effective crop cultivation methods, and processing knowledge is now required. This rapid development in technologies has meant that farmers either cannot access the knowledge or do not have the knowledge at present (Skobelev, 2019).

This section explores the competencies, knowledge and skills required in the Industry 4.0 and precision farming context. A summary and categorisation of the findings are given in Appendix E. The tables give a summary of what the available components can provide in the irrigation system, and compound when added to the system. The farmer therefore has the opportunity to choose what benefits he or she would like to have in each component.

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2.1.7.1. Competencies, Knowledge and Skills

Agriculturists will always be reliant on domain knowledge (expertise learned from years of trial-and-error experience) but will need to adapt to perform smart agricultural functions. Real-world agricultural outcomes are being codified into data products and enhanced through AI and machine learning. The following skills are adapted from the World Economic Forum: (Sulecki, 2020)

Table 18: Knowledge and Skills Required as Defined by the WEF

Skill	Smart Agriculture Contextualised Description
Creativity	The novelty of technology allows users and developers to perform creative applications. There is room for development if results are achieved.
Emotional intelligence	Farming is said to be an art alongside being a science. Farmers need to be able to manage and understand their emotional connection to traditional methods and discern when their emotions are withholding them from adopting new technologies.
Complex problem solving	IoT and I4.0 technologies are becoming more complex and advanced. Farmers need to be able to solve ever-changing problems in increased dimensions.
Coordinating with other stakeholders	Farmers will need to lean on the expertise of others to perform smart farming operations. The entire labour force and management needs to be able to communicate and understand the new technology.
Critical thinking	It refers to the ability to think clearly and rationally, understanding logical connections between objects. It requires objective analysis and analysis of issues to form judgements.
People management	Managing those who are averse to adopting agriculture. Farmers require people skills to manage the pushback and frustrations from their labour force.
Cognitive flexibility	Farmers need to be able to think about different concepts simultaneously. Farmers need to react to changes indicated by smart farming systems, and they must be able to manage data overload.
Service orientation	Being able to recognise and meet others’ needs even before such needs have been articulated. Farmers need to manipulate systems to produce outcomes that meet their needs.
Negotiation	Farmers need to be able to reach agreements regarding acquiring capital and new technologies.
Judgement and decision making	Farmers need to be able to conduct analysis on data generated by systems and be able to act upon the data.

Precision farming practices are aimed at increasing the efficiency of agricultural practices. This is especially enabled through cloud technologies in precision farming management.

Farmers need to combine their knowledge base and multi-agent technologies to develop coordinated decisions regarding farm management. Precision farming practices can be divided into three stages:

I. Collection of information on the farm, crops, field, and culture

II. Data analysis and decision making

III. Decision implementation (agro-technical operation)

When creating smart systems, there is always the task of building knowledge of the domain it operates in and understanding the interrelations. Skobelev et al. (2019) describe using an ontological approach in describing a knowledge base. For smart systems, ontology is said to be knowledge based on conceptualisation. It involves the descriptions of objects and concepts, knowledge about them and relations between them. It should provide a vocabulary of concepts for knowledge exchange and relationships. The image below shows the approach of a knowledge base needed for crop production.

Boaz (1998) defines a competence as a critical behaviour (knowledge, attitude, values, abilities, behaviours, and personal attributes) that relates directly to successful performance by people in their work, responsibilities, and functions. Competences aid personnel in solving real problems and often represent the intersection of the individual, specialty, and context. Gehrke et al. (2015) conducted a study to determine the qualifications and skills that will be needed in the future from manufacturing workers. They followed a three-tier approach where they firstly identified the tools and technologies, organisation and structure, the working environment, and the cooperation needed within the industry. The second tier was to identify tasks and the last tier was completed by identifying the skills and qualifications needed to perform these tasks. From this they identified the skills that workers must, should, and could have in their skillsets to perform tasks in I4.0. Prifti (2017) indicates that the model can be followed to gather all competencies needed by a group and that it cannot be expected that all competencies will be mastered. Nevertheless, competency dimensions and the competencies that populate them can be identified and applied to a specific industry and the people working in the industry.

From the skillsets identified above and an analysis of the German and American education systems, they derived a framework for educating the workforce in three phases, namely early education, transition from school to work, and continuous vocational training. The figure below indicates the process and which methods should be used in each phase. Phases 2 and 3 are of importance in this study as they focus on those already in the industry performing farming practices.

		Technical Q&S													Personal Q&S							Eval.
		IT knowledge and abilities	Data and information processing and analytics	Statistical knowledge	Organizational and processual understanding	Ability to interact with modern interfaces	Knowledge Management	Interdisciplinary / generic understanding	Specialized knowledge	Awareness for IT security and data protection	Computer programming/coding abilities	Specialized knowledge about technologies	Awareness for ergonomics	Understanding of legal affairs	Self- and time management	Adaptability and ability to change	Team working abilities	Social skills	Communication skills	Trust in new technologies	Mindset for improvement	++ = Very Effective (>70% of max. effectiveness) + = Effective (>50% of max. effectiveness)
Early education	Mandatory school subjects	●	●	●	○	○	○	○	●	○	●	○	○	○						○	○	+
	School Internships		○		●	●	○	●	●	○	○	○	○	○	○	○	○	○	○	○	●	+
	Summer school initiatives	○	○	○	○	●	○	○	○	○	○	○	○	○	○		○	○	○	●	○	+
	Open day tours				○			○		○			○							●	●	
Transition from School to Work	2Yr. 'light' manufacturing degree	●	●	●	●	●	●	○	●	○	●	●	○	○	○	○	○	○	○	●	○	++
	Engineering mentoring program	○			○	○	○	○	○	○		○	○	○	○	○	○	●	●	○	●	
	Workshops	●	●	●	○	●	○	○	●	●	●	●	●	●	○	○	○	○	○	○	○	++
	Internships	○	○	○	●	●	○	●	●	○	○	●	●	○	○	○	●	○	○	○	○	+
	Professional Development Courses	●	●	●	○	●	○	○	●	●	●	●	●	●	○	○	○	○	○	○	○	++
	MOOC	●	●	●	○	○	○	○	●	○	○	●	○	●	○					○	○	
	Open day tours				○	○		○		○			○							●	●	
	University/industry collaboration	○	○	○	●	●	●	●	●	●	●	●	○	○	○	○	○	○	○	●	●	++
Continuous Vocational Training	MOOC	○	●	○	●	○	○	●	●	○	○	●	○	●	○	○			○	○		+
	Workshops	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	○	●	●	○	○	++
	Open day tours				●			○		○			○							●	●	
	Industry/university collaboration	●	●	●	○	●	○	○	●	○	○	●	○	○	○	○	○	○	○	●	●	+
	Department presentations				●		○	●	○	○			○	○	○	○	○	○	○	●	●	
	Professional Development Courses	●	●	●	○	●	●	○	●	○	●	●	●	●	○	○	●	○	●	○	○	++

● well-suited ○ suited - not suited

Figure 25: Training and Education Measures for PF Skill Development

Precision farming technicians apply geospatial technologies to agricultural management and production activities. They therefore are in direct operation with a smart system and need to be able to install, calibrate and maintain these systems. Mymajors (2020) describes the competencies, knowledge and skills required in the PF technician profession. Hecklau et al. (2016) developed a competency model to address the education which employees need to cope with technological complexities which are ever increasing in I4.0. They developed a strategic approach to qualify employees. Focus should firstly be placed on the largest competence gaps, and qualification strategies be developed through education. . Farmers should be able to use the framework to identify the skills needed to address their competency shortcomings. Prifti et al. (2017) developed a competency model in which they identified 68 I4.0 skills in the literature and presented them in a model in clusters under three disciplines comprising 8 dimensions of competencies. The disciplines are IT, IS and engineering. The dimensions are leading and deciding, supporting and cooperating, interacting and presenting, analysing and interpreting, creating and conceptualising, organising and executing, adapting and coping, and enterprising and performing. Analysing and interpreting was the most common dimension across the disciplines. Schrimpf (2018) provides 6 competencies needed to excel in precision farming. They are: knowledge of agronomy, knowledge of technology knowledge, understanding of agricultural economics, analytical skills, communication skills, and ethics. The broad range of competencies encompasses the multidisciplinary approach required.

2.1.7.2. Green Revolution

Green revolutions refer to a sequence of scientific breakthroughs and development activities that have resulted in increased food production in the agricultural industry.

Figure 26 was adapted from Cullum (2019) and explains the green revolution sequence. Skills are needed in data collection and actionable intelligence; combatting the challenge of more data does not bring about more economic value if the data is not well managed. Cullum identifies 5 skillsets that could contribute towards leveraging the technology better. They are:

I. Systems thinking: Design thinking, critical thinking, project management, problem solving, exponential thinking and process thinking.

II. Data management: Being able to store, analyse and collect data whilst providing security.

III. Soft skills such as collaboration, communication, customer service, sales, and general business principles.

IV. Basic natural science skills: Soil biology, plant, and animal knowledge.

V. Technological integration at low and high technical levels.

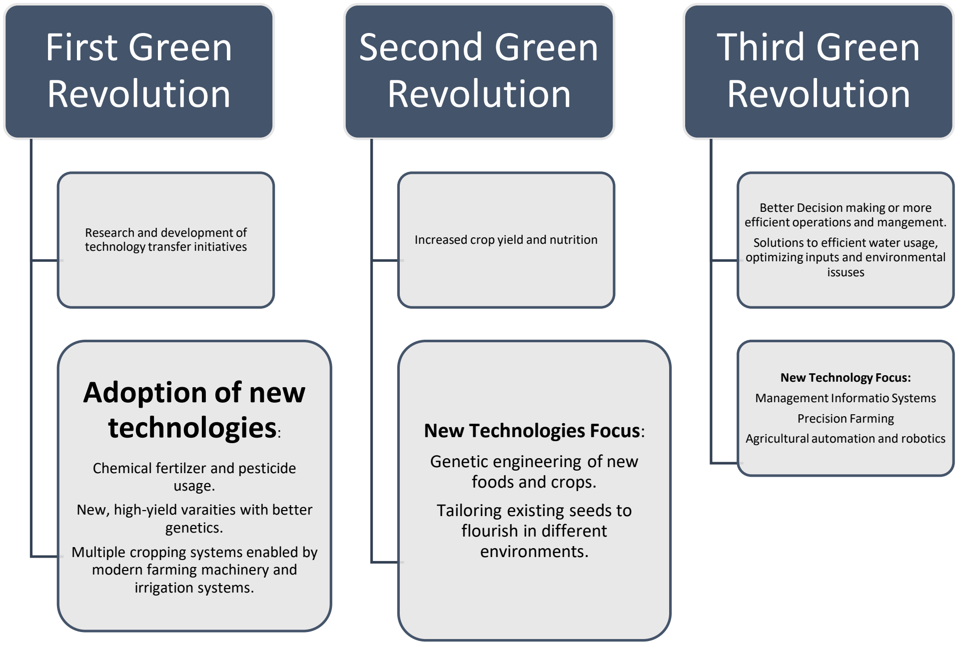


Figure 26: Green Revolution [Adapted from Cullum (2019)]

Cullum (2019) identified a gap between the use of technology in the agricultural industry and relevant training and education, and concludes that there is an increased need to invest significantly in reskilling the workforce because advancement in technology requires a highly specialised workforce.

2.1.8. Decision Support for Precision Farming

Decision support is a field concerned with providing resources to support stakeholders to make decisions. Small-scale farmers need support to implement precision farming. Each precision farming technology requires its own decision-making support. Mare (2017) argues that providing decision support tools results in positive impacts on economic sustainability, provides food more efficiently, and utilises resources better. In the literature, there are different decision support systems proposed to support farmers with their resources and operations.

Xu (2010), provided a decision support system which uses a service-oriented architecture that enables the development of an on-demand decision making model for agricultural production. Service-oriented architectures make software components reusable through the use of service interfaces that have a common language. This decision support system aided the development of a system that would fill the need to apply water and meet the needs of irrigation. In light of this, various architectural techniques need to be explored when developing a product such as an irrigation system. The high technical knowledge required to use the decision support system proposed by Xu (2010) could be of too high a level for farmers who are not familiar with technology. Bourgeois (2015) developed a decision support model which successfully implements a smart irrigation system

that can observe data from a distance, communicate with the farmer, and enable the farmer to include weather variables into his decision making.
Lindblom et al. (2017) found that farmers do not use precision farming to its full potential. The study found a problem with implementing PF technologies and argued that external stakeholders need to facilitate sustainable development to increase the implementation success of the technologies. Decision support systems should include the necessary support to increase the success rate of implementation and the transition from traditional farming techniques to PF.

Zhang (2021) found that opportunities lie within decision support systems and frameworks to develop easy-to-use tools with flexibility and to also increase levels of government support. It is noted that there is a need to provide support that is easy to use and easy to understand by the farmer. Current decision support in precision farming was reviewed in a study by Zhaoyu (2020), who found that the support was helpful in aiding farmers in performing various farming activities. The study also stressed the need to simplify the process in order to improve accessibility and usability.

2.1.9. Conclusion

Various precision farming technologies can be applied to farming and irrigation is no exception; technological advances are increasing the capacity of irrigation systems. The challenge lies in selecting the right components to design a system that fits the farming requirements. Farmers need knowledge and skills to operate and Industry 4.0 systems and need to adapt, learn and improve on current irrigation practices to keep up with advances.

2.2.Industry 4.0

The term Industry 4.0 refers to the next stage in the organisation and control of the life cycles of products. The fourth industrial revolution is the result of an increase in individualised customer needs and increasing variations in implementation, order, development, production, and delivery to the end customer.

Industry 4.0 is categorised by the real-time availability of information that is enabled through the networking of all the value-added actions involved in providing a service or a product.
Value adding networks can be optimised according to a range of criteria such as availability of resources, cost, and consumption of resources. They also have to be cross-organisational, real-time optimised, self-organised, dynamic and able to connect people. Industry 4.0 relies on the secure communication of cross-department companies in real-time over the entire life cycle of a product. Improved communication abilities through internet-based platforms enables adherence to all frameworks and requirements (Zvei 2016).

Industry 4.0 products are reorganised through digitisation. The products address the challenges of new manufacturing industries that shorten time-to-market, enhance flexibility, increase efficiency and ensure required quality (Löwen, 2016).

This section provides insights on the fourth industrial revolution and the potential impact it has on industry. It also evaluates reference architectures that provide standardisation for the development of Industry 4.0 products. The knowledge and skills needed to perform new I4.0 tasks are also articulated in this section.

2.2.1. Industry 4.0 Strategy and Goals

Industry 4.0 implementation strategies provide a cross-sector approach for technology, standards and business and organisation models, and lead to new automated value streams and networks enabled by increasing digitalisation. The core components are security of networked systems, standardisation through reference architectures and research, and innovation. Research and innovation provide the roadmap for implementing I4.0 concepts (Zvei, 2016).

Of concern is firstly horizontal integration through value creation networks. Here, the focus is placed on figuring out collaboration across companies which includes aspects and methods for new business models. Secondly, the end-to-end nature of engineering across a product's entire life cycle is evaluated. PLM-based engineering provides a link between products and production design which enables consistent support along entire value streams. This addresses technical points such as integrated system assessment, modelling, engineering, and simulation. Thirdly, vertical integration and networking of production systems, which enables knowledge transfer through the network. This ensures that all stakeholders in the production process have access to all the information generated in the process. New social infrastructures for work emphasise the value of knowledgeable employees. Lastly, I4.0 is concerned with the continual development of cross-sectional technologies that improves the current value offering of the product and service. Different prerequisites must be established to implement Industry 4.0 at different levels. Examples of such technologies are cloud computing, data analytics, cyber security, network communication and broadband networking (Zvei, 2016). The German Science and Industry Research Union provides action areas which identify where Industry 4.0 has the potential to influence future industries.

I. Standardisation: The standards of a reference architecture allow for cross-organisational networking and integration through value networks.
II. Complex system management: This is performed through integrating the digital and actual world and modelling to achieve automation.
III. Safety: It is important to provide guaranteed data privacy, IT security, and operational safety.
IV. Legal framework conditioning: This is required to create worldwide uniformity in contract law, digital asset protection and liability issues.
V. Industry-wide broadband for industry infrastructure: This satisfies implementation of the requirements of Industry 4.0 data exchanges in terms of volume, quality, and time.
VI. Training and further training: Employees need formulating content as well as innovative approaches in training.
VII. Work organisation and workplace design: This needs to be clarified in terms of the implications for people and employees as planners and Industry 4.0 decision makers.

VIII. Resource efficiency: Responsible resource handling practices are paramount.

A dual strategy will be followed by the German manufacturing industry to transform industrial production to Industry 4.0. The path towards Industry 4.0 is evolutionary. Existing technologies must be developed to enhance experiences and gain insights with respect to optimising entire value streams. Disrupting elements need to be implemented through new business models (Zvei, 2016).

2.2.2. Technologies in Industry 4.0

Digital technology has caused radical disruptions in various business industries and has become an integral tool for achieving business goals. Businesses should be supported to improve processes that improve digital innovation management. Frameworks that support improvements cover the following areas: value proposition, improvisation, user experience, skills, and digital evolution scanning. These areas need to be measured and evaluated to manage digitals service and product innovation. Table 19 presents the different areas to be addressed (Nylen and Holmström, 2015).

Table 19: Digital Product Innovation

Areas that support digital product and service innovation	
Key Area	Description
Value proposition	The value proposition should be clearly articulated by the company for each digital product and service. How value is created for users should be addressed. Assessments of the quality of value propositions are made on the dynamics of customer segmentation, service and product bundles, and commissions sent to channel owners.
Improvisation	Digital innovation is accelerated through employees interacting with new digital technology through active learning and assessing time availability to coordinate such learning.
User experience	Digital products should be easy to learn and provide rich user experiences. User experiences are measured on the level of engagement, aesthetics, and usability.
Skills	New digital products and services require new skills to understand and operate. Businesses should support continuous learning of digital technologies.
Digital evolution scanning	This process involves gathering information on new devices, digital channels such as mobile operating systems, web services and social media. This is done to identify and exploit opportunities for innovation across new user behaviours and user contexts.

Implementing digital innovation involves making informed decisions that cover products, their digital environment, and organisational properties. It requires businesses to continuously adjust their operations to harness the benefits of digital innovation. For businesses to successfully implement innovation managers need to be well-versed in specific technologies. Previously only macro-level topics were addressed when companies looked at digital innovation which resulted in high level descriptions of strategic innovations. Addressing the key areas mentioned above will cover the gap from micro level management to a macro-level perspective (Nylen and Holmström, 2015).

The unique properties of digital innovation processes require businesses to alter their established views and predetermined assumptions about the function and role of new products and services. Additionally, removing bias regarding their relationships with the digital environment and how the organisational resources are allocated, is required to support innovation (Nylen and Holmström, 2015).

New products are emerging that merge digital components with traditional products. These are known as smart products. The combination of digital product components with traditional physical components enables companies to provide online and web services; in other words, real-time monitoring and communication. Table 20 links the five key areas with the three dimensions covered by digital innovation. Elements are added that describe where each area is measured (Nylen and Holmström, 2015).

Smart product development (SPD) plays a crucial role in manufacturing transformation. Smart products can store large amounts of data, self-process and communicate with industrial systems. They are capable of gathering information from their environments and interact with them without human intervention. Small businesses are facing challenges to design innovative smart products that can meet market requirements (Alves, Pereira, and Lopez Nunes, 2017).

Table 20: Digital Innovation Dimensions

Digital innovation and the five key areas addressing the product innovation dimensions		
Dimension	Area	Element
Product	User experience	Usability
		Aesthetics
		Engagement
	Value proposition	Segmentation
		Bundling
		Commissions
Environment	Digital evolution scanning	Devices
		Channels
		Behaviours
Organization	Skills	Learning
		Roles
		Skills
	Improvisation	Space
		Time
		Coordination

Digital disruption in the industrial sector represents a set of new technological advancements in cyber- physical systems, big data, smart robots, augmented reality, and the Internet of Things.

Product design and development processes have a high impact on value chain and businesses decisions. It is also a crucial aspect in achieving competitive advantage. Product development integrates engineering and industrial design requirements through a process that allows the achievement of lower cost, higher quality, and shorter development times. The challenge is to integrate the technologies with products and services. Architectures provide a framework to perform this integration (Alves, Pereira, and Lopez Nunes, 2017).

2.2.3. Reference Architecture Model for Industry 4.0

RAMI 4.0 is a three-dimensional map showing how to approach Industry 4.0 in a structured way. The model ensures that all participants involved in Industry 4.0 discussions understand each other. It is a service-orientated architecture that combines all the elements and IT components in a layer and life cycle model. RAMI 4.0 is used as a guideline to provide universal criteria for Industry 4.0 product development, and. Provides clarity about the performance and features that products should provide. This ensures transparency and security for the market. It addresses the inflationary use of terms such as IoT ready and RAMI 4.0 compliant (Zvei, 2016).

The model provides a single holistic view for all the relevant and important aspects of Industry 4.0 required by the stakeholders. It provides general guidelines and relevant views that should be considered in the overall domain organisation but does not prescribe a specific modelling approach. The six-layered vertical axis defines the structure of the ICT representation for an Industry 4.0 component. The axis also represents various ICT perspectives such as business applications, functional aspects, information handling, communication and integration capability, and assets involved. The life cycle axis captures the life cycle of products, machines, and factories. The third axis describes the functional classification of various circumstances within Industry 4.0 from the product to the factory environment.

For Industry 4.0 technologies to prosper and develop further than just being business opportunities, effective communication and clear visualisation of the new strategies and underlying operational processes among all the stakeholders involved in the manufacturing value chain, are required. It will be difficult to unlock the full potential of Industry 4.0 without having a standard communication technique which relies on information about the business needs and requirements along with checking the relationships between the needs of various stakeholders and departments. The RAMI approach can be applied to the framework to validate it for the system configuration of an irrigation system (Cadavid et al., 2017).

2.2.3.1. Reference Architectures

The internet and new industrial revolution have brought about an age of ubiquitous connectivity and seamless information exchange, transforming the workplace. High-speed networks, open architectures and intelligent infrastructures that can communicate between each other are creating technological innovations at a very high rate (Löwen, 2017).

A fundamental part of the success of the new industrial internet of things, is enabling reliable communication and interaction between different stakeholders in the network that is seamless and cost-effective. It is therefore crucial to enable interoperability of connecting components when they are produced to use their abilities within their operational environment in various industries. Platform Industry 4.0, the German strategic initiative, are the leaders in advancing the development of I4.0 in manufacturing solutions in Germany. It has developed the RAMI 4.0 to aid businesses in implementing I4.0 initiatives in their companies. The new industrial revolution presents new age organisation and provides control over the entire value chain and the lifecycle of products which focus on legal and human impacts. RAMI 4.0 places emphasis on the manufacturing industry by providing a detailed model for a next-generation value chain. It coordinates with the Industry 4.0-driven digital transformation of the German industry (Löwen, 2017).

2.2.3.2. RAMI 4.0 Structures

Industry 4.0 focuses on product development and production scenarios. Therefore, it is important to be able to communicate how development processes, production lines, manufacturing machinery, field devices and the products themselves are configured and how they function. The information and communication functionality are of interest to stakeholders, along with the simulation and working of the system involved in products. RAMI 4.0's asset and integration layers, which differentiate it from the Smart Grid Architecture Model, facilitate the digitisation of assets for virtual representation. The communication layer is the platform for the transmission of data and files, the information layer contains the relevant data, the functional layer has all the necessary functions, and the business layer maps all the relevant business processes.

Several systems are grouped together to form larger overall systems. Both the individual and overall system must follow the RAMI. This ensures that the system layers are compatible with each other. The axis complies with the IEC 62890.

Table 21: RAMI 4.0 Architecture Layers (Binder 2020)

Axis 1 Architecture: Layers	**Brief Description**
Business	Organisation and Business Processes – What is the customer willing to pay for? Provides the business view of the informational exchange amongst industrial processes. The model can be used to distribute regulatory and economic structures and policies, business portfolios, business models and market parties. Business processes and capabilities can also be represented in this layer. It supports executives in decision making regarding business models and projects and defining new market models.
Functional	Functions of the Asset – What is my product supposed to do? Describes functions and services, including their relationships from an architectural viewpoint. Functions are derived by developing use case functionality which is independent from actors.
Information	Necessary Data – What data does my product have to provide? Describes the information exchanged

	between functions, services, and components. These information objects and data models represent common semantics for services and functionalities to allow for interoperable information exchange via communication.
Communication	Access to Information – How do I or my customer access the data? Describes protocols and mechanisms for the interoperable exchange of information between components in the context of the underlying use case, function or service, and related information objects or data models.
Integration	Transition from Real to Digital World – Which parts of my product are digitally available in the network? Provides all physical assets to other layers to simulate events between them through administration shells. They are the foundation for further processing and therefore provide the necessary information to perform these actions. It provides information regarding the use of network components such as barcodes, switches, terminals, humans, physical components, and documents.
Asset	Physical Things in the Real World – How do I integrate my product with the process to move it in the real world? The physical distribution of all participating components in the smart grid context. The layer includes applications, humans, physical components, and documents.

When developing RAMI 4.0 products, the architecture provides functionalities that enable the guidance of products in production system. The architecture chooses the equipment that executes a given operation via communication between products and equipment during the developing and manufacturing process. The methods require dividing the architecture into layers and components (Pisching et al., 2018).

It is necessary to distinguish between types and instances due to the interaction of various business partners and their individual life cycles in the planning processes. During the planning phase various alternatives and hypothesis are considered. The planning proceeds based on types. Types refers to the product up until the development of the product. Instances are manufactured or developed iterations of a type. (Zvei, 2016).

Table 22: Life Cycle and Value Stream Axis (Zvei, 2016)

Life Cycle and Value Stream Axis	Brief Description
Life cycle	Industry 4.0 offers great potential for improvement throughout the life cycle of products. To visualise and standardise relationships and links, the second axis is used to represent the life cycle and associated value streams. IEC 62890 is a good guideline for life cycle consideration.
Type	A type is always created with the initial idea, in other words in the development phase. This includes the placing of design orders, development and testing of the prototype production. The type of product is created in this phase. Of all tests and validation, the type is released for production. The "Maintenance Usage" phase under "Type" refers to changes made to improve the design such as software updates, instruction manuals and maintenance cycles.
Instances	Products are industrially manufactured based on a general type. Each product is thus an instance of a type. Instances are sold and delivered to customers. They become instances when they are installed in a system and can change from type over repeated systems. Improvements of products from the sale phase can lead to an amendment of the type documents. The newly created type can be used to manufacture new instances. Under "Production", the physical production of the product takes place. Under "Maintenance Usage", the servicing, recycling, and scrapping of the product takes place.
Value streams	Digitisation and linkages created between value streams provide major potentials for improvements. Links can span across various functions and departments that create value connections.

A standard "Development (Type)" procedure phase in the RAMI 4.0 life cycle would aim to improve product design from a product assembly perspective. A procedure could look like the following:

I. Send digital product description to manufactures
II. Product manufacturers will perform a virtual assembly of the type.
III. OEM (original equipment manufacturer) designers receive the results of a virtual assembly
IV. Rejecting potential manufacturers
V. Modifying the product design and iterating back to the first step if needed
VI. Choosing one manufacturer for production of the physical product.

Hierarchy levels describe the breakdown structure of assembled components. Devices, motors, and machines are controlled and operated by workers. System-specific applications facilitate the automation process.

The third axis, the hierarchy levels, are defined by IEC 62264. A product is provided at the base level and the "connected world" goes beyond the boundaries of the smart factories and workspaces. This gives the RAMI 4.0 a classification into three categories. The first subsequent layer is the external service it provides to its immediate environments and it represents horizontal integration. The second is the product lifecycle and usages. The third layer monitors the properties of the machines and motors providing internal services, which provides vertical integration. The hierarchy levels are as follows:

Table 23: RAMI 4.0 Hierarchy Levels (Zaheer, 2017)

Hierarchy Level	Description
Connected world	This interlinks the levels between stakeholders, suppliers, customers, and service providers. It ensures the flow of information regarding business strategies
Enterprise	This refers to the higher-level management and planning software such as enterprise resource planning (ERP), and involves core business processes such as sales, marketing, commination, production scheduling, financial services, and other business-related expenses.
Work Centre	Where decision making is enhanced through the administrative function of filing manufacturing information, defining the production state and the conversion of raw materials to finished goods. It is used for reporting purposes to improve quality and efficiency.
Station	This is where operators and controllers perform administrative activities that examine the performance of events. At the station, the manufacturing or production processes are monitored, and real-time data is interpreted.
Control device	The processing component of the product or service. The system is responsible for the operating of the product, the machines, and sensors that mange the input and output command. Examples are the GUI, programmable logic controller, and control systems.
Field device	Refers to the electronic devices that use data analysis and data sensors to detect and identify components and sensors. They enable navigation, plus capturing and flow of data.
Product	Physical product at base level. For example, smart phones, irrigation controller, and television.

(Zaheer, 2017)

The hierarchy levels interlink stakeholders in the process of creating a product and facilitate the transfer of information between stakeholders. The levels describe the assembled components in a breakdown of their structure. The machines, devices and motors are controlled and operated by workers. These have system-specific applications which allow for automation.

2.2.3.3. RAMI 4.0 Functions and Criteria

The special function of the RAMI 4.0 is combining the life cycle and value stream with a hierarchically structures approach for the definition of I4.0 components. Maximum flexibility for the description of an I4.0 environment is provided in this way. The approach also permits encapsulation of functionalities where appropriate. It is used for the description and implementation of highly flexible concepts. In this context, the model permits step-by-step migration from the world of today to I4.0 and the definition of application domains with special stipulations and requirements (Suri, 2017).

Using a reference architecture model, tasks and workflows can be broken down into manageable parts. This enables the subject matter to be more accessible. The existing standards in question can be identified, revealing where there may be a need for additions or amendments or where standards are missing. Overlapping functionalities become more transparent and open to discussion. The concepts are reviewed to ascertain the extent to which they satisfy applications in the Industry 4.0 environment. Compliance with the classification of Industry 4.0 standards enables smaller companies to adapt and handle new challenges with increased robustness.

An architecture model makes it possible to develop a system such as an irrigation system, according to a standard. Standardisation is important for both the manufactures and the end customer. This is for:

I. General: Guidance on what is I4.0 and what is not
II. Customer: Universal definitions contribute to clearly articulated benefit articulation
III. Manufacturers: Guidance on what qualifies as I4.0 and the properties will aid in development of the irrigation systems.

(Suri, 2017).

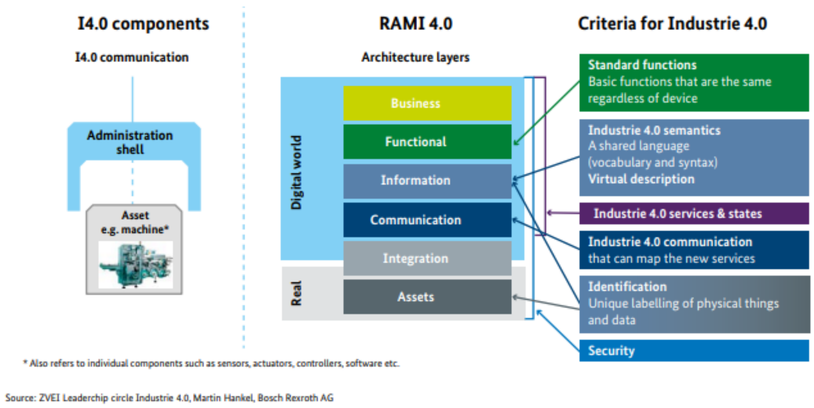


Figure 27: Criteria for Industry 4.0 Products (Zvei, 2016)

To develop an Industry 4.0 product, it should adhere to certain criteria. The principles for adhering to the criteria are:

I. Self-examination: It is important to ensure that the product being developed, will function as an Industry 4.0 product.
II. Simplicity: The product and its properties are presented as simply as possible.
III. Own identifier: Each company uses its own label to reference the criteria and refer customers to the criteria.

IV. Free of charge: Anyone can use the product and product properties.

V. Implementing entity: This is an entity which is independent of manufacturers, and defines and publishes the criteria for I4.0 products in a fixed and transparent process. It ensures that the criteria are valid and the right and necessary technical properties are used.

Table 24: Criteria for Industry 4.0 Products (Zvei, 2016)

Criteria for Industry 4.0	Description
Identification:	Each product requires an identifier that can be used worldwide to clearly identify it. It applies to data, standard functions, and administration shells etc. that belong to the product. A unique identifier is required so that the relationship between the data and functions can be established on a cross-manufacturer basis. It is required in the asset, information, and functional layer.
Communication:	Services are provided, and data is exchanged in I4.0 technologies. It is represented in the communication layer and consists of existing standards and standards already at the development stage.
Semantics:	Common language is required for components, machines, and IT systems to understand each other. It involves shared data and functions that is communicated in a common syntax and in the right context. Standards for semantics are IEC 61360 with IEC CDD (Common Data Dictionary). In RAMI 4.0, the Industry 4.0 semantics are in the information layer. All data and functions that are not standardised according to Industry 4.0 are located here in the integration layer.
Virtual description:	It reflects the entire content of the digital product representation. Semantics and other important data such as descriptions, catalogues pages, models, technical features etc. This provides a digital description of the product, parts of which are also accessible for customers. The information is accessible, freely available and connected to the product and can be retrieved through its ID.
Industry 4.0 services and states:	Components and systems must be able to find each other in networks and communicate with each other. Includes the availability of data, functions, and capabilities. Both communication partners must be able to perform basic services. I4.0 services must be described and implemented independently of manufactures so that an I4.0 network can function. There are basic services the product must be able to provide.
Standard functions	For end users, it is helpful when functions are standardised for all components and systems. If the starting values are standardised across all manufacturers, it is much easier to implement cross-manufacturer condition monitoring in a machine. This is the functional layer of RAMI 4.0
Security:	Security provides stability and must be ensured during the entire lifecycle. IEC 62442 will play a key role in the future of security in I4.0 products.

The RAMI 4.0 references three different standards when developing a product in the reference architecture. The first, IEC 62890, which concerns the lifecycle management for products and services used in control, automation, and industrial-process measurements. The second, IEC 61512, refers to batch control and describes the equipment and its procedures. The third, IEC 62264, refers to enterprise-control system algorithms. It is integral to RAMI 4.0 and for I4.0 development and places emphasis on the key standards for future incentives and developments. It is built on the ISA-95 standard, which controls the development of automated interfaces between the enterprise and manufacturing control systems. It enables seamless information flow, consistency in data models and in terminology in the design and manufacturing processes. (Koh, 2019).

When establishing manufacturing environments and their interoperability, four different dimensions need to be considered. The dimensions of integration are:

I. **Horizontal Integration**. The integration through the value chain and throughout the production networks. Included in this is the integration of business level production networks achieved through an EDI-based supply chain (electronic data interchange) integration.

II. **Vertical Integration**. This refers to the integration along the automation pyramid outlined in the IEC 62264 standard. It includes factory-internal integration from sensors and actuators within the machines in ERP systems.

III. **End-to-end engineering application integration**. This follows the IEC 62890 and enables effortless knowledge sharing and synchronisation between product and service development and manufacturing environments.

(Gøtze, 2016).

The integration therefore takes place between the physical and digital environments of the product. Within the two environments, emphasis is placed on information technology and operational technology. OT (operational technology) specifies utilisation, efficiency, consistency, safety, and continuity. IT provides speed and flexibility, cost reduction, security, and business insights. The Industrial Internet of Things (IIoT) provides a platform to merge these technologies. Industry 4.0 is concerned with making things smartly, in other words, producing products by managing the entire value chain along with product lifecycles. It is therefore important for digitisation and interoperability of manufacturing. (Löwen, 2017).

2.2.4. Competencies, Knowledge and Skills

The future and changes in the workplace from I4.0 will determine new tasks that an employee will have to do, and additional skills are required to perform these new tasks. Aulbur et al. (2018) identified a framework for establishing the skills needed in I4.0. Firstly, they determine which changes I4.0 will bring, then how tasks will differ in the future, and lastly identify the skills which will be required. The implementation of Industry 4.0 is expected to be net with several challenges, the most important of those being unclear economic benefits and digital investments, lack of clear support and vision regarding digital operation, and lack of digital culture and training. This scenario is expected amongst companies across all industries. For companies and business-owners, training and re-training employees is one of the biggest challenges in implementing I4.0 (Leinweber, 2013).

The fourth industrial revolution will bring a higher level of automation and connectivity. Technology, tools, and machines are expected to differ from present ones. Smart machines will coordinate themselves with other devices and their environments. Smart devices and system will be used to gain and analyse real time information. Figure 28 shows some of the changes that I4.0 will bring. New machines and tools will collect data in real time and be able to analyse it. Machines will be able to calibrate themselves based on quality parameters and historical data. Industries will become more flexible and changeable. Workers will be required to handle data using IT and to perform cross-functional tasks.

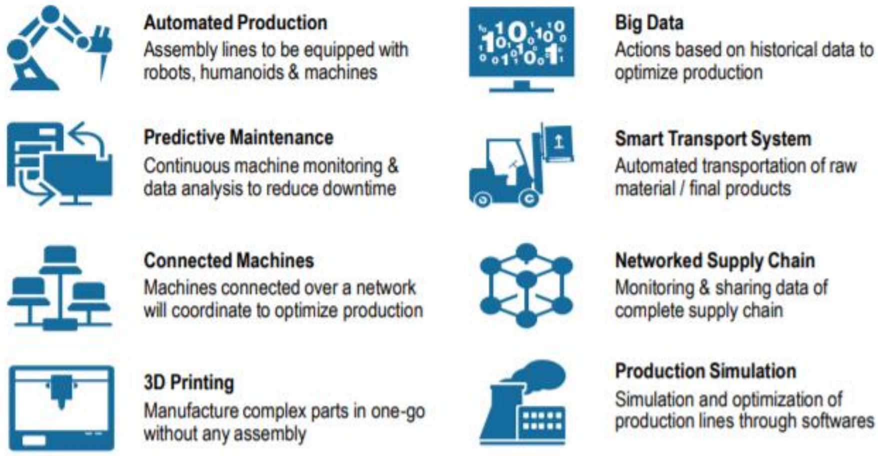


Figure 28: Industry 4.0 Enabling Technologies

The evolution of jobs and skills needed for the successful implementation of Industry 4.0 is becoming increasingly more important. The introduction of technologies such as Big Data, cloud computing, CPS and the IoT has resulted in job content changes and the need for new skills. Pinzone (2017) conducted a focused-group survey and industry-leader interview to identify sets of technical skills for Industry 4.0 in 5 subsections of an organisation. The five areas are: operations management, supply chain management, product-service innovation management, data science management, and IT-OT integration management. The small-scale farmer exists within these organisational areas and the following table is adapted to the technical skills identified by Pinzone et al. (2017) in the context of the application of irrigation systems. These skills are identified in a manufacturing context aimed at outlining the technical skills needed for the present and future of I4.0 systems. It can therefore be applied to irrigation systems.

Table 25: Technical Skills Required in I4.0, Related to Irrigation Systems (Adapted from Pinzone et al. (2017))

Organizational area	I4.0-technical skills
Operations management	Use of digital services. Management of human resources interconnected through digital services. Remote system monitoring and supervision of maintenance interventions.
Supply chain management	1. Real-time management leveraging monitoring and tracking technologies.
Product-service innovation management	1. Research, analysis, and the use of innovative materials. 2. Design of smart products. (Designing own irrigation systems).
Data science management	1. Design of data and workflow models. 2. Big Data management use of cloud computing and data storage. 3. Big Data analytics. 4. Development of applications and tools for Big Data analytics (R, Python). 5. Infographics for intuitive and engaging interpretation of data analytics.
IT-OT integration management	1. Development of roadmaps and strategic decision-making on I4.0 technologies. 2. Implementation of I4.0 components. 3. Selection, specification, and integration of embedded devices. (Irrigation systems, application of phones, tablets). 4. Selection and application of data management protocols. (Cloud, Big Data and IIoT). 5. Use of graphic modelling tools to analyse and design systems.

There will be a reduction in the amount of ergonomically challenging and monotonous jobs. Workers will be interlinked through departments and share workspaces with smart devices and robots. New tasks will involve information and data and workers will be involved in the planning process. New skillsets will be required with the shift of increased digitalisation. The ability to work with data and make decisions based on it will become a major part of the job. With an increase in automation some tasks will no longer be needed; for example, resource management and time management will fall away. The demand for content skills, system skills, process skills and cognitive abilities will see a rise in industries such as manufacturing. The core skills and qualifications that are relevant in current technical and vocational education will remain important and should be adapted to the new industrial revolution. The important skills are summarised in the Figure 29 below.

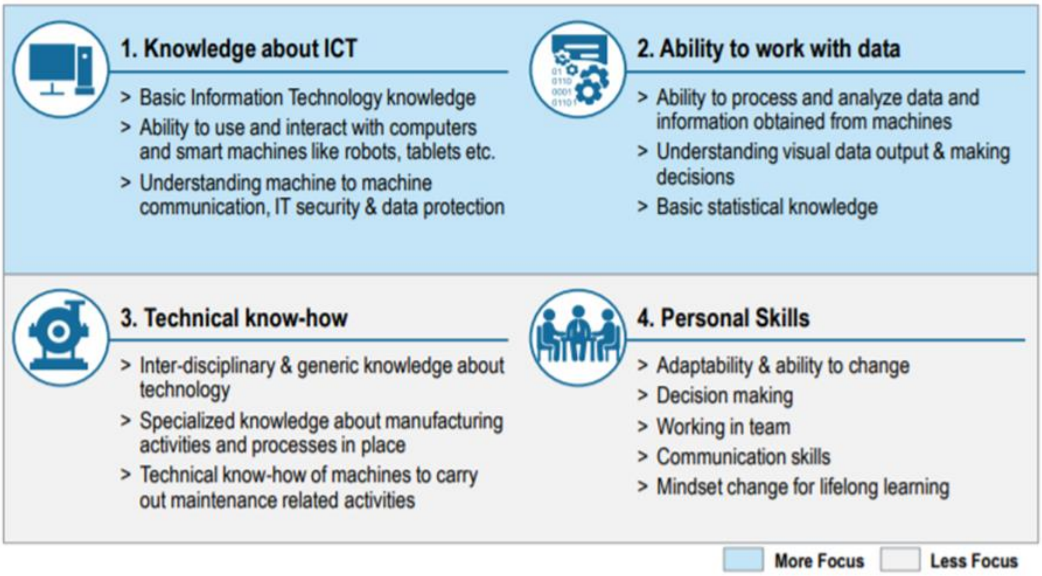


Figure 29: Important Skills in Industry 4.0 (Aulbur, 2018)

Hartmann (2013) developed a diagram that indicates how the developmental phases of emerging technologies impact the skills needed for the technologies, the development and implementation of education and training structures, and general developments through foresight processes.

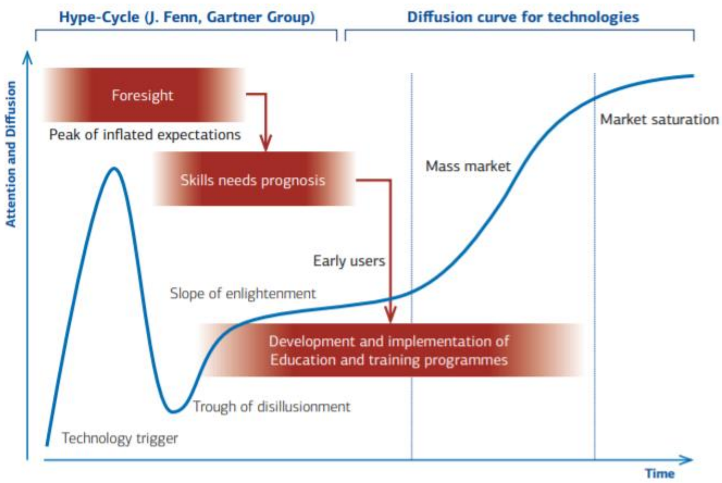


Figure 30: Education and Training of New Technologies [Hartmann (2013)]

Figure 30 shows how education and training is not such a high priority in industry and takes time to be implemented from the time the technology is developed. This is the case for irrigation systems within the precision agricultural context. In other words, there is still a need to develop the knowledge and skills required to use the irrigation system technologies that have been developed.

