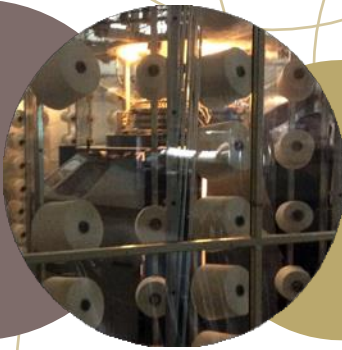


Project summary report: Agri-intelligence in Cotton Production Systems (Stage 1: 2017-2018)



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February 2019

About us

The Institute for Future Environments (IFE) is a multidisciplinary research institute at Queensland University of Technology (QUT) in Brisbane, Australia. Hundreds of QUT researchers and students from across the fields of science, engineering, law, business, education and the creative industries collaborate at the IFE on large-scale research and development projects. Our mission is to generate knowledge, technology and practices that make our world more sustainable, secure and resilient.

Milestone 2.3 report for CRDC Project QUT1701

Agri-intelligence in Cotton Production Systems – Stage 1

Project summary report:

Agri-intelligence in Cotton Production
Systems (Stage 1: 2017-2018)

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Executive Summary

This final summary report presents outcomes from the Cotton Research and Development Corporation (CRDC) funded project, *Agri-Intelligence in Cotton Production Systems – Stage 1 (2017-18)*. Agri-intelligence targets the increasing complexity of farming enterprise operations arising from increasing availability of data, connectedness of decisions, and seeking to optimise operations more tightly, and at finer scales, than ever before.

The project identified current situational awareness about the diversity and complexity of the decision space in cotton production as well as data and information use and utilisation gaps within the industry. In tandem, the project examined the information flows from the cotton value chain, including a segment-by-segment outline of key issues, data creation and use, and consequences of on-farm decision-making.

The chief outcome of the project is a method for identifying and evaluating digital technology investment opportunities in the Australian cotton industry. The method is informed by the findings from the analysis of on-farm decision-making and for the potential for new information flows from the value chain. This method can inform the case for different agri-intelligence solutions in cotton production and also assist CRDC with decisions about their research investment portfolio to transition the sector towards its goals as set in CRDC's Futures Program, which seeks to transform the industry to ensure it is more profitable, sustainable and competitive in the next 20 years.

The report closes with a strategy for segmenting on-farm decision-making for future research. This is a detailed method for identifying and evaluating investment opportunities in new digital technologies that can inform recommendations for continued investment in related areas of research.

Table of contents

1.	Introduction	4
1.1.	Background: Australian cotton industry	4
1.2.	Data, information, and decision-making.....	5
1.3.	Project deliverables.....	6
1.4.	Accessing previous project milestone reports	6
2.	Project method	7
2.1.	Mapping on-farm decision-making and data and information use	7
2.2.	Exploring dominant themes, relationships, and data and information utilisation in the global value chain	8
3.	Findings: Stage One.....	10
3.1.	On-farm decision-making.....	10
3.2.	Information and data use.....	14
3.3.	Value chain findings	18
4.	Findings: Stage Two	21
4.1.	Mapping the decision space.....	21
5.	Key project output: A method for assessing investment opportunities in on-farm digital agricultural solutions	24
5.1.	Step 1: Articulating decision problems from the perspective of on-farm end users	26
5.2.	Step 2: Considering issues, uncertainties and consequences of on-farm decisions	26
5.3.	Step 3: Specify solution requirements	26
5.4.	Step 4: Quantify the market opportunity for a potential solution	27
5.5.	Step 5: Identify the feasibility of a potential solution.....	27
5.6.	Step 6: Calculate scored attributes	28
6.	Conclusions and recommendations.....	29
6.1.	Recommendation 1	29
6.2.	Recommendation 2	29
7.	References	30

1. Introduction

Over the next ten years we expect agriculture to transition even further into the digital age, realising the tremendous potential to understand better the opportunities and risks arising from integrating data across the value chain with sustainable management operations and on-farm data.

This project, *Agri-Intelligence in Cotton Production Systems – Stage 1 (2017-18)*, was designed to help the Australian cotton industry take the first steps towards the integration of deep agricultural knowledge, knowledge across the value chain and systems science with powerful digital technologies to help farming enterprises make the best use of agronomic, environmental and economic data to enhance decision-making and management practices leading to more efficient, profitable and sustainable operations.