2.2.5. Industry 4.0 Applications

I4.0 has enabled various technologies to be applied across new business models. Industry4.0 applications are increasingly being used to improve operations and yields, and increase efficiency. Core competencies are needed in the process, examples of which are visual management, lean tools, ergonomic design, systems thinking, design for manufacturing, and design for assembly, smart logistics and low-cost implementation. The competencies enable the user or I4.0 role player to perform the applications listed below.

Table 26: Industry 4.0 Applications (Du Plessis, 2017)

Industry 4.0 Application	Description
Collaborative work	This is a hybrid workstation where robots and humans work in a collaborative fashion. Collaborative work is defined as three types: namely: true collaborative, cooperative and assistive work
Digital factory	This is a virtual representation of the physical factory and its processes. It allows to run simulations and a general overview of the state of the physical counterpart.
Real time work visualisation	Realising the importance of visual computing. This is the visual representation of KPIs relevant to the production process or deemed necessary by management. The visual representation is not solely bound to KPIs but can be any type of measured or measurable aspect.
Big Data analytics	This includes the analytical tools, methods and programmes used to create value from gathered data, and is an important application for realising Industry 4.0 in the work environment.
Smart products	Hybrid products with physical realisations and digital and information technology capabilities that provide the following characteristics: situated, personalised, pro-active, adaptive, location-aware and network-capable.
Human movement optimisation	Applications that can be addressed through multiple methods such as simulation and workplace organisation. This application involves improving workplace environments and conditions for humans so that product output improvements can be realised.
Smart manufacturing	This is a subset if manufacturing that employs computerised control over processes. It aims to take advantage of the manufacturing and information technologies to enable flexibility and adaptability in physical processes.
Intelligent transport	This refers to the transport method that follows certain criteria such as containing sensory technologies, a data communication mechanism, and a form of computational technology.

A disruptive component of Industry 4.0 is the any-time availability of data to all participants within the connected world. The RAMI 4.0 standard technology for enabling this is Open Platform Communications Unified Architecture. The lack of an established IIoT reference architecture has resulted in developers having to construct home-grown solutions to common tasks that would ideally be addressed by standards-based technologies (Sierla, 2019).

2.2.5.1. Facilitating Industry 4.0 Applications

Technological changes will challenge employees and companies to successfully implement I4.0 applications. There is a need to facilitate this change. Facilitation comes in various forms and Larrson and Nilsson (2019) identified three areas that require focus in order to facilitate the change. The first is motivation, engagement and involvement. The second is transparency. The third is adequate knowledge and skills. The knowledge and skills requirement were discussed in 2.2.4, and it was recommended by Larrson and Nillson to make use of workshops to train employees. Large consultancy firms such as BCG have consulting experts dedicated to facilitating change in Industry 4.0 in companies. This indicates that an Industry 4.0 product's configuration and implementation requires a form of consultation and/or facilitation.

2.2.6. Benefits and Drawbacks of Industry 4.0

Industry 4.0 combines hardware, sensors, connectivity, and data storage to unleash a new type of product that can enhance the competitive advantage of businesses. I4.0 implementation of products includes IT, and changes the integral functioning of each product. It changes the structural setup of products and provides new business opportunities at each life cycle phase. The new competitive environment will see products with high forms of differentiation, customer segmentation, and flexible price settings, value added services and closer customer-business relationships. More information and data around products will be generated which will facilitate greater product control. Firms not only compete around the price of a product but also around value-added services. This in turns improves the entire product market (Fei Yu, 2020).

The ability to adhere to specific customer orders is improved along with increased production flexibility to provide higher profit. Flexibility is increased through dynamic design in business processes and manufacturing. Information availability and new information streams from Big Data, cloud computing and social media, allow for better decision making, early design solutions, flexible disruption responses, and better global resource optimisation (Zezulka, 2016).

There will be an increased production efficiency through increased productivity and resource usage efficiency. Industry 4.0 is synonymous with new value creations in product and service offerings, and also places value on physical and mental abilities. This creates diverse and flexible career paths through employees retaining knowledge and experience from high level training by knowledge-based companies. Production capacity will be optimised to fit resource availability and allow for agile customer order fulfilment. The workplace will change as employees will be better equipped to balance family, leisure, and work through increased staff scheduling efforts (Fei Yu, 2020).

Most organisations attempt to strive for efficiency and effectiveness when entering the market. Efficiency refers to the output given a certain amount of input. Effectiveness is the ability of the firm to procure resources. An organisation's efficiency is resource-focused, which requires them to develop dynamic capabilities that are appropriate, can adapt, integrate, and reconfigure to achieve external and internal competence. The vertical integration from Industry 4.0 that uses hierarchical subsystems, enables organisations to achieve this. Horizontal integration of the physical and informational world enables organisational output that achieves efficient handling of supply chains. This enables better resource use in the value chains. Effectiveness refers to the degree that organisations realize their goals and is determined by a defined key performance indicator such as profitability, market share or growth rate. Success is determined by the effectiveness of horizontal and vertical integration (Zezulka, 2016).

Organisational agility refers to the competence with which an organisation can manage a disruption or uncertainty in the marketplace by providing a rapid response to achieve highly innovative products and services. Two metrics are used for this is, namely quickness and innovativeness. The vertical integration of networked manufactured systems and production lines enables organisations to rapidly respond to market and customer demands. Horizontal integration of cross-company departments in the value chain enable the entire supply chain to respond to the customer. End-to-end integration of the life cycle of the product aids in developing more innovative products and services. This ensures increased competitiveness in companies that apply Industry 4.0 methods, principles, and other factors (Zvei, 2016).

Vertical and horizontal integration in the entire product life cycle will enable data sharing in the competitive environment that will result in other risks such as cyber-attacks and data concerns such as rights and access. When new standards are set by leading organisations, other businesses might struggle to keep up and eventually give up. To facilitate these challenges, businesses are required to redesign existing business models which can result in negative relationships being developed with the integration of new technologies (Zvei, 2016).

To successfully address Industry 4.0 implementation, comprehensive integration is required. This can be difficult due to different design needs for production structures and company sizes. Individual implementation does not yield favourable results. The integration of Industry 4.0 is expected to have a profound impact on the employees of organizations. Lower skilled job positions are expected to be filled by robots and other CPS technologies. Employees will suffer job losses and be expected to acquire higher skills to operate the new technologies. Unions might resist I4.0 technology implementation to protect employee jobs. It is difficult for employees to negotiate with trade unions regarding these issues (Zezulka, 2016).

New competencies will cover technical, methodological, social, and personal competencies. Training programmes and modules will have to be provided to equip labourers to perform new jobs. The Industry 4.0 system is socio-technical. Optimising both these aspects enables sustainable and successful implementation. If not, negative results may arise such as polarising job descriptions, a divide in employee graduates, and proliferation of knowledge societies. Social impacts can result in increased salary disparities, a rise in monopolisation, age demographic changes, and ecological threats. Digital networking between people, products and other third parties increase intelligent data processing and value-adding capabilities of companies. It however brings forth a need to ensure that the value chain is provided with cyber-security measures as companies are vulnerable to data attacks and malware (Contreras, 2017).

To enable the vertical and horizontal integration of Industry 4.0 various technologies, machines, assets and resource need to be acquired. These come with high initial costs and might be too expensive for companies.

2.2.7. Conclusion

Industry 4.0 is providing businesses with the opportunity to satisfy increased demand and individualisation needs from customers. The literature makes it clear that I4.0 aims to provide the maximum outputs with the least amount of resource utilisation. This revolution is radically increasing competition in the farming sector (Simonov et al., 2020).

Small-scale farmers are set to fall even further behind in the value chain of the agricultural sector as they experience barriers to applying I4.0 technologies. These barriers keep them from benefitting from the technological advances I4.0 brings into the farming sector. Zvei (2016) states that having an implementation strategy for implementing I4.0 initiatives will enable stakeholders to open up new value streams. This requires action; the action area of resource efficiency speaks directly to sustainability of the agricultural sector, and adequate training addresses the ethical consideration of not replacing the workforce with new machines. A framework that can serve as implementation strategy needs to take all these action areas into consideration.

To develop the framework) requires standardisation (Zvei, 2016). RAMI 4.0 would serve as the reference architecture to adhere to the standardisation requirement for developing the framework.

2.3.Barriers to Applying Precision Farming

There is a lack of methodology and guidance in identifying the areas that need to be addressed when implementing Industry 4.0. Stakeholders that are willing to implement I4.0, do not have the practical knowledge to do so even when the areas are identified. Certain questions arise in these cases such as, what barriers exist that keep small-scale farmers from implementing I4.0 irrigation systems? How can the farmer implement Industry 4.0? What does the farmer need to acquire and implement the systems? (Du Plessis, 2017).

A Pareto analysis is performed to determine the barriers that keep small-scale farmers from implementing irrigation systems.

2.3.1. Barriers to Applying Irrigation Systems

Kendall et al. (2022) identified limited awareness of the suitability of affordable irrigation technologies amongst small scale farmers. In a study they argue that there is a need for small scale, low-cost PF application to address this barrier, which is understood to be a driving factor in the non-adoption of new technologies. Mongo (2016) performed a study on the adoption of modern agriculture technologies under small-scale farmer in the Thika East, at sib-county of Kenya, and also found that inadequate financial resources kept farmers from adopting the technologies.

There are common barrier themes shared by researchers, and the underlying need for support in applying these technologies is also highlighted by Serote et al. (2021), who emphasise the urgent need for small-scale farmer communities to be provided with the necessary services and intervention to access the benefits of irrigation technologies. In southern Brazil farmers indicated that if the benefits of the technologies are proven, it would increase their adoption.

Anselmi et al. (2014) performed a study to identify the factors that influence the adoption of new technologies such as irrigation in farming activities, and aside from the need for clear benefit articulation, farmers indicated also that high level prices for equipment acquisition is a main problem. This is difficult for farmers who wish to reduce costs on their farms. The study also identified that current PF tend to have higher education, which highlights the need for skilling up to operate irrigation systems.

2.3.2. Pareto Analysis

Various factors influences the rate of application of precision farming. In several studies it is agreed that young well-educated farmers with large farms are more likely to apply PF. Well recognised barriers are the high learning curves and costs. PF tools require a high level of knowledge and skills to manage and interpret large amounts of data (Vecchio et al., 2018).

Helm (2005) found that farmers with a tertiary qualification are more likely to apply PF. This can be attributed to either having a higher degree of understanding or knowledge of the benefits of such systems, or being able to operate the systems. Jacobs et al. (2018) found that the size of the farm also plays a role in applying PF.

Farmers with cultivation areas of less than 1500 ha are far less likely to apply PF technologies. This conflicts with findings from Helm (2005), who indicates that there is uncertainty about whether PF would be beneficial for small-scale farming operations. With most PF technologies economy of scale is applicable; cost per hectare decreases by increases in area.

To fully address the obstacles small-scale farmers experience to applying precision farming technologies, such as an irrigation system a Pareto analysis was performed. This was done to identify the top barriers by reviewing various literature sources. Solving the top 20 % of the barriers is expected to address the remaining 80 %. This multilayered approach is useful in root cause investigations and could verify the critical barriers. The sources for data extraction was selected according to the inclusion and exclusion criteria below.

Table 27: Barriers to Applying Inclusion and Exclusion Criteria

Criteria	Criteria Definition
Type of publication	Website Article, Study, Question and Answer Blog.
Date	The source of data should not be conducted prior to 2000.
Participants	There are no restrictions on the participants involved in the data source.
Key words	1. Precision Farming / Precision Farming/ Smart Farming / Digital Farming. 2. Challenges / Limitations / Obstacles / Problems. 3. Small-scale Farming / Small-scale Farming / Small-Scale Farmer / Small-scale Farmer.

Various definitions and explanations exist for barriers faced by small-scale farmers. It would be necessary to group them under similar themes. The barriers used for analysis and grouping are sourced from Boyer et al. who conducted a survey among cotton farmers across fourteen different states. (Where? USA?) The categories are listed below.

Table 28: Barrier Definition

Barrier	Description
Too risky	Investing in novel technologies and developing new farming practices are deemed too big of a risk to invest in.
Lack of trust	Data security and information sharing concerns prevents farmers from applying PF technology. Lack of regulatory frameworks and legal measures around new technology developments are keeping farmers from applying PF technology.
Not profitable	Implementing precision farming technology is considered not profitable.
Time consuming	Farmers indicate that the maintenance, training, operations, and implementation of PF technology would be too time consuming.
Continuously evolving technology	PF technologies are constantly developing, and newer technologies are becoming available at increasing speeds. The farmer is reluctant to apply precision farming technology since it could become outdated, and interoperability might come under threat when newer technologies become available.
Benefits uncertain	Unclear benefit articulation of precision farming technologies. Small-scale farmers are uncertain of the advantages, benefits, and improvements that PF

	technologies will bring their farming operations. Therefore, they lack information that would justify implementing the system.
Too expensive	The high capital cost and initial implementation and investment costs are deemed too high to apply precision farming technology.
Access to technology and support	Small-scale and small-scale farmers are in rural areas where they do not have access to enabling technologies and support systems to incorporate or implement PF technologies on their farms. Government and external support are not available to small scale farmers.
Ethical consideration	Ethical concerns such as technology replacing the workforce, environmental concerns, and a reluctance to move away from traditional farming methods are preventing farmers from applying PF technologies.
Too complex	Farmers deem PF technologies too complex to operate, implement and maintain. They indicate that the knowledge and skill requirements are too high to apply and would require additional training and expertise.

After extracting data from 426 different sources that fall into the inclusion criteria, the Pareto chart below was constructed. The sources are shown in Appendix C: Barriers to Precision Farming Application: Pareto Analysis.

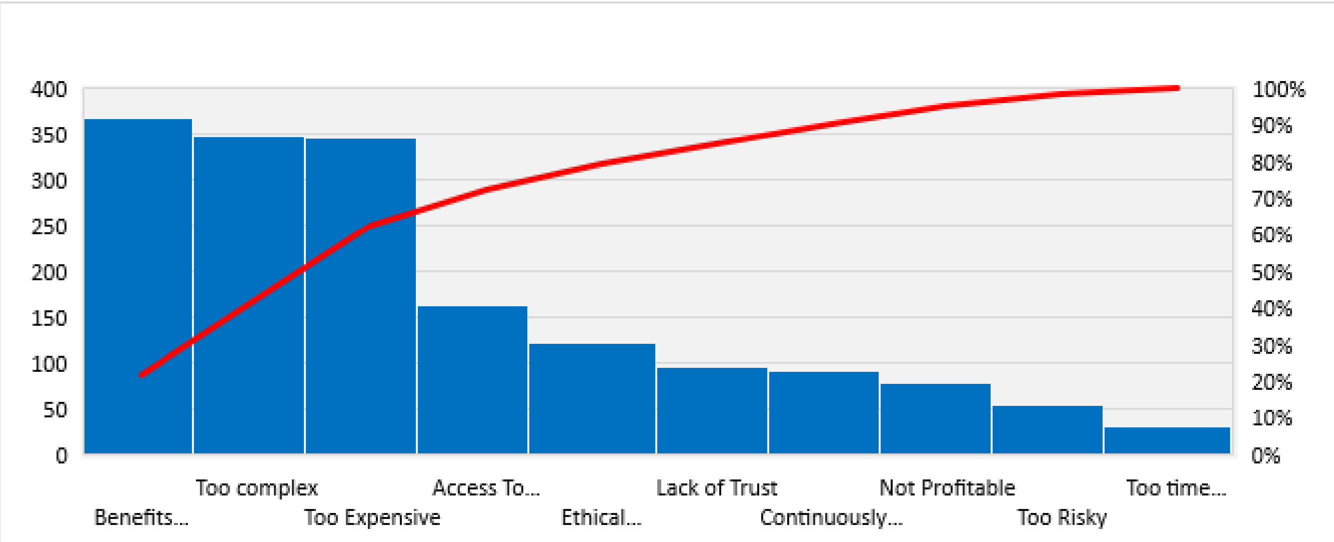


Figure 31: Barriers to Applying Precision Farming (Pareto Analysis)

The top barriers that were identified are Too Expensive, Benefits Uncertain and Too Complex. The system configuration for an irrigation system should therefore focus on addressing these barriers to aid small-scale farmers in the application of such a system.

2.3.3. Conclusion

Irrigation systems are multifunctional and can operate on different levels of complexity that require different knowledge and skills levels. It offers different capabilities and benefits and requires capital investment. The different components in an irrigation system and the selection of these components will affect the benefits the system provides, the capital investment, and the knowledge and skills required there are a variety of available irrigation systems products that can stand in the place of designing your own system that will also affect the abovementioned factors. The framework will provide an opportunity to address the barriers identified in the Pareto analysis by allowing farmers to decide between developing their own systems and choosing an available system.

2.4. Chapter Summary

There is a strong drive from stakeholders and policymakers at all levels to advance irrigation development practices to further economic and rural development. The African Union Agenda 2063 outlines the "Africa we want" in their 10-year action plan, and highlights irrigation as the key to achieving modern agriculture for increased productivity and value addition. Irrigation management is becoming more important as the size of irrigated areas has increased substantially from the year 2000 in Africa, which has a large number of small-scale farmers. The increase ranges from 42.6 % in North Africa to 407.7 % in Central Africa. Improved irrigation management is in line with several food and rural development schemes in the majority of small-scale farming countries (African Union Commission, 2020).

The African Union Commission (2020) found that small-scale irrigation has higher economic returns than larger scale irrigation. You (2010) identified small-scale irrigation development as likely to be suitable for around 70-80 % of future available irrigable areas. This provides the motivation for small-scale farmers to use their own resources and potential irrigable areas more efficiently and effectively to provide them with the best opportunity increase their own farming profits.

Industry 4.0 and the advancement it brings will re-invent the agriculture sector. The emergence of precision farming has led to farmers experiencing increased yields, cost reduction, increased efficiency and other benefits that have raised the demand for the use of new technologies. Irrigation is an integral part of a farm and traditional farming operations are being adapted to form part of the I4.0 landscape.

Such adaptations have required farmers to design new systems and several components enable the functioning of I4.0 technologies. Designing such systems requires frameworks that guide small-scale farmers. RAMI 4.0 is a suitable reference architecture that can be used to ensure that an irrigation system will conform to I4.0 standards.

Due to different technologies becoming rapidly available, the small-scale farming community face several barriers to applying precision farming technologies. The main barriers are that the technologies are too expensive, too complex and that the benefits are uncertain. There is thus a need to provide a framework to configure irrigation systems for Industry 4.0 applications that address the barriers which small-scale farmers face.

Chapter 3 Framework Development

The framework for this study was developed in three different parts. The first was to identify the preconditions for the framework perspectives, each one addressing one of the barriers. It sets the entry level requirements and eliminates large-scale and systems. The second part identifies the existing technologies and their benefits, costs, and requirements, and components within the pre-conditions. The third part develops pathways via a system configurator for using the framework.

3.1.Deriving Framework Perspectives

The pre-conditions for the framework set the criteria for each framework perspective. It underlines the entry levels and optimal requirements to operate, finance and understand an irrigation system. It determines whether certain systems are too complex and whether certain technology requirements disqualify a farmer. The three barriers identified in the previous section are defined as follows:

> **Too Expensive:** *The high capital cost and initial implementation and investment cost are deemed too high to apply precision farming technology.*
>
> **Too Complex:** *Farmers deem PF technologies too complex to operate, implement and maintain. They indicate that the knowledge and skill requirements are too high and would require additional training and expertise.*
>
> **Benefits Uncertain:** *Unclear benefit articulation of precision farming technologies. Small-scale farmers are uncertain of the advantages, benefits, and improvements that PF technologies will bring to their farming operations. This means they lack information that would justify implementing the system.*

These barriers can be rewritten into three questions that establishes what the pre-conditions should aim to achieve:

I. *What knowledge and skills does the small-scale farmer require to implement PF?*
II. *What would an irrigation system be able to do with a certain capital investment?*
III. *How would the irrigation system benefit the small-scale farmer's site-specific requirements?*

The developed framework aims to answer these questions from the three different perspectives. It provides irrigation system selection support to implement it with a focus on Industry 4.0. It will allow the small-scale farmer to configure an irrigation system to address his/her specific capabilities and site requirements. The aim is to therefore empower the small-scale and subsidiary farming community to apply irrigation systems and contribute to their own growth and sustainability.

3.1.1. Too Expensive

A potential budget split needs to be drafted to determine budget allocations towards irrigation. The institute for sustainable food system provides an enterprise budget for the small-scale farmer regarding various crops and products. A 6.4 % of total farming budget allocation towards irrigation is calculated from the allocation for potato production constructed by the Institute for Sustainable Food Systems from the Kwantlen Polytechnic University (Afeworki et al., 2015):

$$Total\ Costs: 100\ \%$$

3. Total Variable Farming Cost

$$\boldsymbol{Total\ variable\ Costs}: \mathbf{50,23}\ \%$$

I. $Irrigation\ Variable\ Cost: 1{,}21\ \%$

II. $\%\ of\ Total\ cost: 0{,}608\ \%\ per\ hectare$

4. Total Fixed Farming Cost

$$\boldsymbol{Total\ Fixed\ Costs}: \mathbf{49,77}\ \%$$

I. $Irrigation\ Fixed\ Cost: 4{,}67\ \%$

II. $Equipment\ and\ Tools: 6{,}99\ \%$

III. $\%\ of\ Total\ Costs: 5{,}8\ \%$

Total Irrigation Cost = 5,8 + 0,608 = 6.4 %

Lass in CSA 2001 provide a model for the expected expenditure of agricultural production. The reported cost per share lists various expenses for operations. Utilities (1,8 %) and farm supplies and hand tools (4,1 %) are potential budget allocations for new irrigation technologies. The Land Redistribution for Agricultural Development programme provides grants for individuals who were previously disadvantaged to acquire farming land. The LRAD Grant ranges from initial investments from the farmer from R 5000 to R 10000. This implies that grants can range from R 20000 to R 400000 depending on the land being distributed per applicant. Assets can also account for investment from the farmer's perspective. The Department of Agriculture provides various grants as indicated with the LRAD Grant. MAFISA is another programme that provides loans to farmers. Their policy states that loans for equipment are to be repaid within 12 months, at an interest rate of 8% per annum and a loan cap at R 100 000. At the time of calculation R 16 4835 is equal to 1 US dollar.

Therefore, the pre-condition for the acquisition of new irrigation equipment is calculated as follows:

5. Minimum Investment Capability

$$Both\ (\text{Afeworki et al.}, 2015)\ and\ (CSA, 2001)\ agree\ upon\ a$$
$$\approx 6\ \%\ allocation\ of\ total\ budget.$$
$$The\ minimum\ investment\ capability\ through\ LRAD\ Grant\ is\ therefore:$$
$$(\boldsymbol{R}\ \mathbf{20000} + \boldsymbol{R}\ \mathbf{5000}) * \mathbf{0.06} = \boldsymbol{R}\ \mathbf{1500} \approx \$\,\mathbf{91}$$

6. Maximum Investment Capability

$$\textit{The maximum LRAD grant investment capability}:$$
$$(\boldsymbol{R\ 100000 + R\ 400000}) * \boldsymbol{0.06} = \boldsymbol{R\ 30000} \approx \$\boldsymbol{1820}$$

7. Medium Investment Capability

$$\boldsymbol{\textit{The MAFISA Loan enables a capital investment of}}$$
$$(\boldsymbol{R\ 100\ 000}) * \boldsymbol{0.06} = \boldsymbol{R\ 6000} \approx \$\ \boldsymbol{364}$$

Summarised:

Table 29: Financial Pre-Conditions for Acquiring Irrigation Systems

Financial Pre-Conditions for Acquiring Irrigation Systems	
Capital investment potential	**Amount**
Minimum capital potential	**$ 0 < x < $ 91**
Medium capital potential	**$ 91 < x < $ 364**
Maximum capital potential	**$ 364 < x < $ 1820**

These three financial potentials are used to categorise the requirements to apply an irrigation system at a small-scale farmer's site.

3.1.2. Too Complex

As mentioned in the problem statement, one of the main challenges faced by small-scale farmers and subsidiary farmers in the implementation of precision farming. The system configuration should therefore address these knowledge and skill requirements for operating irrigation systems. Clay et al. (2018), conducted an industry survey to identify the knowledge, skills and abilities required in a precision farming workforce. A workforce consists of an equipment operator, an agronomist, a precision equipment technician, technical support, precision sales specialist(s) and more. "More" refers to personnel for soil sampling, fertiliser/seed mixing, data analyst, truck drivers and accountants. The two categories that the system configuration is interested in are equipment operator and precision equipment technician. The equipment operator's role is defined as:

> *"Operates the equipment that applies pesticides and fertilizers to farmer's fields."*

Likewise, the role of the precision equipment technician is:

> *"Installs new precision equipment on implements; troubleshoots and repairs precision equipment."*

The reason for considering both workforce categories is firstly, the small-scale farmer will have a limited workforce and would mostly be responsible for the operation of the technologies. The literature review undertaken in the study underlines that small-scale farm owners have limited capital and access to resources. These resources range from capital to external support. Therefore, the small-scale farmer will mostly be required to operate as the precision farming technician and the person to troubleshoot technological difficulties. The survey indicates the current level education of the workforce employee and what respondents feel the future requirement, 5 years after the fulfilment of the survey, would be for the same role. For an equipment operator and a precision equipment technician:

Table 30: Equipment Operator Academic Requirements (Clay et al., 2018)

Equipment Operator Academic Requirements		
Academic Requirement	% of Workforce	% Future Academic Requirement
High school diploma	62	68
1 Year community college degree	2	4
2 Year community college degree	18	19
Bachelor's degree	15	9
Master's degree	3	0

Small-scale farmers in many instances do not have access to education. The lowest qualification in this study, namely high school diploma includes farmers who have no prior education.

Table 31: Precision Equipment Technician Academic Requirements (Clay et al., 2018)

Precision Equipment Technician Academic Requirements		
Academic Requirement	% of Workforce	% Future Academic Requirement
High school diploma	10	6
1 Year community college degree	1	3
2 Year community college degree	7	27
Bachelor's degree	75	62
Master's degree	7	2

Interviewees were asked to evaluate 10 KSAs (knowledge, skills, abilities) related to precision farming for workforce roles. The importance of these proficiencies ranked lowest for the equipment operator for most KSAs. The precision equipment technician scored relatively high on most of the KSAs. The table below captures the respondent feedback, rating the importance out of a score of 3.00.

Table 32: Importance Rating of 10 KSAs for the Equipment Operator and Precision Equipment Technician (Clay et al., 2018)

Importance rating of 10 KSAs for the Equipment operator and Precision Equipment Technician		
KSAs	Equipment Operator	Precision Equipment Technician
(1) Ability to make effective agronomical recommendations	1.50	1.74
(2) General knowledge of precision farming technology	2.12	2.65
(3) Ability to produce accurate digital maps of fields using special information within specialized software	1.51	2.54
(4) Ability to operate precision farming equipment	2.78	2.75
(5) Ability to install, calibrate, troubleshoot, and repair precision farming hardware and equipment.	2.25	2.78
(6) Operational knowledge of computer spreadsheet applications to record and analyse agricultural field data.	1.49	2.19
(7) Effective written and verbal communication skills within precision farming activities.	2.01	2.53
(8) Working understanding of statistical standards to produce means and standard deviations.	1.33	2.03
(9) Operational knowledge of basic business and accounting principles	1.43	1.96
(10) Operational knowledge of precision farming software	1.83	2.4

Knowing these required KSAs and academic requirements, the next logical step is to link the KSAs to the level of academic requirement. This is firstly done by assigning each KSA to the academic level. The numerical value assigned to each KSA in the previous table will be used to represent the KSA in the following table:

Table 33: Academic Requirements Linked to KSAs

Academic Requirement	KSAs obtained through degree
High school diploma	(1), (2), (4), (7), (10)
1 Year community college degree	(1), (2), (4), (6), (7), (10)
2 Year community college degree	(1), (2), (3), (4), (6), (7), (10)
Bachelor's degree	(1), (2), (3), (4), (5), (6), (7), (8), (9), (10)
Master's degree	(1), (2), (3), (4), (5), (6), (7), (8), (9), (10)

The implementation of precision farming technologies was rapid but has slowed down due to the complexity and confusion about how to fully use PF and extract the full value thereof. Early adopters were characterised by having an aptitude for electronic-based IT and decision making along with being primarily self-taught. The current lack of relevant knowledge and skills to precision farming has resulted in the challenge of applying the technologies. It was established that the definition and the KSA requirements of the equipment operator and precision equipment technician is what would apply the best to a small-scale farmer applying and operating irrigation systems. Therefore the above mentioned KSAs are those that the small-scale farmer should have or gain in order to apply the irrigation system. These KSAs will serve as the precondition for the knowledge and skills perspective in the framework.

The knowledge, skills, and abilities that people gain through applying precision farming technologies and using them can follow an orderly learning process. The sequential process is presented below.

Table 34: Learning Process in PF

Step	Description	Examples.
Learning and understanding the concept of spatial data	The understanding, including the importance and value of spatial data, is fundamental. The opportunities for successful precision agricultural decisions are founded both in the variability of the field and in the ability to accurately predict and manipulate these factors.	1. Understanding the scale of variability, being able to measure and making decisions about how things vary in space. Management decisions regarding benefits and costs include understanding the choices of relevant precision agricultural treatments for specific locations. 2. Understanding that mapping the field serves the larger purpose of aiding decision making and analysis, rather than only painting a pretty picture. 3. Implementing critical thinking and referring to agronomic principles on yield limiting factors, accuracy of sampling data and improving systems.
Learning to fully utilize sensor	Using sensors makes it possible to sample large volumes and quality information inexpensively. The novelty of sensors and computer-controlled devices result in issues for farmers on how to manage spatial variability, but also the unknowns of cables, sensors, and computers. Sufficient training and education address the development of skills and provides farmers with the tools and confidence to operate the sensors.	1. GPS – The information obtained through GPS brings together all layers of information obtained from the field 2. Yield Monitoring Systems – Provides a baseline to farmers to assess their management decisions. YM collect real-time data to provide a spatial representation of yield performance. Yield monitors should properly be installed and calibrated. 3. Remote Sensing Data – An emerging practice, using remotely-sensed images. Interpreting and managing these images are the main challenge. 4. VRT – Developing a spatial prescription along with a sensor to apply it requires additional calibration and training to sufficiently apply it.
Learning to use computer software.	This step is essential for implementing precision farming practices. Large amounts of data can be stored and interpreted using computer software.	1. The computing component (information technology) is the foundation of PF management and decision-making.

		2. Software, cloud services and computing power provides the ability to obtain, analyse and interpret data. 3. Applications and interface provide the opportunity to create, view and store data on irrigation at varying degrees of functionality, depending on the software.
Improved crop production decisions through assessing yield variation and narrowing potential cases.	Identification of relevant and manageable irrigation and crop field influencing factors are essential to PF management.	1. Irrigation and yield variation patterns can indicate natural and management induced variation. 2. Analysing sensor and irrigation data through visual association (soil, fertility, topography, and remotely sensed images), simple mathematical analysis (correlation, average, standard deviation, histograms) and complex mathematical analysis (multiple regression, spatial modelling, and nonlinear methods). 3. The end goal would be to be able to conceptualise and determine a hierarchy of irrigation requirements and variation.
Interpreting, summarizing, and collecting information.	Developing site-specific management plans.	1. Knowing the hierarchy of the yield limiting factors and sensor data, management options can be prioritised. 2. Understanding the irrigation needs of the farmer's site-specific requirements and to invest in PF technology that will aid them the most in these endeavours.
Strategic sampling and on-farm trails	Optimising farm management through the benefits from PF technologies. Making better decisions through the efficiency of PF technologies.	1. Sensor data on irrigation requirements 2. Reduce water usage 3. Save irrigation efforts 4. Increase yields.

Adapted from Snyder (2002)

3.1.3. Benefit Articulation

When considering the benefits that the system configuration will provide the farmer, the system is broken down into its components and the benefits of each component is stated. In addition, for each component, available technologies and their benefits are determined.

From the various architectures shown and discussed in the literature review, the main components of an irrigation system can be identified:

I. Microcontrollers/Microcomputers and Processor
II. Sensors
III. Drivers/Receivers
IV. Display
V. Analog to Digital Converter

VI. GSM Module
VII. Wi-Fi Modules
VIII. Relay Modules
IX. Application (Smartphone/Computer)

3.1.3.1. Microcontrollers

Microcontrollers are an integrated circuit encased in a component that controls the necessary operations to perform certain tasks routinely without requiring another boom. It consists of memory units, a microprocessor, input-output interfaces, analog-to-digital converters, control and communication modules, and pulse width modulation. Within the processor, the microcontroller has an arithmetic-logical unit (ALU), special registers, a processing core and a processor control unit. The memory units have special functions such as random-access memory (RAM) which stores the information which the processor needs during operation. EEPROM, EPROM, PROM and ROM memories do not store information such as command set, change the contents, programme, and programme data if they are not programmed. The input and output interfaces allow microcontrollers to receive data from external units and to send data (Güven, 2017).

Microcomputer systems are used in many control, automation, and signal processing applications. They can run multiple systems simultaneously with high memory capacity, powerful processing power, can be programmed through various platforms, and can run operating systems. Microcomputers have a wide range of applications which are enabled through different processor and memory capacities and input/output interfaces (Ethernet, HDMI, DSI, CVBS, and PCI etc.). They can be used in various electronic applications through using general-purpose inputs and outputs (GPIOs). Microcomputers can be wired, or wireless connected, and Bluetooth, and messaging protocols can be used in support of industrial communication standards. They act as embedded systems which include control system. They are useful due to their small size and costs relative to their capabilities. They can thus be programmed for specific functions (Güven, 2017)**.**

3.1.3.2. Sensors

Sensors are used to determine characteristics regarding various soil properties, crop stress, pest incidence, temperatures, light exposure, and rainfall. Sensors can determine these characteristics while resources are active, such as a tractor or scout moving across a field and when airplanes and satellites are flying over the field and taking photos. Yield monitors are currently the leading on-the-go sensing systems. Remote sensors is a term used to describe satellites and aerial sensors that can provide instant field characteristic maps (Rains and Thomas, 2009).

Weather Based Sensor

This sensor includes either a mini on-site weather station or weather sensor capable of monitoring conditions such as rainfall, temperature, and solar radiation for crops. Depending on the model, sensor hardware requires an existing controller or a weather-based controller with the technology integrated into the controller or as an add-on receiver to the existing controller. They are more suitable for residential areas and are affordable, especially considering the fact that they lower water consumption by 20-25 % (National Association of Landscape Professionals, 2020).

Weather-based controllers monitor various environmental factors such as temperature, solar radiation, wind velocity and humidity. From this data, it decides how much water needs to be applied to the crops. It therefore maximises the time that the soil is exposed to water whilst being efficient with the water usage. (Resuccia, 2016).

Weather based sensor also measure evapotranspiration. This is defined as the amount of water that evaporates from soil and plant surfaces, including the plant transpiration. All these environmental factors that are measured influence evapotranspiration. This allows for an accurate representation of the plant's watering needs. The controllers are easy to install, and provide a platform to monitor water usage with a combination of accurate weather data (Resuccia, 2016).

Soil Moisture Sensor

This sensor measures actual moisture in the soil. It then adjusts the irrigation requirements based on the information received. The sensors can be both add-on technologies and integrated controller. The prices for these systems vary from low to high. There are two types:

I. Suspended-cycle irrigation, using a traditional timed and automated watering schedule. Many of these sensors can be added to an existing traditional controller.
II. Water-on-demand system. This sensor requires two moisture thresholds. One for a high and one for a low threshold.

(National Association of Landscape Professionals, 2020).

The main action performed by soil sensors is measuring the water content held between soil particles. They are extremely accurate and have proved to be successful in most agricultural applications. Many scientists believe them to be the most appropriate tools to determine water content, and to measure whether you need to water crops. The sensor, however, falls behind other methods due to its calibration difficulties and need to be connected to transmission lines (Resuccia, 2017).

> A properly designed and installed irrigation system can save significant water and money while improving plant health by providing optimal soil moisture conditions. However, it is important to remember that even the most advanced irrigation system is not guaranteed to save you money. Especially if only a smart controller is added, and nothing is done about the inefficient system. Its effectiveness depends upon careful set up and monitoring by a knowledgeable human being (National Association of Landscape Professionals, 2020).

Soil moisture sensor-based smart irrigation controllers use one of several well-established technologies to measure soil moisture content. When buried in the root zone of turf, trees or shrubs, the sensors accurately determine the moisture level in the soil and transmit this reading to the controller (Hydropoint, 2017).

The difference between soil sensor-sensor based systems and traditional systems, is that the soil sensor-based system will stop the next scheduled irrigation when there is enough moisture in the soil. The traditional system relies on manual intervention to stop the irrigation process. Water-on-demand irrigation requires no programming of irrigation duration (only start times and days of the week to water). It has a user-set lower and upper threshold which initiates irrigation when the soil moisture level fails to meet those threshold levels (Hydropoint, 2017).

Ultrasonic Sensor

Ultrasonic sensors are used to monitor functions in irrigation systems. They aim to prevent overwatering or underwatering crops and to measure water reservoir levels to determine if enough water is in reserve to irrigate crops. In soil monitoring applications, ultrasonic sensors prove to be useful for monitoring and controlling the application of pesticides, insecticides, and fertilisers. Ultrasonic sensors are used to improve crop control and management to improve the overall efficiency of the farm.

They make use of high frequency ultrasonic waves that detect the water levels. It performs such measurements in different ways. One is to have a constant ultrasonic wave being emitted and sending a signal when the wave has been interrupted, in other words, when the water level reaches a certain point. Another application is when the sensor is placed at the top of a tank and aimed downwards. It then transmits a wave and measures the time for a signal to return from the water to the sensor. Different types of ultrasonic sensors are:

I. **Ultrasonic diffuse proximity sensor**: Uses a sonic transducer which enables alternate transmission and reception of sound waves. The sensor emits sonic pulses and “listens” for the return reflected from the target.

II. **Ultrasonic retro-reflective sensor**: Detects objects within a specified sensing distance through measuring propagation time. Emits a series of sonic pulses that bounce off a fixed opposing reflector surface.

III. **Ultrasonic through-beam sensor**: The emitter and receiver in the sensor is kept in separate housings. The emitter sends out a signal, which in return is captured by the receiver. When an object obstructs the signal, an output is triggered.

Temperature Sensor

A temperature sensor detects changes of temperature in its environment. Certain crops may require different amounts of irrigation depending on the atmospheric temperature. The temperature sensor allows the small-scale farmer to reduce their irrigation when temperatures are cooler, and less water is expected to be lost due to evaporation. Types of temperature sensors are:

I. **Thermocouples**: Thermocouples are used as they are self-powered and operate at a wide range of temperature. It uses the seedback effect, where a temperature difference of two dissimilar conductors produces a voltage difference between the two substances.
II. **Resistance temperature detector (RTD):** When temperature changes, the sensor's metal resistance changes. It offers a near liner response and has a wide temperature range.
III. **Thermistors**: Similarly, to RTDs, temperature changes result in resistance changes. Thermistors are less expensive than RTDs as they are constructed from cheaper materials. They have a nonlinear relationship with temperature: as the temperature increases the resistance decreases.
IV. **Semiconductor based ICs**: This can either be a local temperature resistor or a remote digital sensor. The remote sensors measure the temperature of an external resistor while the local sensor measure their own resistance change. Outputs can either be analog or digital.

Light Sensor

Light sensors are known as passive devices that convert the energy for light emission into an electrical signal output. They convert photons into electrons. Light sensors are applicable in irrigation systems for water saving and cost saving functions. When the reading from a light sensor is high, i.e., in the middle of the day, the system will receive the input and irrigate less, or stop irrigation, to minimise water evaporation losses. Light sensors are often used in conjunction with temperature sensors.

Light sensors create a yield that corresponds to increased light exposure. The measurement takes place on a wide range of frequencies. Frequency examples range from infrared, bright and direct. Types of light sensors are:

I. **Photo resistors (LDRs):** Light dependent resistors (LDRs) are variable resistors that change their resistance relative to the intensity of light incident on it. Usually, a voltage divider network is needed to read the output. Very useful and can be applied to most projects.

II. **Photodiodes**: Sensors that convert light into an electric current. The current is induced when the photon from light is absorbed in the photodiode. It is the fastest photo detector and has a long lifetime.

III. **Phototransistors**: Similar to diodes where light is converted into an electrical current. They are more accurate as they can adjust their settings based on the amount of light received.

Humidity Sensor

Humidity sensors are electronic devices that measure humidity in the environment and converts the value into a corresponding electrical signal. Humidity sensors are grouped into two categories based on the method used to calculate the humidity.

I. **Relative humidity sensors**: Calculates humidity by comparing the live humidity reading at a given temperature to the maximum allowable humidity at the same temperature. Therefore, they also measure the temperature, and in systems they are often used due to this characteristic. Examples of such sensors are capacitive and resistive sensors.

II. **Absolute humidity sensors**: Calculates the humidity in the air without calculating the temperature in the air. An examples is thermal humidity sensors that detect thermal conductivity.

Air Sensor

Greenhouse agriculture practices are practices that mostly concern air and wind as parameters in cultivation. An application of these sensors would be to sanitise the air from pathogens and chemical contaminants (CO, CO_2, O_3 etc.) Air sensors are used to measure and report the presence of contaminants in the air.

3.1.3.3. Transmitter/Receivers

These devices allow the user, system, or device to exchange data between devices through radio frequencies. In embedded systems, especially when Industry 4.0 is the focus, it is desirable to be able to communicate between devices wirelessly. These modules use radio frequencies to communicate over distances and use RF CMOS technologies when manufactured. RF Modules can be applied over various applications and assemblies of electronic devices. They boast a wide range of functionalities and use communication protocols such as UART and Serial Peripheral Interface Bus to communicate. Higher speed RF communication protocols require a high-speed serial interface such as a USB.

3.1.3.4. Display

This describes the platform or interface onto which information regarding irrigation systems inputs and outputs are shown. The display can come in various forms and be present at various places in the system. For example, certain displays are in the field at the sensor nodes, others are on smart phones and computers. The level of information display is not only limited by the irrigation systems itself, but also the capabilities of the display module. Some displays can only display analog numbers, while other can be seen on smartphone applications.

3.1.3.5. Analog to Digital Converter (ADC)

An ADC is a data converter that allows for digital circuits to interface with the real world by encoding an analog signal into binary code. It converts an analog voltage signal on a pin that converts it into a digital number.

ADCs allows for a high rate of data acquisitions from multiplexed inputs. Most measurable parameters such as temperature, sound and light are in analog form. The ADC acts as an intermediate device that coverts analog data for processing into digital data that enables communication with the digital processors (microcomputers and microcontrollers.)

Types of Analog-to-Digital Converters (ADCs)

Flash ADC: The fastest type of ADC. It makes use of comparators and a string of resistors. Comparator outputs connect to a block of logic that determines the output based on which comparators have a low or high voltage. Flash ADC consumes high IC capacity.

Successive approximation converter: This converter uses comparators and a counting logic to perform conversions. The conversion starts by determining if the input is greater than half the reference voltage. If it satisfies this requirement, the most significant bit of the output is set and is subtracted from the input and is then checked for one quarter of the reference voltage. The counting logic takes as long depending on the amount of output bits to perform a conversion.

Sigma-delta: This type of ACD creates very accurate conversions by using a 1-bit DAC, filtering, and oversampling. The conversion is controlled by an input reference and an input clock rate. Its accuracy is due to the number of samples it uses in its conversions.

3.1.3.6. Communication Technologies

Communication technologies play a crucial role in an IoT device within a wired or wireless network. The networks they operate in consists of energy constraint-devices requiring low power communication technologies. IoT provides connectivity between smart sensing objects to attain management and identification in a heterogeneous environment. IoT involves all objects around communicating between devices locally and globally through the internet.

GSM/GPRS Modules

These modules are chips or circuits used to establish communication between a mobile device and a computing machine with a GSM/GPRS system. A Global Standard for Mobile Communication (GSM) is a standard that was developed by the European Telecommunications Standards Institute (ETSI). The module was created to describe the protocols for second-generation digital cellular networks used by mobile phones.

Global Packet Radio Services (GPRS) is a packed oriented mobile data service for GSMs on 3G and 2G communication systems. The modules are embedded element of the system, while modems and mobiles are their own embedded systems that provide intermediate platforms for communication with users and mobile networks. The modules uses AT commands and features functionalities such as making/receiving calls, SMS, and MMS.

WIFI Modules

Wi-Fi modules are popular in IoT applications. A module such as the ESP8266, is a self-contained system-on-chip (SOC) that has an integrated TCP/IP protocol stack that enables microcontrollers and computers to access a Wi-Fi network.

Depending on the module, users are enabled to host an application or to offload all Wi-Fi networking functions from another application processor. The on-board processing and storing capabilities allow for integration with sensors and general purpose input/output pins (GPIO) empowered application specific devices.

3.1.3.7. Relays

These modules are used in various applications where switches, ON/OFF functions and START/STOP functions are present. Relay modules are electrical switches powered by an electromagnet. The switches close and open the circuits electronically and electromechanically. It is activated by a separate low-power signal received from a microcontroller. When the switch is activated, it is either pulled to open or to close in the electrical circuit. In irrigation systems, it is used to open and close valves, turn on/off pumps and start/stop irrigation efforts.

3.1.3.8. Processors

When considering which processor to use, farmers are encouraged to develop their own node designs to address their site-specific requirements. The type of processor therefore relies on the characteristics of the IoT irrigation system, and the type of crop being cultivated. The processors are integrated circuits, often referred to as a chip, present on microcontrollers. It is a set of semiconductor materials that integrates large numbers of tiny MOS transistors. Processors have revolutionised electronic components by being low-cost, high performing devices encapsulated in small sizes. The processors enable development boards and microcontrollers to perform their functions and enable the integration of nodes, ports, and external components. They are integral to the functioning of an irrigation system.

3.1.3.9. Communication Modules

Communication modules are responsible for exchanging messages between modules on different systems. Communication modules have 3 major tasks, namely maintaining aliases, forwarding, and sending messages between devices. The communication module is used by communication technologies to allow devices to connect to the various communication technologies. The communication allows systems to perform I4.0 functions.

3.1.3.10. Applications

"Apps" are enabled through IoT and other I4.0 technologies to perform high complex functions, display information and improve control in precision farming. The application serves as an interface where data is displayed from inputs of sensors and system outputs. It enables the farmer to monitor information and perform irrigation management and control.

3.1.3.11. Cloud and Database Platforms

Cloud platforms refer to the hardware and operating system of a server in an internet-based data centre that allows software and hardware to interact and co-exist remotely and at different scales. IoT and WSN technologies use cloud platforms and have brought about advances in the capabilities of irrigation systems.

The cloud is a platform where the data collected through sensors and transmitted to remote locations, is processed and stored. With irrigation systems, most of the processing takes place on the cloud itself, where users view their information when accessing the cloud. The cloud platform therefore collects and stores the data provided by the sensors of the irrigation system. This data can be accessed to provide value in decision-making and for the farmer. Most dissertations on irrigation systems do not stipulate the cloud platform they use for IoT functions. The most popular platform is Thingspeak. Thingspeak is known as a very intuitive cloud that provides free and paid options for storing, analysing, and displaying data on different devices. Algorithms can be set through MATLAB. Other cloud platforms used are FIWARW, Dynamo DB, MongoDB, InfluxDB, Firebase, InteGra, NETPIE, SAP, UDIBOTS, AMAZON and M2X. The lesser used platforms are either more expensive or provide fewer services and are less intuitive.

If cloud platforms are not use, storage systems use databases. The most used databases are MySQL, followed by SQL and then SQLite, NoSQL and JSON.

3.1.3.12. Power Supply

Power supplies is a device that supplies power to an electric load required by another electrical device. Power supplies can be standalone pieces of equipment or can be embedded in the device it powers.

3.2. Connecting the Perspectives through Identifying the Components

An irrigation system consists of a display, sensors, power supply, microcontroller, and computing component. Each component can be selected based on the needs of the farmer and to the extent that the system is expected to satisfy various farming pre-conditions. A basic representation of how each component should satisfy capital, and knowledge and skill level pre-conditions, are captured in the tables below.

Table 35: Component Financial Pre-Conditions

Component Distribution for Capital Pre-Conditions			
Component	Minimum Capital Potential	Medium Capital Potential	Maximum Capital Potential
Display			
Sensors			
Power supply			
Microcontroller			
Computing component			

Table 36: Component Knowledge and Skill Pre-Condition

Component Distribution for Knowledge and Skill Pre-Conditions					
Component	**High School Diploma**	**1 Year Community College Degree**	**2 Year Community College Degree**	**Bachelor's Degree**	**Master's degree**
Display					
Sensors					
Power supply					
Microcontroller					
Computing component					

In Appendix B: *System Configuration Pre-Conditions*, the financial pre-conditions are assigned to each available irrigation systems in Table 54. The financial pre-conditions determine the limits within which the system configuration is developed. The recommended academic requirements needed to operate, implement, and maintain such a system needed to be established to create the boundaries for knowledge and skill requirements. Appendix A provides a reference for all available irrigation systems and appendix D is a reference for irrigation system components. From the various architectures shown and discussed in the literature review, the main components of an irrigation systems can be identified. The main components present across the studies are microcontrollers/microcomputers and processor, sensors. Drivers/receivers, display, analog to digital converter, GSM module, Wi-Fi modules. Relay modules, application (Smartphone/Computer). Knowing this, the irrigation system can be developed on RAMI 4.0.

3.3. Developing a System Configurator

RAMI 4.0 is the first reference when developing a model that allows the development of a representation of a physical object in the digital world. It is a modern roadmap for the class of architectures and provides a framework with the minimum requirements to develop an Industry 4.0 product. This includes the definition of terms and a methodology describing the physical world for the purpose of mirroring it in the information world (DIN/DKE, 2016).

When evaluating an irrigation system on a product lifecycle and value stream axis, it should be noted that the framework describes a product before its development stage. A product needs to be updated, restructured, maintained, reformed and redesigned. Each layer of the product life cycle has certain properties. The process layers have two different life cycle stages of a product associated with it, namely types and instances. When the product is in the development stage, it is referred to as a type. The system configuration for an irrigation system falls in this stage. It does not progress past this stage in the framework, and when it moves into production it becomes an instance. If the product is redesigned whilst in the instance stage, it will become a type again (Zaheer 2017).

The product lifecycle aligned with the process layer for an irrigation system is summarised in Table 37.

In the scenario of the irrigation system, the conversion of the items to a product must follow a certain number of rules, standards, and specifications. The production rules are defined in the business model. The product life cycle and value stream layer can therefore be linked to a process layer. The following table is a simplified representation thereof.

Table 37: System Configuration Components on RAMI 4.0 Layers Axis

Process Layer	**Type**	
	Development	Maintenance Usage
Business layer	Pricing and business model, budget, and advertisements	Backup and restore utility
Functional layer	Product features, production rules and control systems	Backup and restore utility
Information layer	1. Order Management 2. Product Information 3. Data Storage 4. Supplier Information 5. Sales Information 6. Component Information 7. Supplier Information	Technology changes, component, and product statuses.
Communication layer	1. Transmitter/Receiver 2. TCP/IP 3. HTTP 4. UDP 5. MSG Transfer/Interpreter 6. Courier	Fibre optics and digital subscriber lines (DSL)
Integration layer	1. Sensor Interpreter	Version updates

	2. System Drivers 3. Scanners 4. Algorithms 5. HMI Device	New sensors
Asset layer	1. Screen 2. Microcontroller 3. Computer Software 4. Sensors 5. Power Supply 6. Ethernet Cable 7. Memory Card 8. Motherboard 9. Battery 10. Documentation 11. Packaging 12. Customers 13. Suppliers 14. Components 15. Project Plan	Test components Product life cycle Redesign capabilities

The table represents the mapping of layers to each process of the product lifecycle. The irrigation system therefore only exists in the development stage of the lifecycle but still occupies process layers on the RAMI 4.0. This is a characteristics of the RAMI 4.0; it shows the integration and divergence of elements, processes and stakeholders and their relationships.

In the development phase, there are several stages. The stages are concerned with developing the software and hardware components and how they work together. The RAMI 4.0 is a highly generalised description within defined target parameters. The hierarchy levels allocate functions and responsibilities within factories/plants/businesses. This allows for logical grouping of functions and mapping of interfaces and standards.

The three-dimensional model of the RAMI 4.0 can be represented as a combination of several 2D layers stacked on top of each other. Each layer is expressed as part of the production lifecycle in a hierarchal phased approach. The system configuration development in this framework does not surpass the control device level in hierarchy, therefore it is only expressed up to this stage. This is due to the system configuration not including the operator into the design, but only the physical product, the data collection devices in the field device, and the processing components within the product (control device). The hierarchy levels indicate the functional properties in each stage and represent all levels of the hierarchy of the system configuration. IIoT connects the device to all the components of the system (Zaheer, 2017).

Table 38: Summary of System Components on RAMI 4.0

Business Layer		
Type		Hierarchy Level
Development	Maintenance	
Manufacturing costs and Analysis	-	Control device
-	-	Field device
-	-	Product

Functional Layer		
Type		Hierarchy Level
Development	Maintenance	
Power generation	On/Off function, product features and production rules and knowledge skill requirements.	Control device
-	-	Field device
-	-	Product

Information Layer		
Type		Hierarchy Level
Development	Maintenance	
System information and part details. product information, item information, data storage, supplier information, manufacturing information, component information and data storage	-	Control device
Soil information, weather patterns, temperature, water content, soil data, Ph levels and rainfall percentages	-	Field device
Irrigation systems	Packaging	Product

Communication Layer		
Type		Hierarchy Level
Development	Maintenance	
Transmitter and receivers, http	batteries	Control device

Sensor values, weather and rainfall	New sensor and maintenance requirements	Field device
-	-	Product

Integration Layer		
Type		Hierarchy Level
Development	Maintenance	
HMI device and firmware	-	Control device
Sensor reader	Time periods	Field device
-	-	Product

Asset Layer		
Type		Hierarchy Level
Development	Maintenance	
Users and **system algorithms**	Test commands	Control device
Machines, motors, devices, Sensors, actuators, motherboard, Wi-Fi, and Ethernet cable	Temperature analysis	Field device
Irrigation system with components	Redesigned feature or add-on	Product

The working functions of the irrigation system are supported by enabling I4.0 technologies. The four enabling technologies are involved in different phases of the working functions. The irrigation system is depicted in the layers of the RAMI 4.0 framework. It consists of building a system network, implementing communication in the cloud network and performing cloud computing. The practices are created within the "type" phase of the life cycle on the x-axis on the RAMI 4.0. Before the mapping of essential components of the system configuration can take place on a two-dimensional platform that consists of three levels of hierarchy on the y-axis and the six IT layers on the x-axis, the irrigation system task classifications are clustered in terms of the IT layers and hierarchy levels (Febriani, 2020).

The z-axis includes the six IT layers ranging from asset through to integration, communication, information, functional and business layers. The main tasks required of an irrigation system are captured in these layers. The tasks of each IT layer are captured in the table below.

Table 39: RAMI 4.0 Layers

IT Layer	Description
Asset layer	Interacts directly with the irrigable environment and digital elements of an irrigation system, such as the controller, power source and sensors.
Integration layer	The modelling if communication requirements between the irrigation system and the control server that can be processed by computers in the cloud.
Communication layer	Controls the connecting access point and the cloud computing element using the HTTP/FTP in the direction of the information layer to manage the data that is being collected.
Information layer	Coordinates sensor signal from soil and weather pattern inputs, as well as previous data generated.
Functional layer	Sets up the irrigation process parameters, such as the battery power and sensor characteristics to respond to real-time information that occurs in the irrigable area.
Business layer	The business model and benefits of using the system configuration and price of such as system.

The hierarchy levels represent the location of the functionalities and responsibilities in the system's physical architecture. The configuration covers three levels: interacting with the environment, data collecting, and process automation. These three levels of the configuration are represented through the control device, field device and product hierarchy levels on RAMI 4.0.

The hierarchy starts with the product level, where the physical asset interacts with the environment. It consists of all the hardware components and physical properties directly and indirectly associated with the product. The field device consists of a set of sensors and data collectors that is imbedded in the irrigation system. At this level, data regarding the irrigation process (soil characteristics, rain patterns, moisture content, irrigation scheduling) is collected and processed by the computing component. The control device enables direct automation control of the irrigation process using automation systems (Alabi, 2019).

3.3.1. Visual Representation of the System Configurator on RAMI 4.0

The main tasks of the irrigation system are proposed in a five-layer description, and differs in perspectives and levels of control and automation. The main tasks involved in the irrigation systems are to monitor and collect soil and weather information and patterns, control the irrigation process in real time, and perform decision making on the irrigation system. The tasks determine the essential components of the irrigation system configuration. An irrigation system can automate the irrigation process by analysing the moisture of the soil and the climate conditions such as rainfall patterns. It supplies water at the right time, in the right quantity and at the right place in the irrigable area for optimal crop growth. Remote water management is enhanced through using soil and moisture sensors. Water supply for irrigation can easily be managed through analysing the condition of the soil and climate. The sensors smartly measure soil moisture based on data; the field gets irrigated automatically with fewer human interventions. The moisture data is remotely available to farmers (Kumar, 2017).

The components that make these tasks possible need to be structured properly to ensure synchronicity. The layers include the hardware concept of a smart management irrigation system in the asset layer, integration with the network in the integration layer, communication via cloud computing in the communication layer, a soil moisture and rainfall information database controlling and monitoring in the information layer, physical configuration in the functional layer, and a business model and pricing in the business layer.

In the asset layer, the physical networks of an irrigation system are designed and coupled with the technology to control the process. It includes the farmer who can operate the system through a human machine interface (HMI) influenced by actuators. The sensors and actuator assess the environment and collects data. The integration layer couples the IT elements with a gateway and a sensor node. Network integration provides information regarding rainfall, moisture, and soil characteristics. The communication layer provides an interface for the irrigation system. A communication protocol such as TCP, IP and HTTP is selected for information management. The information provided on system interfaces enables decision making which is based on the structured data. This data needs to be interpreted, analysed, and executed. A data analysis monitoring and control system is used in the information layer. The sensor values, rainfall, and irrigation requirement parameters are analysed, and the irrigation process can be executed based on an algorithm.

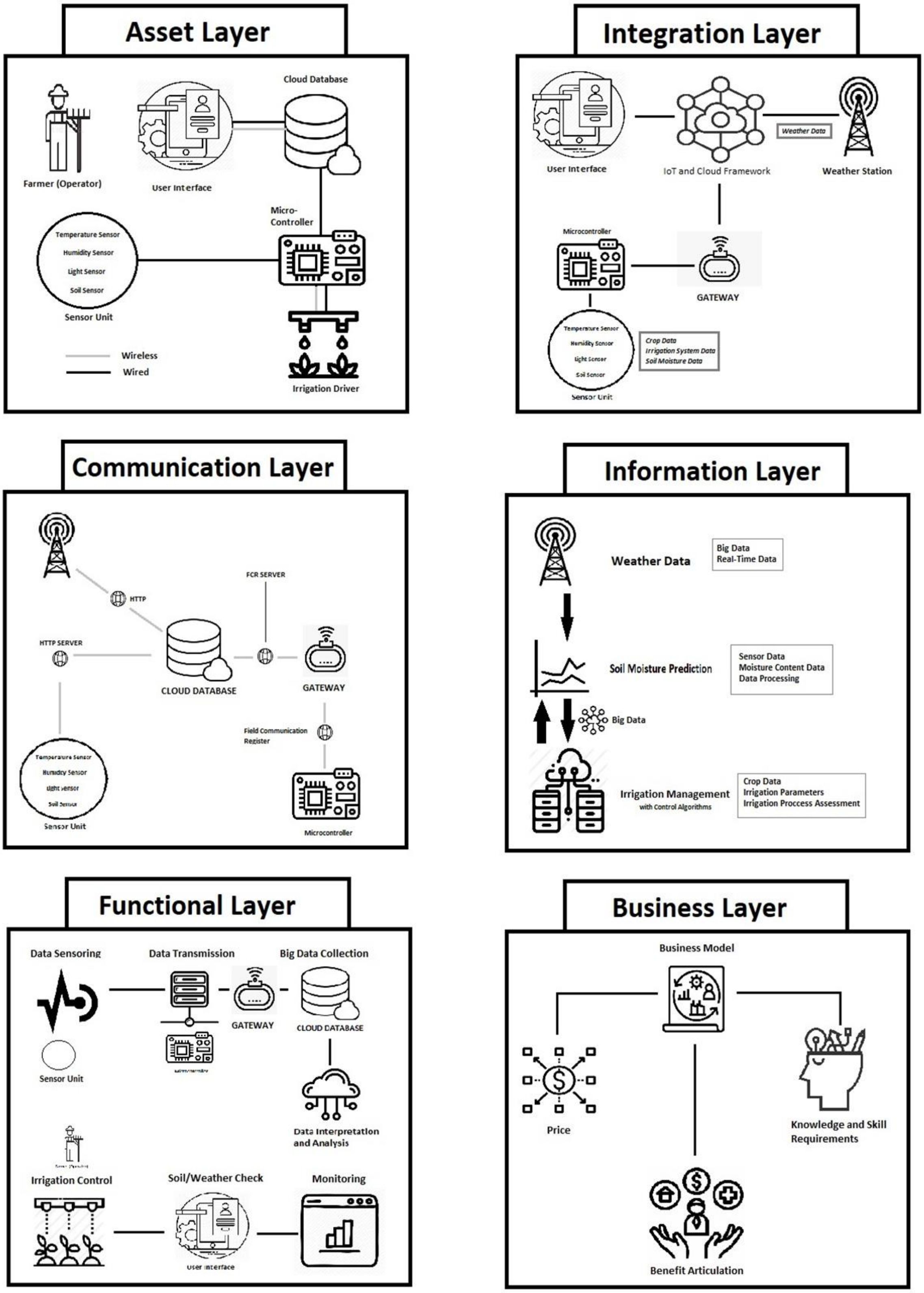


Figure 32: Visual Representation of the System Configuration Layers

The functional layer describes the model and integration services of the irrigation system through decision making strategies for irrigation management. Real-time soil and moisture characteristics and rainfall patterns are collected through IIoT by sensors, and the irrigation process data acts as system inputs. The system processes the data, makes decisions based on the inputs, and can control the irrigation process. The business layer concerns the communication of the functions of the system configuration and other characteristics such as price and knowledge requirements (Febriani, 2020).

3.3.2. System Configurator Layers on RAMI 4.0

Moghaddam et al. (2018) propose dividing fundamental architectural elements into three architectures namely, functional architecture that describes the system functional requirements, physical architecture that describes the components of the system and an architecture that integrates the two. The elements are modelled into a platform with an I4.0 component allocated to each aspect of RAMI 4.0 to fully describe the irrigation system. This includes the physical network functional architecture, the interface architecture connected to the cloud, enabling technologies, and the documentation required for each aspect.

Standards and mechanisms need to be developed to guide, educate and simplify interactions between the small-scale farmer and the human machine interface. The design and interaction rules and architectures must conform to open communication and self-description standards such as the OPC-UA.

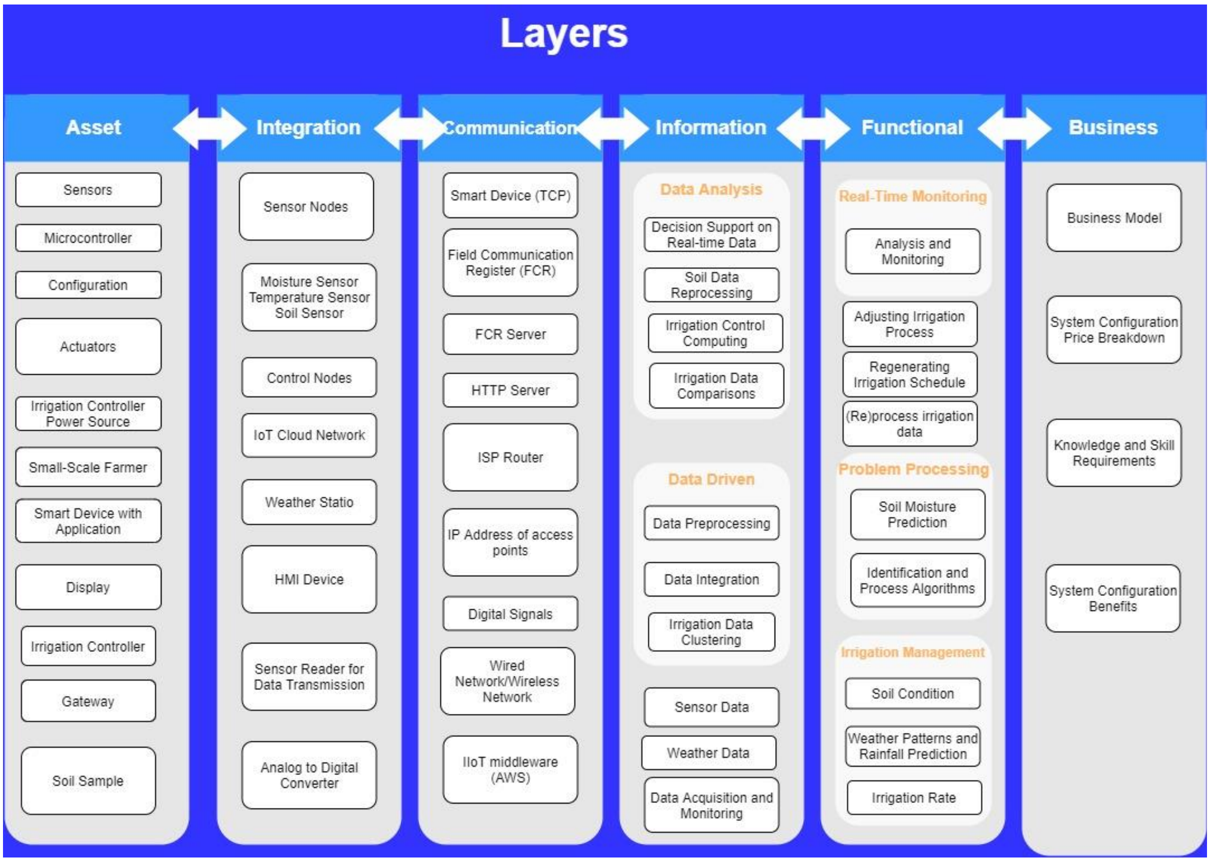


Figure 33: System Configuration Mapped on Layers Axis

The system configuration is designed at the product level. The system is designed based on the platform architecture and modelling thereof. The usage of the system can thus be described with I4.0. The proposed RAMI 4.0-led irrigation system configuration identifies the main components and enabling I4.0 technologies. This allows the user to design the system that is efficient, effective, and simplified to increase practicality. The hardware and software components, information, and capabilities can be derived from the layer architecture. Core benefits and technologies encourage the application of the system.

RAMI 4.0 standardises automation services that use cloud computing and improves interface transparency for the user. This value-added service is integral to I4.0, due to it is enabling flexible management of systems such as the irrigation system. The service comes in the form of data collection, sensor input processing, data interpretation and decision- making. Each layer, hierarchy level and lifecycle phase in the configuration is represented. The layers consist of the technology functions, and the components arranged on the platform such as hardware, data collection and connection, information processing, and operating and control strategies. The hierarchy levels indicate the required components that support the proposed approach.

Table 40: Hierarchy Levels of the System Configuration

Product	The smart irrigation controller placed in the irrigable field among crops.
Field device	The sensors and actuators of the s
Control device	Controller in a machine and/or application.

Irrigation systems involve the physical device and creates a platform for flexible, self-aware, and autonomous irrigation practices.

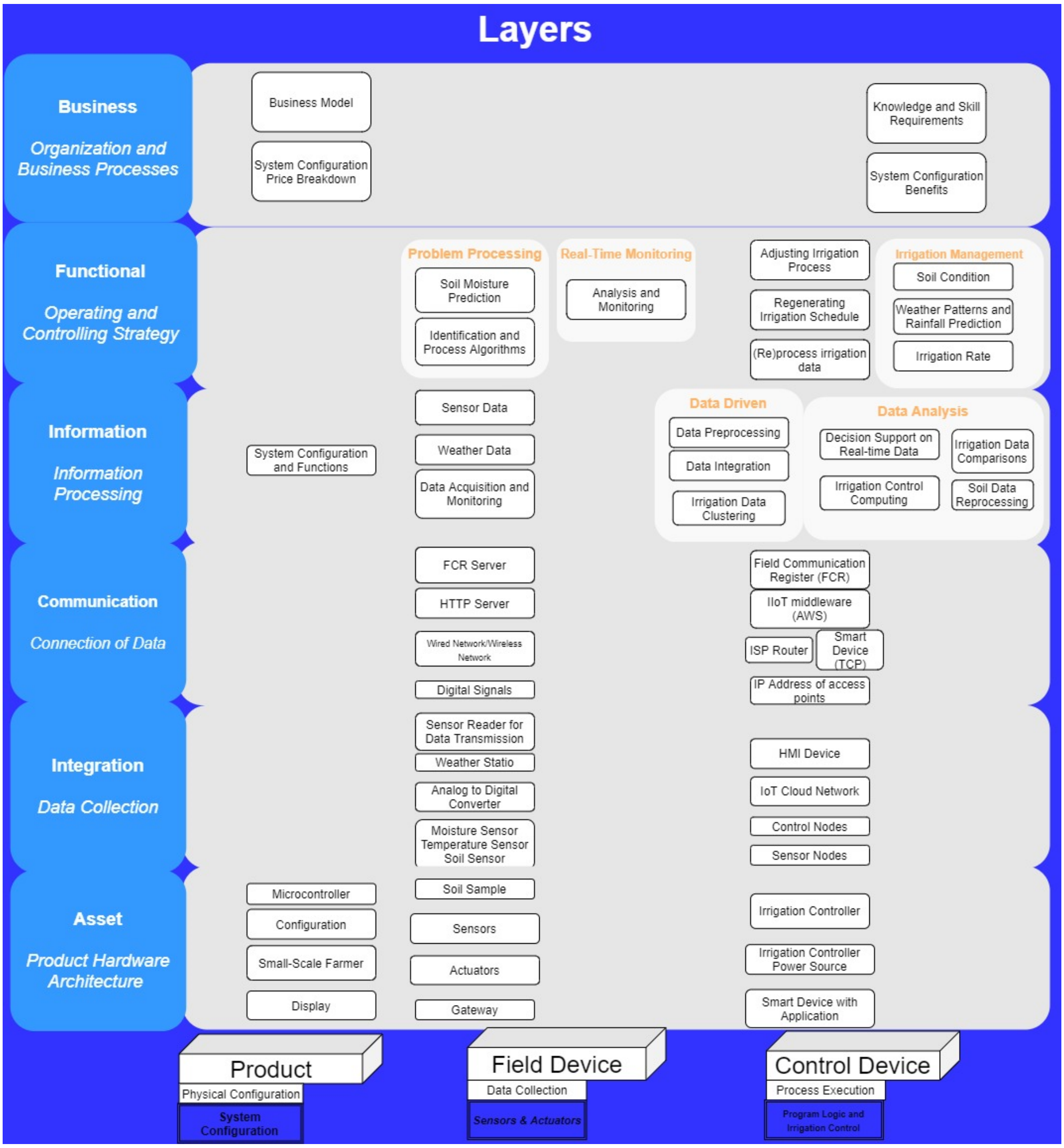


Figure 34: Components at Hierarchy Levels of the System Configuration

The irrigation system environment requires a high-level complex network with multiple interacting layers that involve the functional, physical, and value-network aspects of the system. From the requirements outlined by RAMI 4.0 for an irrigation system, a configurator can be designed which can be used by small-scale farmers to select components that will enable them to develop their own irrigation systems.

3.3.3. System Configurator Design

From RAMI 4.0, we can determine which components are needed to develop an irrigation system that qualifies as an I4.0 product. The layers describe all the available components, technologies, and functions available to the farmer on each hierarchy level. The visual representation in Figure 35 shows the integral or core elements of such a system. The core components of the system enable the operations of the irrigation system.

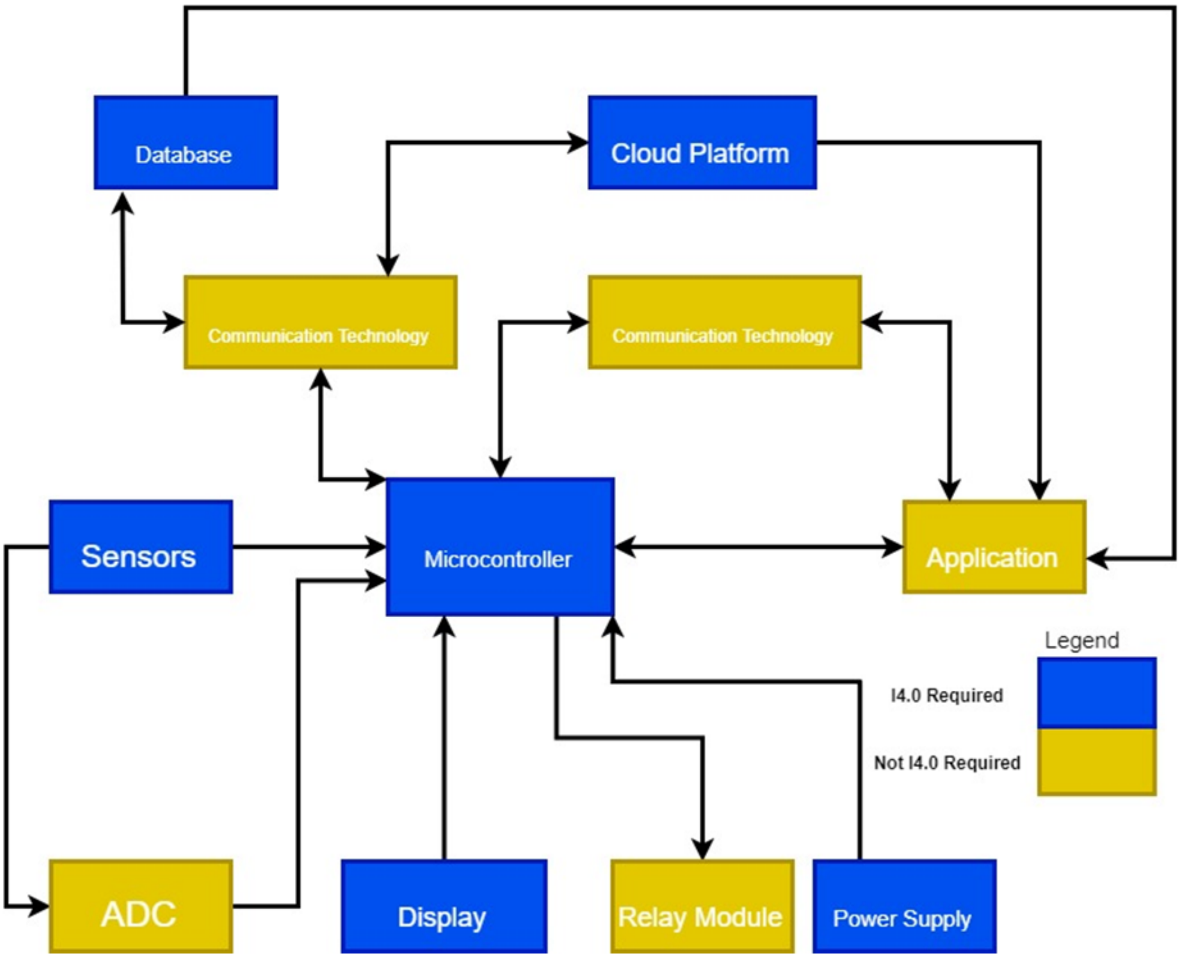


Figure 35: Components of an Irrigation Systems

In Figure 35, the microcontroller, sensor, display, database and/or cloud platform are the components needed for the irrigation system to qualify as an I4.0 product. The microcontroller, depending on the type, can perform most of the tasks required as outlined in the layers on the RAMI 4.0. Microcontrollers such as the Raspberry Pi range, Arduino and other mentioned in the literature study have features that enable the system to perform tasks. For example, the Raspberry Pi 3 has communication technologies installed on it, has nodes, and comes with a platform for human-machine integration and cloud software. The sensors are needed to provide input for data analysis and interpretation. A power supply is required for the system to perform. A display is necessary to provide an interface for human-machine interaction. The display can also be defined as a smartphone, a computing device or another interface that the farmer already owns. The cloud platform and database are required to store and collect big data for analysing and interpreting.

The relay module is set as "not I4.0 required" as it is possible for the small-scale farmer to desire a system that provides data for analysing and interpreting, while performing manual irrigation practices. For example, the farmer sees that the soil moisture is below the desired threshold for his crop, and he manually turns on the sprinkler until the desired moisture content is reached. The irrigation systems will still perform I4.0 functions in this instance. The ADC is optional if a sensor is chosen that provides a digital output, and would therefore not require an ADC. Communication technologies are optional provided that the microcontroller already has certain technologies embedded in the system. An application, which is an interfacing platform between the small-scale farmer and the irrigation system, is also optional. Small-scale farmers can programme the microcontroller to indicate relevant information on a display without the need of performing control and management via an application.

The optional components are still included in the configuration due to their extensive benefits that a small-scale farmer may deem appropriate for their farming requirements. Processors and communication modules are not included in the component selection process as they are embedded in the microcontroller and communication technology. It is of interest when the farmer wants to develop their own microcontroller, which does not form part of this framework, but information is provided if that is what the farmer desires. Having the pre-conditions to use the framework, knowledge of the components, and a system configurator that enables design, the framework can be applied.

3.4. Chapter Summary

In this chapter the development process of the framework was described. The framework is developed to enable a small-scale farmer to configure their own irrigation system which they can implement on their farm. The configuration of the irrigation is the main output that the small-scale farmer would get from using the framework, whilst adhering to their financial capability, operating within their knowledge and skill levels, and providing the benefits to the site-specific requirements they desire. The three-part development process started by identifying preconditions for each framework perspective by using resources from the literature study. The financial preconditions aim to include small-scale farmers at the lowest financial capacity, i.e. those who require grants and loans. The upper financial limit was set as the highest grant a small-scale farmer can receive, and not a commercial income figure, to eliminate large-scale and complex irrigation systems.

The knowledge and skills requirement perspective was developed to guide the farmer to identify which knowledge and skills are required to use the new technologies from I4.0 identified in the literature. The farmer and/or his labour force have certain knowledge and skill levels available to operate a system and want to ensure that the system aligns with this level. This perspective provides the competency, knowledge and skills required for components and systems. The benefit of each component is given to provide the farmer with the opportunity to choose a component based on what he/she would want the component to provide in the irrigation process. A selection of options is given for each component to increase the potential to make an educated decision.

RAMI 4.0 was implemented to design a system configurator that can ease the process of component selection by providing a visualisation of the system configuration. The configurator provides the necessary components that the farmer has to include in the irrigation system.

In the following chapter, the deployment of the framework to gain this output, is described.

Chapter 4 Framework Deployment

The framework for a configuration of an irrigation system was developed through an extensive literature and market review firstly, of what key barriers to applying the system would be experienced by small scale farmers. Secondly, the top barriers identified by a thorough a Pareto analysis were addressed. The literature analysis supports the development of the framework, the validation thereof, and determining the rationale for the framework. Market reviews aided in identifying readily available irrigation systems, components, and case studies. This allowed for the construction of boundaries for the framework and the barriers that are addressed. To use the framework, the small-scale farmer should establish a starting position before using the configurator. This will allow them to determine what they can achieve and require them to take stock of farming-related factors. The factors include site-specific requirements, goals, and constraints. The pre-conditions are captured in Appendix B.

4.1.Introduction

In this chapter, the deployment of the framework is outlined. It describes how the framework will be used in practice. The deployment is constructed to ensure the aspects are included that will best enable a small-scale farmer to develop an effective irrigation system and that the irrigation system will be able to perform the tasks required of a precision farming irrigation system. The framework provides support up until the acquisition and subsequent implementation of the irrigation system.

The process starts by the small-scale farmer defining their site-specific requirements, goals and constraints. Thereafter the perspectives are used to select components and available systems within the framework that adhere to the requirements, constraints and goals. The system configurator is then used to select the appropriate components that will satisfy the requirements.

4.2. Defining Site-Specific Requirements, Constraints and Goals

To use the framework, the small-scale farmer should first establish a starting position. This will allow them to make decisions in the framework knowing what they can and want to achieve. It requires the small-scale farmer to take stock, assess and analyse the factors, listed below, that will determine what they are able to achieve.

I. Site-specific requirements: Under what conditions does the small-scale farmer farm?

II. Constraints: Under what limitations does the small-scale operate?

III. Goals: What does the small-scale farmer want the irrigation system to achieve?

4.2.1. Site-Specific Requirements

The site-specific requirements prompt the small-scale farmer to evaluate what his farming conditions are and under what conditions the irrigation system will operate. This allows the farmer to choose irrigation systems and components based on the farm's characteristics. The requirements are defined and categorised in Appendix B. Table 41 and Table 42 are extracts of the tables in Appendix B. They indicate the categories and definition for sensor types.

Table 41: Extract of Site-Specific Requirements

Requirement	Description	Category
Sensor type	Device or part of irrigation controller that is used to detect and respond to electrical or optical signals. It converts the physical parameters into a signal that can be measured electrically. (Bhatt, 2011)	Weather-Based Sensor
		Soil-Based Sensor

Table 42: Extract of Definition of Site-specific Requirements

Requirement	Category	Definition
Sensor type	Weather-based sensor (W)	The irrigation controller uses local weather data to adjust irrigation schedules.
	Soil-based sensor (S)	The irrigation controller uses soil characteristics to provide information or adjust irrigation schedules.
	Hybrid (H) / None (N)	Hybrid systems make use of both weather and soil-based detection, while None refers to those that do not make use of these detection methods

These site-specific requirements initiate the process which determines what the irrigation system can achieve.

4.2.2. Constraints

The constraints determine what the limits of the framework are. The constraints should be defined with reference to the barriers identified. The first constraint is financial so the farmer needs to determine how much capital can be allocated towards an irrigation system. Referring to 3.1.1, a good measure would be to allocate 6% of the yearly farming budget towards irrigation.

The second constraint would be the available knowledge and skills. Using Table 78, the farmer can identify which knowledge and skill sets are present within their farming practice and labour force.

Defining this constraint would help to determine which components and available irrigation system would be of use.

4.2.3. Goals

Before the framework is used, the small-scale farmer needs to articulate the goals they wish their system to achieve. The literature indicates that the following common goals below can be achieved by implementing an irrigation system.

I. Improve yields

Irrigation systems are known for their ability to improve yields of crops by applying the correct amount of water in the correct quantities at the correct time. Therefore, some systems are applied to do just that.

II. Reduce water usage and irrigation operating costs

Certain irrigation technologies and irrigation systems can save more water than others. The application difficulties and costs may also differ. The small-scale farmer should therefore estimate the percentage of water they want to save. When water usage is reduced, irrigation operating costs are also reduced. The small-scale farmer can stipulate the percentage irrigation cost he/she would want to save to achieve water reduction.

III. Reduce labour costs

If the farmer wants to reduce labour costs, more automated irrigation systems should be considered. The more automated the system is, the less human input is required.

IV. Improve irrigation efficiency and preserve the environment

Irrigation systems are characterised by the efficient use of natural resources. If the farmer's concerns are to operate under conditions that preserves the environment, certain irrigation systems are more inclined to use water as sparingly as possible. This includes systems that uses weather data to make irrigation decisions and systems that regularly test soil and moisture content.

Certain market available system lends themselves better towards certain goals, which makes it easier for farmers to determine which systems they should implement. After the constraints, goals and site-specific requirements are defined, the irrigation system can be designed to reach specific goals, operate within constraints and satisfy site-specific requirements.

4.3. Design of the Site-Specific Irrigation System

4.3.1. Perspective 1: Financial Capability

Costs to convert and implement PF varies in applications, companies, and cultivation areas. Computers, software, and yield monitors can be added to existing equipment on farms. Jacobs et al. (2018) found that all farmers who apply PF agreed that expenses incurred were compensated within two years.

Description: This perspective addresses the barrier of high capital cost required by initial implementation and investment. Irrigation systems and components are defined according to the capital requirements to implement the system.

Small-scale farming characteristics: Farmers who approach the system configuration framework from this perspective are risk adverse and have limited financial capabilities that the system needs to satisfy. They may also already be aware of the other requirements and are only interested in choosing the configuration that matches their financial plan.

Component identification, description, benefits, and costs are all addressed in the literature. This information can be applied to the RAMI 4.0 by the small-scale farmer to develop their configuration of an irrigation system based on their financial capability. This allows the farmer to develop several component combinations to find the best configuration for them. An example of a system comprising a soil moisture sensor, a temperature sensor, a microcontroller, ADC, a relay module, and a cloud platform is discussed.

The first iteration of the perspective requires the farmer to develop their own system configuration based on the component requirement and availability outlined in Figure 35. To choose the amount the small-scale farmer wishes to invest in each component or the system as a whole, Appendix F: Financial Capabilities is used to guide the cost. Table 81 provides the information to perform this action. The table provides product costs for each component in ascending order.

Table 43 is used in the following equation to determine a system comprising a Raspberry Pi Zero W microcontroller, a FC37 Rain Sensor, Geekcreit 3.2 Inch MEGA2560 display, a MCP4725 ADC, 50-meter Ethernet Communication Technology, a HiLetgo 2pcs 5V relay module, 4 Battery Power Supply and the Raspberry Pi Cloud Platform.