Agri-intelligence is created by harnessing the collective intelligence and information from cotton stakeholders throughout the industry and across the value chain.

To this end, the project has collected data from cotton growers across Australian cotton growing regions about how they make decisions on farm across the cotton production phases: planning, in-season, harvest and post-harvest and business. Our study examined the following three areas:

1. Decisions: We asked growers to discuss the nuance and complexity of each decision, including whether they perceive the decision difficult and/or impactful, and what uncertainties make decisions difficult such as changing market demand, weather, labour availability and a varying social license to operate. We developed an interactive decision map that highlights the interconnection between decisions, their impact and their difficulty.

2. Data and information use: We discussed where growers get their information to reduce uncertainty; whether information was sufficient; and what changes might need to be made to improve the quality and quantity of information for growers to make decision-making less difficult and take less time.

3. Value chain perspectives: In parallel to speaking with growers, the team interviewed cotton merchants, ginners, spinners, textile and apparel manufacturers, and retailers to examine value chain expectations and issues that could be better communicated to growers.

This report summarises our findings across these three areas and presents a method for assessing investment decisions.

Bringing together agri-intelligence across the cotton production system and value chain could enable the CRDC to invest in digital solutions that get to the core of what makes on-farm decisions difficult and ensures solutions are designed with the end-user in mind. Intelligent solutions harness precise information flows to reduce uncertainties to achieve significant return on investment (ROI).

1.1. Background: Australian cotton industry

Cotton is a major agricultural industry in Australia that is worth approximately \$2 billion annually (Cotton Australia 2016b). Australian cotton is grown in over 1000 farms operating in NSW and Queensland (Cotton Australia 2016a). In 2015-16 Australia produced an estimated 2.4 million bales over 270,000 hectares of land (Cotton Australia 2016a, 4) and 3.8 million bales in 2017 (ACSA 2018). Australia exports over 95% of raw cotton produced and is the third largest exporter behind the US and India, and accounts for approximately 3% of the world's cotton (ICAC 2017; Cotton Australia 2016a, 2017). Approximately 80% of the world's cotton is produced by China, India, United States, Pakistan, Brazil and Uzbekistan (SEEP and FAO 2015, 5). With close proximity to Asian textile markets, the Australian cotton industry has a competitive advantage over other cotton growths as cotton can be shipped in the opposite season to northern hemisphere. Australian cotton is valued by customers for its contamination-free status and other premium qualities, particularly staple length. Due to innovations in varieties, Australia produces a long

staple (LS) variety of Upland cotton, meaning that in cotton quality, Australian cotton sits at the top end of Upland growths, below the Extra Long Staple varieties (ELS, Pima/Egyptian cotton).

1.2. Data, information, and decision-making

A great deal of activity in farming relates to decision-making. Farming decisions can be disaggregated, for example, according to stages such as a planning, in-crop management, harvest and post-harvest, and business. The key difficulty of decision-making lies in the uncertainty associated with attributes that together with the action decided upon by the decision maker determine the outcomes, and thus the consequences of a decision. If a decision maker had no uncertainty, then the decision reverts to a choice - choose what is best in some sense and this choice alone would guarantee the outcome. This section sets the language that will be used throughout the report and the rest of the project.

Every decision situation is different. A decision situation can be described in terms of three components: the decision maker, the context, and the decision problem – this is illustrated in figure 1. The decision problem requires determining a collection of feasible actions that the decision maker can take, the attributes outside the control of the decision maker that have a bearing on the outcome, and the consequences associated with the outcomes (monetary, environmental, social, health, etcetera). A decision maker brings their knowledge, experience and cognitive capacity for analysis. Finally, the decision context characterises the conditions under which the decision maker is making the decision. In the case of farming, the same decision problem may be faced each season by the same decision maker (grower or consultant), but under different contexts. Hence, each decision situation is different.

Data can be critical for decision-making since when combined with knowledge, it can be used to extract information to reduce uncertainty and therefore ease the difficulty associated with decision-making. In the following, we define some key concepts that will be used within the context of this report and the project.

Decision maker: A person in charge of deciding upon a course of action to be taken and being responsible for the potential consequences. The decision maker, in some cases, may also be responsible for explaining the rationale being the action choice to an external regulator, a stakeholder, a line manager, or the executive team.