8. Financial Requirement for a Configured Irrigation System

$$(\boldsymbol{Raspberry\ Pi\ Zero\ W})\mathbf{10} + (\mathbf{FC37})\mathbf{2} + (\boldsymbol{Geekcreit\ 3.2\ Inch\ MEGA2560})\mathbf{9} + (\boldsymbol{Ethernet})(\mathbf{50})(\mathbf{0.19}) + (\boldsymbol{HiLetgo\ 2pcs\ 5V})\mathbf{6} + (\boldsymbol{MCP4725})\mathbf{5} + (\boldsymbol{Batteries})(\mathbf{4})(\mathbf{1}) + (\boldsymbol{Raspberry\ Pi\ Cloud})(\mathbf{0}) = \mathbf{45.5}\ \boldsymbol{USD}$$

Table 43: Extract From Appendix G: Financial Capabilities

Microcontrollers		Sensors		Display		ADC		Communication Technologies		Relay Modules		Application		Cloud Platform		Database		Power Supply	
ESP8266 Microcontroller Board	3 USD	Rain Sensor		Arducam 1602	6 USD	MCP3008 / MCP3004	2 USD	Ethernet	0.19 USD	HiLetgo 2pcs 5V	6 USD	Spruce	≈ 180 dollars for the controller and application	Raspberry Pi	Free	SQLite	Free	Batteries	1 USD
		FC37	< 2 USD																
		YL83	< 2 USD																
WEMOS MINI D1	8 USD	Rain Sensor Module - Microcircuits	4 USD	Geekcreit 3.2 Inch MEGA2560 Display Module	9 USD	MCP4725	5 USD	Bluetooth	9 USD	KNACRO 1-Channel	8 USD	Rachio	≈ 200 US Dollars for the controller and application	NETPIE	Free	NoSQL	Free	USB Port	2.6 USD
		HALJIA	6 USD																
		Leaf Wetness 12V DC Rain Sensor Module	10 USD																
Raspberry Pi Zero W	10 USD	AZDelivery 5 x Rain Sensor Module	11 USD (5pcs)	Geekcreit® UNO R3	10 USD	LTC2499	6 USD	GSM	Price dependant on	JBTek	8 USD	GreenIQ	≈ 249 US Dollars for	Firebase	Free	JSON	Dependant on service database	Solar Cell	2.91 USD

The second iteration of this perspective provides industry-ready irrigation systems that perform set functions and are provided by third party companies. Small-scale farmers can evaluate if the system configuration they develop would better suite their financial capabilities compared to available irrigation systems. Table 54 provides the financial requirements for the selected irrigation system sourced in the literature. The system is advantageous as it does not require development, but it is less site-specific and the design is limited to the specifications determined by third party providers.

4.3.2. Perspective 2: Benefit Articulation for Farming Requirements

Jacobs et al. (2018) found that 94 % of the farmers who applied PF felt that problem areas with regards to soil fertility were adequately addressed. All of them agreed that the application of PF has increased yield and yield potential significantly within 0.5 and 2.5 t. ha^{-1}*. The majority of the farmers also indicated that labourers require further knowledge and skills to be trained to operate the PF.*

Description: Benefit articulation for farming requirements aims to describe the benefits that the system configuration will have for their individual needs. This addresses the barrier of farmers being uncertain of the advantages, benefits, and improvements that irrigation systems will bring to their farming operations. They thus lack the information that would justify implementing the system.

Small-scale farming characteristics: Farmers approaching the framework from this perspective are uncertain about new irrigation systems and their functionalities, capabilities, components, legality, and limitations. They also have specific requirements that the system should perform for them to apply the system.

In the first iteration of the perspective small-scale farmer refer to Figure 35 when developing their own system configurations to ensure they adheres to the required components for an I4.0 product and additional components. After the components are selected, 3.1.3 is used to determine the benefits of the specific product of each component. Information is provided in 3.1.3 regarding the functions performed by each component, the available products for each component, and their benefits. The small-scale farmer can choose the components based on the benefit they would provide him/her and can develop a system configuration that serves his/her personal, professional, and crop-specific needs.

The second iteration of the perspective enables the farmer to evaluate if the benefits and functions of available irrigation systems would suit their personal and/or professional farming requirements. Table 49 in Appendix A provides a categorisation of available irrigation systems for reference in evaluating the functionality of each product. The farmer is encouraged to refer to further online material regarding each product to make more informed decisions; the scope of including all the information about each product falls outside the scope of this study.

A thorough literature review of available technologies was conducted, and various market-ready, available irrigation systems were identified. A technical review by the U.S Department of the Interior on market ready products is summarized in the 5th Edition of the Report on page 157-159. This summary of weather-based and soil-based devices is used in the current framework as supplementary information regarding the benefits of available products.
The variety of product benefits are vast and tested across a large variety of soil conditions, landscapes, rainfall patterns and site-specific requirements. Companies thus aim to articulate benefits as averages over annual periods or as a list of features. Table 50 captures the benefits reported by several studies, reviews, company reports, and tests conducted on various available irrigation systems.

If the small-scale farmer requires more technical specifications for each available irrigation system, Table 49 in Appendix A summarises specifications which the farmer can use based on their pre-conditions. Appendix D includes specifications of the core irrigation system components regarding their benefits, price, and competitors if the farmer wants to develop the system to a further level of detail.

4.3.3. Perspective 3: Knowledge and Skill Capability

Jacobs et al. (2018) conducted a survey where farmers identified the fact that application of PF can be accelerated by making improvements in training programmes for labourers, simplifying software, and accessing thorough advice and farm-specific benefit articulations.

Description: Most studies indicate that there is a perception (justified or not) that PF and irrigation systems are too complex to implement. This perspective identifies the knowledge and skill requirements needed to operate a developed system.

Small-scale farming characteristics: The small-scale farmer is concerned about the complexity of the system and levels of technological literacy required to operate the irrigation system. The farmer and/or his labour force has certain knowledge and skill levels available and wants to ensure the system is operable within this level.

The knowledge and skill requirements are identified in the framework below.

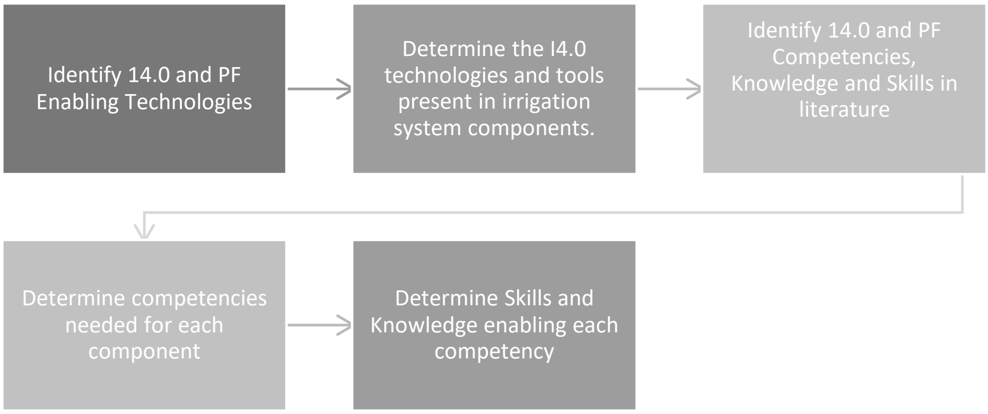


Figure 36: Framework for Determining Knowledge and Skill Requirements

Competencies, knowledge and skills are related to each component in a comprehensive framework. The table reads from left to right. The small-scale farmer identifies the component they want to add to their system, and the next column is the subset of that component. For example, the component: "Sensor", has a subset: "Temperature Sensor". After identifying the subset, the competency letter from A to D, refers to the competency's domain in Table 78, and the second letter refers to the relevant competence. The knowledge areas in the table refer to the ones also listed in Table 78. From this, the small-scale farmer can identify the relevant skills needed for each component. It must be noted that one cannot be expected to master each skill in the knowledge area, but it serves as a starting point to identify which skills they already have, and to identify gaps where training and education should be provided. The following table is an extract of Table 78, to illustrate the abovementioned logic.

Table 44: Knowledge and Skills Required for a Temperature Sensor

Component	Description	Competencies	Knowledge & Skills
Sensor	Temperature sensor	A	A.A.1 & A.A.2.; A.B.2.; A.C.1.
		B	B.B.1.
		C	C.A.1; C.C.1; C.D.1.; C.D.2 & C.D.3.
		D	D.A.3. & D.A.4

The second iteration of the perspective allows the farmer to evaluate available irrigation systems based on the knowledge and skills required to use the products, based on the components of the system. Farmers can thus evaluate whether an available irrigation system would require less knowledge and skills than developing their own system configuration.

If a farmer wishes to acquire the competencies, skills and knowledge required to operate different components of an irrigation system, Table 80 is provided as an additional resource. It indicates different qualifications as education levels, starting from "No Education" up to "Master's Degree" and the relevant competencies, skills and knowledge gained when completing each level of education. For example, if the farmer lacks the knowledge and skills Area, "D.A.3 Operational knowledge of PF Software", they can refer to the table and see that it can be learned theoretically through an institution at the education levels "2 Year Community College Diploma", "Bachelor's Degree", or "Master's Degree".

4.3.4. Integrating Perspectives to Achieve Goals

To integrate the perspectives, the results of each are combined. The framework is initiated when the farmer identifies the requirements, constraints, and goals, and the following example illustrates how this can be achieved. A small-scale farmer has the following constraints:

I. Capital of less than $ 100 to allocate to the system

Goals:

I. Goals of improving water savings of up to 30 %

Requirements:

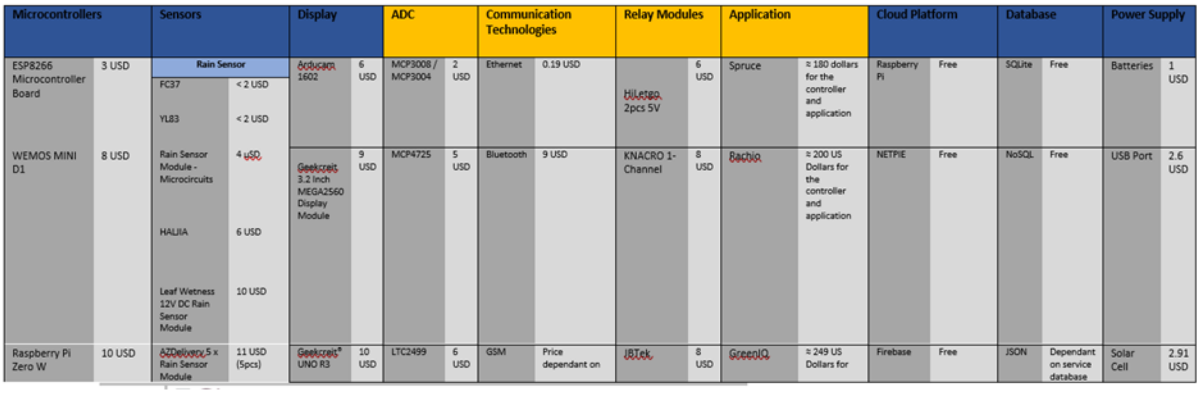
I. Having a soil-based sensor
II. The benefit of a soil-moisture sensor that has low power consumption and analog to digital output potential
III. A display that needs no extra wiring or soldering and low power consumption
IV. WIFI or ethernet connectivity, and
V. Operational capacity in more than 10 zones.

From this the farmer goes through the perspectives to configure a system, and then refers back to the framework to ensure that the choices adhere to the constraints, requirements, and goals.

Perspective 1: Financial Capability

For the first perspective, the system configurator in Figure 35 along with Appendix F is used to construct an irrigation system under $ 100 that has a soil-based sensor and can operate in more than ten zones. One iteration of such as system would include the following:

Table 45: Extract From Appendix G: Financial Capabilities



Microcontrollers		Sensors		Display		ADC		Communication Technologies		Relay Modules		Application		Cloud Platform		Database		Power Supply	
ESP8266 Microcontroller Board	3 USD	Rain Sensor		Arducam 1602	6 USD	MCP3008 / MCP3004	2 USD	Ethernet	0.19 USD	HiLetgo 2pcs 5V	6 USD	Spruce	≈ 180 dollars for the controller and application	Raspberry Pi	Free	SQLite	Free	Batteries	1 USD
		FC37	< 2 USD																
		YL83	< 2 USD																
WEMOS MINI D1	8 USD	Rain Sensor Module - Microcircuits	4 uSD	Geekcreit 3.2 Inch MEGA2560 Display Module	9 USD	MCP4725	5 USD	Bluetooth	9 USD	KNACRO 1-Channel	8 USD	Rachio	≈ 200 US Dollars for the controller and application	NETPIE	Free	NoSQL	Free	USB Port	2.6 USD
		HALJIA	6 USD																
		Leaf Wetness 12V DC Rain Sensor Module	10 USD																
Raspberry Pi Zero W	10 USD	AZDelivery 5 x Rain Sensor Module	11 USD (5pcs)	Geekcreit® UNO R3	10 USD	LTC2499	6 USD	GSM	Price dependant on	JBTek	8 USD	GreenIQ	≈ 249 US Dollars for	Firebase	Free	JSON	Dependant on service database	Solar Cell	2.91 USD

$$(Raspberry\ Pi\ Zero\ W\ )10 + (\mathrm{FC37})2 + (Geekcreit\ 3.2\ Inch\ MGA2560)9 + (Ethernet)(50)(0.19) + (HiLetgo\ 2pcs\ 5V)6 + (MCP4725)5 + (Batteries)(4)(1) + (Raspberry\ Pi\ Cloud)(0) = \mathbf{45.5}\ \boldsymbol{USD}\ \ [\mathbf{11}]$$

The system configurator is used to determine which components are necessary to implement a system that will adhere to site-specific requirements, constraints, and goals. When choosing an available irrigation system there are various products available: Orbit B-Hyve 12 Zone Smart Indoor/Outdoor Controller retails under $100.

Perspective 2: Benefit Articulation

For the benefit requirements set out by the farmer, The FC37 soil moisture sensor has an analog to digital output potential and low power consumption. The Geekcreit 3.2 Inch MEGA2560 display requires no additional wiring or soldering and also has low power consumption. These benefits are found in the tables in 3.1.3.

The Orbit B-Hye claims to save up to 50 % of water compared to traditional irrigation systems. The Orbit B-Hyve can also function in more than 10 zones, comes with WIFI connectivity, and requires no additional wiring and soldering for its display. The benefits of available irrigation systems are found in Appendix A.

Perspective 3: Knowledge and Skills Requirement

From a knowledge and skills perspective, the following are needed to operate an irrigation system based on the components chosen in Table 78.

Orbit B-Hyve systems are, according to the product, easy to install and operate. Wiring and connecting a controller to an irrigation technology is made easy through manuals and clear instructions. The additional knowledge and skills mentioned above are therefore not necessary.

The configurator below is constructed with the components that the small-scale farmer selected for his irrigation system. The required components can then be acquired, connected, and implemented on the farm. Table 46 is a representation of the framework, based on site-specific requirements, goals, and constraints, in matrix form. The table reads from left to right. The first two columns represent the irrigation system. The first column includes the components selected by the farmer using the system configurator. The second column is the available irrigation system from the market selected by the farmer based on site-specific requirements. The following columns each represents one of the perspectives. Each perspective provides the necessary information for each component and the available irrigation system from the market. For example, the financial capability perspective provides the financial requirement for each component selected plus the market available irrigation system.

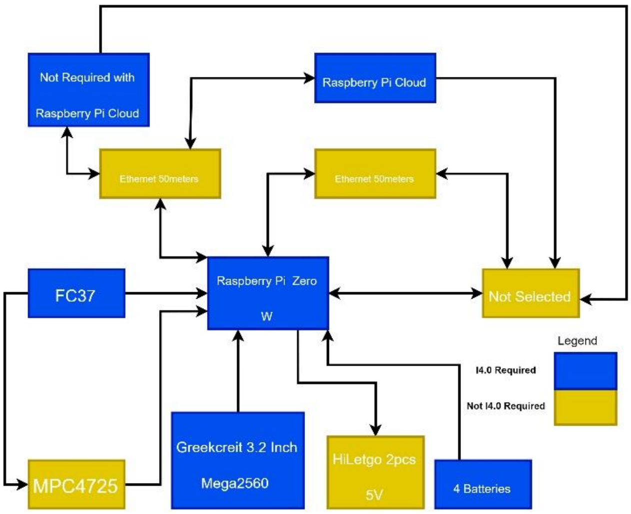


Figure 37: Configured System Based on Selected Components

The integration of the perspectives using the system configurator enables the farmer to construct a system that satisfies their requirements and capabilities. After the perspectives are integrated, the small-scale farmer can proceed to develop their irrigation system and implement it. The farmer will now know what he requires from each perspectives and will be able to apply the system to their practices or outline what they additionally require. The system is developed at a low cost of 45.5 USD, which is under the lower limit of 91 USD. This provides the ability to also finance the cost of the delivery of components and the use of other resources.

The configured system's components allow it to perform the necessary tasks described by Restuccia (2016) in 2.1.5.2., for it to function as an I4.0 irrigation system. The FC37 moisture sensor communicates with the system if the irrigable area is subject to rainfall or moisture. This would provide information for the system or small-scale farmer, to decide to stop the provision of water and to adjust the watering times based on the moisture data. The farmer can use the information to adjust watering times manually or through a programme enabled by the Raspberry Pi microcontroller. The programme's setup would require additional support. The sensors in conjunction with the relay module, cloud database, and microcontroller can provide real-time characteristics of water usage and soil data and can be displayed on a Greekcreit display. The framework will now enable the development of an irrigation system that can adhere to the requirements of the farmer while providing the functionality that can provide the benefits of the available technology.

Table 46: Integrated Perspectives Matrix

Irrigation System			Financial Requirement ($)		Benefit Articulation		Knowledge and Skill Requirement			
Component		Available Systems	Component	Available Systems	Component	Available Systems	Component		Available Systems	
Microcontroller	Raspberry Pi Zero W	Orbit B-Hyve 12 Zone Smart Indoor/Outdoor Controller	10	83	1. Various I/O pins which can interface to other boards and circuits. 2. USB port, 14 I/O pins, ICSP header, power supply and reset press. 3.Compatible with computers 4.Low cost with online libraries available	The Orbit B-Hyve claims to save up to 50% of water compared to traditional irrigation systems. The Orbit B-Hyve also can functions at more than 10 zones and comes with WIFI connectivity and requires no additional wiring and soldering for its display. Orbit B-Hyve systems are according to the product, easy to install and operate. Wiring and connecting a controller to an irrigation technology is made easy through manuals and clear instructions. Therefore, additional knowledge and skills mentioned above are not necessary. Up to 12 zone capacity. Any Biome.	A	A.A.1 A.A.2; A.C.1.	A	A.A.1 A.A.2; A.C.1.
							B	B.A.1.	B	B.A.1.
							C	C.A.1. C.A.2.; C.B.1. C.B.2.; C.C.1.; C.D.1. C.D.2. C.D.3.	C	C.A.1. C.A.2.; C.B.1. C.B.2.; C.C.1.; C.D.1. C.D.2. C.D.3.
							D	D.A.1. & D.A.3. & D.A.4.	D	D.A.1. & D.A.3. & D.A.4.
Sensor	FC37		2		1.Analog and digital output potential 2.Easy installation features 3.Low power consumption 4.Adjustable digital output threshold with potentiometer		A	A.A.1 A.A.2.; A.B.2.; A.C.1.	A	A.A.1 A.A.2.; A.B.2.; A.C.1.
							B	B.B.1.	B	B.B.1.
							C	C.A.1; C.C.1; C.D.1.; C.D.2 C.D.3.	C	C.A.1; C.C.1; C.D.1.; C.D.2 C.D.3.
							D	D.A.3. D.A.4	D	D.A.3. D.A.4
Display	Geekcreit 3.2 Inch MEGA2560		9		1. High image quality and fast response. 2. Module can be inserted directly into a Mega board. 3.Low power consumption 4. Easy installation.		A	A.A.2.		
							B	B.B.1.		
							C	C.A.1. C.A.2.; C.C.1.; C.D.1 C.D.2. C.D.3.		
							D	D.A.1. D.A.2. D.A.3.		
Power Supply	Batteries		(4) x (1)		1. Batteries are low-cost devices. 2.Small size 3. Can be inserted on device. 4. Does not require external components and provides the irrigation systems with freedom to be placed wherever it is needed.		A	A.A.2.; A.C.2		
							B	B.B.1.		
							C	C.A.1. C.A.2.; C.B.1. C.B.2.; C.C.1.; C.D.1 C.D.2. C.D.3.		
							D	D.A.1.		
ADC	MCP4725		5		1.Lower Power consumption 2. Ease of use and fast setting time. 3.6-pin package suitable for applications requiring power saving during off times.		A	A.A.2.; A.C.2		
							B	B.B.1.		
							C	C.A.1. C.A.2.; C.B.1. C.B.2.; C.C.1.; C.D.1 C.D.2. C.D.3.		
Database	*On Microcontroller*		0						A	A.A.1 A.A.2; A.C.1. A.C.2. A.C.3.
									B	B.B.1 B.B.2.B.A.1. B.A.2.
									C	C.A.1. C.A.2.C.B.1. C.B.2.C.C.1.C.D.1. C.D.2. C.D.3.
									D	D.A.1. & D.A.3. D.A.4.

Relay Modules	HiLetgo 2pcs 5V		6		1.Enables user to set high and low trigger threshold 2. Very convenient interface through direct connection. 3.High quality relay		A	A.A.2. ; A.C.2		
							B	B.B.1.		
							C	C.A.1. C.A.2. ; C.B.1. C.B.2.; C.C.1.; C.D.1 C.D.2. C.D.3.		
							D	D.A.1. D.A.3. D.A.4.		
Application	-		0							
Communication Technology	WIFI & Ethernet		(50m) x (0.19)		WIFI: 1.Wireless communication of data. 2. High internet speeds. 3. Wi-Fi strengths can be increased through mesh and extenders. 4. Remote monitoring and control capabilities. Ethernet: 1.Enables communication between devices. 2. Can carry information over long distances up to 10,000 meters. 3. Cable's bypass obstacles that can interfere with transmission. 4. Fast speeds, low latency. 5. Greater security and reliable connections.		A	A.A.1 A.A.2; A.B.1; A.C.1. A.C.2	A	A.A.1 & A.A.2; A.B.1; A.C.1. & A.C.2
							B	B.A.1. ; B.B.1 B.B.2.	B	B.A.1.; B.B.1 & B.B.2.
							C	C.A.1. C.A.2. ; C.B.2. C.C.1.; C.D.1 C.D.2. C.D.3.	C	C.A.1. & C.A.2.; C.B.2.; C.C.1.; C.D.1. & C.D.2.
							D	D.A.1. D.A.2. D.A.3. D.A.4.	D	D.A.1. & D.A.2. & D.A.3. & D.A.4.
Cloud Platform	Raspberry Pi Cloud		0		1.No costs 2. Allows user to customize data, share and store incoming data. 3. It uses PHP scripts to access SQLite and MySQL databases installed on the server and runs on Windows and Linux systems. 4. Easy usage and implementation.		A	A.A.1 A.A.2; A.C.2. A.C.3.	A	A.A.1 A.A.2; A.C.2. A.C.3.
							B	B.B.1 B.B.2.	B	B.B.1 B.B.2.
							C	C.A.1. C.A.2. ; C.B.1. C.B.2.; C.C.1.; C.D.1. C.D.2. C.D.3.	C	C.A.1. C.A.2.; C.B.1. C.B.2.; C.C.1.; C.D.1. C.D.2. C.D.3.
							D	D.A.1. D.A.2. D.A.3. D.A.4.	D	D.A.1. D.A.2. D.A.3. D.A.4.
			45.5							

4.4. Chapter Summary

The output of the chapter satisfies the objectives of providing the farmer with a configured irrigation system that can operate within their knowledge and skill levels, while being within their financial capability and providing the benefits that each system will bring to the entire system. According to the theoretical literature of the components of the configured irrigation system, it has the ability to perform the tasks outlined by Restuccia (2016) in 2.1.5.2, if adequately implemented.

The system is configured while adhering to the requirements of RAMI 4.0. Each perspective is adequately addressed to adhere to the requirements, constraints and goals.

Decisive constraints set the financial limitations of the configured or market available system plus the knowledge and skill limitations that the system has. The site-specific requirements and goals guide the farmer to select components and systems based on the benefits they would provide. It incorporates Industry 4.0 irrigation technologies, and the output of the framework is dependent on the identification of the pre-conditions.

The framework provides the guidance needed to overcome the three barriers, identified in the literature, that keep small-scale farmers from applying irrigation systems on their farms.

Chapter 5 Framework Validation

5.1. Introduction

The previous chapters described how the framework was developed and what the output of a theoretical deployment of that framework would be. This chapter explores what techniques are available to validate the framework. The overall objective of the irrigation system configuration is to address the challenges faced by small-scale farmers to implement relevant precision farming irrigation technologies on their farms. The outcome should provide small-scale farmers with the knowledge and ability to navigate past the barriers that they face.

5.2. Validation Method

This method sets out to determine whether a framework succeeds in developing a system that adheres to the requirements outlined from each perspective. The non-experimental validation methods that were considered, were a survey and a focus group process. A case study using the framework to develop a system was considered an experimental validation method.

5.2.1. Experimental Validation

An experimental validation method is designed around a case study. Elliot (1990) states that the case study approach provides data in a given situation that reflects how a framework would be applied in practice. This can be done over a period of time and can be designed to capture as many variables as possible. A small-scale farmer will be guided through using the framework to configure an irrigation system where after the components are acquired and implemented. In an experimental validation, a standard should be established to which a change in a variable is compared and tested. In the case, a designated site will be subjected to regular irrigation practices that are currently used by the small scale farmer. This would be the standard site. Another site, that has the same characteristics as the standard site, will be subjected to irrigation from the configured irrigation system. The yield and soil characteristics of both sites are tested and compared to determine the impact the configured irrigation system will have on it.

Materials and Methods

Field measurements are used to determine the performance of both the standard irrigated area and the configured system's irrigated area. Gomo et al. (2014) used field measurements such as yield to determine the performance of irrigation schemes of the Mooi River. After a period of irrigation is completed and crops have presented a yield, the crops' data is captured on a database and compared based on the field measurements listed below.

I. Yield: Crop yields are measured from 3 different locations in the irrigable area. The individual harvested mass (in grams) of each plant in the irrigable area is weighed, and the average yield for the irrigable site is compared.

II. Soil moisture average: The crop has a defined crop water requirement, and the soil moisture of each irrigable site is compared to evaluate the proximity of the soil moisture to the crop water requirement.
III. Water usage: The amount of water applied (in litres) to each irrigable site is compared.
IV. Yield per litre of water: As stated in the literature, study precision farming technologies aim to increase yield whilst reducing resource usage. The yield generated per litre of water presented in a quantitative format can be compared for both irrigation sites.

The variables below are controlled and kept the same for both areas.

I. The size of the irrigable site. The small-scale farmer and researcher will agree upon an area that the small-scale farmer would reserve for the case study to be performed on his farmland. It will qualify as a minor project, in accordance with the definition provided in Table 13 of the literature study.
II. The crop type: The same crop will be used to compare field measurements.
III. Crop volume: How much of each crop is planted will be measured.
IV. Weather exposure: Both sites will be subjected to the same weather conditions.
V. Soil: Irrigatable sites will have the same soil characteristics.

The experimental validation approach is subject to small-scale farmer availability, farming environment, and resources available. The experimental approach isolates the type of environment and resources, which can lead to data bias and influence the validity of the results.

5.2.2. Non-Experimental Validation

The non-experimental validation methods considered in this study were a survey and a focus group. Both of these methods require qualitative research.

Kraemer (1991) states that a survey aims to describe the characteristics of a population and its relationship towards certain variables. The survey is then used to create a profile of the small-scale farmer and provide an opportunity to establish usability and applicability, in other words, determining whether the framework can overcoming the barriers faced in applying the irrigation system. The survey would be able to provide feedback on the need for the framework outside of the literature, gaining valuable insights into how the framework can serve small-scale farmers.

The survey's results can be analysed in both qualitative and quantitative approaches. The qualitative feedback is used to determine the attitude of the respondent's feedback towards a certain variable. The use of ratings, rankings and selections in a survey provide the opportunity to apply analytical techniques that can be used to express the correlation between two variables and enables the researcher to develop a statistical view of the feedback. Data biases occur when feedback is influenced by prior experiences in the subject area, the amount of feedback, and the characteristics of the survey group. Bias can affect the results of the survey and has to be taken into consideration when making decisions about suitable validation methods.

Groenwald et al., (2001) conducted a survey of small-scale cattle farming systems in the North West province of South Africa. The survey was able to determine the reasons for employing farming activities, in other words the goals of the farmers. The survey was also undertaken to determine the commercial orientation and economic potential of the farmers. A survey in the context of this study will be used to determine similar topics.

A focus group provides the opportunity for participants to validate their shared experiences and expertise on a certain topic that is being presented (Hanbyul and Eunseok, 2019).

A focus group would consist of small-scale farmers who can provide input on whether the framework succeeds in its objectives. The researcher will be present to guide the small-scale farmer on the use of the framework as shown in the previous chapter. Farmers are then prompted to develop their system using the framework. The framework's applicability is discussed, and the performance is measured based on the objective of the framework through the focus group feedback. The focus group is also subject to bias, due to selecting a small group to represent a larger population. The smaller group can have shared beliefs that can influence the results.

5.2.3. Validation Method Selection

The validation methods were compared to determine which would be applied to this study. A case study can provide information that is not yet present in literature, and can therefore determine whether using this framework would be a solution to the identified problems. Case studies are heavily subject to bias and the data cannot stand alone when formulating conclusions from the findings (Rowley, 2002).

The experimental approach is however time dependant. The time it would take to produce a sufficient yield for analysis would be too long for the timeline of the study. Gaining access to a small-scale farmer's resources would also prove to be difficult. Case studies are dependent on the selection of the control and case groups. Bias in the selection of these groups can cause inaccurate assessments of the relationships between the two groups. Case studies are uniquely susceptible to bias due to the retrospective nature of the data in the results and the effect of the ability to control results by the researcher.

Focus groups allow data to be gathered from a purposely selected group of small-scale farmers. (Nyumba et al., 2018). The researcher is able to interact and explain the use of the framework with the participants. Non-verbal responses can be recorded, and information can be distributed to participants at a quicker rate. The drawback is that the group might not be an accurate representation of the larger small-scale farming community, and respondents may feel a need to agree with the researcher which could present bias in the data (Smithson, 2000).

Focus groups were eliminated as a possible method for validation during the time of the study, because during the COVID-19 pandemic and resulting lockdowns, health and safety concerns limited the movement of the researcher and ability to perform in-person focus group validations. Focus groups are also susceptible to bias as participants can feel the need to agree with each other in face-to-ace workshops.

Surveys provide the opportunity to reach larger sample sizes with less degrees of interaction. They are well suited to gathering data regarding demographics and can include number variables to be analysed. They also enable the researcher to generalise based on feedback. The survey method can be subjected to data bias which can result in inaccurate results. The overall success is also dependent on the number of respondents (Glasow, 2005).

Based on these considerations, a non-probability sampling survey is considered suitable to gather input from small-scale farmers who differ in their farming practices, knowledge and skill levels, geographical location and financial environments. The survey method is also subject to less bias than the other validation methods described above.

5.3. Objectives and Expected Results

The general objective of this survey is to determine if the developed framework is understandable, usable, and applicable to small-scale farmers. It is also used to determine whether a small-scale farmer would desire such a framework, or if they identify with such a need. The survey serves as an opportunity to identify shortcomings and gaps in the framework by acting s as a platform to present small-scale farmers with a possible solution to the problems they face and to contribute to the small-scale and subsidiary farming industry.

5.3.1. Specific Objectives

Breaking down the general objective, entails:

I. Determining the small-scale farmer demographic
II. Determining if small-scale farmers experience the identified barriers.
III. Determining if small-scale farmers are knowledgeable about irrigation systems and precision farming.
IV. Establishing if a small-scale farmers would be able to identify their site-specific requirements, constraints and goals?
V. Establishing how small-scale farmers prefer benefits to be communicated.
VI. Establishing if the competencies, knowledge and skills are present in the small-scale farmer community.
VII. Determining whether the use of the framework is understandable.
VIII. Determining if the farmer could use the system configurator to select components.
IX. Assessing if they would use the framework to configure an irrigation system to their site-specific requirements and goals.
X. Identifying what additional benefits the small-scale farmer would like the framework to provide for them.

5.3.2. Expected Results

At the end of the survey, feedback from small-scale farmers provides the research leader with enough criticism, suggestions, and validation regarding the applicability of the framework. Also, it is expected to receive feedback that will allow for future work to build on the developed framework.

5.4. Survey

5.4.1. Sampling Techniques of the Survey

The survey participants were identified through establishing inclusion criteria. It is thus a non-probability sampling survey as potential participants are actively identified. The criteria state that the small-scale farmer should be a participant in the agricultural sector, knowledgeable on either irrigation systems or currently use irrigation, and he/she should be a member of the small-scale farmer community.

5.4.2. Delimitation of the Survey

The survey participants become stakeholders in the validation of the system configuration, and they are identified and selected as a result of satisfying certain criteria. The criteria are expanded on in the table below.

Table 47: Small-Scale Farmer Criteria

Criteria	Description
1. Participant in the agricultural sector	The participant should be active in the agricultural sector in a farming capacity. The requirement ensures that the input provided from the participant would be from the perspective of an agricultural background.
2. Knowledgeable on irrigation or utilising irrigation	The system configuration is developed around irrigation system technologies, and the participant should be knowledgeable or employ irrigation practices. The requirement ensures that the system configuration not only satisfies the challenges faced by small-scale farmers but also satisfies irrigation requirements.
3. A member of a small-scale/subsidiary farming community	The system configuration aims to address the challenges faced by small-scale/subsidiary farmers in implementing precision farming technologies. To ensure that the outcome of the system configuration addresses the challenges sufficiently, the participants in the survey should be members of a small-scale farming community.

Based on the criteria set out by the sampling technique used in the validation, small-scale farmer groups and organizations representing small-scale farmers utilizing irrigation were identified, they are as follows:

Members of the Agric Vhulusi group, Umthunzi farming community members. Commodity chamber members of AgriSA. AgriSA is a South Africa agricultural industry association and a federal organisation representing the needs of its members. It comprises the congress consisting of board of directors who represent either corporate, commodity or provincial chambers. The chamber of interest in this study is the commodity chamber which includes agronomy, horticulture and animal production farming practices. The commodity organisations in the agronomy and horticulture sections were contacted to participate in the survey.

Member of the Agric Vhulusi Group. This social media group represents small-scale farmers and role players in the small-scale farming community. Members are predominantly from African countries and have varying farming practices to one another and commercial and household production goals.

Members of the Umthunzi Farming Community. This group empowers its members and provides skills development for small-scale farmers to promote sustained food systems in the local community.

The groups and association identified above provide an accurate representation of members that satisfy the criteria of the survey participants. This enables relevant feedback to be generated in the framework so that the objectives of the survey can be achieved.

5.4.3. Survey Design

The design is constructed to satisfy the objectives of the survey. The written survey would be distributed through Google Forms to the participants identified above. The survey is designed as a non-probability sampling survey; small-scale farmer groups are chosen but in this case the individuals are not specified. It is easier to access the small-scale farmer community through these already established groups compared to accessing farmers on an individual basis. The survey data is collected between a single time interval, which follows the design of a cross-sectional study.

The questions listed in Chapter 6, are the questions that were accepted through evaluating their rationale. The researcher shared the questions with the study leaders to determine whether they contribute towards the objective of the survey. The survey length was reduced after feedback indicated that it could deter participation. The questions were also shortened to reduce the time spent reading the survey. An example is included to provide a clear representation of the output of the system

The survey contains open-ended questions for small-scale farmers to add additional feedback, but mainly relies on close-ended questions to gain precise feedback on particular variables. The questions are designed to satisfy the specific objectives in 5.1.3. Each objective of the survey is addressed by allocating survey questions directed at that objective. The questions are firstly given with variables that participant scan select. They are also provided with a rationale that argues the validity of the questions being able to satisfy the objectives. The questions listed in the table below were accepted through evaluating their rationale and contribution towards the survey objective. The questions were then narrowed down through to only include questions that contribute most to the survey objectives. The questions are allocated as follows:

Table 48: Survey Question Design

Survey Objective	Survey Question	Question Variables	Rationale
Determine the small-scale farmer demographic.	Please indicate your highest level of education.	• High School Diploma • 1 Year College Diploma • 2 Year College Diploma • Bachelor's degree • Master's Degree or Higher • Prefer Not to Say	The education levels are what is present in the framework and provides insight to the farmer demographic
	Please indicate your experience I\in the farming industry	• None • 0-2 Years • 2 - 5 Years • 5 - 10 Years • 10 - 20 Years • More than 20 Years • Prefer not to say	In literature, younger farmers are more willing to apply precision farming technologies. Knowing their experience, the researcher can evaluate if this is relevant in practice
	Please indicate what describes your farming practice best	• Household • Commercial • Majority Household, Minority • Commercial • Majority Commercial, Minority • Household • Other • NA	This question is used to determine the small-scale farmer's occupation. In the literature, those who have a commercial farm are more likely to deploy new technologies.
	Please indicate the farming sub-sector you work in	• Crops • Livestock • Forestry • Fisheries • Agricultural Engineering • Agricultural Economic • Other	The questionnaire might reach small-scale farmers that use irrigation for different reasons. If it is to only grow crop to feed livestock for example, they might want to employ the irrigation system.
Determine if small-scale farmers experience the barriers identified.	Which of the following barriers prevent you from applying precision farming technologies at our farm?	• Too Risky • Not Profitable • Lack of Trust • Too Time Consuming • Technology is Continuously Evolving • Benefits Uncertain • Too Expensive • Lack of Access to Technology • Ethical Consideration • Too Complex	The question lists the barriers that were identified in the Pareto analysis to compare if the literature corresponds to real world findings.
	In your opinion, what other barriers to applying irrigation systems do you experience? (N/A if none)	Open-ended Question	The question is added to determine if any additional barriers are present.
	Do you agree with the Following Statements: A barrier for small-scale F-farmers to applying irrigation systems is not having the financial	• Strongly Agree • Agree • Neutral • Disagree • Strongly Disagree	The question aims to identify if the main barriers identified in the Pareto analysis can be supported by the small-scale farmer community.

	capability to acquire the technology? *1. A barrier for Small-Scale Farmers to applying irrigation systems is not having sufficient knowledge, abilities and skills to operate such systems?* *2. A barrier for Small-Scale Farmers to adopting irrigation systems is not having sufficient knowledge on the benefits of the systems?*		
Determine if small-scale farmers are knowledgeable on irrigation systems or precision farming.	Please indicate your level of practical experience working with irrigation systems	• 1 • 2 • 3 • 4 5	A scale of experience of working with irrigation is used to establish if the farmers are familiar with working the technologies before using the framework.
	Please indicate your level of knowledge of irrigation systems	• 1 • 2 • 3 • 4 • 5	A scale on the level of knowledge on irrigation systems is used to determine whether pre-existing knowledge can contribute towards the use of the framework by finding a correlation with question regarding the usability of the framework.
Establishing if a small-scale farmers would be able to identify their site-specific requirements, constraints and goals?	When considering an irrigation system, which of the flowing goals for applying an irrigation system is important to you	• Water Saving Potential • Cost Reduction • Improving Yield • Labor Reduction • Environmental Impact	The success of articulating the benefits of the framework is influenced by the ability of the small-scale farmer to determine their goals.
	Are you able to identify your goals as qualitative or quantitative?	• Qualitative • Quantitative • Both • None	Identifying the goals qualitatively or quantitatively determine in which format the benefits need to be communicated to the farmer.
	When considering an irrigation system, which of the following requirements for applying an irrigation system is important to you	• Sensor Type • Connectivity • Automation Level • Capacity • Smart Connectivity • Application • Component • Biome	The site-specific requirements determine what components are applicable in the framework that adhere to the requirements.
	Are you able to identify your requirements as qualitative or quantitative?	• Qualitative • Quantitative • Both • None	Identifying the requirements qualitatively or quantitatively determine in which format the component requirement need to be communicated to the farmer.
Establishing how small-scale farmer prefer benefits to be communicated	Rank the relevance of the benefits of irrigation systems to you in descending order	• Save Water • Reduce Manual Labor • Reduce Irrigation Costs • Improved environmental Sustainability • Improved Irrigation Control • Increased Yields • Other	Identifying in order of importance that the theoretical benefits of precision farming provide.
	Rank, in order of relevance, The level of detail you are interested in when deciding on an irrigation system?	• Benefits of Different Component Technologies • Benefits of Entire System • Benefits of Available Irrigation Systems	The question aims to determine on what level the farmer wants the benefits to be communicated. The

		• Benefits of Different Options of a Component Technology	question would serve the purpose of determining if the framework itself is simplified enough.
	Are the benefits of the irrigation systems components relevant for you? (provide extract of a table in Appendix D)	• Strongly Agree • Agree • Neutral • Disagree • Strongly Disagree	The abovementioned question is expanded to this question to determine if the component benefits need further simplification or are required by the farmer.
	Would the following representation of the benefits of a component aid your decision making? (provide an extract of available irrigation systems benefits)	• Strongly Agree • Agree • Neutral • Disagree • Strongly Disagree	The abovementioned question is expanded to this question to determine if the available system benefits are a more desirable way of articulating benefits.
	The following is an extract from the benefits of an available irrigation system: *"Weathermatic reports indicate estimated water savings at 32% and 26% estimated cost savings. This is an average of results from reports complied by the producer of the system and is therefore subject to the study conditions and limitations."* Do you agree with the statement: More site-specific, detailed information is required to decide which irrigation system configuration is suitable for you?	• Yes • No • Undecided	To determine if a high-level explanation of an available irrigation would be sufficient to assist in selection of an available irrigation system.
	Do you agree with the following statement: benefits of available system are relevant to your decision making	• Strongly Agree • Agree • Neutral • Disagree • Strongly Disagree	Determine whether including available irrigation system's benefits is required in the framework.
Establish if the competencies, knowledge and skills are present in the small-scale farmer community	Indicate whether the following competency domains are applicable to farming for you:	• Personal Competence • Organizational Competence • Professional Competence • Industry 4.0 Competence • Prefer not to say	Determining the presence of the various competencies in the small-scale farmer community.
	Indicate whether pursuing a degree in the following career paths are relevant to operating an irrigation system	• Agricultural Economist • Agricultural Engineer • Agricultural Technical Services • Agronomy. • Farm Manager. • Farmer • Precision Agriculture Technician • Other	Determining whether small-scale farmers are interested in up-skilling to derive the benefits of precision farming.
Determine whether the use of the framework is understandable.	The following figure indicates The components of an irrigation system. Which of the following components are you knowledgeable on?	• Microcontroller • Sensors • Database • Cloud Platform • Power Supply • Communication Technology • Analog to Digital Converter • Application	The framework's usability increases if the small-scale farmer is knowledgeable about the components, which will ease the configuration process.
	Referring to the following Table (Table 81 in Appendix F), moving from left to right: Do you agree with the following statements:	• Strongly Agree • Agree • Neutral • Disagree • Strongly Disagree	Determine whether the table developed in the financial capability perspective enables the farmer to choose components based on financial constraints

	1. *I am able to determine the cost of the entire system by adding the cost of components* 2. *The table and the system configurator would enable you to make an informed decision on irrigation system components?*		
	Would you be able to determine which knowledge and skills are needed for microcontrollers through using the following tables? (Extract of Table 78 and Table 79 provided)	• Yes • No • Undecided	Determine if the small-scale-farmer can use the framework to identify the knowledge and skills requirement for a specific component.
	25. Would the following representation of the educational institution providing opportunities to acquire certain knowledge and skills prove helpful in determining whether further education is feasible for you? (Provide extract of Table 80)	• Yes • No • Undecided	Determine the usability of Table 80 in the pursuit of supplying possible educational paths to acquire knowledge and skills.
Determine if the farmer could use the system configurator to select component/	Do you agree with the statement: *I would be able to use this configurator to develop an irrigation system?*	• 1 • 2 • 3 • 4 • 5	This ease of use of the configurator in the framework also address one of the main barriers found in the Pareto analysis, being too complex by easing the process of component selection.
Would they use the framework to configure an irrigation system to their site-specific requirements and goals?	An example is provided on how the framework is used to integrate benefits, financial requirements and knowledge and skills requirements, how satisfied are you with the following: (Table 46) 1. *Financial requirement for a developed system for a small-scale farmer.* 2. *Financial requirement of available systems.* 3. *Benefit articulation of irrigation system components.* 4. *Benefit articulation of available irrigation systems.* 5. *Knowledge and skill requirement of the developed irrigation system.* 6. *Ability to configure the irrigation system that satisfies site-Specific requirements, constraints and goals.*	• Very Dissatisfied • Somewhat Dissatisfied • Neutral • Somewhat Satisfied • Very Satisfied	The question determines whether the outcome of the configured system with the integrated table is desired.
What the small-scale farmer would like the framework to provide them in addition?	Indicate the level of difficulty in using the framework	• 1 • 2 • 3 • 4 • 5	If the scores are too high the farmer might not wish to use the framework
	What changes w you make to improve the framework?	Open-ended Question	Gain feedback on how to improve the framework
	29. In your opinion, would you refer to this framework when you want to apply an irrigation system to your farm?		

In summary, the survey is designed to be distributed to small-scale farmers in a non-probability sampling format. It has closed- and open-ended questions aimed towards satisfying the objectives of the framework.

Any information participants shared during this study which could possibly identify participants, are protected. The collection of data in this research study uses appropriate methodology and recording practices and applies quality assurance towards acquiring the data. Data will be published through outlets that support FAIR Data Principles and will only be used towards the dissertation through Stellenbosch University's institutional research data repository under its regulations. Stored research data will be available to access only through private access settings, which means that only the research leader and the supervisor will have access to the data. The data is protected and stored by making use of the institutional storage provided by the University of Stellenbosch.

The data of the respondent feedback is analysed in a quantitative and qualitative approach where possible. Questions allowing for graphic and numerical expressions are explored. Themes that are present through the survey and identifiable in respondent feedback are analysed. The analysis of themes has the potential to relate statements to the research questions and objectives to provide a more detailed and well-rounded account of respondent feedback. Low response rates limits the amount of statistical analysis that can be applied to the data. The analysis of the themes can create nuances within the data that is subject to the researcher's understanding of contextual information which can be subject to bias.

5.4.3.1. Validation of Survey Design

The survey was designed and validated through providing the rationale for each question. The rationale states what the question contributes towards specific objectives. The validation process is described below.

I. List each objective of the survey.
II. Design questions that enable the objective to be satisfied.
III. List the variables in the question. In other words, what selection of variables will the participants be able to choose from within the question?
IV. Provide rationales as to why the questions enable specific objective of the survey to be completed.

5.4.3.2. Survey Data Analysis Approach

The question design enables the data to be analysed both quantitatively and qualitatively. Qualitative analysis requires generalising responses and linking them to the literature study, research question and validation objectives. The literature is used to support the themes and trends in the feedback. Quantitative analysis of feedback can be split between statistical analysis and descriptive analysis. With a high response rate, the validity of a more statistical analysis approach can be justified.

Applying statistics can provide a deeper understanding of the feedback through determining the correlation between answers and what is found in other literature sources. If the response rate is low, a more descriptive approach is taken through charting, calculating averages and looking at how answer are distributed amongst the variables for the answer.

By the end of the data analysis, one would be able to argue firstly that the survey objectives were reached, after which the validity of the study can be discussed by combining the findings from the survey, the findings from the literature, and the framework development and deployment.

5.4.3.3. Method of Data Collection

After reviewing the rationale of each question and making the necessary modifications, the survey was administered to the groups via email to provide a link to the survey. The groups were asked to distribute the survey to small-scale farmers who are part of the group. The online forms automatically record the responses and provide the anonymity required. The survey was accompanied with an electronic consent form.

5.4.4. Survey Results

The survey was distributed under the small-scale farmer groups and 3 full responses were received. The number of responses limits the statistical analysis of the data; a descriptive analysis approach was therefore followed. The responses were recorded for each question and analysed based on the rationale for the question. The majority of the farmers who participated in the survey farmed with crops.

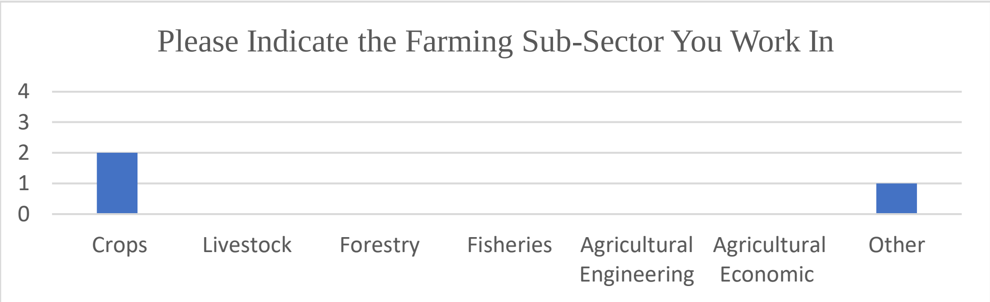


Figure 38: Survey Respondent Sub-Sector

The framework would therefore be applicable to the respondents and their feedback would be biased towards configuring an irrigation system. The practical experience of the respondents provided an insight into the characteristics of farmers who are interested in precision farming.

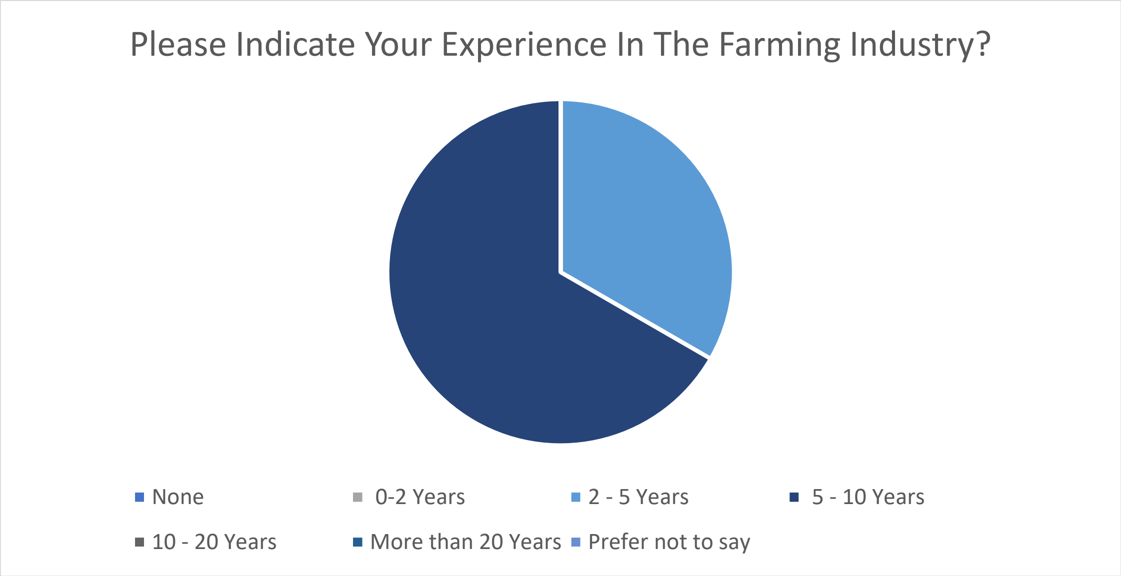


Figure 39: Survey Respondent Experience

Vecchio et al. (2018) state that younger farmers are more willing to adopt precision farming technologies. The trend is seen in the respondent feedback as the respondents all have less than 10 years' of farming experience. This directly translates into their practical experience and knowledge levels of irrigation system as seen in the figure below. Low level scores are given in both instances.

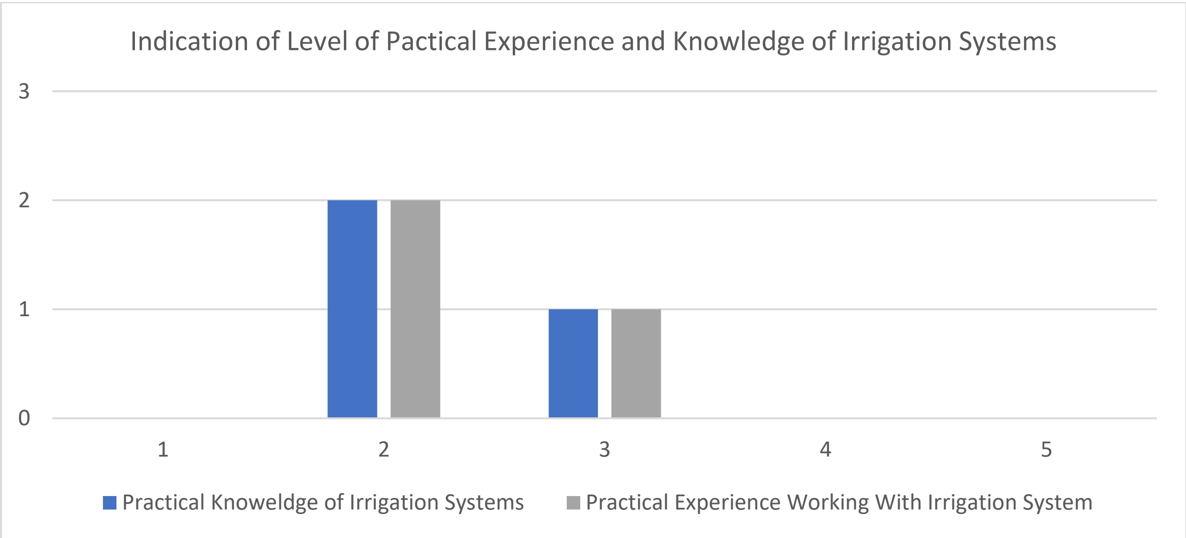


Figure 40: Survey Respondent's Practical Knowledge and Experience with Irrigation Systems

Farmers farm both for commercial and household reason. It was expected to see that commercial farmers were more interested in responding to the survey and would be interested in using the framework.

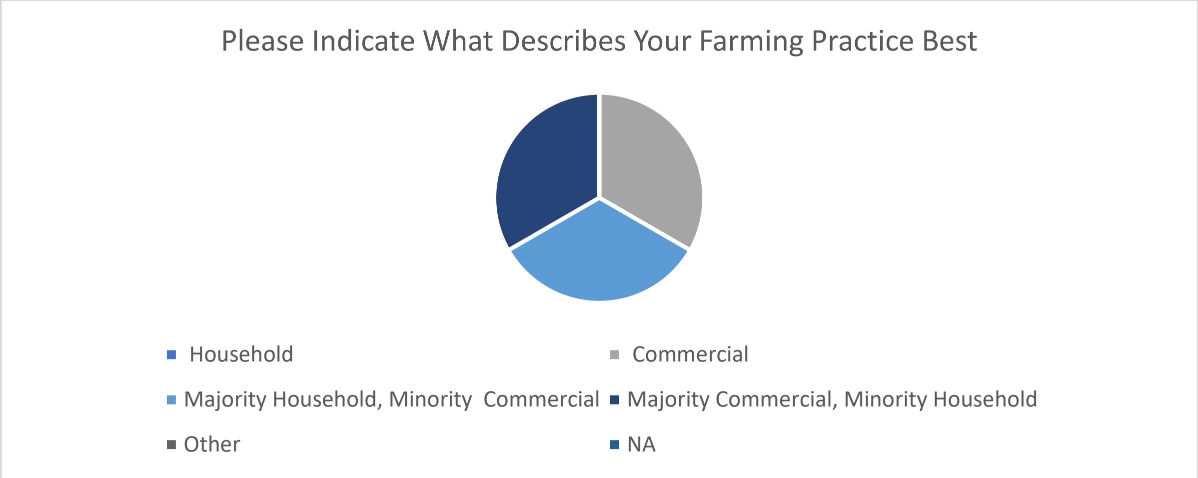


Figure 41: Survey Respondent Farming Practice

The respondents all farm for commercial purposes, which according to the literature makes them more likely to use PF technologies.

The farmers confirmed that they experience the barriers identified in the literature. The low feedback made it difficult to determine which of the barriers were the biggest to overcome. The farmers could select multiple barriers and a total of 10 selections were made. From the survey feedback "Too Expensive" received 55,5 %, "Not Profitable" received 11,1 % of, "Too Complex" received 11,1 %, "Lack of Access to Technology" 11,1 % and "Benefits Uncertain" 11,1%. Therefore, the three main barriers to applying precision farming is still present. The financial capability perspective addresses the main barrier.

Farmers were able to determine their site-specific goals in either a qualitative or quantitative manner. The most desired goal was that of water saving which received 2 out of the 3 selections. Water saving potential according to the figure below can be identified in either a quantitative or qualitative manner. The usability of the framework is increased when the farmers are able to identify their goals, therefore this feedback is encouraging.

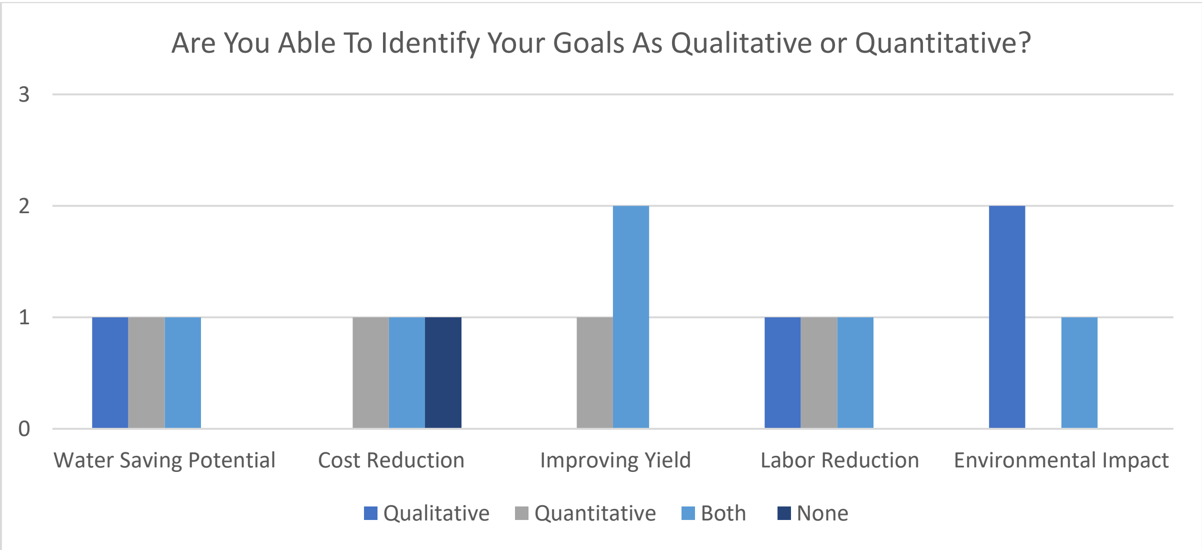


Figure 42: Survey Respondent Goal Identification

The framework's usability is addressed in the survey to determine if it succeeds in its objectives and if the small-scale farmer would be able to configure a system by themselves using only the framework. The usability of the system configurator is of particular importance as it provides a visual aid and guides the farmer to select the components he/she would require. Survey feedback showed that two of the respondents found it easy to use whilst no respondents found it difficult. The other respondent gave a neutral score.

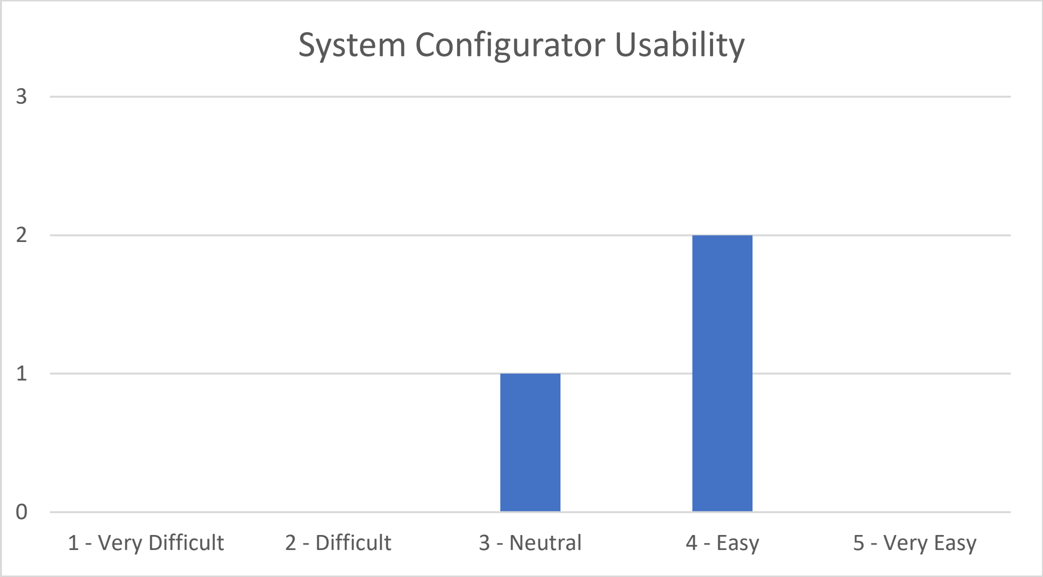


Figure 43: Survey Respondent's Configurator Usability Score

The system configurator is used to aid in component selection within the framework. The system configurator contains the enabling components of an irrigation system and the components that qualify it as an industry 4.0 system. The framework on its own contains the requirements and information to develop an irrigation system. The system configurator therefore enhances the use of the framework.

The usability of the system configurator is important due to the abovementioned. The respondent was asked to indicate which component they were most knowledgeable about, which is part of the configurator. The results indicate that the application received 100 % of the selections. The other components might be too technical, and the farmer would only be interested in the end-product, rather than each component. This should then reflect in the preference towards benefit articulation. This was confirmed as all the respondents indicated that the benefits of available system were relevant in their decision making.

The respondents indicated that tables which the benefits of each individual component would aid their decision-making. Two of the respondents agreed with this statement. When the farmers were asked whether the irrigation system components are relevant in their decision making, two selected "Neutral", and one "Agreed" with the statement.

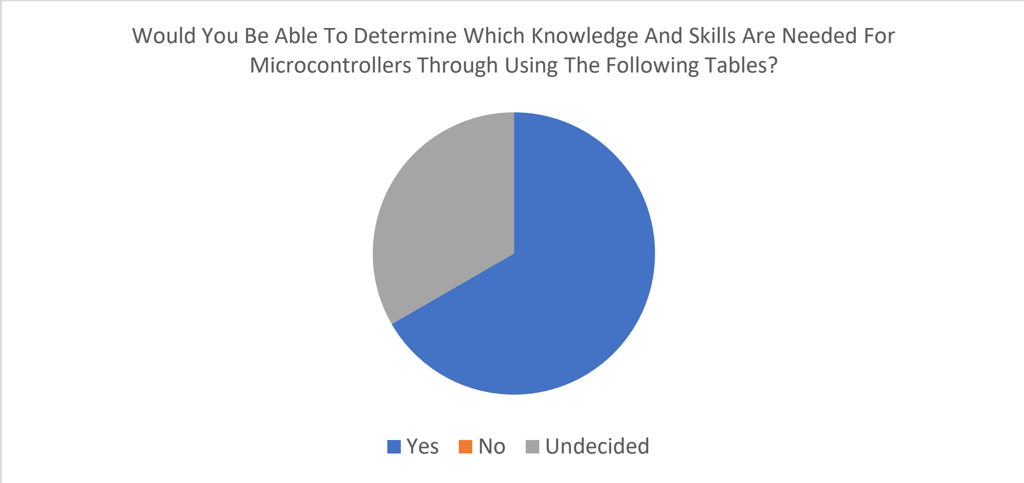


Figure 44: Survey Respondent Knowledge and Skill Identification

The knowledge and skills requirement perspective provided alphabetic codes to determine which were required for each component of the irrigation system. The figure above shows that the respondents felt they were able to determine which knowledge and skills are required for different components. In the survey the example of a microcontroller was used. The only competence indicated by the farmers, that were relevant to them, were "professional competence" which received two of selections whilst the third respondent preferred not to make a choice. Shields (2018) and Sulecki (2020) both identified the importance of up-skilling to fully utilize I4.0 technologies. The small-scale farmer was asked if any career path is applicable in small-scale farming and if the framework provided them with the ability to determine the knowledge and skills they would gain from education relevant to the field. Two of the farmers indicated that they could determine the knowledge and skills they would acquire. One of the respondents indicated that an agricultural engineer career path would be relevant in using irrigation systems while two indicated that a "Farmer" career path should be sufficient. Farmers are known to rely on their practical experience but can also benefit from up-skilling, as seen in the literature.

In the survey an example of the output of the framework is provided and the farmer's satisfaction of the variables relating to the output is evaluated. The code for the variables in the table below are the following:

- A: Financial requirement for a developed system for a small-scale farmer
- B: Financial requirement of available systems
- C: Benefit articulation of irrigation system components

D: Benefit articulation of available irrigation systems

- E: Knowledge and skill requirements of the developed irrigation systems
- F: Ability to configure the irrigation system that satisfies site-specific requirements, constraints and goals

The feedback indicated overall satisfaction with the output (F) is 33, 3 % Very Satisfied, 33, 33% Somewhat Dissatisfied, 22, 2 % Neutral and 11, 1 % Somewhat Satisfied. There is a positive skew towards satisfaction of the output as 44, 4 % lies above the Neutral Rating.

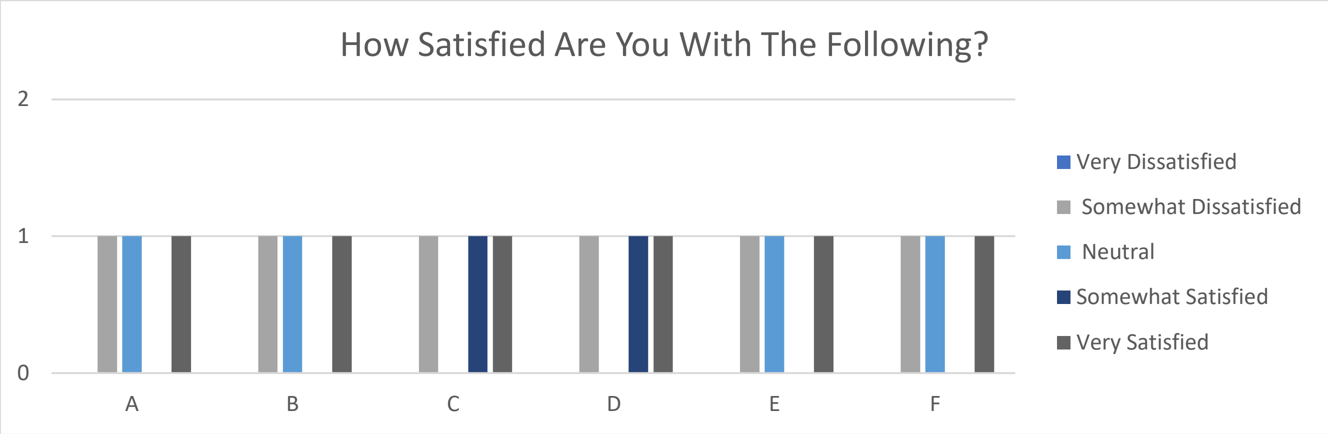


Figure 45: Satisfaction Indication of Benefit Articulation

The mode score is shared between Very Satisfied and Somewhat Dissatisfied. The statistical median of the rating is at Neutral. The overall satisfaction was the highest towards C and D, which both address the Benefit Articulation the score of which is 66, 7 % above Neutral.

The usability of the entire framework, which includes the use of the system configurator, each perspective, and the identification of preconditions, is determined in the survey. The farmers were asked to indicate the difficulty of the use of the framework from level 1 to 5; level 1 being very easy, while level 5 would be very difficult.

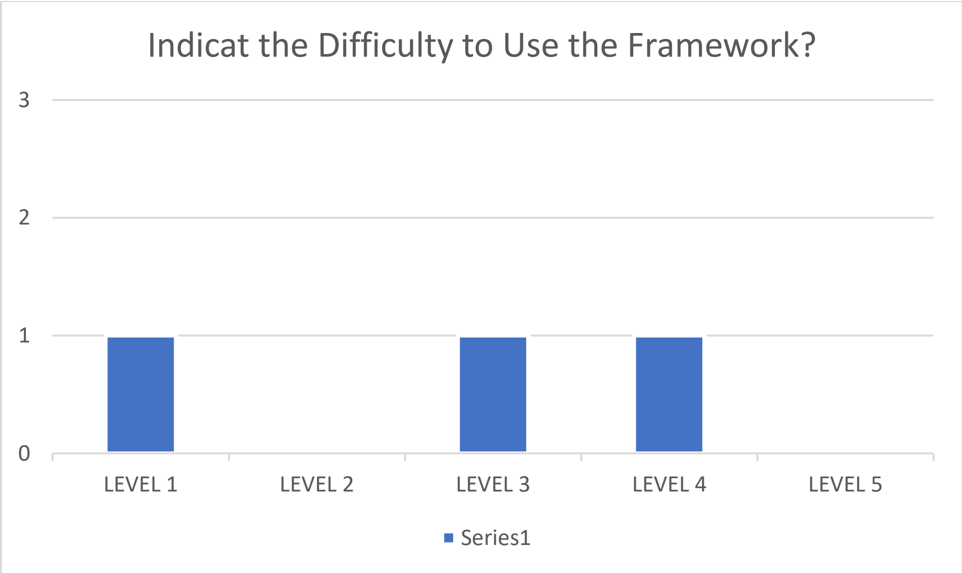


Figure 46: Framework Difficulty According to Survey Respondents

In the feedback, one of the farmers indicated a difficulty Level of 1, one farmer indicated Level 3 and the other indicated Level 4. The results from the findings are further discussed.

5.4.5. Discussion of Results

The survey reinforced the findings in the literature and underlined the need for support to be provided to the small-scale farming industry. Most of the farmers experience the barriers that are identified in the literature, and their responses also indicate that certain farmers feel an irrigation system may not be profitable for their farming operations. This can be interpreted in two different ways. Farmers may not require having an irrigation system at their site due to the scale of farming not requiring additional resources. The literature also indicates that farmers are more willing to apply irrigation systems if they want to upscale their farming operations or aim to increase yields for increased revenue.

The barrier that received the most entries is too expensive, which corresponds with the findings in literature. Among the three main barriers identified in the literature, farmers strongly agree with the financial capability being a barrier, while the other two barriers received votes across the board. One of the participants indicated that the barrier that keeps them from applying irrigation systems is *"*low income for the purchase of farm inputs".

This is in line with the barrier of high expense which raises a different issue. A farmer might want to apply an irrigation system that could increase their income by reducing irrigation costs and improving yields, but can only do so if they have the initial capital to acquire a system. They are thus stuck in wanting to implement a system to raise their income, but due to their low income cannot acquire it. It indicates a need for grants and loans for small-scale farmers to enable them to purchase farming inputs.

The survey respondents indicated that they could determine their site-specific goals mostly in a qualitative manner. "Cost Reduction" was the only category in which farmers indicated that they could not indicate any quantitative or qualitative goal. Being able to identify site-specific goals as is the first step towards developing an irrigation system and can dramatically improve the use of the framework. Therefore, the farmers being able to identify most of their goals, supports them in the use of the framework, The farmers also indicated that they were mostly interested in the cost reduction and water saving potential of the irrigation system. The indication of the farmers being interested in the water saving potential, aligns with literature, which states that a majority of small-scale farmers are limited with regards to their access to water. In studies such as the one performed by Rain and Thomas in 2009, where precision farming was applied to increase corn and soybean yields, and reduce costs. The framework allows a farmer to develop an industry 4.0 irrigation system, which according to the literature, would satisfy the site-specific goals defined in the framework.

Various factors need to be considered when developing or choosing an appropriate irrigation systems. Among the more popular choices were the automation levels of the system and the biome (environment) in which the farmer conducts their practice. Environment can refer to the availability of natural resources such as water and typography. It is accounted for in the framework as farmer are prompted to define their site-specific constraints. The biome can also refer to other types of resources such as internet and technological availability. Farmers would want the system to be able to perform in the presence or the lack thereof. The farmers also identified that Improving Yield, is the goal that they can identify with most as both a quantitative and qualitative consideration. Environmental Impact was the goal that could mostly only be determined qualitatively. What is encouraging is that the majority of the farmers were able to determine their goals in a qualitative measure. This could aid them in developing the system and eventually evaluate its performance based on the goals they have for the system.

The framework's usability is based on the system configurator. The configurator enables farmers to develop their own irrigation systems. The respondents indicated that they were able to use the configurator to select components. The ease of use of the configurator in the framework also address one of the main barriers found in the Pareto analysis, namely being too complex. This also underlines the success of using RAMI 4.0 as it enables complex structures to be broken down into easy-to-use packages or components.

It would be preferable if farmer are knowledgeable about most components. If not, the framework should provide the knowledge for them. Most farmers indicated that they have knowledge regarding an irrigation application, rather than each component by itself. The system configurator was determined to be useable by farmers in order to develop a system. The respondents mostly agreed with the statement that they would be able to develop a system using the configurator. The financial capability perspective proved to be the most positively received perspective since it would enable farmers to determine the cost of the irrigation system. It was that the knowledge and skill capability perspective and the system configurator alone would not be enough to develop a system and additional resources would be required.

The system configurator may pose problems as the majority of the farmers indicated that they could only identify their requirements for the system in a qualitative manner. This implies that the function and benefits of the system configurator should be communicated in a general and descriptive manner rather than at a technical level. The majority of farmers indicated that they are not knowledgeable on most of the components, but only on the applications. This would indicate that most farmers would rely on a readily available system rather than to develop their own thereby reducing the learning curve required at the initiation of an irrigation system project.

In considering the benefits of the irrigation system, reducing costs and saving water are the most desired benefits for the farmer. The benefit of least interest came out to be increasing overall yields. It can therefore be concluded that farmers are primarily interested in reducing their overall cost and resource consumption. The benefits of irrigation systems were communicated at both component and available irrigation system levels, and the farmers indicated that they would mostly be interested in the benefits of the entire system or available irrigation systems. Therefore, providing benefits at component level does not seem to be of interest to the farmer. This can be due to the farmer not having to construct the benefits by compiling them component by component. They would rather have the benefits captured at a high level.

Even though the farmers indicated that component level benefits are inferior to entire systems, they felt that component-level benefits would be beneficial and could help them develop their own systems. Available irrigation systems have limited performance information readily available on product websites and informational documents, and this limited information could be enough to persuade farmers to acquire the system, the survey indicated.

The framework difficulty should be revisited to determine if the pathway can be made clearer to the small-scale farmer since there is a vast amount of information in the framework. The communication of the framework objectives can be improved through developing the objectives based on the small-scale farmer's current knowledge level of irrigation system. The farmers however mostly indicated that they would not refer to the framework to aid them in developing their own irrigation systems because of the time it would take or informational load being too high. Farmers seemed to prefer using "currently available system components instead of trying to develop new ones."

The farmers felt that the benefits of developing their own systems do not outweigh the ease of acquiring already available systems. This indicates a need to rely on established products, and corresponds to the farmers' indication that the systems may not be profitable. Having a proven system with case study findings that indicate water savings and increased yields can prove to be a stronger motivating factor to acquiring a system even if it would cost more than developing their own systems. One farmer indicated that the framework should do the following:

"Explain clearer what knowledge and skills are needed. Ex. Need to solder on board, be able to set up cloud data base, etc."

This implies that the farmer felt that the knowledge and skills requirements should be less general and more focused on what exactly is needed to perform tasks in the developing process. This aligns with a survey Clay (2018) conducted and found that the most desired knowledge and skills for both an equipment technician and an operator in combination were to install, calibrate, troubleshoot, and repair PF hardware and equipment. The knowledge and skills are vast and should therefore be combined to provide a clearer indication of the specific skills are that are required for the development of an irrigation system. The majority of the feedback indicated that professional competence is required the most for irrigation systems on farms. This includes knowledge areas such as technology, statistical, analytical, and farming related knowledge.

The farmers indicated that they are mostly satisfied with the results and the outcome of the framework. This refers to the examples provided in the survey on developing a system. The respondents were mostly "Somewhat Satisfied" with the ability of the framework to configure an irrigation system based on a site-specific goals, constraints, and requirements. This is an encouraging indication, which means that if the framework is improved based on farmer feedback it could achieve the goals farmers are interested in.

It is noted that only three farmers completed the survey. Reluctance to complete the survey was a limitation to the outcome of the survey. This could be due to the large number of questions in the survey deterring potential participants, or could indicate a general unwillingness to participate in the study. Unwillingness could be attributed to lack of interest, lack of digital access to complete the survey, or being uninterested in applying irrigation systems and precision farming in general.

Ideally, personal interviews would yield better results. The farmers all however provided valuable feedback regarding improvements needs and the overall potential of the framework.

Chapter 6 Conclusion and Future Recommendations

The results of the survey and the development of the framework are discussed. A conclusion is drawn on the contributions of the research study and future recommendations are made.

6.1. Conclusion

This study developed a framework, addressing the key barriers to applying an irrigation system that enables a small-scale farmer to configure an appropriate system, which is within the farmer's financial capability, knowledge and skill capability, and can provide the necessary and desired benefits.

The study identified that the majority of the literature on Industry 4.0 and small-scale farmers, is aimed at problem diagnosis. Holmann and McDermott (2013) state that the impact of I4.0 in the agricultural sector can result in small-scale farmers being left behind in the value chain. Bigger companies and farmers, in terms of financial capability and land capacity, stand to benefit most from the PF technologies due to their access to resources. A gap in the literature was identified, namely a practical solution to the existing problems. There is a need to provide a guide, reference or framework to overcome the problems attached to implementing I4.0 technologies and improving farming practices. The framework in this study fills this need for irrigation systems. Small-scale farmers are noted to have vast knowledge about their own crops, resources, and environments. The survey also indicated that farmers could identify what goals they want to achieve if they were to apply irrigation systems on their farms. If they can combine this with the technology that precision farming brings, they can elevate their farming practices.

Chapter 4 outlined the framework that can be developed according to the standardisation requirements of RAMI 4.0, and the system configurator ensures that the system adheres to the requirements. Deployment of the framework also confirms that the configured irrigation system's components can enable it to perform the tasks required by an irrigation system. According to the survey respondents, the system configurator eases the process of component selection and also addresses the complexity barrier identified in the Pareto analysis.

The framework development was limited due to limited research in the following areas. The first is a universally agreed definition of a small-scale farmer in terms of financial capability or farming capacity. This would provide definite preconditions and boundaries for constructing a framework. Secondly, there is limited research available on the requirements for operating and implementing an irrigation system, ranging from knowledge requirements to the physical and environmental requirements of the farm itself. Thirdly, a quantitative representation of the benefits of using I4.0 irrigation systems for small-scale farmers is lacking and especially limited the benefit articulation perspective. In the framework the benefits are communicated in different formats such as per component and for available irrigation systems, which proved to be difficult to standardise.

The survey indicated there was a perceived difficulty in using the framework. The researcher suggests that a consultant be trained in the use of the framework to guide the small-scale farmer. The survey also received a low response rate. Upon reflection a case study could have been deployed as an alternative which would have had less variables and relied more on the researcher. Small-scale farmers might not have direct access or regular access to the resources to would have enabled them to participate in the survey. The statistical results were limited due to the feedback and a more descriptive approach to validation had to be used.

The framework provides the small-scale farmer with a configured irrigation system and integrated perspectives regarding the financial requirements of a system plus market-available systems, and the benefit of each component in the system. The knowledge and skill requirements are generated for each component and market-available system. The satisfaction indicator of the output of the framework shown in Figure 45, shows that the framework serves the purpose of configuring an irrigation system for a small-scale farmer that can be applied to their site-specific requirements. This positive skew in the satisfaction indication of the framework outputs and deployment in Chapter 4, supports the argument that the framework can be a feasible solution to the barriers that small-scale farmers face.

6.2.Future Recommendations

Irrigation systems make up a part of precision farming technologies. Small-scale farmers face the same barriers, to varying degrees, to implement other technologies. The framework developed in Chapter 3 can be used as a reference to develop another framework or guide to configure the technology.

Government agencies, learning centres, small-scale farming organisations and groups can use the framework as an educational tool or resource when launching programmes and schemes. Programmes and schemes normally provide financial support, but a framework such as this will provide extra value. The external stakeholders listed above can provide the support that is required after the system is configured, such as providing financial and implementation support. The framework can be used in potential learning programmes with a trained consultant to aid small-scale farmers in configuring an irrigation system.

Due to the novelty of some of the technologies, the information regarding their performance in the agriculture sector is limited. Performing case studies with configured irrigation systems from the framework and available irrigation systems will contribute towards the knowledge base of the irrigation system market. This can allow farmers to make more educated decisions that enable them to compare different configurations of an irrigation system with available irrigation systems. It can automatically address the questions or uncertainty farmers may have regarding the benefits and requirements of the system. Small-scale farmers are difficult to reach, and their input is valuable to the objectives of the research. More platforms can be provided to farmers to connect them with each other and with support structures. When researching small-scale farming practices, little to no research or guides are available on general farming practices. Frameworks for financial management, risk management, crop estimation, and sales would be useful to better farming operations.

The framework with the system configurator can be digitised to be an interactive tool. The digitised version can be used as a click-to-select tool to build a system while providing information on each component along the way. This could provide a more visual solution, which can reduce the complexity of the framework. Furthermore, the framework in this dissertation will promote further discussion and provide a catalyst to solve small-scale farming issues in the future.

References

1. Aeon Matrix (2020). Aeon Matrix Yardian Indoor/Outdoor Smart Sprinkler Controller 8 Zone With HD Security Camera, Compatible With Alexa, EPA Watersense Certified [Online] Available at: <https://www.amazon.com/Aeon-Matrix-Multi-Functional-Controller-Weather-Proof/dp/B01NAV2N6F> (Accessed 6 July 2020)
2. Afeworki E., Polasub W., Chiu, Mullinix K. (2015) Southwest British Columbia Small-Scale Farm Enterprise Budget: Potato. Institute for Sustainable Food Systems Kwantlen Polytechnic University
3. African Union Commission (2020 Framework for Irrigation Development and Agricultural Water Management in Africa. 1st ed. Addis Ababa, pp.1, 2.
4. Akubattin, Vishal L., et al. “Smart Irrigation System.” International Journal of Scientific Research in Science and Technology, vol. 2, no. 5, 2016, pp. 343–345.
5. Alabi, M., Telukdarie, A.; Van Rensburg, N. (2019) Industry 4.0: Innovative solutions for the water industry. International Annual Conference of the American Society for Engineering Management, Huntsville, Alabama, USA.
6. Allied Market Research (2020). Smart Irrigation Market Size, Share, Outlook & Industry Forecast – 2026. [online] Allied Market Research. [Online]. Available at: <https://www.alliedmarketresearch.com/smart-irrigation-market> (Accessed 15 February 2020)
7. Anselmi, A. A., Bredemeier, C., Federizzi, L. C., & Molin, J. P. (2014). Factors related to adoption of precision agriculture technologies in southern Brazil. Retrieved March, 12, 2018.
8. Aulbur, W., Arvind, C.J., Bigghe, R. (2018). Skills Development for Industry 4.0. BRICS Skill Development Working Group, Roland Berger GMBH.
9. Barkunan, S. R., Bhanumathi, V., & Sethuram, J. (2019). Smart sensor for automatic drip irrigation system for paddy cultivation. Computers & Electrical Engineering, 73. https://doi.org/10.1016/j.compeleceng.2018.11.013
10. Baseline (2021) Basestation 1000. [Online]. Available at: <https://www.baselinesystems.com/mediafiles//pdf/1000_Brochure_Web.pdf> (Accessed 6 July 2020)
11. Battilani, A. (2014) Irrigation Strategy Selection Criteria, tools and Algorithms for Precision Irrigation Application. FIGARO, Consorzio Bonifica CER.
12. Bevacqua, R.F. (2001) “Drip Irrigation for Row Crops,” New Mexico University Cooperative Extension Service, Circular 573.