Decision analyst: A person who assists the decision maker in understanding the key characteristics of the decision problem, the decision context, and guides the decision maker through the decision process. Decision analysts are often domain experts who may, in some cases, also suggest courses of action to be taken by the decision maker. For some decisions in crop production, this role is often played by a consultant agronomist.

Decision problem: A description of the decision in terms of a collection of feasible actions, uncertain attributes that affect the outcomes, and the consequences of the potential outcomes. Decision problems can be of different type depending on whether there is a single decision maker, or multiple decision makers; whether a decision is considered at a single point in time or as sequence of decisions to be made over a time period, whether the multiple decision makers are in conflict or acting as a group. Each type of decision problem has a precise definition, but this is outside the context of this report. For further details see Peterson (2009).

Data: describes the aggregate of all data available. These data can be either generated by sensors and that gathered from other sources such as news, internet, consultants, government, social, visual, etcetera.

Information: describes data organised and summarised such that it is useful within a context of a decision or management problem. Information can be either a subset of the gathered data or new data generated through the use of data analytics.

Knowledge: describes aggregate of experiences that are relevant to decision problem and the underlying process that generates the data the context within which ones seeks to analyse these data. Part of this knowledge often ends up embodied in a mathematical model used in data analytics;

Data analytics: A process that combines data and knowledge to produce information within a particular context of a decision or management problem. Hence, we usually say that analytics is the process of extracting information from data.

Uncertainty: inability to state the truth or falsity of an event or statement about an event. Uncertainty is often reduced by information. Therefore, the value of a piece of information may be characterised by how much it can reduce uncertainty. These concepts can be made quantitative by the use of probability, but this is outside the scope of this report.

1.3. Project deliverables

This project has captured the state of on-farm decision-making, information use, and value chain consequences for the Australian cotton industry via:

1. Cotton Compendium describing grower perceptions of the impact and difficulty of decision-making on-farm (see Appendices 2-5 in Milestone Report 1.3;
2. Interactive decision map, showing interconnected production decisions;
3. Report on grower data and information use; and
4. Value chain state of knowledge report, including identified value chain priorities and consequences of grower decision-making.

1.4. Accessing previous project milestone reports

This report refers to previous milestone reports published during the project. For further details, you may request a copy of these reports by contacting research@crdc.com.au. The full titles of each milestone report are included in the reference list for this report.

2. Project method

The first stage of our project involved two concurrent programs of interviews with Australian cotton producers and representatives from segments of the global cotton value chain. Interviews with Australian cotton growers focused on decision-making and data and information use, while value chain interviews were focused on exploring dominant themes, relationships, and data and information utilisation across key segments of the value chain.

2.1. Mapping on-farm decision-making and data and information use

We developed a practical, mixed methods approach of workshops and contextual interviews in order to discover:

- key decisions and broad decision areas faced by cotton growers throughout the entire cotton production cycle;
- the impact of on-farm decisions on the cotton farming enterprise and the difficult experienced by growers in making those decisions;
- frequencies of use and access of identified cotton production data and information sources;
- attitudes, behaviours and experiences of growers exhibited in the access and management of data and information assets.

In order to determine broad trends in relation to key on-farm decisions and the role played by data and information in supporting those decisions, datasets were collected through card-sorting activities during semi-structured on-farm interviews with growers.

We identified and conducted interviews with participants from 29 distinct farming enterprises between 23 May 2017 and 28 September 2017. These were predominantly what may be referred to as family growers, with 5 enterprises identified as having a typical corporate structure, i.e. owned by a corporation comprised of a number of investors. All participants were either owners or farm managers. We visited the following cotton-producing regions to conduct interviews:

- Emerald, Qld
- St George, Qld
- Dalby, Qld
- Moree, NSW
- Upper Namoi (centred on the NSW towns of Gunnedah and Boggabri)
- Lower Namoi (centred on the NSW towns of Narrabri)
- Griffith, NSW.

2.1.1. Data collection: Industry workshops

Two workshops were conducted to elicit a representative set of critical decisions faced by growers during the entire cotton production cycle. The first workshop was held in St George in April 2017 with a follow-up workshop held in Moree in June 2017. The workshops allowed us to discover and validate critical decisions and decision areas faced by growers for each broad phase of cotton production as defined by CottonInfo's Australian Cotton Production Manual (2016). We also used the workshops to develop a broad sample of representative information sources used by growers to support their decision-making. The decisions discussed during our first workshop were refined in the second workshop, and further refined to a set of 61 decisions and decision areas focused on by growers during the cotton production cycle. Data and information sources discussed with growers were refined to a set of 50 representative sources. These

decisions and data/information sources were used in activities conducted during semi-structured interviews with growers and acted as material prompts for areas of the discussion.