13. Binder, C. (2020) Introduction to the RAMI 4.0 toolbox (Online). Available At: https://rami-toolbox.org/wp-content/uploads/2020/07/Introduction_RAMI-Toolbox.pdf (accessed on 11 November 2020)
14. Bjorneberg, D. L. (2013). IRRIGATION | Methods. In Reference Module in Earth Systems and Environmental Sciences. Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.05195-2
15. Bluespray (2021). Bluespray - Web Based, Wireless (Wifi) Irrigation Controller. [Online]. Available at: <https://www.bluespray.net/> (Accessed 6 July 2020)
16. Boaz, G. (1998). Parámetros de Benchmarking para los modelos de competencias. Training and Development Digest. Vol 10, May 1998
17. Bongiovanni, R., & Lowenberg-Deboer, J. (2004). Precision Agriculture and Sustainability. Precision Agriculture, 5(4). https://doi.org/10.1023/B:PRAG.0000040806.39604.aa
18. Bongiovanni, Rodolfo & Lowenberg-DeBoer, James. (2004). Precision Farming and Sustainability. Precision Farming. 5. 359-387.
19. Bourgeois, D. Cui, S., Obiomon, P. (2015). Development of a decision Support System for Precision Agriculture. IJERT, 4 (10)
20. Boyer, C. N., B. C. English, R. Roberts, J. Larson, D. M. Lambert, M. M. Velandia, V. Zhou, S. L. Larkin, M. C. Marra, R. M. Rejesus, L. L. Falconer, S. W. Martin, A. K. Mishra, K. P. Paudel, C. Wang, J. Johnson, . Segarra, and J. M. Reeves. (2014) 'Results from a Cotton Precision Farming Survey Across Fourteen Southern States 'New Orleans, LA: National Cotton Council of America [Online]. Available online at https://ncc.confex.com/ncc/2014/webprogram/Paper14957.html (Accessed 16 June 2019)
21. Brooks, J., Cervantes-Godoy, D., & Jonasson, E. (2009). "Strategies for Smallholders in Developing Countries: Commercialisation, Diversification and Exit". 111 EAAE-IAAE Seminar 'Small Farms: decline or persistence', University of Kent, Canterbury, UK.
22. Bryman, A. (2014). Research methodology. 1st ed. United Kingdom: Oxford University Press South Africa, pp.87-98.
23. Calsense. (2019) Smart Irrigation: Technologies That Use Water Efficiently – Calsense [0nline].Available at: https://www.calsense.com/smart-irrigation-technologies-use-water-efficiently/ (Accessed 15 November 2020).
24. Circular Ecology. (2020) Sustainability and Sustainable Development (Online). Available at: https://circularecology.com/sustainability-and-sustainable-development.html (Accessed 12 February 2020).
25. Clay, D., Erickson, B., Fausti, S. & Clay, S. (2018). Knowledge, skills and abilities in the Precision Farming workforce: An industry survey. Natural Sciences Education, 47, 180010. https://doi.org/10. 4195/nse2018.04.0010

26. Clune, W. H., & Zehnder, A. J. B. (2018). The Three Pillars of Sustainability Framework: Approaches for Laws and Governance. Journal of Environmental Protection, 09(03). https://doi.org/10.4236/jep.2018.93015
27. Collins, D. (2020) What Are RAMI 4.0 and Asset Administration Shells? (Online). Available at: https://www.motioncontroltips.com/what-are-rami40-and-asset-administration-shells-in-the-context-of-industry40/ (Accessed 11 July 2020).
28. Contreras, J. D., Garcia, J. I., & Diaz, J. D. (2017). Developing of Industry 4.0 Applications. International Journal of Online Engineering (IJOE), 13(10). https://doi.org/10.3991/ijoe.v13i10.7331
29. Cullum, S. (2019). Agriculture Skills of the Future, Olds College (Online). Available at: https://cahrc-ccrha.ca/sites/default/files/StuartCULLUM_en_0.pdf. (Accessed on: 15 February 2020).
30. Czyzewska, M., & Mroczek, T. (2020). Data Mining in Entrepreneurial Competencies Diagnosis. Education Sciences, 10(8). https://doi.org/10.3390/educsci10080196
31. Daberkow, S. G., & McBride, W. D. (2003).). Farm and Operator Characteristics Affecting the Awareness and Adoption of Precision Farming Technologies in the US. Precision Agriculture, 4(2). https://doi.org/10.1023/A:1024557205871
32. Davis, S. L., & Dukes, M. D. (2015). Methodologies for Successful Implementation of Smart Irrigation Controllers. Journal of Irrigation and Drainage Engineering, 141(3). https://doi.org/10.1061/(ASCE)IR.1943-4774.0000804
33. Dell (2018) Automated Irrigation System. Production Design Assets [Online]. Available at: https://www.dellemc.com/content/dam/uwaem/production-design-assets/emea/campaigns/envisionthefuture/Final_report_DELL_EMC_Automated_irrigation%20 System.pdf (Accessed 3 April 2019)
34. Diagne, A., & Demont, M. (2007). Taking a new look at empirical models of adoption: average treatment effect estimation of adoption rates and their determinants. Agricultural Economics, 37(2–3). https://doi.org/10.1111/j.1574-0862.2007.00266.x
35. DIN/DKE e Roadmap (2016) German Standardization Roadmap Industry 4.0 Version 2 (Online). Available at: https://sci40.com/files/assets_sci40.com/pdf/german-standardizationroadmap-industry-4-0-version-2-data.pdf. (Accessed January 12, 2020).
36. Draw.io. (2019) Flowchart Maker & Online Diagram Software [Online]. Available at: https://www.draw.io/ (Accessed 13 May 2019).
37. du Plessis, C.J. (2017) “A framework for implementing Industrie 4.0 in learning factories”. Thesis presented at Stellenbosch University, South Africa

38. Dukes, M., Shedd, M., & Cardenas-Lailhacar, B. (2009). Smart Irrigation Controllers: How Do Soil Moisture Sensor (SMS) Irrigation Controllers Work?
39. DWMM, (2015) MODERN IRRIGATION TECHNOLOGIES AND POSSIBILITY OF THEIR APPLICATION IN KYRGYZSTAN.
40. Edward, Lahifff, (2008). Land Reform in South Africa: A Status Report 2008. School of Government, UWC. Programme for Land and Agrarian Studies. Cape Town.
41. John Elliott (1990) Validating Case Studies, Westminster Studies in Education, 13:1, 47-60, DOI: 10.1080/0140672900130107
42. FAO. (1997) Small-Scale Irrigation for Arid Zones Criteria and Options for Appropriate Irrigation Methods (Online). Available at: http://www.fao.org/3/W3094E/w3094e05.htm (Accessed 4 June 2019).
43. Farahani, H.J., Oweis, T.Y., Bruggeman, A. (2006) Management of modern irrigation systems for high water productivity. FAO-IPTRID, March 28–31, Damascus, Syria.
44. Farming, D. (2020) Digital Farming and Smart Water Irrigation Controller from Netafim (Online). Available at: https://www.netafim.com/en/digital-farming/netbeat/ (Accessed 8 July 2020).
45. Febriani, R.A., Park, H., & Lee, C. (2020). An approach for designing a platform of smart welding station system. The International Journal of Advanced Manufacturing Technology, 106, 3437-3450.
46. Fischler, A. S. (2010) Quantitative Research Methods [Online]. Available at: 18/08/2021https://education.nova.edu/Resources/uploads/app/35/files/arc_doc/quantitative_research_methods.pdf (Accessed 11 May 2019)
47. GardenSoft (2020) Choosing an Irrigation Control System (Online). Available at: http://www.fresnogardening.org/Garden-Resources/Choosing.php (Accessed 10 January 2020).
48. Gebhart, A. (2014) Save Water with Blossom's Smarter Sprinkler System. (Online). Available at: https://www.cnet.com/reviews/blossom-smart-watering-controller-preview/ (Accessed 6 July 2020).
49. Gehrke, L., Kühn, A.T., Rule, D., Moore, P., Bellmann, C., Siemes, S., Dawood, D., Singh, L., Kulik, J., Standley, M. A. (2015). Discussion of qualifications and skills in the factory of the future: A German and American perspective.
50. Gianesini, G., Cubico, S., Favretto, G., & Leitão, J. (2018). Entrepreneurial Competences: Comparing and Contrasting Models and Taxonomies. https://doi.org/10.1007/978-3-319-89336-5_2
51. Goldblatt, A (2010) Agriculture: Facts & Trends: South Africa.

52. Goldblatt, A., Kotze; I., Corcoran, B., Botha, M., Brinkcate, T. Hawkins, H.J. (2015). Agriculture: Facts and Trends South Africa. WWF.
53. Gomo, T., Senzanje, A., Mudhara, M. and Dhavu, K. (2014), Assessing the performance of smallholder irrigation and deriving best management practices in South Africa, Irrig. and Drain., 63, doi: 10.1002/ird.1815
54. Gøtze, J. (2016) Reference Architectures for Industry 4.0 | Qualiware Center of Excellence (Online). Available at: https://coe.qualiware.com/reference-architectures-for-industry-4-0/ (Accessed 9 September 2020).
55. Glasow, P. A. (2005). Fundamentals of survey research methodology. McLean, VA: Mitre.
56. Grangel-Gonzalez, I., Halilaj, L., Auer, S., Lohmann, S., Lange, C., & Collarana, D. (2016, September). An RDF-based approach for implementing industry 4.0 components with Administration Shells. 2016 IEEE 21st International Conference on Emerging Technologies and Factory Automation (ETFA). https://doi.org/10.1109/ETFA.2016.7733503
57. Groenewald, I.B., MArfo, C.B., Schwalbach, L.M. (2001). A survey of small-scale cattle farming systems in the North West Province of South Africa. South African Journal of Animal Science, 31 (3).
58. Gronau, N., Ullrich, A., & Teichmann, M. (2017). Development of the Industrial IoT Competences in the Areas of Organization, Process, and Interaction Based on the Learning Factory Concept. Procedia Manufacturing, 9. https://doi.org/10.1016/j.promfg.2017.04.029
59. GS Campos, N., Rocha, A.R., Gondim, R., Coelho da Silva, T.L. and Gomes, D.G., (2020) Smart & Green: An Internet-of-Things Framework for Smart Irrigation. Sensors, 20(1), p.190.
60. Güven, Y., Coşgun, E., Kocaoğlu, S., Gezici, H., Yilmazlar, E. (2017). Understanding the Concept of Microcontroller Based Systems to Choose the Best Hardware for Applications. Research Inventy: International Journal of Engineering and Science. 7. 38.
61. Hall, R., Williams, G. (2015). Land Reform in South Africa: Problems and Prospects. University of the Western Cape.
62. Hamilton, K. (1995). Sustainable development, the Hartwick rule and optimal growth. Environmental & Resource Economics, 5(4). https://doi.org/10.1007/BF00691576
63. Hanbyul, J. Eunseok, R. (2019) Validating common experiences through focus group interaction, Journal of Pragmatics, Volume 143, 2019, Pages 169-184, ISSN 0378-2166, https://doi.org/10.1016/j.pragma.2019.02.019.
64. Hartmann, E. & Bovenschulte, M. (2013): Skills Needs Analysis for “Industry 4.0” based on Roadmaps for Smart Systems. In: SKOLKOVO Moscow School of Management International Labour Organization (ed.) (2013): Using Technology Foresights for Identifying Future Skills Needs. Global Workshop Proceedings, Moscow; p. 24-36

65. Hecklau, F., Galeitzke, M., Flachs, S., & Kohl, H. (2016). Holistic Approach for Human Resource Management in Industry 4.0. Procedia CIRP, 54. https://doi.org/10.1016/j.procir.2016.05.102
66. Hecklau, F., Galeitzke, M., Flachs, S., & Kohl, H. (2016). Holistic Approach for Human Resource Management in Industry 4.0. Procedia CIRP, 54. https://doi.org/10.1016/j.procir.2016.05.102
67. Helm, C. 2005. Precision farming in South Africa. Farm Technology Proceedings, 76-80.
68. Hernandez-de-Menendez, M., Morales-Menendez, R., Escobar, C. A., & McGovern, M. (2020). Competencies for Industry 4.0. International Journal on Interactive Design and Manufacturing (IJIDeM), 14(4). https://doi.org/10.1007/s12008-020-00716-2
69. Hollmann, D., McDermott, M. & Naguib, J. (2013) Developing inclusive business models – the BoP Sector Dialogues: How German development cooperation has been advancing the debate on inclusive business (Online). Available At: https://www.giz.de/fachexpertise/downloads/giz2013-en-africa-value-chain-development.pdf (Accessed August 14, 2019)
70. Hydrawise (2020) Wifi Smart Irrigation Controllers (Online). Available at: https://www.hydrawise.com/sites/hydrawise.com/files/Contractor-Brochure.pdf (Accessed 6 July 2020).
71. HydroPoint (2020) What Is Smart Irrigation? (Online). Available at: https://www.hydropoint.com/what-is-smart-irrigation/ (Accessed 4 April 2019).
72. Indhumathi, G., Suresh, C., Sangeetha, M. (2015) “A Study on Modern Techniques Used in Irrigation for Farming in Coimbatore City”, International Journal of Interdisciplinary Research in Arts and Humanities, Volume 2, Issue 2
73. Ismail, Samir. (2003). Modern Irrigation Systems Operation and Maintenance.
74. Jacobs, A. J., van Tol, J. J., & du Preez, C. C. (2018). Farmer’s perceptions of precision agriculture and the role of agricultural extension: a case study of crop farming in the Schweizer-Reneke region, South Africa. South African Journal of Agricultural Extension (SAJAE), 46(2). https://doi.org/10.17159/2413-3221/2018/v46n2a484
75. Kakade, R.K., Pisal, A.R., Chavanss, A.V., Khedkar S.B. (2017) Smart Irrigation and Crop Suggestion Using Raspberry-Pi. International Journal of Advance Engineering and Research Development, Scientific Journal of Impact Factor (SJIF), Volume 4, Issue 4
76. Katungi, E., Farrow, A., Chianu, J., Sperling, L. and Beebe, S. (2009). Common bean in Eastern and Southern Africa, a situation and outlook analysis. Agricultural System, 40: 265-282.

77. Kendall, H., Clark, B., Li, W. et al. (2022). Precision agriculture technology adoption: a qualitative study of small-scale commercial "family farms" located in the North China Plain. Precision Agric 23, 319–351 https://doi.org/10.1007/s11119-021-09839-2
78. Khalil, C. A., Conforti, P., Ergin, I., & Gennari, P. (2017). Defining small scale food producers to monitor target 2.3 of the 2030 agenda for sustainable development. Rome: FAO.
79. Kitchen, N. R., Snyder, C. J., Franzen, D. W., & Wiebold, W. J. (2002). Educational Needs of Precision Farming. Precision Farming. Precision Agriculture, 3(4). https://doi.org/10.1023/A:1021588721188
80. Koh, C. (2019) The Industry 4.0 Framework: Idea, Tool, & Guide Part 2 – RAMI 4.0 Model (online). Available at: https://www.precicon.com.sg/industry_4_0/the-industry-4-0-model (Accessed 24 May 2020).
81. Koopmans, M. (2017). Perspectives on Complexity, Its Definition and Applications in the Field. Complicity: An International Journal of Complexity and Education, 14(1). https://doi.org/10.29173/cmplct27611
82. Kraemer, K.L., and Dutton, W.H. (1991) Survey research in the study of management information systems. The Information Systems Research Challenge: Survey Research Methods, vol. 3. Cambridge, MA: Harvard Business School Press.
83. Krithiga, B., Sindhuja. R. (2017). "Soil Nutrient Identification". Asian Journal of Applied Science and Technology. Vol 1(4) pp: 40-42.
84. Kumar, A., & Sharma, P.K. (2017). Smart Irrigation System using IoT : SIS. International Journal of Engineering & Technology.
85. Kumar, R. and Ansari, H. M. (2014) Smart Irrigation Control System. International Journal of Environmental Research and Development. ISSN 2249-3131 Volume 4, Number 4, pp. 371-374
86. Larsson, L., & Nilsson, J. (2019). Facilitating an Industry 4.0 Implementation.
87. Lass, D.A., Bevis, A., Stevenson, G.W., Hendrickson, J., and Ruhf, K. (2003) Community Supported Agriculture Entering The 21st Century: Results From The 2001 National Survey. University of Massachusetts, Department of Resource Economics, Amherst
88. Liang, D., Shicheng, S., Jing. L., Chi, T., Yuwei, H., Peng, X. (2021). A Survey of Smallholder Farms Regarding Demographics, Health Care, and Management Factors of Donkeys in Northeastern China, Frontiers in Veterinary Science, 8.
89. Lindblom, J., Lundström, C., Ljung, M., Jonsson, A. (2017). Promoting sustainable intensification in precision agriculture : review of decision support systems development and strategies. Precision Agriculture 18(3), 309–331. https://doi.org/10.1007/s11119-016-9491-4

90. Lödding, H., Riedel, R., Thoben, K., Von Cieminski, G. and Kiritsis, D., 2017. Advances in Production Management Systems. The Path to Intelligent, Collaborative and Sustainable Manufacturing. Springer.
91. Lono (2020) Lono Connected Smart Home Irrigation System with up To 20 Zones (online). Available at: https://www.amazon.com/Lono-Connected-Smart-Irrigation-System/dp/B00UNELCXM (Accessed 6 July 2020).
92. Löwen U, Braune A, Diesner M, et al (2016) Industrie 4.0 components – Modelling examples. VDI/VDE Society Measurement and Automatic Control (GMA) Status Report.
93. Löwen, U., Neubert, R., Bachmann, G., IIC, S.M., & Munz, H. (2017). Architecture Alignment and Interoperability.
94. Manenzhe, T. D., Zwane, E. M., & van Niekerk, J. A. (2016). Factors affecting sustainability of land reform projects in Ehlanzeni District Mpumalanga Province, South Africa. South African Journal of Agricultural Extension (SAJAE), 44(2). https://doi.org/10.17159/2413-3221/2016/v44n2a377
95. MECC (2021) Green IQ Water Saving (Online). Available at: http://www.mcwadeslandscapes.co.za/pdf/greeniq.pdf (Accessed 6 July 2021).
96. Moghaddam, M., Cadavid, M. N., Kenley, C. R., & Deshmukh, A. v. (2018). Reference architectures for smart manufacturing: A critical review. Journal of Manufacturing Systems, 49. https://doi.org/10.1016/j.jmsy.2018.10.006
97. Mutero, J., Munapo, E., & Seaketso, P. (2016). Operational challenges faced by smallholder farmers: a case of Ethekwini Metropolitan in South Africa. Environmental Economics, 7(2). https://doi.org/10.21511/ee.07(2).2016.4
98. Mymajors.com (2020) Precision Farming Technician Skills and Knowledge (Online) Available at: https://www.mymajors.com/career/precision-agriculture-technicians/skills/ (Accessed 6 February 2020).
99. National Association of Landscape Professionals (2020) Shopping For A Smart Irrigation System? (Online). Available at: https://www.loveyourlandscape.org/expert-advice/water-smart-landscaping/smart-irrigation/shopping-for-a-smart-irrigation-system/ (Accessed 7 August 2019).
100. Nda.agric (2004). CURRENT METHODOLOGY OF OFFICIAL CROP FORECASTING IN SOUTH AFRICA.
101. Netro Inc (2020) Netro Smart Sprinkler Controller, Wifi, Weather Aware, Remote Access, 6 Zone, Compatible With Alexa (Online) Available at: https://www.amazon.com/Netro-Sprinkler-Controller-Weather-Compatible/dp/B076CZ6DHR (Accessed 6 July 2020).
102. Ngongo, P., (2016). Adoption Of Modern Agricultural Technologies By Small Scale Farmers: The Case Of Thika East Sub-County, Kenya

103. Nunes, M. L., Pereira, A. C., & Alves, A. C. (2017). Smart products development approaches for Industry 4.0. Procedia Manufacturing, 13. https://doi.org/10.1016/j.promfg.2017.09.035

104. Nylén, D., & Holmström, J. (2015). Digital innovation strategy: A framework for diagnosing and improving digital product and service innovation. Business Horizons, 58(1). https://doi.org/10.1016/j.bushor.2014.09.001

105. Nyumba, T., Nyumba, W., Wilson, Nibedita, D., Nibedita, C., Nibedita, M., (2018). The use of focus group discussion methodology: Insights from two decades of application in conservation. Methods in Ecology and Evolution. 9. 20-32. 10.1111/2041-210X.12860.

106. Ogidan, O. K., Onile, A. E., & Adegboro, O. G. (2019). Smart Irrigation System: A Water Management Procedure. Agricultural Sciences, 10(01). https://doi.org/10.4236/as.2019.101003

107. Olhager, J. and Persson, F., 2011. Advances in production management systems. New York: Springer.

108. Orbit (2020) Smart Watering For the Smart Yard (Online). Available at: https://bhyve.orbitonline.com/wp-content/uploads/2020/02/B-hyve-Media-Kit-2020_Print_HighRes_Single-Pages.pdf (Accessed 6 July 2020).

109. Parameswaran, G., Sivaprasath, K. (2016)"Arduino Based Smart Drip Irrigation System Using IOT" International Journal of Engineering Science and Computing (IJESC).

110. Park, H.-S., & Febriani, R. A. (2019). Modelling a Platform for Smart Manufacturing System. Procedia Manufacturing, 38. https://doi.org/10.1016/j.promfg.2020.01.118

111. Pinheiro, P., Putnik, G., Castro, A., Castro, H., Dal, B., & Romero, F. (2019). Industry 4.0 and industrial revolutions: An assessment based on complexity. FME Transactions, 47(4). https://doi.org/10.5937/fmet1904831P

112. Pinzone, M., Fantini, P., Perini, S., Garavaglia, S., Taisch, M., & Miragliotta, G. (2017). Jobs and Skills in Industry 4.0: An Exploratory Research. https://doi.org/10.1007/978-3-319-66923-6_33

113. Pisching, M. A., Pessoa, M. A. O., Junqueira, F., dos Santos Filho, D. J., & Miyagi, P. E. (2018). An architecture based on RAMI 4.0 to discover equipment to process operations required by products. Computers & Industrial Engineering, 125. https://doi.org/10.1016/j.cie.2017.12.029

114. Pisching, M. A., Pessoa, M. A. O., Junqueira, F., dos Santos Filho, D. J., & Miyagi, P. E. (2018). An architecture based on RAMI 4.0 to discover equipment to process operations required by products. Computers & Industrial Engineering, 125. https://doi.org/10.1016/j.cie.2017.12.029

115. Plattform Industrie 4.0 and ZVEI. (2016) Reference Architectural Model Industrie 4.0 (RAMI 4.0) (Online). Available At: http://www.plattformi40.de/I40/Redaktion/EN/Downloads/Publikation/rami40anintroduction.html. (Accessed 18 November 2019)

116. Prasanna, G. Parvatham, S., Kirshna, S. (2016) Web Based Automatic Irrigation System Using Raspberry Pi Processor on Embedded Linux. International Journal & Magazine of engineering, Technology management and Research. Volume 3. ISSN No: 2348-4845

117. Prifti, L., Knigge, M., Kienegger, H., & Krcmar, H. (2017). A Competency Model for "Industrie 4.0" Employees. Wirtschaftsinformatik und Angewandte Informatik. St. Gallen, Switzerland, 12–15 February 2017; pp. 46-60.

118. Radwan, H. A. (2008 Estimating Irrigation Demand. 2nd ed. Kharagpur: IIT.

119. Rainmachine (2020) Rainmachine - Forecast Wi-Fi Irrigation Controllers (Online) Available at: https://www.rainmachine.com/features.html#:~:text=With%20savings%20typically%20ranging%20from,in%20less%20than%20two%20years (Accessed 6 July 2020).

120. Rains, Glen & L. Thomas, Daniel. (2009). Precision farming: an introduction. University of Georgia.

121. Raspberry Pi, (2016) Raspberry Pi Beginners' Guide, the MagPi, September 2016, Issue 49. Pp 15 -27

122. Restuccia, R. (2015) 5 Features That Make Smart Controllers Smart | Jain Irrigation USA. (Online) Available at: https://jainsusa.com/blog/5-features-that-make-smart-controllers-smart/ (Accessed 7 May 2019).

123. Rooney, P. (2002). Microsoft's CEO: 80-20 Rule Applied to Bugs, Not Just Features. (Online) Available at: https://www.crrn.com/news/security/18821726/microsofts-ceo-80-20-rule-applies-to-bugs-not-just-features.htm (Accessed 28 January 2022)

124. Rowley, J. (2002) 'Using case studies in research', Management Research News, 25(1): 16–27.

125. Schrimpf, P. (2020) 6 Essential Competencies for Any Precision Farming Staff (Online). Available at: https://www.precisionag.com/market-watch/6-essential-competencies-for-any-precision-agriculture-staff/ (Accessed 10 February 2020).

126. Shields, R. (2018) Precision Farming Is the Biggest Opportunity in Farming for a Generation (Online) Available at: https://www.agrirs.co.uk/blog/2019/02/precision-agriculture-is-the-biggest-opportunity-in-farming-for-a-generation (Accessed 9 February 2020).

127. Serote, B.; Mokgehle, S.; Du Plooy, C.; Mpandeli, S.; Nhamo, L.; Senyolo, G.(2021) Factors Influencing the Adoption of Climate-Smart Irrigation Technologies for Sustainable Crop

Productivity by Smallholder Farmers in Arid Areas of South Africa. Agriculture1, 11, 1222. https://doi.org/10.3390/agriculture11121222

128. Simoes, A., & Hidalgo, C. (2011). The Economic Complexity Observatory: An Analytical Tool for Understanding the Dynamics of Economic Development. Scalable Integration of Analytics and Visualization.
129. Simon, M. K., Goes, J. (2011). Dissertation and scholarly research: Recipes for success (2011 Ed.). Seattle, WA, Dissertation Success, LLC.
130. Simonović A, Marković D, Simonović V, Krstić D. (2020). Impact of Industry 4.0 on agricultural industry. Industry 4.0.; 5(4):164-6.
131. Skobelev, P. O., Simonova, E. V., Smirnov, S. V., Budaev, D. S., Voshchuk, G. Yu., & Morokov, A. L. (2019). Development of a Knowledge Base in the "Smart Farming" System for Agricultural Enterprise Management. Procedia Computer Science, 150. https://doi.org/10.1016/j.procs.2019.02.029
132. Smith, M., Muñoz, G. and Sanz Alvarez, J. (2014). Irrigation techniques for small-scale farmers: Key practices for DRR implementers. FAO.
133. Smithson, J. (2000). Using and Analysing Focus Groups: Limitations and Possibilities. International Journal of Methodology: Theory and Practice. 3. 103-119. 10.1080/136455700405172.
134. Southern California Area Office and Water Resources Planning and Operations Support Group (2015) Weather- and Soil Moisture-Based Landscape Irrigation Scheduling Devices. Reclamation, 5th Edition, pp.15-139, 157-159.
135. Spruce (2020) Spruce – The Smart Irrigation Controller | Save Water, Money, and Time with Spruce. (Online). Available at: https://spruceirrigation.com/ (Accessed 6 July 2020).
136. Sulecki, J., 2020. Precision Agriculturists Will Need These 10 Skills In The 2020S. (Online) Available at: https://www.precisionag.com/digital-farming/precision-agriculturists-will-need-these-10-skills-in-the-2020s/ (Accessed 14 February 2020).
137. Suri, K., Cadavid, J., Alferez, M., Dhouib, S., & Tucci-Piergiovanni, S. (2017, September). Modeling business motivation and underlying processes for RAMI 4.0-aligned cyber-physical production systems. 2017 22nd IEEE International Conference on Emerging Technologies and Factory Automation (ETFA). https://doi.org/10.1109/ETFA.2017.8247702
138. Trattner, AL, Hvam, L, Forza, C & Herbert-Hansen, ZNL 2019, 'Product complexity and operational performance: A systematic literature review', CIRP Journal of Manufacturing Science and Technology, vol. 25, pp. 69-83. https://doi.org/10.1016/j.cirpj.2019.02.001
139. Tyson, A. (2015) Factors To Consider In Selecting A Farm Irrigation System | UGA Cooperative Extension (Online). Available at:

https://extension.uga.edu/publications/detail.html?number=B882&title=Factors%20to%20Consider%20in%20Selecting%20a%20Farm%20Irrigation%20System (Accessed 19 August 2019).

140. UNESCO Bangkok Communication and Information Unit (2008). Strategy Framework for Promoting ICT Literacy in the Asia-Pacific Region (Online). Available at: https://resources.hrsg.ca/blog/understanding-general-and-technical-competencies (Accessed on 20 August 2020)

141. University of the Western Cape, (2016) Diagnostic Report on Land Reform in South Africa (Online) Available at: https://www.parliament.gov.za/storage/app/media/Pages/2017/october/High_Level_Panel/Commissioned_Report_land/Commissioned_Report_on_Land_Restitution_Ramutsindela_et_al.pdf (Accessed on March 15 2019)

142. Vecchio, Y., Agnusdei, G. P., Miglietta, P. P., & Capitanio, F. (2020). Adoption of Precision Farming Tools: The Case of Italian Farmers. International Journal of Environmental Research and Public Health, 17(3). https://doi.org/10.3390/ijerph17030869

143. Wiesner, K. and Ladyman, J. (2019) Measuring complexity (Online). Available at: https://arxiv.org/abs/1909.13243 (Accessed 14 August 2019)

144. Xu, L, Chen, L., Chen, T., Goa, Y. (2011). SOA-based precision irrigation decision support system, Mathematical and Computer Modelling, Volume 54, Issues 3–4, Pages 944-949, ISSN 0895-7177, https://doi.org/10.1016/j.mcm.2010.11.020.

145. Yli-Ojanperä, M., Sierla, S., Papakonstantinou, N., & Vyatkin, V. (2019). Adapting an agile manufacturing concept to the reference architecture model industry 4.0: A survey and case study. Journal of Industrial Information Integration, 15. https://doi.org/10.1016/j.jii.2018.12.002

146. Yu, F., & Schweisfurth, T. (2020). Industry 4.0 technology implementation in SMEs – A survey in the Danish-German border region. International Journal of Innovation Studies, 4(3). https://doi.org/10.1016/j.ijis.2020.05.001

147. Yu, F., & Schweisfurth, T. (2020). Industry 4.0 technology implementation in SMEs – A survey in the Danish-German border region. International Journal of Innovation Studies, 4(3). https://doi.org/10.1016/j.ijis.2020.05.001 (remove goes)

148. Zaheer, M. (2017) RAMI 4.0 (Part 2): Product Lifecycle and Value Streams – Dzone Iot (Online) Available at: https://dzone.com/articles/part-2-rami-40-startup-of-smart-electronic-industr (Accessed 4 July 2020).

149. Zaheer, M. (2017). RAMI 4.0 (Part 3): Smart Electronic Industry 4.0 Hierarchy Level – Dzone Iot (Online). Available at: https://dzone.com/articles/rami-40-part-3-smart-electronic-industry-40-hierar (Accessed 4 July 2020).

150. Zambon, I., Cecchini, M., Egidi, G., Saporito, M. G., & Colantoni, A. (2019). Revolution 4.0: Industry vs. Agriculture in a Future Development for SMEs. Processes, 7(1). https://doi.org/10.3390/pr7010036

151. Zezulka, F., Marcon, P., Vesely, I., & Sajdl, O. (2016). Industry 4.0 – An Introduction in the phenomenon. IFAC-PapersOnLine, 49(25). https://doi.org/10.1016/j.ifacol.2016.12.002

152. Zhang, J. et al. (2021). Challenges and opportunities in precision irrigation decision-support systems for centre pivots. Environmental Research Letters. 16. 10.1088/1748-9326/abe436.

153. Zhai, Z. et al. (2020). Decision support systems for agriculture 4.0: Survey and challenges, Computers and Electronics in Agriculture, Volume 170,105256, ISSN 0168-1699,

Appendix A: Criteria and Categories for Available Irrigation Systems

Appendix A involves the site specific pre-conditions for irrigation systems. The criteria can be subdivided into categories under which irrigation systems can fall. The categories describe the capabilities, limitations, characteristics, and potential of irrigation systems. The definitions for the criteria and categories are given in section 4.1.

They are then applied to current available irrigation systems in the industry in Table 49. The purpose of identifying these products is to establish what is available in the market, to determine the upper and lower limits of these products and whether developing a configuration would serve the purpose of overcoming the barriers to applying precision farming. Knowing the upper and lower limits, the framework can be developed within these limits.

Table 49: Available Irrigation Systems

Product Name	Company	Available Irrigation Systems Classification										
		Sensor Type	Connectivity	Automation Level	Price	Price Category	Capacity	Capacity Category	Smart Connectivity	Component	Application	Biome
Orbit B-Hyve 12 Zone Smart Indoor/Outdoor Controller	B-Hyve	W AND S	WF	S	83	M	12	M	SA	SD	AC	X
Rachio Smart Controller 3rd Gen	Rachio	W	WF	S	280	MH	16	M	SA	SD	AC	X
Irrigation System Controller – Electronic Automatic Garden Watering	RA Smart Technologies	N	N	SA	38	L	8	L	N	WT	D	X
Aifro Watereco	Aifro	S	WF	S	180	MH	16	M	A	TS	AC	X
Aifro Watereco Lite	Aifro	S	WF	S	140	MH	16	M	A	TS	AC	X
Blue Spray 8 Zone	Blue Spray	H	WEC	A	250	MH	8	L	B	FS	AC	X
Blue Spray 16 Zone	Blue Spray	H	WEC	A	300	H	16	M	B	FS	AC	X
Blue Spray 24 Zone	Blue Spray	H	WEC	A	350	H	24	H	B	FS	AC	X
Rainmachine Mini-8	Rainmachine	H	WEC	S	160	MH	8	L	SA	FS	AC	X
Rainmachine Pro	Rainmachine	H	WEC	S	170	MH	16	M	SA	FS	AC	X
Mainmachine Touch HD	Rainmachine	H	WEC	S	240	MH	16	M	SA	FS	AC	X
Blossom 12 Smart	Blossom	W	WF	S	180	MH	12	M	SA	SD	AC	X

Watering Controller												
Blossom 7 Smart Watering Controller	Blossom	W	WF	S	140	MH	7	L	SA	SD	AC	X
Skydrop ARC	Skydrop	W	WF	S	150	MH	13	M	SA	SD	D	X
Skydrop Halo Controller	Skydrop	W	WF	S	180	MH	8	L	SA	SD	D	X
Koubachi K001 Indoor Wi-Fi Plant Sensor	Koubachi	S	WF	A	80	M	8	L	A	TS	AC	X
GREENIQ SMART GARDEN HUB GEN3 16 STATION	GreenIQ Controller	S	WF	S	370	H	16	M	SA	FS	AC	X
GALPRO	Galcon	N	N	SA	OR	NA	8	L	N	WT	AC	X
Galileo	Galcon	N	N	SA	OR	NA	8	L	N	WT	AC	X
HC	HydraWise – Hunter	H	W	S	OR	NA	12	M	SA	FS	AC	X
Pro-HC	HydraWise – Hunter	H	W	S	OR	NA	24	M	SA	FS	AC	X
Pro-C	HydraWise – Hunter	H	W	S	OR	NA	16	M	SA	FS	AC	X
HCC	HydraWise – Hunter	H	W	S	OR	NA	54	VH	SA	FS	AC	X
Plantlink Wireless Sensor	Plantlink	S	W	S	80	M	64	VH	A	SD	AC	X
Netro Sprite Smart Sprinkler Controller	Netro	H	W	S	200	MH	12	M	A	SD	AC	X
BaseStation 1000	Baseline	H	WEC	S	OR	NA	100	VH	A	FS	AC	X
BaseStation 3200	Baseline	H	WEC	S	OR	NA	200	VH	A	FS	AC	X
Spruce Irrigation Smart Controller 3rd Gen	Spruce	S	WF	S	53	M	1	L	A	FS	AC	X
Lono Connected Smart Home Irrigation System	Lono	H	WF	S	50	L	20	H	A	FS	AC	X
Aeon Matrix Yardian	Aeon Matrix	H	WF	S	130	MH	8	L	SA	FS	AC	X

Available irrigation systems have descriptions of their criteria and categories as given above. The benefits of the system are also of importance as seen in literature. The benefits of the available irrigation systems are given in the table below.

Table 50: Available Irrigation Systems Benefits

Company	Available Irrigation Systems	Benefits
	Weather-Based Technologies	
Accurate Weatherset	Smart Timer™	The controller (Smart Timer™) is developed for a 9, 12, 16, 24, 32, 40 and 48-station models. The controller provides seven runoff limits that are set for each station. The maximum cycle run time of 2, 4, 6, 8, 11, 15, 20, and allows or an unlimited number of minutes being set for each valve. The controller can be installed by the user. It provides 33% average water savings, 2.5 times more than its nearest competitor. A testing programme indicated that the WeatherSet only watered plants 6 % more than required.
Alex-Tronix	Enercon Plus and Enercon+ Jr.	The Alex-Tronix controller comes in a 4, 8, 12-station models and is housed in a stainless-steel pedestal. The installation of the Enercon Plus and Enercon+ Jr. from Alex-Tronix comes with a step-by-step instruction manual which allows the user to perform installation. Results shown from a SWAT Testing that the Enercon Plus controller saved 75 % of water costs to previous years.
Calsense	Calsense ET2000e	Calsense reported an overall average water savings rate of approximately 37 % which is dependent on past water usage and project history.
Cyber Rain	Cyber Rain XCI controllers	Cyber Rain XCI controllers come in 8, 16, 24-station XCI-models. The controller is placed in a suitable, weatherproof box. A five-year study conducted by Cyber Rain showed an average water savings of 34%.
ETwater Systems	ETwater SmartBox	ETwater SmartBox controllers are available from 8 to 48 stations. ETwater reports an overall water savings ranging from 20 to 50%.
HydroPoint	WeatherTRAK	The HydroPoint controller features a 24/7 customizable smartphone alert notifications, leaks detection, usage analytics tracking and automatic fault detection. The WeatherTRAK ET Pro3 is offered in a wide range of enclosures in a 12 to 48-station. HydroPoint has indicated that results from testing indicates water savings of 16 to 58 % and runoff reductions of 64 to 71 %.
Irrisoft	Weather Reach Water Management System	The Weather Reach Water Management System is shown to save money by improving irrigation scheduling efficiency through automation. The controller receives internet provided information regarding solar radiation, wind, humidity, and temperature. Customer reports shown water savings ranging from 20 to 70 %.
Irritrol	Smart Dial controllers	Irritrol controllers are given in a 6, 12 and 24 station controller. The Smart Dial controllers indicate through testing of water savings from 16 to 58% and runoff reductions of 64 to 71 %.
OnPoint EcoSystems	Connect WaterSage	The Connect WaterSage connects to a local Wi-Fi network and provides three pre-configured modes namely full water, drought and converse which comes with certain conditions. It is available in an 8 and 16 zone version. EA certified algorithms are used with site-specific ET and precipitation data that achieves water savings typically around 20 to 50% water savings
Rachio	Rachio Smart Controller 3rd Gen	The models are priced for an 8 and 16 zone capacity. Rachio reports water savings ranging from 20 to 50 % and they are an EPA WaterSense partner.
Rain Bird	ESP-ET & ESP-LX	The Rain Bird ESP-SMTe smart controllers have an onsite weather sensor and smart controller. It has a 4-station base model and can accommodate up to 22 stations.

		Rainbird field test responses indicate a 4.5 out of 5 rating score for the ease of use of the product.
Raindrip	WeatherSmartPRO™ & WeatherSmart	Raindrip models are relatively inexpensive and boasts a straightforward installation feature. Raindrip reports annual water savings of up to 30 % by end users over extended time periods.
Rain Master	RME Eagle and Eagle Plus	Rain Master manufactures a RME Eagle controller which is available in a 6, 12, 18, 24, 30 and 36 station model. The Eagle Plus is available in an 8, 16, 24, 32, 40 and 48 station configuration and with two wires can be up to 200 stations. Rain Master reports average water savings of 25 to 49 %. The 5-year warranty provides extra reliability.
Skydrop	Skydrop ARC & Skydrop Halo Controller	Skydrop has an 8-station and 16-station model with both operating with Wi-Fi features. It estimated water savings is reported at 20 to 50 %.
Weathermatic	SmartLine™	Weathermatic has a large catalogue of controllers ranging from 110 dollars to 700 dollars. Weathermatic reports indicate estimated water savings at 32% and 26% estimated cost savings.
B-Hyve	Orbit B-Hyve 12 Zone Smart Indoor/Outdoor Controller	B-Hye Smart Controller report an average reduction in outdoor water usage between 30-50 %. The B-Hye controller is SWAT certified and comes with a programmable app or a timer.
Blossom	Blossom 12 Smart Watering Controller & Blossom 7 Smart Watering Controller	Blossom claims that users can save up to an average of 30 percentage on watering costs.
HydraWise – Hunter	HC & Pro-HC & Pro-C & HCC	The Hydrawise controllers automatically adjusts watering schedules depending on local weather conditions. Hydrawise Reports that user's experience 40 % average water saving compared to a controller with a fixed schedule.
	Soil Moisture Sensors	
Acclima	Acclima Closed Loop Irrigation®	The Acclima Commercial Controller are provided in a 24 and 36 station model. Acclima recommends professional assistance when installing a system, but manuals and videos are available to assist self-installation. Acclima reports on an approximate 30 to 40 average water savings and can increase based on rainfall patterns.
Baseline	biSensor™ BaseStation 1000 & BaseStation 3200 V12	Baseline has a large catalogue of controllers that ranges from a 149-dollar model to a 200 zone, 4400-dollar model. The Portland Water Bureau stated that Baseline systems are more efficient than traditional methods and provide substantial water savings and could prove cost effective for many small to medium commercial landscapes.
Calsense	Calsense 1000-S model and ET 200e	The Calsense 1000-S model and ET 200e has provided users with water savings across 23 years of operations and has an impeccable track record.
Dynamax	GP-1 and GP-2 Data Logger/Irrigation Monitors	Dynamax's ML2 and ML3 Theta Probes and SM200, SM300 and SM`50 models have been tested extensively in irrigation trials over several time periods. Results from studies show that they have beneficial results in dry conditions and in high soil variability.
Hunter Industries	Soil-Clik	Hunter Industries provides a Soil-Clik Module and Probe that can perform soil monitoring at a 149-dollar price point. It is a proven module design. Hunter has 15 years of experience providing sensors for commercial needs and are providing highly compatible controllers.
Irrometer	WATERMARK	Irrometer product catalogues are priced competitively and are stand-alone units and allows for add-on purchasing. Irrometer participated in a study conducted by the American Society of Agricultural

		Engineers found that Irrometer provided products that were beneficial with regards to irrigation efficiency and cost effectiveness.
MorpH20	AguaMiser™	The AguaMiser™ landscape irrigation system includes add-on control devices that utilizes the ECH20 soil moisture sensors. The Magna City conducted a study that indicated a 69 % average water savings and Brigham Young University indicted a 40 % savings compared to other systems.
Rain Bird	SMRT-Y Soil Moisture Sensor Kit	Rain Bird develops a controller that comes with an SMRT-Y Soil Moisture Kit. Water savings are reported at an average of 40 % or more. The University of Florida indicated savings at up to 73 %.
GreenIQ Controller	GREENIQ SMART GARDEN HUB GEN3 16 STATION & GREENIQ – SMART GARDEN HUB 8 ZONES WIFI IRRIGATION CONTROLLER	The GreenIQ Hub connects your irrigation to the internet through Wi-Fi or 3G to control irrigation scheduling and accessing weather forecasts. This enables the user to save up to 50 % of their water usage.
Blue Spray	Blue Spray 8/16/24 Zone	The Bluespray controller is user friendly with a powerful programming capability. The flexible scheduling is powerful enough for a commercial setup and for residential usage as well. The control and access of the system can be performed from anywhere with the application or browser through a computing device.
Rainmachine	Rainmachine Mini-8 & Rainmachine Pro & Mainmachine Touch HD	The RainMachine controllers are EPA certified and report a costs saving range of 25 to 50 %.
Galcon	GALPRO & Galileo	Galcon does not provide an average water savings estimate. Other advantages include a precise fertilizer flow meter, high response speed and short stabilization time, ongoing control of channel flow and selecting the amount of fertilizer channels up to 8.
Netro	Netro Sprite Smart Sprinkler Controller	Netro controllers are fully automatic and EPA WaterSense certified. Netro Reports average water saving usage up to 50 % through weather forecasting and historical statistics.
BaseStation	BaseStation 1000 & BaseStation 3200	Baseline reports that the user saves on equipment costs through the reduction of maintenance costs compared to competitors. Saving on operational costs through less labour required to perform irrigation and water savings averages of 62%.
Spruce	Spruce Irrigation Smart Controller 3rd Gen	Spruce irrigation systems are controllable from anywhere, uses a real-time soil moisture sensor and provides accurate flow measurement. Spruce uses both soil and weather data to reduce water usage up to 60% compared to commercial time-based scheduling irrigation.
Lono	Lono Connected Smart Home Irrigation System	Lono systems uses soil moisture, weather, evapotranspiration, and geographic location data to reduce water usage up to 40-50%.
Aeon Matrix	Aeon Matrix Yardian	The Yardian controllers are EPA Watersense certified and Aeon Matrix reports an average reduction of water usage of up to 50%.

[(Aeon Matrix, 2020), (Lono, 2020), (Spruce, 2020), (Baseline, 2020), (Netro Inc, 2020), (Rainmachine, 2020), (Bluespray, 2021), (MECC, 2020), (Hydrawise, 2020), (Gebhart, 2014), (Orbit, 2020), (Southern California Area Office and Water Resources Planning and Operations Support Group, 2015)]

Appendix B: System Configuration Pre-Conditions

The farmer needs to indicate their site-specific requirements as a pre-condition to use the framework. The following tables provide the categories and definitions of site-specific requirements.

Table 51: Categories for Site-Specific Requirements

Requirement	Description	Category
Sensor type	Device or part of Irrigation Controller that is used to detect and respond to electrical or optical signals. It converts the physical parameter into a signal that can be measured electrically. (Bhatt, 2011)	Weather-Based Sensor
		Soil-Based Sensor
Connectivity	The ability of the irrigation controller to connect to other computers or to the internet. (Barry and Crowley, 2012)	Wi-Fi
		Ethernet
		Cellular
Automation level	The extent to which the irrigation controller replaces human labour. (Frohm et al., 2008)	Manual
		Semi-Automated
		Automated
		Smart
Capacity	The potential or suitability of the irrigation controller to accommodate irrigation zones. (Merriam-Webster, 2020)	Low
		Medium
		High
		Very High
Smart connectivity	The availability of a reliable data channel between the irrigation controller and a device enabling an interface to the cloud/network where information gets personalised. (Mihovska and Sarkar, 2017)	None
		Browser
		Application
		Smart assistant
Component	The main component type associated with the irrigation controller to perform tasks. (Burt, 2011)	Smart detection
		Flow sensor
		Temperature sensor
		Water timer
		Rain sensor

Application	The scale type for the irrigational controller.	Agricultural
		Domestic
Geography/Biome	The areas of vegetation characterised by the same life-form that the irrigation controller can be applied. (Kelly et al.,2004)	Desert
		Savannah
		Temperate grassland
		Chaparral
		Tropical rainforests
		Tundra
		Coniferous forest

Definitions of the various site-specific requirements are:

Table 52: Definition of Site-Specific Requirements

Requirement	Category	Definition
Sensor Type	Weather-based sensor (W)	The irrigation controller uses local weather data to adjust irrigation schedules.
	Soil-based sensor (S)	The irrigation controller uses soil characteristics to provide information or adjust irrigation schedules.
	Hybrid (H) / None (N)	Hybrid Systems make use of both weather and soil-based detection, while None refers to those that don't make use of these detection methods
Connectivity	Wi-Fi (WF)	The irrigation controller can connect wirelessly through radio wave network technology that provides high speed internet and network connections.
	Ethernet (E)	The irrigation controller is connected to other computing systems through a local area network, commonly bridges through a router.
	Cellular (C)	The irrigation controller is connected to an external

		computer through a radio network that is distributed over land through cells where each cell includes a fixed location transceiver known as the base station.
Automation level	Manual (M)	Mostly human labour required.
	Semi-automated (SA)	Some form of human labour required.
	Automated (A)	Little to no human labour required.
	Smart (S)	Full automated irrigation controller requiring no human assistance.
Capacity	Low (L)	< 10 Zones
	Medium (M)	10 < x < 20 Zones
	High (H)	20 < x < 50 Zones
	Very high (VH)	> 50 Zones
Smart connectivity	None (N)	The irrigation controller provides no platform for could/network interfaces.
	Browser (B)	The irrigation Controller provides a platform for cloud/network interface and personalization of information through a network browser.
	Application (A)	The irrigation Controller provides a platform for cloud/network interface and personalization of information through an application.
	Smart assistant (SA)	The irrigation Controller provides a platform for cloud/network interface and personalization of information through a smart assistant such as Alexa or Google Assistant.
Component	Smart detection (SD)	The identification of characteristics through

		smart infrastructure and/or components.
	Flow sensor (FS)	The irrigation controller uses a flow sensor instrument that measures linear, nonlinear, or mass volumetric flow rate.
	Temperature sensor (TS)	The irrigation controller uses a temperature sensor that measures the temperature of its environment and converts the input data into electronic data to record, signal and/or monitor temperature changes.
	Water timer (WT)	The irrigation controller is an electrochemical device that when placed on a water line, increases, or decreases the flow rate.
	Rain sensor (RS)	The irrigation controller uses a rain sensor that activates/deactivates irrigation based on rainfall parameters.
Application	Agricultural (AC)	The irrigation controller can be used to aid the cultivating of plants and livestock.
	Domestic (D)	The irrigation controller is used to aid the self-sustaining farming practices.
Biome	Desert (DT)	The irrigation controller can be applied in the Desert biome.
	Savannah (SV)	The irrigation controller can be applied in the Savannah biome.
	Temperate grassland (TG)	The irrigation controller can be applied in the

		Temperature Grassland biome.
	Chaparral management	The irrigation controller can be applied in the Chaparral biome.
	Tropical rainforests (TR)	The irrigation controller can be applied in the Tropical Rainforests Biome.
	Tundra (T)	The irrigation controller can be applied in the Tundra biome.
	Coniferous forest (CF)	The irrigation controller can be applied in the Coniferous Forest biome.
	All (X)	Applicable to all biomes.

These site-specific requirements initiate the process of the farmer to determine what the irrigation system can achieve on their farm.

To satisfy the financial preconditions for developing the framework for a system configuration for an irrigation system, the available irrigation systems are classified based on the capital potential described in Table 53.

Table 53: Financial Pre-Conditions for Acquiring Irrigation Systems

Financial Pre-Conditions for Acquiring Irrigation Systems	
Capital investment potential	**Amount**
Minimum capital potential	**$ 0 < x < $ 91**
Medium capital potential	**$ 91 < x < $ 364**
Maximum capital potential	**$ 364 < x < $ 1820**

The colour coordination is only used to easily identify the financial pre-condition for the available irrigation systems. Green is used for satisfying the minimum capital requirement, Yellow for the medium and red for the maximum capital requirement.

Table 54: Available Irrigation Systems Financial Requirements

Product Name	Company	Available Irrigation Systems Classification		Financial Pre-Conditions		
		Price ($)	Price Category	Minimum Capital Potential	Medium Capital Potential	Maximum Capital Potential
Orbit B-Hyve 12 Zone Smart Indoor/Outdoor Controller	B-Hyve	83	M	x		
Rachio Smart Controller 3rd Gen	Rachio	280	MH		x	
Irrigation System Controller – Electronic Automatic Garden Watering	RA Smart Technologies	38	L	x		
Aifro Watereco	Aifro	180	MH		x	
Aifro Watereco Lite	Aifro	140	MH		x	
Blue Spray 8 Zone	Blue Spray	250	MH		x	
Blue Spray 16 Zone	Blue Spray	300	H		x	
Blue Spray 24 Zone	Blue Spray	350	H		x	
Rainmachine Mini-8	Rainmachine	160	MH		x	
Rainmachine Pro	Rainmachine	170	MH		x	
Mainmachine Touch HD	Rainmachine	240	MH		x	
Blossom 12 Smart Watering Controller	Blossom	180	MH		x	
Blossom 7 Smart Watering Controller	Blossom	140	MH		x	
Skydrop ARC	Skydrop	150	MH		x	
Skydrop Halo Controller	Skydrop	180	MH		x	
Koubachi K001 Indoor WiFi Plant Sensor	Koubachi	80	M	x		
GREENIQ Smart Garden Hub Gen3 16 stations	GreenIQ Controller	370	H			x
STATIONSmart Garden Hub 8 8 zones Wi-Fi irrigation controller	GreenIQ Controller	277	MH		x	
Galpro	Galcon	OR	NA			x
Galileo	Galcon	OR	NA			x

HC	HydraWise – Hunter	OR	NA			x
Pro-HC	HydraWise – Hunter	OR	NA			x
Pro-C	HydraWise – Hunter	OR	NA			
HCC	HydraWise – Hunter	OR	NA			x
Plantlink Wireless Sensor	Plantlink	80	M	x		
Netro Sprite Smart Sprinkler Controller	Netro	200	MH		x	
BaseStation 1000	Baseline	OR	NA			x
BaseStation 3200	Baseline	OR	NA			x
Spruce Irrigation Smart Controller 3rd Gen	Spruce	53	M	x		
Lono Connected Smart Home Irrigation System	Lono	50	L	x		
Aeon Matrix Yardian	Aeon Matrix	130	MH		x	
Aeon Matrix Yardian	Aeon Matrix	107	MH		x	

Appendix C: Barriers to Precision Farming Application: Pareto Analysis

Pareto analysis is used in statistical process control (SPC) and decision making for the selection of a limited number of tasks that produce the most significant overall effect. The technique is used to determine the top 20 % of causes that needs addressing to resolve the remaining 80 %. In this instance, it will be used to determine to top barriers to applying precision farming technologies by looking at various literature sources.

Pareto analysis is a useful tool in this instance as it can be applied to root cause investigation and risk analysis. Is uses a multi-layered approach by helping to identify the principal causes of the principal failures. The tool can be further enhanced through combining other analytical tools such as fault tree analysis and fishbone diagrams to correctly identify critical areas.

The analysis was used in this thesis to determine the barriers of applying Precision Farming technologies to determine which barriers the framework for a system configuration of an irrigation system should address. The following table summarizes the sources and the barriers that were identified within those sources.

Table 55: Summary of Source Material Results in the Pareto Analysis

Sources	Too Risky	Don't Trust It	Not Profitable	Too time consuming	Too complex	Continuously Evolving Technology	Benefits Uncertain	Too Expensive	ethical problems	access to technology	
Websites	14	33	8	4	123	28	133	116	34	57	
Studies	40	62	70	26	225	64	235	229	88	106	
Totals	54	95	78	30	348	92	368	345	122	163	1695

The analysis found that the top three barriers that small-scale farmers face are being too complex, the benefits being uncertain and being too expensive.

Appendix D: Benefits of Irrigation System Components

Irrigation system components are given along with their description, benefits and price.

Table 56: Microcontrollers

Microcontroller	Description	Benefits	Price
Arduino Uno R3 Microcontroller Board	Microcontroller with on-board ATmega328P chip.	1. Various I/O pins which can interface to other boards and circuits. 2. USB port, 14 I/O pins, ICSP header, power supply and reset press. 3. Compatible with computers 4. Low cost with online libraries available	≈ 19 US Dollars
Teensy 4.0	6000Mhz processor microcontroller boards	1. Fast microcontroller board available. 2. Small compact size with commands through USB ports. 3. Can be programmed by Arduino IDE with minimum add-ons. 4. Large Ram space.	≈ 29 US Dollars
Arduino Pro Mini 328	Microcontroller powered by Arduino	1. Only applicable for small-scale operations. 2. Very low cost comes without ports. 3. Can run up to 8MHz	≈ 10 US Dollars
ESP32 Microcontroller Board	Single-chip board operating at 2.4 GHz		≈ 15 US Dollars
Raspberry Pi	Highly functional microcontroller board.	1. Extremely fast board. 2. Can build powerful and advanced systems. 3. Onboard WLAN, Bluetooth HDMI input and Ethernet capabilities	≈ 40 – 60 US Dollars
MBED LPC1768	Microcontroller board best for prototyping	1. Has I/0 pins, USB ports and Ethernet. 2. Supports developing and programming functions.	≈ 140 US Dollars
BeagleBone Black	Microcontroller with various ports available.	1. Easy to start development with USB connection to PC 2. 2 USB ports, Ethernet, flash storage and pins 3. Reduced power consumption with no heat sink requirements. 4. Supports Wi-Fi, WLAN and Bluetooth	≈ 45 Dollars
NUCLEO STM32	Affordable and flexible microcontroller for various projects.	1. Low cost 2. Easy functionality expansion and open development platform. 3. Does not require separate probe for programmer	≈ 12 US Dollars
ESP8266 Microcontroller Board	IoT compatible microcontroller.	1. Compact size providing IoT capabilities. 2. Compatible with smart home projects. 3. 4MB flash memory 4. Uses its own network to connect to devices.	≈ 3 US Dollars
Quark D2000	Intel Galileo Single ATX DDR2 1066 Microcontroller Motherboard	1. Very flexible and supports various functions. 2. Low power consumption. 3. Large amount of I/O pins 4. A full sized mini-PCI Express slot, 100Mb Ethernet port, Micro-SD slot, RS-232 serial port, USB Host port, USB Client Port, and 8 MByte NOR flash come standard on the board	≈ 15 Dollars
Launchpad MSP430	Group of ultra-lower power consumption microcontrollers	1. Ultra-lower power consumption 2. Robust decision support for MCU 3. Wide range of portable applications. 4. Maximum code efficiency	≈ 13 US Dollars
Raspberry Pi Zero W	Extensions of the Raspberry Pi microcontroller family for advanced systems.	1. Comes with added wireless LAN and Bluetooth connectivity. 2. Supports Embedded IoT projects.	≈ 10 US Dollars
Arduino Mega	Microcontroller based on the ATMgega2560 processor with 54 pins, 16 MHz crystal oscillator, power jack, ICSP header, USB connection and 4 UARTSs	1. Free open source IDE 2. Protected with a plastic base plate with added SDA and SCL pins 3. Low cost and can be connected to computers. 4. No fear of electrical discharge	≈ 27 US Dollars
IPex16	Data logger and controller in DIN rail	1. Compatible with various accessories performing increased communications and functionalities	Available on contact

	for electrical outputs with 16 I/O pins.	2. Can be configured with embedded web servers. 3. Compatible with various wireless modules. (3G/loRa/Sigfox)	
Node MCU DevKit	Low-cost open source IoT platform running om ESP82666 Wi-Fi SoC and ESP32	1. Stand-alone device in IoT applications 2. Wide range of remote applications 3. Low-cost	≈ 10 US Dollars
Wemos Mini D1	A smaller "Arduino with Wi-Fi" at a low cost based on the ESP8266 processor.	1. Low operating voltage and logic levels for all parts at 3.3V. 2. Compatible with Arduino IDE, NodeMCU and micropython 3. Can be programmed through USB port 4. Can use Raspberry pi Web Server	≈ 8 US Dollars
Intel Gallieo Gen-2	A microcontroller board based on the Intel Quark SoC X1000 processor.	1. Can operate at speeds of 400MHz. 2. Integrated Real-Time Clock with a 3V battery. 3. Supports various inputs and outputs, ports, connections, headers, and resets. 4. Compatible with Arduino IDE and Hardware	≈ 75 US Dollars
Waspmote	IoT device development board based on Atmel's 8-bit low power microcontroller ATmega1281	1. Used in low consumption IoT applications and allows nodes to work autonomously. 2. Long battery life. 3. Plug and sense through sockets. 4. Popular for smart applications	≈ 153 US Dollars
crowduino	Development board compatible with Arduino based on ATmega8.	1. Has 14 digital I/O pins, 6 analogue inputs, USB port etc. 2. USB cable power and connecting to a computer. 3. Evolve with SMD components	≈ 17 US Dollars

Table 57: Rain Sensors

Rain Sensor	Description	Benefits	Price
Rain Sensor Module - Microcircuits	Easy tool for rain detection.	1. Can be a switch when raindrop falls through the raining board measuring rainfall intensity. 2. Adjustable sensitivity through a potentiometer. 3. Adopts a high-quality RF-04 double sided material. 4. Long lifetime	≈ 4 US Dollars
Halja	Humidity, rain and droplet sensor compatible with microcontrollers.	1. Easy installation 2. Low operating voltage 3. Sensitivity level adjustable with potentiometer. 4. High conductivity	≈ 6 US Dollars
AZ Delivery 5 x Rain Sensor Module	Rain sensor that can be used for rain detection, rain intensity and switching modules.	1. Adjustable switching with potentiometer. 2. Low power consumption. 3. Digital or analog output.	≈ 11 US Dollars (5pcs)
Leaf Wetness 12V DC Rain Sensor Module	Humidity regulator used for weather monitoring applications.	1. High quality material. 2. High oxidation resistance, electrical conductivity and long lifetime. 3. Indicators showing switching status. 4. Comes with relay switch.	≈ 10 US Dollars
SEN-08942	Weather sensor kit using a wind vane cup anometer, rain gauge, tipping bucket and mounting hardware	1. No electronic components use sealed magnetic reed switches. 2. Can measure wind and rain values. 3. RoHS Compliant	≈ 75 US Dollars
YL83	Rain sensor that comes in two pieces, an electronic and collector board.	1. Collects water droplets. 2. Built in potentiometer for sensitivity adjustment of the digital output. 3. LED lights to show sensor status. 4. Output voltage increases and decreases during certain weather patterns	< 2 US Dollars
FC37	Rain sensor that comes in two pieces, an electronic and collector board.	1. Collects water droplets. 2. Built in potentiometer for sensitivity adjustment of the digital output. 3. LED lights to show sensor status. 4. Output voltage increases and decreases during certain weather patterns	< 2 US Dollars

Table 58: Soil Moisture Sensors

Soil Moisture Sensor	Description	Benefits	Price
FC-28	Simple for measuring the moisture in soil and similar materials.	1. Analog and digital output potential 2. Easy installation features 3. Low power consumption 4. Adjustable digital output threshold with potentiometer	≈ 3 US Dollars
YL-69	Simple moisture sensor that detects soil moisture when the soil moisture deficit module outputs high levels.	1. Enables automatic soil monitoring and management. 2. Easy installation. 3. Analog and digital output interface. 4. Sensitivity is adjustable through the blue digital potentiometer.	≈ 4 US Dollars
HL-69	Humidity moisture detection sensor with Dupont Wires	1. Enables automatic soil monitoring and management. 2. Easy installation. 3. Analog and digital output interface. 4. Sensitivity is adjustable through the blue digital potentiometer.	≈ 3 US Dollars
LM393 Pi Sensor	Soil moisture sensor that measures moisture content.	1. Analog and digital output that provides a variable voltage. 2. Moisture content threshold can be set using adjustable on-board potentiometer 3. Wide sensor area and LED indicators 4. Low cost	≈ 4 US Dollars
SEN-13637	Simple breakout for measuring the moisture in soil and similar materials.	1. Easy to use and very affordable 2. PCB coated finish to increase lifetime. 3. Enables automatic soil moisture sensing.	≈ 7 US Dollars
VH400	Soil moisture sensor probes allowing for precise and low-cost soil moisture monitoring.	1. Low cost 2. Insensitive to water salinity and does not corrode over time. 3. Rugged and high accurate readings	≈ 45 US Dollars
200SS	Solid-state electrical resistance sensor used to measure soil water tension.	1. Stable calibration 2. Does not dissolve inn soil 3. Not effected by low temperatures 4. Does not corrode over time. 5. Inexpensive and easy to implement.	≈ 38 US Dollars through reseller.

Table 59: Ultrasonic Sensors

Ultrasonic Sensor	Description	Benefits	Price
HC-SR04	An ultrasonic distance sensor which includes an ultrasonic transmitter, receiver, and control circuit.	1. Easy setup 2. Sends out automatic signal. 3. Low operating voltage. 4. Can detect distance from 2cm to 4m	≈ 4 US Dollars
WLC Ultrasonic Sensors	Cost-effective and reliable sensor for volume, level and open flow channel measurement.	1. Easy setup with no moving parts 2. Continuous measurement 3. Suitable for liquids and some solids 4. High accuracy and sensitivity	Receive quote depending on application
RS Pro	Proximity sensor used to receive ultrasonic waves.	1. Easy setup 2. Sends out automatic signal. 3. Low operating voltage. 4. Can detect distance from 2cm to 4m	≈ 12 Dollars
RS Pro	Proximity sensor used to receive ultrasonic waves	1. Easy setup 2. Sends out automatic signal. 3. Low operating voltage. 4. Can detect distance to 300mm	≈ 12 Dollars

Table 60: Temperature Sensors

Temperature Sensor	Description	Benefit	Price
LM35	Temperature measuring device having an analog output voltage proportional to the temperature. Requires ADC	1. Accurate temperature measurement 2. Low costs 3. It does not require any external calibration circuitry. 4. Requires minimum power supply and can measure temperatures from -55 to 150 degrees Celsius	≈ 2 US Dollars
LM335Z	Precision temperature sensor which can be calibrated. Requires ADC	1. Error of less than 1-degree Celsius 2. Low costs 3. It does not require any external calibration circuitry. 4. Requires minimum power supply and can measure temperatures from -40 to 100 degrees Celsius	≈ 1 Dollar
LMT89	Cost-competitive sensor to thermistors. Requires ADC	1. Error of less than 1-degree Celsius 2. Low costs 3. Suitable for remote applications 4. Requires minimum power supply and can measure temperatures from -55 to 130 degrees Celsius	≈ 1 Dollar
DS18B20	Programmable Resolution 1-Wire Digital Thermometer	1. User programmable upper and lower trigger points. 2. Can derive power directly from data line 3. Reduces system components 4. 0.5-degree Celsius accuracy.	≈ 2 Dollars
PT temperature sensor	Thermistor sensor RTD with protected casing.	1. Suitable for precise control systems. 2. Temperature ranges from -50 to 600 degree Celsius. 3. Fast response times 4. Requires ADC	≈ 2 Dollars
DHT11	Basic, ultra-low-cost digital humidity and temperature sensor.	1. Low-cost 2. Can detect both humidity (capacitive sensor) and temperature (thermistor. 3. No analog pins needed. 4. Ease to use and implement. 5. Good for 20-80% humidity readings with 5% accuracy 6. Good for 0-50°C temperature readings ±2°C accuracy	≈ 3 US Dollars
DHT-22	Low-cost, basic digital humidity and temperature sensor.	1. Low-cost and more accurate than DHT11 2. Can detect both humidity (capacitive sensor) and temperature (thermistor. 3. No analog pins needed. 4. Ease to use and implement. 5. Good for 0-100% humidity readings with 2-5% accuracy 6. Good for -40-80°C temperature readings ±0.5°C accuracy	≈ 9 US Dollars
TMP-36	Analog temperature sensor indicating ambient temperature.	1. Analog voltage signal directly proportional to temperature. 2. Easy to use. 3. Precise and does not need any calibration. 4. Works under any environmental conditions.	≈ 1.5 US Dollars
AM2315	I2C-interface temperature and humidity sensor in an enclosed capsule.	1. Has an embed microcontroller providing simple I2C interface for reading calibrated output data. 2. Rugged case and mounting bracket. 3. Easy to interface with microcontrollers. 4. Good for 0-100% humidity readings with 2% accuracy 5. Good for -20 to 80°C temperature readings ±0.1°C typical accuracy	≈ 30 US Dollars

Table 61: Light Sensors

Sensor	Description	Benefit	Price
Grove – Light Sensor v1.2	Highly sensitive and reliable photodiode with analog reading.	1. Easily paired with microcontroller 2. Highly sensitive 3. On-board grove port for easy interfacing 4. Small form	2.9 US Dollars
Grove – Light Sensor (P) v1.1	Highly sensitive and reliable phototransistor with linear analog output.	1. More linear analog output that conforms to luminance. 2. Small Form factor. 3. Low dark current a low working flux 4. Integrated Grove Port for easy interfacing	2.9 US Dollars

Grove – Digital Light Sensor	Photoresistor providing a digital output option.	1. Provide digital outputs (No ADC needed) 2. 3 reading and detection modes 3. Programmable interrupt function with user-defined upper and lower thresholds	9.9 US Dollars
Grove – Sunlight Sensor	Made for direct sunlight detection through UV.	1. Wide dynamic and spectrum detection range. 2. Suitable for UV, Visible and Infrared. 3. Programmable configuration 4. Digital Output	9.9 Dollars
Grove - Heelight Sensor	Contactless light control through voice detection.	1. Controlled by digital sound waves. 2. Operates without Bluetooth, Wi-Fi and Zigbee	7.9 US Dollars
BH1750	16-Bit ambient light sensor.	1. Small size. 2. Capable and inexpensive. 3. Able to measure from 0 to 65K+ lux. 4. Plug and use capability in development boards.	≈ 5 US Dollars
TSL2561	Advanced digital light sensor, ideal for wife ranges of light situations.	1. Very precise sensor 2. Exact Lux calculations can be configured to detect light at 0.1 – 40K+ Lux. 3. Can detect infrared, full-spectrum or human-visible light.	≈ 6 US Dollars
SN-500	Digital solar-radiation meter	1. Provides individual measurement of net radiation components. 2. Sensor features an SDI-12 output removing the need for analog channels. 3. Fast and accurate readings.	Price available on contact

Table 62: Humidity Sensors

Humidity Sensors	Description	Benefits	Price
DHT11	Basic, ultra-low-cost digital humidity and temperature sensor.	1. Low-cost 2. Can detect both humidity (capacitive sensor) and temperature (thermistor. 3. No analog pins needed. 4. Ease to use and implement. 5. Good for 20-80% humidity readings with 5% accuracy 6. Good for 0-50°C temperature readings ±2°C accuracy	≈ 3 US Dollars
DHT22	Low-cost, basic digital humidity and temperature sensor.	1. Low-cost and more accurate than DHT11 2. Can detect both humidity (capacitive sensor) and temperature (thermistor. 3. No analog pins needed. 4. Ease to use and implement. 5. Good for 0-100% humidity readings with 2-5% accuracy 6. Good for -40-80°C temperature readings ±0.5°C accuracy	≈ 9 US Dollars
AM2315	I2C-interface temperature and humidity sensor in an enclosed capsule.	1. Has an embed microcontroller providing simple I2C interface for reading calibrated output data. 2. Rugged case and mounting bracket. 3. Easy to interface with microcontrollers. 4. Good for 0-100% humidity readings with 2% accuracy 5. Good for -20 to 80°C temperature readings ±0.1°C typical accuracy	≈ 30 US Dollars
SH10	Humidity sensor calibrated in a precision humidity chamber.	1. Small size 2. Low power consumption 3. Good for demanding applications. 4. Rugged and waterproof casing 5. Humidity Ranger: 0-100%RH 6. Temperature ranger: -10-80°C 7. Humidity accuracy: ±5.0%RH	≈ 34 US Dollars
HH10D	Relative humidity sensor	1. Can respond to humidity changes quickly. 2. -10 to 60 degrees C temperature range 3. +-3% accuracy 4. I2C interface	≈ 12 US Dollars

Table 63: Air Sensors

Air Sensors	Description	Benefits	Price
MQ135	Air quality sensor present in professional weather stations.	1. Low cost 2. Can detect benzene, CO2, alcohol, NH3, NOx, and smoke. 3. Fast response and high accuracy 4. Stable and long lifetime	66 US Dollars
MQ131	Semiconductor air quality sensor for Ozone.	1. Used for Ozone, NO_2 and Cl_2 monitoring. 2. Long life and low cost 3. Simple drive circuit 4. High accuracy and sensitivity	≈ 12 US Dollars
MQ2	Gas monitoring metal oxide Semiconductor sensor	1. Can measure methane, Butane, LPG and smoke. 2. Used as a digital or analog sensor 3. Low cost and operating voltage of 5V. 4. Digital Pin sensitivity can be varied through using the potentiometer.	≈ 4 US Dollars
MQ9	Semiconductor gas sensor with analog output.	1. Can measure carbon monoxide (10 to 1,000 ppm) and flammable gasses (100 to 10,000 ppm. 2. Low cost 3. Easy interfacing with microcontrollers	≈ 6 US Dollars
CDM461A	Air quality sensor detecting carbon dioxide in the air.	1. Low Cost 2. Low power consumption 3. Small size and pre-calibrated 4. Maintenance free	≈ 73 US Dollars

Table 64: Transmitters/Receivers

Transmitter/Receiver	Description	Benefit	Price
433 MHz RF Module (Geekcreit®)	RF Decoder Transmitter with Receiver Module Kit for ARM MCU Wireless Geekcreit for Arduino	1. Fitting for various applications 2. Low operating voltage. 3. MCU capabilities. 4. Antennas can increase communication distances	≈ 4 US Dollars
418 MHz RF Module	RF Module operating on 418MHz	1. Ideal for setting up short range wireless links. 2. Low operating voltages and operates on a license free industrial FCC band	≈ 2 US Dollars
315 MHz XD FST RF Module	RF Module with 315 MHz Working Frequency	1. Wider range of working voltage. 2. Stable performance. 3. Low power consumption.	≈ 4 US Dollars

Table 65: Displays

Display	Description	Benefit	Price
Arducam 1602	16x2 LCD Display Module based on HD44780	1. Wide viewing angle and high contrast 2. Character LCD display type. 3. 2-line with 16 characters 4. White on blue with backlight	≈ 6 US Dollars
BMT 2.8IN TFT LCD TOUCH SHIELD	Touch shield display with micro SD socket	1. 5V compatible supporting a 2GB micro SD TF card 2. Simple plug and load capability 3. No wiring or soldering needed. 4. Touchscreen with 240 x 320 pixels	≈ 16 US Dollars
Adafruit 2298 LCD (PiTFT)	Touchscreen LCD display for microcontroller platforms	1. 2.8" display with 320x240 16-bit colour pixel touchscreen display. 2. High speed SPI interface that can display image and video. 3. Four tactile GPIOs 4. Easy installation.	≈ 38 US Dollars
Geekcreit® UNO R3	2.8 TFT LCD Touchscreen display for Arduino microcontroller compatibility	1. No wiring or soldering needed. 2. ILI9340 controller with built in video buffer 3. 4-wire resistive touchscreen. 4. Easy installation 5. Low power consumption	≈ 10 US Dollars
Share to: Geekcreit 3.2 Inch MEGA2560 Display Module	Large 3.2" display based on the HX8357B LCD Controller	1. High image quality and fast response. 2. Module can be inserted directly into a Mega board. 3. Low power consumption 4. Easy installation.	≈ 9 US Dollars

Table 66: ADCs

ADC	Description	Benefits	Prices
MCP3008 / MCP3004	10-bit converter with on-board sample and hold circuitry.	1. Applicable for battery operated systems 2. Programmable to provide two pseudo-differential input pairs or eight single-ended inputs. 3. 4 or 8 input channels	≈ 2 US Dollars
ADS1115	High precision ADC with 16-bit precision.	1. Can be configured as 4 single-ended input channels, or two differential channels. 2. Includes a programmable gain amplifier to boost smaller signals. 3. Easy to use and 4. Can measure a large range of signals	≈ 15 US Dollars
MCP4725	12-bit converter which is low-power, highly accurate and single channelled.	1. Lower Power consumption 2. Ease of use and fast setting time. 3. 6-pin package suitable for applications requiring power saving during off times.	≈ 5 US Dollars
LTC2499	16-cannel 24-bit ADC with Easy Drive technology.	1. Enables rail-to-rail inputs with zero differential input current. 2. Eliminates dynamic input current errors. 3. Integrated temperature sensor	≈ 6 US Dollars
ADS1231ID	Precision 24-bit ADC converter.	1. Can be configured as 4 single-ended input channels, or two differential channels. 2. Includes a programmable gain amplifier to boost smaller signals. 3. Easy to use and 4. Can measure a large range of signals	≈ 6 US Dollars

Table 67: Communication Technologies

Communication Tech	Description	Benefits	Price
GSM	These modules are chips or circuits used to establish communication between a mobile device and a computing machine. A Global Standard for Mobile Communication (GSM) is a standard that was developed by the European Telecommunications Standards Institute (ETSI).	1. Remote management 2. GSM modules have security protocols in place. 3. GSM speeds are high and sufficient for IoT applications. 4. Easy to deploy the GSM for your IoT application. 5. Quick and automatic connections to Wi-Fi services.	Price dependant on manufacturer and module.
WIFI	Enables devices to access wireless networks.	1. Wireless communication of data. 2. High internet speeds. 3. Wi-Fi strengths can be increased through mesh and extenders. 4. Remote monitoring and control capabilities.	Price dependant on manufacturer and module.
Ethernet	Connects multiple computer network and devices together within a Local Area Network (LAN), such as a home or an office to enabling the transferring of data. Connected through Ethernet cables, to a central hub.	1. Enables communication between devices. 2. Can carry information over long distances up to 10,000 meters. 3. Cables bypass obstacles that can interfere with transmission. 4. Fast speeds, low latency. 5. Greater security and reliable connections.	Just Electronics: R3.04 (0.19USD) per meter
Zigbee	IEEE 802.15.4 based specification for high level communication protocols that allows smart objects to communicate with each other.	1. Complete IoT solution. 2. Increased user flexibility 3. Communicates with IoT compliant language. 4. Easy smart monitoring capabilities 5. Energy efficient and backwards compatible.	Modules start at ≈ 26 US Dollars
Bluetooth	Shared wireless information across devices within short distances.	1. Low power consumption 2. Cheap alternative when short distances are applicable. 3. Easily upgradeable. 4. Minimal interference 5. Easy automation	Bluetooth chips are very affordable (≈ 9 US Dollars)

LoRa	Low Power, Wide Area (LPWA) networking protocol that is designed to wirelessly connect battery operated things to the internet.	1. Targets key IoT requirements such as end-to-end security, localizations service and mobility. 2. LoRa Alliance us an open association of collaborating members. 3. Long battery lifetime. 4. Optimized cost, capacity, and range.	Price dependant on part needed in microcontroller.
MQTT	OASIS standard messaging protocol for the Internet of Things (IoT)	1. Lightweight and efficient 2. Reliable message delivery 3. Highly scalable 4. Bi-directional communication	MQTT Buddy (enables home automation solutions for IoT devices, managing sensors and creating customized scenarios.
GPRS	Global Packet Radio Services (GPRS) is a packed oriented mobile data service for GSMs on 3G and 2G communication systems.	1. Offers High speed "always-on" internet access. 2. Provides real-time, 24/7 accessibility of information. 3. Performs at high speeds and high data rates.	Price dependant on manufacturer and module. 3 US Dollars
4G	The fourth-generation broadband cellular mobile technology.	1. High speeds of data transferring. 2. Low latency. 3. Improved spectrum efficiency and 4. Does not require external components.	Data Prices are dependent on mobile provider
6LoWPAN	Combines the latest version of the internet protocol (IPv6) and Low-power Wireless Personal Area Network (LoWPAN).	1. Enables small and limited devices to connect and transfer information wirelessly. 2. Good or small devices. 3. Can communicate over IPs like Wi-Fi protocols. 4. Communicates over IEEE 802.15.4 protocols and other standards. 5. Direct connectivity to a variety of networks	Built into development boards.
IEEE 802	The Institute of Electrical and Electronics Engineers developed protocol for ethernet networks.	1. Controls how data is exchanges between devices over the LAN. 2. The protocol evolves with technologies. Allowing for increased speeds	None

Table 68: GSM/GPRS Modules

GSM/GPRS Module	Description	Benefit	Price
SIM800C	Complete quad-band solution for embedded applications.	1. Capable of both GSM and GPRS communications 2. Transmits voice, SMS and data information 3. Low power consumptions 4. Low cost and small size	≈ 7 US Dollars
SIM900A	Cellular modem with plug and play features that has RS232 serial communication supported.	1. Applicable of embedded applications 2. Low cost and compact 3. Low power consumption	≈ 8 US Dollars
MINI A6	Highly advanced compact module that fits into a micro SD card.	1. Capable of connecting to GSM and GPRS networks. 2. Applicable for various wireless applications. 3. Low power consumptions and long usage time. Good functionality and can reduce power consumption when not used.	≈ 12 US Dollars
SIM868 HAT	Multi-communication module that provides GSM/GPRS/GNSS/Bluetooth functionality	1. Plug and Play module 2. Easy for beginners and high functionality. 3. Enables GPS, communications between devices, internet, MMS and SMS 4. Applicable for advance projects due to large channel capacity and tracking sensitivity.	≈ 30 US Dollars

Table 69: WIFI Modules

Wi-Fi Module	Description	Benefits	Price
Bluetooth LE/BLE (HM-11)/ (JDY-10)/(JDY-24M)	Subset module of the Bluetooth specification for wireless communication. Used when battery life is preferred to high transfer speeds.	1. Low energy consumption 2. Allow for multiple simultaneous connections 3. Simple and real-time operations. 4. Short range radio frequency connectivity	≈ 3.5 - 6 US Dollars
nRF24L01+ Wireless Module	A single chip radio transceiver for the worldwide 2.4 – 2.5 GHz ISM Band.	1. Enables remote sensor data transmission 2. Inexpensive module 3. Very compact design 4. Lower power consumption 5. Data transmission up to 2 Mbps	≈ 2 - 6 US Dollars
ESP8266	Self-contained SOC with integrated TCP/IP protocol stack compatible with any microcontroller to provide wireless access.	1. Capable of hosting an application or offloading Wi-Fi network functions from another application 2. Cost-effective 3. Supports most applications with powerful on-board processing and storage which allows it to integrate with sensors. 4. Requires no external RF parts	≈ 4 US Dollars
CC2530	A system-on-chip module for 2.4 GHz IEEE 802.15.4 and Zigbee Applications	1. Low consumption power 2. Very few external components with a programmable output power. 3. High performance operation and compliant with worldwide radio frequency. 4. Excellent receiver sensitivity	≈ 6 US Dollars
Adafruit WINC1500 Wi-Fi Shield with PCB Antenna	Arduino-compatible Wi-Fi Shield connecting systems to the internet wirelessly	1. SSL Support and solid performance. 2. Uses SPI to communicate and GPIO for control 3. High speeds and reliable data transferring. 4. The shield is used to enhance the current Wi-Fi module attached to a microcontroller.	≈ 25 Dollars

Table 70: Relay Modules

Relay Modules	Description	Benefits	Price
HiLetgo 2pcs 5V	One channel relay module with switch and OPTO Isolation for threshold triggers.	1. Enables user to set high and low trigger threshold 2. Very convenient interface through direct connection. 3. High quality relay	≈ 6 US Dollars
KNACRO 2-Channel 5V Relay Module	Opt coupler isolation load for threshold triggers.	1. Strong anti-jamming capability. 2. Strong operating performance 3. User cans ET a high and low threshold trigger.	≈ 9 US Dollars
KNACRO 1-Channel	DC power switch relay module for water control.	1. Uses a high-quality ultra-sensitive opt coupler. 2. Stable performance 3. Stable and solid hardware 4. Reliable performance.	≈ 8 US Dollars
SunFounder 5V 8 Channel Relay	8-channel interface board for programmable functions.	1. Equipped with a high-current relay. 2. Programmable by most microcontrollers 3. Indication of relay output status with LEDs	≈ 11 Dollars
JBTek	4 Channel Dc relay module for microcontrollers	1. High current relays. 2. Able to control various appliances with large currents 3. Supports MCU control, PLC and smart home control 4. Indication LEDs for Relay Output Status	≈ 8 Dollars

Table 71: Processors

Processors	Description	Benefits	Price
ATmega328	A high performance, low power AVR 8-bit microcontroller	1. High endurance and non-volatile memory segments 2. Has 6 different sleep modules 3. Simple to use when integrated on microcontrollers. 4. Code efficient and is incredibly fast. 5. Readily useable	≈ 9 US Dollars
ATmega2560	The high-performance, low-power Microchip 8-bit AVR RISC-based microcontroller.	1. Atmel QTouch library support 2. High Endurance Non-volatile Memory Segments 3. Low power consumption and fast start-up 4. Easy to use and less complex. 5. Unambiguous detection of key events.	≈ 11 US Dollars
ATmega1281	The high-performance, low-power Microchip 8-bit AVR RISC-based microcontroller.	1. Balances power consumption and processing speed. 2. Ultra-low power consumption 3. High Endurance Non-volatile Memory Segments 4. Atmel QTouch library support	≈ 9 US Dollars

LPC2148	16/32-Bit ARM7TDMI-S CPU microcontroller with embedded high-speed flash memory ranging from 32 – 512 kB	4. Tiny size and low power consumption. 5. Power saving capabilities 6. Various features enabling developers to perform multiple functions.	≈ 11 US Dollars
ATmega16	ATmega16 is an 8-bit high performance microcontroller based on Atmel's Mega AVR range.	1. High endurance and non-volatile memory segments 2. Has 6 different sleep modules 3. Simple to use when integrated on microcontrollers. 4. Code efficient and is incredibly fast. 5. Readily useable	≈ 1 US Dollars

Table 72: Communication Modules

Communication Modules	Description	Benefits	Price
ESP82666	It is a cost-effective and highly integrated Wi-Fi MCU for IoT Technologies	1. High durability functioning consistently in wide temperature ranges. 2. Reliable, compact, and robust. 3. Small size 4. Low Power consumption 5. Real-time operating system and Wi-Fi stack allow for 80% of the power to be allocated to user application programming	≈ 3 – 6 US Dollars
SIM900	Complete quad-band solution for embedded applications.	1. Capable of both GSM and GPRS communications 2. Transmits voice, SMS and data information 3. Low power consumptions 4. Low cost and small size	≈ 7 US Dollars
nRF24L01+ Wireless Module	A single chip radio transceiver for the worldwide 2.4 – 2.5 GHz ISM Band.	1. Enables remote sensor data transmission 2. Inexpensive module 3. Very compact design 4. Lower power consumption 5. Data transmission up to 2Mbps	≈ 2 - 6 US Dollars
XBee S2	2mW Wire Antenna operating on ZigBee mesh communication.	1. Enables the creation of complex mesh networks based on ZigBee mesh firmware. 2. Built-in Antenna 3. Cost effective wireless connectivity. 4. Programming directly on the module eliminates need for processor. 5. Provides a high-speed interface and embedded integration.	≈ 27 US Dollars
SX1276	The transceiver features the LoRa long range modem for communication.	1. High interface immunity. 2. Low power and current consumption. 3. High sensitivity and efficiency. 4. Built-in synchronizer for clock recovery.	≈ 12 US Dollars

Table 73: PF Applications

Available Irrigation Systems Software	Description	Benefits	Price
Rubbicon's Farmconnect	Used with Rubicon Water's hardware to the enable the application of water to crops using high-flow, high-performance surface irrigation. Web application that can be used for crop monitoring and manage irrigation with wireless soil moisture probes.	1. Geographical display of the farm. Showing the status of all field devices. 2. Ease of scheduling, control and automating irrigation remotely. 3. Real-time device monitoring and control 4. Meaningful performance indicators of system.	Price depended on site-specific requirements
GreenIQ	Smartphone or tablet application enabling irrigation control.	1. User friendly with programs enabling easy irrigation control. 2. System factors in weather data. 3. Detects pipe leakages. 4. Uses WeatherIQ smart algorithms.	≈ 249 US Dollars for the entire system.
Spruce	The Spurce application is one of the most advanced sprinkler system available. Enables control, monitor or scheduling sprinklers from anywhere.	1. Easy water scheduling around local restrictions. 2. Combines both real-time moisture sensor data and weather predictions. 3. Real-time scheduling	≈ 180 dollars for the controller and application
Hydrawise	Irrigation application adjusts watering requirements based on highly accurate, internet-sourced local weather data.	1. Cloud software and Wi-Fi based irrigation controllers. 2. Sends out automatic job sheets to in-field staff and fixes issues before they are irreversible 3. Provides irrigation schedules and layouts. 4. Advanced reporting	Prince depended on enquiry and site-specific requirements
Rachio	Rachio acts as a personal watering assistant that is dedicated to utilizing every water droplet through irrigation scheduling, highly accurate water monitoring and control.	1. Highly accurate monitoring and control. 2. Wind and rain skip functions 3. Adjust watering requirements based on seasons.	≈ 200 US Dollars for the controller and application

Table 74: Cloud Platforms

Cloud Platform	Description	Benefits	Price
Raspberry Pi	Smart cloud storage (OwnCloud) for ARM devices.	1. No costs 2. Allows user to customize data, share and store incoming data. 3. It uses PHP scripts to access SQLite and MySQL databases installed on the server and runs on Windows and Linux systems. 4. Easy usage and implementation.	Free
Thingspeak	IoT analytics platform	1. Allows users to aggregate, visualize and analyse live data streams in the cloud. 2. Can write and execute MATLAB code to perform pre-processing, visualizations and analyses. 3. Allows users to build IoT systems without setting up servers or developing web software.	≈ 75 to 650 US Dollars
FIWARE	A curated framework of open source platform components that accelerate the development of smart solutions.	1. Open-sources software enabling connection to IoT with CIM and Big Data services in the Cloud. 2. Smart usage of data 3. Provides smart solutions and services and large ecosystem.	≈ price ranging depending on membership
Dynamo DB	Fast and flexible NoSQl database service for any scale	1. Delivers single-digit millisecond performance at any scale. 2. Built-in backup, security and restore for internet-scale applications. 3. Provides low-latency data access at any scale. 4. Encrypts user data and provide cross-region table backups	Pricing depending on application and size of database needed.
MongoDB	A general purpose, document-based, distributed database built for modern application developers and for cloud applications.	1. Stores data in JSON documents. 2. More expressive and powerful model. Allows for flexible and dynamic schemas. 3. Great for best-in-class automation and providing continuous availability, elastic scalability, and support. 4. Managed for operational efficiency.	Starting at ≈ USD 57/month
InfluxDB	Purpose-Built open source time series database that is designed to handle high write and query loads.	1. Enables users to develop IoT, analytics and monitoring software 2. Can handle large data volumes from multiple sources (sensors, applications, and infrastructure.) 3. High speeds for detection and resolution with powerful APIs and tools	Data In: 0.002USD/MB Query Count: 0.01USD per 100 query operations. Storage: 0.002USD/GB-hour Data Out: 0.09USD/GB
Firebase	A Google powered mobile platform that helps users to quickly develop high-quality applications and grow businesses.	1. Building fast apps without having to manage infrastructure. 2. The platform boasts with comprehensive services and functionalities. 3. Real-time databases and cloud storage.	Basic plan: Free
NETPIE	IoT cloud-based platform, providing services that enables users to connect IoT devices.	1. Seamless IoT connection of devices. 2. Moving complexity from user to the cloud. 3. Free open platform 4. Highly scalable and commercially ready.	Free
SAP	Integrated and extended cloud platform built to connect devices and create applications seamlessly.	1. Can provide cloud services for various business domains. 2. High speed and accessibility. 3. Orchestrates the entire business. 4. Enable smart decision making.	Pricing depending on scale.

Table 75: Database Platform

Databases	Description	Benefits	Price
MySQL	Database service is a full managed database service that deploys cloud-native applications that uses a highly popular open source database.	1. Instant provisioning connecting applications faster. 2. Protects user data and provides regulatory compliance. 3. Integrated with oracle technologies.	Custom quotations
SQLite	In-process library that implements server less, zero-configuration and transactional SQL database engine.	1. Provides software storage capabilities for embedded systems. 2. Public domain, free of use 3. Embedded into the end program. 4. Supports various programming languages.	Free
NoSQL	Database type that stores information in JSON documents used by relational databases.	1. Flexible and scalable 2. Capable of rapidly responding to data management demands of modern businesses. 3. Scoping for changing requirements.	Free
JSON	Standard format for collecting and strong semi-structured data sets from IoT devices.	1. Easy for machine usage and to generate programming actions. 2. Enables data sharing and easy usage. 3. Simple and compact data storage.	Price dependant on service database.

Table 76: Power Supply

Power Supply	Description	Benefits	Price
Batteries	A group of cells that convert chemical energy into electricity as a source of power.	1. Batteries are low cost devices. 2. Small size 3. Can be inserted on device. 4. Does not require external components and provides the Irrigation Systems with freedom to be placed wherever it is needed.	≈ 1 USD per battery
Wall adapters	Used in practice to supply electrical power to device through outlets that draws power from the external electricity grid	1. Relative long lifetime 2. Less maintained and replacement required 3. Constant power supply	≈ 5.4 USD per metre + plug adapter
USB port	Power supplied to an electrical device through a USB port and connected to an external device providing electrical power	1. Relative long lifetime 2. Less maintained and replacement required 3. Constant power supply	≈ 2.6 USD
Solar cell	Refers to an electrical device that coverts light energy into electricity.	1. Relative long lifetime 2. Does not require external components and provides the irrigation systems with freedom to be placed wherever it is needed. 3. Environmentally friendly	Price dependant on Watts required. A 0.5W cell ≈ 2.91 USD

The tables are a summary of what the available components can provide the irrigation system and compound when they are added to the system. The farmer therefore has the opportunity to choose what benefits he or she would like to have per component.

Appendix E: Competencies, Knowledge and Skills

The tables are a summary of what the available components can provide the irrigation system and compound when they are added to the system. The farmer therefore has the opportunity to choose what benefits he or she would like to have per component.

Appendix E involves the competencies, skills and knowledge that can be found in literature and relating those relevant to precision farming and irrigation systems to each component to the s. By relating them to each component, the small-scale farmer can use it as a reference in the framework. On what skills and knowledge would be required to implement, operate and maintain that component in their configuration of an irrigation system.

The Merriam-Webster online dictionary defines a competency as the *"possession of sufficient knowledge or skill"*. The knowledge and skills enable the user to perform a specific job. When determining which knowledge and skills are required by small-scale farmers, we first need to define the competence under which it can be categorised (Gronau, 2017).

Personal Competence: A person's disposition and willingness to reflect actions. This means self-estimation and to develop a productive attitude, unfold talent, values, motivation, and performance capability (Gronau, 2017).

Social Competence: The social and communicative abilities of an individual or a group of people, that refers to the creative design of social relationships and processes within a group or an organisation.
Financial Competence: Having the financial knowledge, skills and awareness to understand and effectively use finance-related information to make decisions, perform actions and manage resources (Gronau, 2017).

Technical Competence: Describes the persons applying the knowledge and skills required to perform effectively in a specific job within the business. It is the behaviours that are directly related to the nature of training and the technical proficiency required to perform effective control (Gronau, 2017).

Entrepreneurial Competence: The abilities and characteristics that enable a person to become competitive and successful in an unstable and unpredictable environment. The knowledge and skills enable a new venture creations and growth (Gianesini, 2018).

Organisational and Strategic Competence: The ability to perform goal-oriented structuring, planning, organisation of resources, and the manufacturing process as well as the purposeful usage of technical equipment (Gianesini, 2018).

Analytical Competence: Refers to the ability to analyse and collect information, problem-solve, and make decisions. Being able to apply logical reasoning, critical thinking, communication, research, data analysis and creativity to deconstructing information into smaller categories to draw conclusions (Gronau, 2017).

Methodological Competence: Comprises situation- and interdisciplinary flexible applicable and cognitive capabilities, which enables the acquisition of new knowledge and capabilities (Gronau, 2017).

Information and Communication Technology Competence: The confident and critical use of electronic media for communication, work, and leisure. The competencies are related to both logical and critical thinking, high-level information management skills, and to well-developed communication skills (UNESCO, 2008).

Professional Competence: The disposability of professional capabilities, skill, and knowledge, which are obtained and developed through action contexts (Gronau, 2017).

E.1. Competencies, Knowledge and Skills in Literature

The rapid implementation of Industry 4.0 technologies and concepts has resulted in the need for workforce up skilling. There are various competencies, skills, knowledge areas and skills needed to perform different tasks within I4.0 industries. Education and training have been emphasised in literature as a major factor in providing the new workforce with the skills and knowledge needed to perform the new tasks.

Due to the novelty of precision farming, there is no standardised job description for it. Roles and job titles vary from agricultural technician, agronomist, agronomy consultant, crop specialist or precision agricultural specialist. Roles vary depending on the type of farming and technology being utilized. There are universal skills across all job descriptions and farming landscapes. They are:

I. Good analytical skills
II. Goo team building skills
III. Good communication skills
IV. Training and entry to the profession
V. The ability to plan, organise and prioritise work
VI. Good computer skills
VII. The ability to document and record information.

There are various ways to gain the necessary skills to master precision farming. University degrees, apprenticeships, colleges and self-study are ways to acquire the skills (Shields, 2018).

Thematic analysis is a data analysis method that identifies patterns through various data qualitative data sets. The technique was applied to 15 data sources to determine the competencies, knowledge and skills required for irrigation systems and Industry 4.0. The knowledge and skill areas are categorised under each competency

Table 77 Provides the competency domain indicated from letters A – D, after which the relevant competency in the domain is indicated by the second letter. For example. Competency Domain: "A" refers to Personal Competence and Competency: "A.B" refers to Social Competence, which is under the Competency Domain "A". The Knowledge area is the next entry in the list which is indicated by the number following the second entry referring to the competence. For example, Competency Domain: "C" refers to Professional Competence, Competency: "C.A." refers to Technical Competence, which is under Competency Domain C and knowledge area: "C.A.1." that refers to technology knowledge, under Competence "C.A.". The next entry in the table lists the skills that can be found in the knowledge area.

Table 77: Competency Categorization

Competency Domain	Competency	Description	Knowledge	Skills
A. Personal competence	A.A. Personal competence	A person's disposition and willingness to reflect actions. This means self-estimation and to develop a productive attitude, unfold talent, values, motivation, and performance capability.	A.A.1. Self-knowledge	1. Time-and-self management 2. Teamwork 3. Adaptability 4. Trust in new technologies 5. Emotional Intelligence 6. Active Listening 7. Speaking 8. Active learning 9. Taking responsibility 10. Leadership skills 11. Problem sensitivity 12. Physical strength
			A.A.2. Cognitive	1. Mathematical reasoning 2. Decision making 3. Cognitive flexibility 4. Logical reasoning 5. Systems analysis 6. Critical thinking 7. Visualization 8. Judgement 9. Manual dexterity 10. Manual precision
	A.B. Social competence	The social and communicative abilities of an individual or a group of people, that refers to the creative design of social relationships and processes within a group or an organization.	A.B.1. People management	1. Social skills 2. Communication skills 3. Negotiation 4. Social perceptiveness 5. Ergonomics awareness 6. External relation development 7. Language skills
			A.**B**.2. Biodiversity and environmental factors	1. Environmental awareness 2. Guaranteeing the safety and security of food 3. Sustainable use of resources
			A.B.3. Legal affairs	1. Policy and regulations
	A.C. Entrepreneurial competence		A.C.1. Innovation	1. Continuous improvement mindset 2. Creativity 3. Research, analysis, and the use of innovative materials
			A.C.2. Business approach	1. Persuasion 2. Ability to adopt new models of work and organization
B. Organizational competence	B.A. Financial competence	Having the financial knowledge, skills and awareness to understand	B.A.1. Economics	1. Extract business value from social Media 2. Operational knowledge of basic business principles 3. agricultural economics 4. Trans disciplinarily 5. Cost benefit approaches

		and effectively use finance-related information to make decisions, perform actions and manage resources.	B.A.2. Accounting	1. Return on investment and profit 2. Management of personnel resources 3. Operational knowledge of basic accounting
	B.B. Business and strategic competence	The ability to perform goal-oriented structuring, planning, organisation of resources, and the manufacturing process as well as the purposeful usage of technical equipment.	B.B.1. Organizational and process understanding	1. Service orientation 2. Operation and control 3. Design thinking 4. Critical thinking 5. Exponential thinking 6. Process thinking 7. Planning and organizing work 8. Ownership of information 9. Quantifying benefits
			B.B.2. Administration and management	1. Cross border services 2. Project management 3. Coordinating with other stakeholders 4. Management ability 5. Developing management plans 6. Customer and personal service 7. Business change management
C. Professional competence	C.A. Technical competence	Describes the persons applying the knowledge and skills required to perform effectively in a specific job within the business. It is the behaviours that are directly related to the nature of training and the technical proficiency required to perform effective control	C.A.1. Technology knowledge	1. Ability to operate PF equipment 2. Ability to make effective recommendation 3. Ability to produce accurate digital maps of fields using spatial information within specialized software 4. Ability to install calibrate, troubleshoot, and repair PF hardware and equipment within PF activities 5. Design of smart products. (designing their own irrigation systems) 6. Breadboards
			C.A.2. Knowledge management of software and interfaces that support operations management	1. Following instructions and procedures 2. Operation monitoring 3. Repairing 4. Operational knowledge of computer spreadsheet applications to record and analyse agricultural field
	C.B. Analytical competence	Refers to the ability to analyse and collect information, problem-solve, and make decisions. Being able to apply logical reasoning, critical thinking, communication, research,	C.B.1. Statistical knowledge	1. Judgement and decision making 2. Systems analysis 3. Systems evaluation 4. Operations analysis 5. Optimizing 6. movement 7. Multiple parameters and data fusion 8. Working understanding of statistical standards to produce means and standard

		data analysis and creativity to deconstructing information into smaller categories to draw conclusions.	C.B.2. Analytical knowledge	1. Analytical skills 2. Linking data to decision making 3. Collecting data 4. Interpreting data 5. Data analysis ability and the use of the relevant tools 6. Evaluating programmes and measures 7. Information integration
	C.C. Methodological competence	Comprises situation- and interdisciplinary flexible applicable and cognitive capabilities, which enables the acquisition of new knowledge and capabilities	C.C.1. Linking variables to practice	1. Monitoring 2. Device compatibility 3. Semantics and codification 4. Diversity of farms 5. Evaluating programmes and measures 6. Input cost to Outputs 7. Research to on-farm practice 8. Scale and timing of data collection 9. Models of causality and interrelations
	C.D. Vocational competence	The disposability of professional capabilities, skill, and knowledge, which are obtained and developed through action contexts.	C.D.1. General knowledge of PF technologies	1. Mobile computing 2. GIS & spatial mapping 3. Proximal sensors 4. Remote sensing & UAVs 5. Variable rate technology 6. The ability to document and record information. 7. Troubleshooting 8. Development of roadmaps and strategic decision making on I4.0 technologies. 9. Implementation of I4.0 components. 10. Managing complexity 11. Digital literacy 12. Learning and understanding the concept of spatial data. 13. Interpreting, summarizing, and collecting information 14. Strategic sampling and on-farm trails 15. Learning to fully utilize sensor 16. Learning to use computer software. 17. Improved crop production decisions through assessing yield variation and narrowing potential cases. 18. design for assembly 19. design for manufacture, 20. ergonomic design 21. lean tools 22. low cost implementation 23. systems thinking 24. Recording farm machinery 25. Quantifying the physiological status of plants 26. Read displays 27. Site-specific sensors & control
			C.D.2. Knowledge required to Farm	1. Farm type and size 2. Location sampling 3. Biomass monitoring 4. Storage systems 5. Yields 6. Fertilizer 7. Communications and media 8. Mathematics 9. Reading comprehension 10. Training and entry to the profession 11. The ability to plan, organise and prioritize work 12. Causalities and determinants of yield. 13. Targeted treatments 14. Site specific crop management 15. Precision seeding & planting density 16. Water management
			C.D.3. Agronomy knowledge	1. Soil 2. Biology 3. Plant 4. Animal 5. Soil types 6. Vegetation indices 7. Biology 8. Basic natural science skills 9. Heterogeneous or homogeneous environment 10. Soil variability 11. Water and nutrients

D. Industry 4.0 competence	D.A. Information and communication technology competence	The confident and critical use of electronic media for communication, work, and leisure. The competencies are related to both logical and critical thinking, high-level information management skills, and to well-developed communication skills.	D.A.1. IT knowledge	1. Data and Information processing and analytics 2. HMI abilities 3. Computer programming/coding abilities 4. Good computer skills 5. Use of digital services 6. Management of human resources interconnected through digital services. 7. Real-time management leveraging monitoring and tracking technologies 8. Design of data and workflow models. 9. Infographics for intuitive and engaging interpretation of data analytics. 10. Use of graphic modelling tools to analyse and design systems. 11. Being able to store, analyse and collect data, whilst providing security 12. IT architectures 13. System development 14. Network technology 15. Modelling and programming 16. Statistics 17. In-Memory DHs 18. ICT literacy 19. Digital agenda 20. Data and information structures 21. Knowledge and management of simulation systems
			D.A.2. IT Security and data protection	1. Data security 2. Network security
			D.A.3. Operational knowledge of PF Software	1. Remote system monitoring and supervision of maintenance interventions 2. Sensors/Embedded systems 3. Predictive maintenance 4. User terminals for PF applications 5. Services & applications 6. Knowledge sharing 7. Weather forecasting 8. Yield monitoring & mapping
			D.A.4. Knowledge of big data, cloud computing and emerging technologies	1. Big data management use of cloud computing and data storage. 2. Selection and application of data management protocols. (cloud, Big data and IIoT) 3. Big data analysis and interpretation 4. Development of applications and tools for big data analytics (R, Python) 5. Machine learning 6. Robotics/AI 7. Mobile technologies 8. Selection, specification, and integration of embedded devices. (irrigation systems application of phones, tablets) 9. Virtual collaboration 10. Cloud computing 11. Interpreting from large data sets 12. Transforming data into maps

[(Gehrke et al., 2015), (Precisionag.com 2020), (Agrirs 2019), (Snyder 2002), (Mymajors 2020), (Erickson et al. 2018), (Du Plessis 2017), (Leinweber 2013), (Cullum 2019), (Bermúdez et al., 2017), (Prifti et al., 2017), (Agriteach, 2020), (Aulbur, 2018)]

E.2. Competencies, Knowledge and Skills Required for Irrigation Systems

A review of the competencies, knowledge and skills needed for Industry 4.0, and PF was conducted to identify which were applicable to the framework being used. The competencies, knowledge and skills are related to each component to serve as a comprehensive reference in the framework. The table reads from left to right. The small-scale farmer identifies the component they want to add to their system, and the next column is the subset of that component. For example, the component: "Sensor", has a subset: "Temperature Sensor". After identifying the subset, the competency letter from A to D refers to the competency's domain in Table 77, and the second letter refers to the relevant competence. The knowledge areas in the table refer to those also listed in Table 77. From this, the small-scale farmer can identify the relevant skills needed for each component. It must be noted that it cannot be expected of one to master each skill in the knowledge area, but it serves as a starting point to identify which skills of those listed are present, and to identify gaps where training and education can be provided.

The same logic is applied to the available irrigation systems. The components of the available irrigation systems are identified, and the knowledge and skills required for these components are identified as in the following table.

Table 78: Knowledge and Skills Requirements per Irrigation System Component

Irrigation System Component	Description	Competencies	Knowledge & Skills
Microcontrollers/ Microcomputers	There was no needed to differentiate between microcontroller technologies as largely require the same competencies, knowledge, and skills to use.	A	A.A.1 & A.A.2; A.C.1.
		B	B.A.1.
		C	C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1. & C.D.2. & C.D.3.
		D	D.A.1. & D.A.3. & D.A.4.
Sensors	Rain sensor	A	A.A.1 & A.A.2.; A.B.2.; A.C.1.
		B	B.B.1.
		C	C.A.1; C.C.1; C.D.1.; C.D.2 & C.D.3.
		D	D.A.3. & D.A.4
	Soil moisture sensor	A	A.A.1 & A.A.2.; A.B.2.; A.C.1.
		B	B.B.1.
		C	C.A.1; C.C.1; C.D.1.; C.D.2 & C.D.3.
		D	D.A.3. & D.A.4
	Luminosity sensor	A	A.A.1 & A.A.2.; A.B.2.; A.C.1.
		B	B.B.1.
		C	C.A.1; C.C.1; C.D.1.; C.D.2 & C.D.3.
		D	D.A.3. & D.A.4
	Temperature sensor	A	A.A.1 & A.A.2.; A.B.2.; A.C.1.
		B	B.B.1.
		C	C.A.1; C.C.1; C.D.1.; C.D.2 & C.D.3.
		D	D.A.3. & D.A.4
	Ultrasonic sensor	A	A.A.1 & A.A.2.; A.B.2.; A.C.1.
		B	B.B.1.
		C	C.A.1; C.C.1; C.D.1.; C.D.2 & C.D.3.
		D	D.A.3. & D.A.4
	Air sensor	A	A.A.1 & A.A.2.; A.B.2.; A.C.1.
		B	B.B.1.
		C	C.A.1; C.C.1; C.D.1.; C.D.2 & C.D.3.
		D	D.A.3. & D.A.4
Transmitters/Receivers	There was no needed to differentiate between transmitter/receivers as largely require the same competencies, knowledge, and skills to use.	A	A.A.2; A.B.3.; A.C.1
		B	B.A.1.; B.B.1. & B.B.2.
		C	C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1 & C.D.2.
		D	D.A.1 & D.A.2. & D.A.3. & D.A.4.

Display	There was no needed to differentiate between display modules as largely require the same competencies, knowledge, and skills to use.	A	A.A.2.
		B	B.B.1.
		C	C.A.1. & C.A.2.; C.C.1.; C.D.1 & C.D.2. & C.D.3.
		D	D.A.1. & D.A.2. & D.A.3.
Analog to digital converter	There was no needed to differentiate between microcontroller technologies as largely require the same competencies, knowledge, and skills to use.	A	A.A.2.; A.C.2
		B	B.B.1.
		C	C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1 & C.D.2. & C.D.3.
		D	D.A.1. & D.A.3. & D.A.4.
Communication technologies	GSM	A	A.A.1 & A.A.2; A.B.1; A.C.1. & A.C.2
		B	B.A.1.; B.B.1 & B.B.2.
		C	C.A.1. & C.A.2.; C.B.2.; C.C.1.; C.D.1. & C.D.2.
		D	D.A.1. & D.A.2. & D.A.3. & D.A.4.
	WIFI	A	A.A.1 & A.A.2; A.B.1; A.C.1. & A.C.2
		B	B.A.1.; B.B.1 & B.B.2.
		C	C.A.1. & C.A.2.; C.B.2.; C.C.1.; C.D.1. & C.D.2.
		D	D.A.1. & D.A.2. & D.A.3. & D.A.4.
	Ethernet	A	A.A.1 & A.A.2; A.B.1; A.C.1. & A.C.2
		B	B.A.1.; B.B.1 & B.B.2.
		C	C.A.1. & C.A.2.; C.B.2.; C.C.1.; C.D.1. & C.D.2.
		D	D.A.2. & D.A.3. & D.A.4.
	Zigbee	A	A.A.1 & A.A.2; A.B.1; A.C.1. & A.C.2
		B	B.A.1.; B.B.1 & B.B.2.
		C	C.A.1. & C.A.2.; C.B.2.; C.C.1.; C.D.1. & C.D.2.
		D	D.A.1. & D.A.2. & D.A.3. & D.A.4.
	Bluetooth	A	A.A.1 & A.A.2; A.B.1; A.C.1. & A.C.2
		B	B.A.1.; B.B.1 & B.B.2.
		C	C.A.1. & C.A.2.; C.B.2.; C.C.1.; C.D.1. & C.D.2.
		D	D.A.2. & D.A.3. & D.A.4.
	LoRa	A	A.A.1 & A.A.2; A.B.1; A.C.1. & A.C.2
		B	B.A.1.; B.B.1 & B.B.2.
		C	C.A.1. & C.A.2.; C.B.2.; C.C.1.; C.D.1. & C.D.2.
		D	D.A.1. & D.A.2. & D.A.3. & D.A.4.
	MQTT	A	A.A.1 & A.A.2; A.B.1; A.C.1. & A.C.2
		B	B.A.1.; B.B.1 & B.B.2.
		C	C.A.1. & C.A.2.; C.B.2.; C.C.1.; C.D.1. & C.D.2.
		D	D.A.1. & D.A.2. & D.A.3. & D.A.4.
	GPRS	A	A.A.1 & A.A.2; A.B.1; A.C.1. & A.C.2
		B	B.A.1.; B.B.1 & B.B.2.
		C	C.A.1. & C.A.2.; C.B.2.; C.C.1.; C.D.1. & C.D.2.
		D	D.A.1. & D.A.2. & D.A.3. & D.A.4.
	4G	A	A.A.1 & A.A.2; A.B.1; A.C.1. & A.C.2
		B	B.A.1.; B.B.1 & B.B.2.
		C	C.A.1. & C.A.2.; C.B.2.; C.C.1.; C.D.1. & C.D.2.
		D	D.A.1. & D.A.2. & D.A.3. & D.A.4.
	6LoWPAN	A	A.A.1 & A.A.2; A.B.1; A.C.1. & A.C.2
		B	B.A.1.; B.B.1 & B.B.2.
		C	C.A.1. & C.A.2.; C.B.2.; C.C.1.; C.D.1. & C.D.2.
		D	D.A.1. & D.A.2. & D.A.3. & D.A.4.
	IEEE 802	A	A.A.1 & A.A.2; A.B.1; A.C.1. & A.C.2
		B	B.A.1.; B.B.1 & B.B.2.
		C	C.A.1. & C.A.2.; C.B.2.; C.C.1.; C.D.1. & C.D.2.
		D	D.A.1. & D.A.2. & D.A.4.

Communication modules	There was no needed to differentiate between communication modules as largely require the same competencies, knowledge, and skills to use.	A	A.A.1 & A.A.2; A.B.1; A.C.1. & A.C.2
		B	B.A.1.; B.B.1 & B.B.2.
		C	C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1. & C.D.2.
		D	D.A.1. & D.A.2. & D.A.3. & D.A.4.
Relaymodules	There was no needed to differentiate between relay modules as largely require the same competencies, knowledge, and skills to use.	A	A.A.2.; A.C.2
		B	B.B.1.
		C	C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1 & C.D.2. & C.D.3.
		D	D.A.1. & D.A.3. & D.A.4.
Processors	There was no needed to differentiate between processor technologies as largely require the same competencies, knowledge, and skills to use.	A	A.A.1 & A.A.2; A.C.1.
		B	B.A.1.
		C	C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1. & C.D.2. & C.D.3.
		D	D.A.1. & D.A.3. & D.A.4.
Application (Smartphone/Computer)	There was no needed to differentiate between applications as largely require the same competencies, knowledge and skills to use.	A	A.A.1 & A.A.2; A.C.1. & A.C.2. & A.C.3.
		B	B.B.1 & B.B.2.; B.A.1. & B.A.2.
		C	C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1. & C.D.2. & C.D.3.
		D	D.A.1. & D.A.3. & D.A.4.
Cloud platform	Raspberry Pi	A	A.A.1 & A.A.2; A.C.2. & A.C.3.
		B	B.B.1 & B.B.2.
		C	C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1. & C.D.2. & C.D.3.
		D	D.A.1. & D.A.2. & D.A.3. & D.A.4.
	Thingspeak	A	A.A.1 & A.A.2; A.C.2. & A.C.3.
		B	B.B.1 & B.B.2.
		C	C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1. & C.D.2. & C.D.3.
		D	D.A.1. & D.A.2. & D.A.3. & D.A.4.
	FIWARE	A	A.A.1 & A.A.2; A.C.2. & A.C.3.
		B	B.B.1 & B.B.2.
		C	C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1. & C.D.2. & C.D.3.
		D	D.A.1. & D.A.3. & D.A.4.
	Dynamo DB	A	A.A.1 & A.A.2; A.C.2. & A.C.3.
		B	B.B.1 & B.B.2.
		C	C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1. & C.D.2. & C.D.3.
		D	D.A.1. & D.A.2. & D.A.3. & D.A.4.
	MongoDB	A	A.A.1 & A.A.2; A.C.2. & A.C.3.
		B	B.B.1 & B.B.2.
		C	C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1. & C.D.2. & C.D.3.
		D	D.A.1. & D.A.2. & D.A.3. & D.A.4.
	InfluxDB	A	A.A.1 & A.A.2; A.C.2. & A.C.3.
		B	B.B.1 & B.B.2.
		C	C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1. & C.D.2. & C.D.3.
		D	D.A.1. & D.A.2. & D.A.3. & D.A.4.
	Firebase	A	A.A.1 & A.A.2; A.C.2. & A.C.3.
		B	B.B.1 & B.B.2.
		C	C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1. & C.D.2. & C.D.3.
		D	D.A.1. & D.A.3. & D.A.4.
	NETPIE	A	A.A.1 & A.A.2; A.C.2. & A.C.3.
		B	B.B.1 & B.B.2.
		C	C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1. & C.D.2. & C.D.3.
		D	D.A.1. & D.A.2. & D.A.3. & D.A.4.

	SAP	A	A.A.1 & A.A.2; A.C.2. & A.C.3.
		B	B.B.1 & B.B.2.
		C	C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1. & C.D.2. & C.D.3.
		D	D.A.1. & D.A.3. & D.A.4.
Database	MySQL	A	A.A.1 & A.A.2; A.B.1 & A.C.1. & A.C.2. & A.C.3.
		B	B.B.1 & B.B.2.; B.A.1. & B.A.2.
		C	C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1. & C.D.2. & C.D.3.
		D	D.A.1. & D.A.3. & D.A.4.
	SQLite	A	A.A.1 & A.A.2; A.B.1 & A.C.1. & A.C.2. & A.C.3.
		B	B.B.1 & B.B.2.; B.A.1. & B.A.2.
		C	C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1. & C.D.2. & C.D.3.
		D	D.A.1. & D.A.3. & D.A.4.
	NoSQL	A	A.A.1 & A.A.2; A.B.1 & A.C.1. & A.C.2. & A.C.3.
		B	B.B.1 & B.B.2.; B.A.1. & B.A.2.
		C	C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1. & C.D.2. & C.D.3.
		D	D.A.1. & D.A.3. & D.A.4.
	JSON	A	A.A.1 & A.A.2; A.B.1 & A.C.1. & A.C.2. & A.C.3.
		B	B.B.1 & B.B.2.; B.A.1. & B.A.2.
		C	C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1. & C.D.2. & C.D.3.
		D	D.A.1. & D.A.3. & D.A.4.
Power supply	Batteries	A	A.A.2.; A.C.2
			B.B.1.
			C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1 & C.D.2. & C.D.3.
			D.A.1.
	Wall adapters	B	A.A.2.; A.C.2
			B.B.1.
			C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1 & C.D.2. & C.D.3.
			D.A.1.
	USB port	C	A.A.2.; A.C.2
			B.B.1.
			C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1 & C.D.2. & C.D.3.
			D.A.1.
	Solar cell	D	A.A.2.; A.C.2
			B.B.1.
			C.A.1. & C.A.2.; C.B.1. & C.B.2.; C.C.1.; C.D.1 & C.D.2. & C.D.3.
			D.A.1.

Agricultural degrees allow individuals to acquire skills and knowledge to perform farming operation better. There are various agricultural degrees, diplomas, certificates and qualifications available around the world to supplement a farmer in farming operations. To this study, South African institutions are used to determine which competencies and skills are developed at certain levels of education. Competencies, knowledge and skills acquired through experience and information learned outside education is not considered when determining which level a competency, knowledge and skill is acquired. It is determined with the following logic:

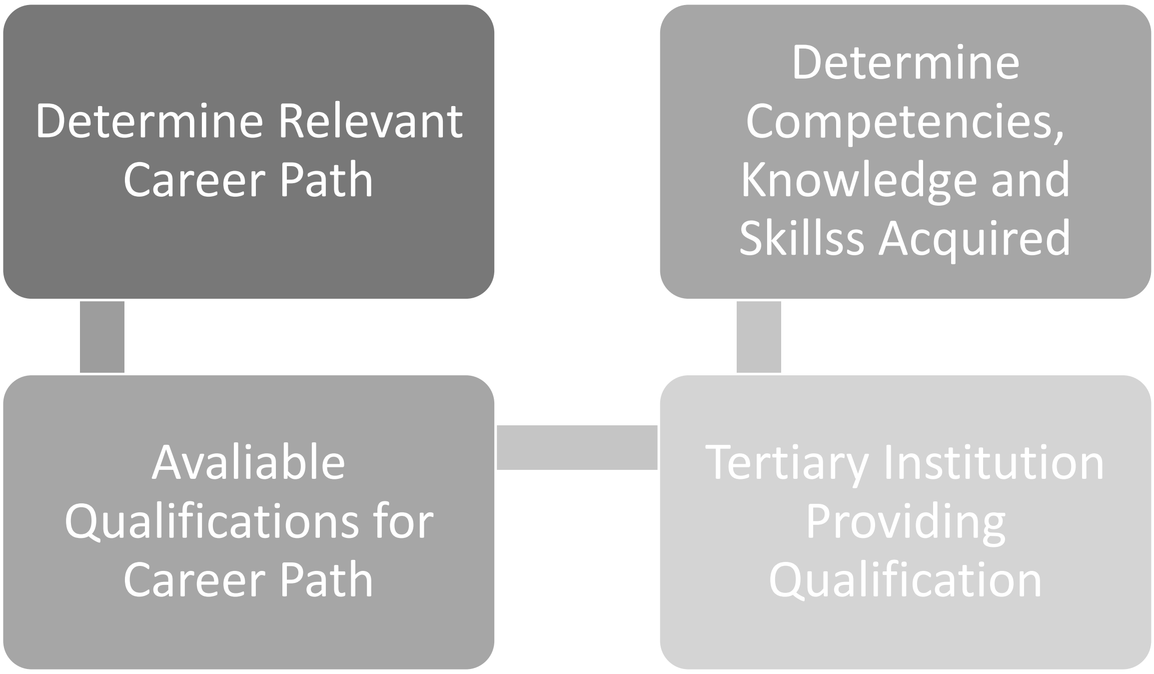


Figure 47: Tertiary Institution Logic

Using the logic, the following table was constructed.

Table 79: Available Qualifications in South Africa

Agricultural Career Path	Qualification Level	Available Qualifications	Tertiary Education Institution
Agricultural economist	1 Year community college		North-West University; University of Fort Hare; University of KwaZulu-Natal; University of Limpopo; University of Pretoria; University of Stellenbosch; University of the Free State; University of Venda
	2 Year community college		
	Bachelor's degree	B.Sc. Agricultural Economics; B.Com. Agricultural Economics	
	Master's degree		
Agricultural engineer	1 Year community college		Cape Peninsula University of Technology; Central University of Technology; Nelson Mandela University; Unisa; University of Cape Town; University of Mpumalanga - University of the Free State; University of Venda
	2 Year community college	National diploma	
	Bachelor's degree	B.Eng.	
	Master's degree		
Agricultural technical services	1 Year community college		Cape Peninsula University of Technology; Cedara College of Agriculture; Coastal KZN TVET College; Elangeni TVET College; Elsenburg Agricultural Training Institute; Fort Cox Agriculture and Forestry Training Institute; Madzivhandila College of Agriculture; Mangosuthu University of Technology; Nelson Mandela University; North-West University; -Owen Sitole College of Agriculture; Potchefstroom College of Agriculture; Taletso TVET College; Umfolozi TVET College; - Unisa; -University of Fort Hare; University of Limpopo; University of Pretoria; University of Stellenbosch; University of the Free State; University of Venda; University of Mpumalanga; Vuselela TVET College;
	2 Year community college	Certificate in agriculture	
	Bachelor's degree	B.Sc. Agric	

Agronomy	1 Year community college		Fort Hare University; Unisa; University of the Free State; University of KwaZulu-Natal; University of Mpumalanga; University of Pretoria; University of Stellenbosch; University of Zululand
	2 Year community college	Diploma with agronomy	
	Bachelor's degree	B.Sc. Agronomy	
	Master's degree		
Farm manager	1 Year Community College		Boland College; Cape Peninsula University of Technology; Cedara College of Agriculture; Central University of Technology; Coastal KZN TVET College; Elangeni TVET College; Elsenburg Agricultural Training Institute; Fort Cox Agriculture and Forestry Training Institute; Grootfontein Agricultural Development Institute; Madzivhandila College of Agriculture Mangosuthu University of Technology; Nelson Mandela University; Owen Sitole College of Agriculture; Potchefstroom College of Agriculture; Taletso TVET College; Umfolozi TVET College; Unisa; University of Fort Hare; University of Mpumalanga; Vuselela TVET College
	2 Year community college	Diploma certificate	
	Bachelor's degree	Relevant bachelor's degree	
	Master's degree		
Farmer	1 Year community college	Diploma in field of choice	Boland College; Cape Peninsula University of Technology; Cedara College of Agriculture; Central University of Technology; Coastal KZN TVET College; Elangeni TVET College; Elsenburg Agricultural Training Institute; Fort Cox Agriculture and Forestry Training Institute; Grootfontein Agricultural Development Institute; Madzivhandila College of Agriculture; Mangosuthu University of Technology; Nelson Mandela University; Owen Sitole College of Agriculture; Potchefstroom College of Agriculture; Taletso TVET College; Umfolozi TVET College; Unisa; University of Fort Hare; University of Mpumalanga; Vuselela TVET College
	2 Year community college	Diploma in field of choice	
	Bachelor's degree	Degree in field of choice	
	Master's degree	Degree in field of choice	
Precision farming technician	1 Year community college		Cape Peninsula University of Technology; Mangosuthu University of Technology; North-West University; Unisa; University of Fort Hare; University of Limpopo; University of Mpumalanga; University of Pretoria; University of Stellenbosch; University of the Free State; University of Venda
	2 Year community college	Diploma in field of choice	
	Bachelor's degree	B.Sc. Agriculture; B.Sc. Agronomy; B.Sc. Soil Science; B.Sc. Agricultural Economics	
	Master's degree	Master's degree dependent on bachelor's degree.	

Referring to the education levels from Clay et al., 2018, the tertiary institutions and qualifications are used to determine which competencies, knowledge and skills are acquired from Table 80.

Table 80: Competencies, Skills and Knowledge Acquired at Education Levels

Education Level	Competency Acquired	Knowledge and Skills Acquired
No previous education	A.A.; A.B.; A.C.	A.A.1.; A.A.2; A.B.1; A.B.2.; A.C.1.; A.C.2.
	B.B.	B.B.1; B.B.2;
	C.B.2; C.C.	C.B.2.; C.C.1.
High school diploma	A.A.; A.B.; A.C.	A.A.1.; A.A.2; A.B.1; A.B.2.; A.B.3.; A.C.1.; A.C.2.

	B.A.; B.B.	B.A.1.; B.A.2; B.B.1; B.B.2;
	C.A.; C.B.; C.C.	C.A.2.; C.B.2.
	D.A.	D.A.1.; D.A.2.
1 Year community college diploma	A.A.; A.B.; A.C.	A.A.1.; A.A.2; A.B.1; A.B.2.; A.B.3.; A.C.1.; A.C.2.
	B.A.; B.B.	B.A.1.; B.A.2; B.B.1; B.B.2;
	C.A.; C.B.; C.C.; C.D.	C.A.1.; C.A.2.; C.B.2.; C.C.1.; C.D.2.; C.D.3.
	D.A.	D.A.1.; D.A.2.
2 Year community college	A.A.; A.B.; A.C.	A.A.1.; A.A.2; A.B.1; A.B.2.; A.B.3.; A.C.1.; A.C.2.
	B.A.; B.B.	B.A.1.; B.A.2; B.B.1; B.B.2;
	C.A.; C.B.; C.C.; C.D.;	C.A.1.; C.A.2.; C.B.2.; C.B.1; C.C.1.; C.D.1.; C.D.2.; C.D.3.
	D.A.	D.A.1.; D.A.2.; D.A.3.
Bachelor's degree	A.A.; A.B.; A.C.	A.A.1.; A.A.2; A.B.1; A.B.2.; A.B.3.; A.C.1.; A.C.2.
	B.A.; B.B.	B.A.1.; B.A.2; B.B.1; B.B.2;
	C.A.; C.B.; C.C; C.D;	C.A.1.; C.A.2.; C.B.2.; C.B.1; C.C.1.; C.D.1.; C.D.2.; C.D.3.
	D.A.	D.A.1.; D.A.2.; D.A.3.; D.A.4.;
Master's degree	A.A.; A.B.; A.C.	A.A.1.; A.A.2; A.B.1; A.B.2.; A.B.3.; A.C.1.; A.C.2.
	B.A.; B.B.	B.A.1.; B.A.2; B.B.1; B.B.2;
	C.A.; C.B.; C.C; C.D;	C.A.1.; C.A.2.; C.B.2.; C.B.1; C.C.1.; C.D.1.; C.D.2.; C.D.3.
	D.A.	D.A.1.; D.A.2.; D.A.3.; D.A.4.;

Appendix F: Financial Capabilities

The barrier to applying precision farming technology including an irrigation system, the most popular reason, was that small-scale farmers deem it too expensive. This table serves as a reference for small-scale farmers to compute the cost of developing their own system. The colour coding follows the same colour coding as in Figure 35, where blue indicates an "I4.0 required" component and therefore has to be included in the system, and yellow refers to a "not I4.0 required" and can be added to improve, enhance, and build the system.

Table 81: Financial Requirements for Irrigation System Components

Microcontrollers		Sensors		Display		ADC		Communication Technologies		Relay Modules		Application		Cloud Platform		Database		Power Supply	
ESP8266 Microcontroller Board	3 USD	**Rain Sensor**		Arducam 1602	6 USD	MCP3008 / MCP3004	2 USD	Ethernet	0.19 USD	HiLetgo 2pcs 5V	6 USD	Spruce	≈ 180 dollars for the controller and application	Raspberry Pi	Free	SQLite	Free	Batteries	1 USD
		FC37	< 2 USD																
		YL83	< 2 USD																
WEMOS MINI D1	8 USD	Rain Sensor Module - Microcircuits	4 USD	Geekcreit 3.2 Inch MEGA 2560 Display Module	9 USD	MCP4725	5 USD	Bluetooth	9 USD	KNACRO 1-Channel	8 USD	Rachio	≈ 200 US Dollars for the controller and application	NETPIE	Free	NoSQL	Free	USB Port	2.6 USD
		HALJIA	6 USD																
		Leaf Wetness 12V DC Rain Sensor Module	10 USD																
Raspberry Pi Zero W	10 USD	AZDelivery 5 x Rain Sensor Module	11 USD (5pcs)	Geekcreit® UNO R3	10 USD	LTC2499	6 USD	GSM	Price dependant on manufacturer and module.	JBTek	8 USD	GreenIQ	≈ 249 US Dollars for the entire system.	Firebase	Free	JSON	Dependant on service database	Solar Cell	2.91 USD
		SEN-08942	≈ 75 USD																
		Soil Moisture Sensor																	
Arduino Pro Mini 328	10 USD	FC-28	3 USD	BMT 2.8IN TFT LCD TOUCH	15 USD	ADS1231ID	6 USD	GPRS	Price dependant on manufacturer and module.	KNACRO 2-Channel 5V Relay Module	9 USD	Hydrawise	Price depended on enquiry and site-specific	InfluxDB	Data In: 0.002USD /MB Query Count: 0.01USD per 100 query operations.	MySQL	Custom quotations	Wall Adapter	5.4 USD
		HL-69	3 USD																

		LM393 Pi Sensor	4 USD	SHIELD					3 US Dollars				requirements		Storage: 0.002 USD/GB-hour Data Out: 0.09USD/GB		
Node MCU DevKit	10 USD	SEN-13637 200SS VH400	7 USD 38 USD 45 USD	BMT 2.8IN TFT LCD TOUCH SHIELD	38 USD	ADS1115	15 USD	Zigbee	Modules start at ≈ 26 US Dollars	SunFounder 5V 8 Channel Relay	11 USD	Rubbicon's Farmconnect	Price depended on site-specific requirements	Mongo DB	Starting at ≈ USD 57/month		
NUCLEO STM32	12 USD	**Ultrasonic Sensor**						LoRa	Price dependant on part needed in microcontroller.					Things peak	≈ 75 to 650 US Dollars		
		HC-SR04	4 USD														
		RS Pro	12 USD														
Launchpad MSP430	13 USD	RS Pro	12 USD					4G	Data Prices are dependent on mobile provider					Dynamo DB	Pricing depending on application and size of database needed.		
		WLC Ultrasonic Sensors	Receive quote depending on application														
		Temperature Sensor															
ESP32 Microcontroller Board	15 USD	LMT89	1 USD					6LoWPAN	Built into development boards.					FIWARE	≈ price ranging depending on membership		
		LM335Z	1 USD														
		TMP-36	1.5 USD														
Quark D2000	15 USD	LM35	2 USD					MQTT	MQTT Buddy (enables home automation solutions for IoT devices, managing sensors and creating customized scenarios.					SAP	Pricing depending on scale.		
		DS18B20	2 USD														
		PT TEMPERATURE SENSOR	2 USD														

crowduino	17 USD	DHT11	3 USD		WIFI	Price dependant on manufacturer and module.	
		DHT-22	9 USD				
		AM2315	30 USD				
Arduino Uno R3 Microcontroller Board	19 USD	**Light Sensor**			IEEE 802	None	
		Grove – Light Sensor v1.2	2.9 USD				
		Grove – Light Sensor (P) v1.1	2.9 USD				
	27 USD	BH1750	5 USD				
		TSL2561	6 USD				
		Grove - Heelight Sensor	7.9 USD				
Teensy 4.0	29 USD	Grove – Digital Light Sensor	9.9 USD				
		Grove – Sunlight Sensor	9.9 USD				
		SN-500	Price available on contact				
BeagleBone Black	45 USD	**Humidity Sensors**					
		DHT11	3 USD				
		DHT22	9 USD				
Raspberry Pi	40 – 60 USD	HH10D	12 USD				
		AM2315	30 USD				
		SH10	34 USD				
Intel Gallieo Gen-2	75 USD	**Air Sensors**					
		MQ2	4 USD				
		MQ135	6 USD				
MBED LPC1768	140 USD	MQ9	6 USD				
		MQ131	12 USD				
		CDM461A	73 USD				

Waspmote IPex16	153 USD Available on contact				