2.1.2. Data collection: On-farm interviews

In-depth interviews with growers formed the basis of the main data collection activities required to complete Milestone 1.3. These interviews were typically conducted on-farm in the participant's home or office and lasted between 1-3 hours, usually within a single sitting. A total of almost 46 hours of audio was recorded (the equivalent to watching 27 movies).

The interview structure included two parts:

- an information-ranking exercise (to determine the frequency with which a set of information sources was used, and attitudes towards each information source and information more generally)
- a decision-ranking exercise (to determine the impact of each decision on the grower's farming enterprise and the difficulty experienced by the grower when making each decision).

A complete overview of this aspect of the project methodology is included in Milestone Report 1.3, Section 2.

2.2. Exploring dominant themes, relationships, and data and information utilisation in the global value chain

We used a qualitative approach informed by value chain analysis to develop situational awareness of the issues of concern to value chain stakeholders.

2.2.1. Data collection: In-depth interviews

We conducted interviews with value chain stakeholders and other participants who are experts in their field with direct knowledge of their relevant value chain segment. We interviewed 32 representatives from these key groups:

1. cotton ginners (5)
2. classers (2)
3. brokers (3)
4. merchants (4)
5. textile manufacturers (spinners, fabric producers, garment manufacturers) (6)
6. Australian and multinational clothing/sewn product retailers (11)
7. industry bodies (2).

In selecting participants for value chain interviews, we took the approach of locating representatives from each value chain segment that may or may not directly be connected to one another in the chain. For example, although all interviewed spinners source Australian cotton, they do not necessarily source the cotton directly from the interviewed merchants. Similarly, seven of the ten retailers interviewed knew they had Australian cotton in their supply chains, but were not explicitly connected to the six textile manufacturers interviewed. Our aim in this approach was to gather a wide array of views related to the overall value chain segment, rather than to examine the specifics of a single supply chain.

2.2.2. Data collection: Contextual review

Multiple sources were synthesised to develop a contextual review of each stage of the cotton value chain, drawing upon secondary sources such as Cotton Info library; industry reports and websites; ACCC rulings; International Textile Manufacturers Federation (ITMF) conference papers, reports and online material. This exercise supplemented the understanding of value chain processes and relationships gained through the interviews, as well as assisted in testing our key themes around fibre quality, relationships between stakeholders, and issues important to each stakeholder group.

A complete overview of this aspect of the project methodology is included in Milestone Report 1.2, Section 3.

3. Findings: Stage One

3.1. On-farm decision-making

A total of 61 decisions were considered across the four phases of cotton production as outlined in the *Cotton Production Manual*: planning (17); in season (13); harvest and post-harvest (14); and business (17). Specific decisions were elicited during workshops with growers and other industry representatives and further refined through data collection. These decisions, listed in Table 1 on the following page, do not constitute an exhaustive set of possible decisions made by cotton growers, but we believe that they form a significant bulk of the decisions made during the cotton production year.

Each decision was considered by growers with regards to whether the impact of that decision is high, medium or low, and whether the difficulty of that decision is high, medium or low. A complete dataset of difficulty and impact scores for all decisions, as well as detailed grower perspectives in relation to each decision, is included in *Milestone Report 1.3, Appendices 2-5*.

Based on the grower responses, we computed predictive probabilities that the impact of a decision and the difficulty of a decision would be either of high, medium or low. The distribution of probabilities for impact and that for difficulty quantifies our uncertainty about the degree of truth associated with each level (low, medium and high). This uncertainty has two origins: one is due to the impossibility of surveying each grower, and second the potential bias in their responses. As part of our methodology we take a Bayesian viewpoint, which aligns with how we think of a probability distribution as a characterisation of uncertainty.

We also derived an Agreement Index (AI) which quantifies the degree to which growers' responses agree with one another. This is based on a normalisation of the entropy associated with a probability distribution: the higher the agreement and the larger the sample of interviewed growers the closer the index is to 1. Conversely, the lower the agreement and the smaller the sample, the closer the index is to 0.

We consider an Agreement Index for Difficulty (AI-D), an Agreement Index for Impact (AI-I) and Total Agreement across AI-I and AI-D (ADI), which is the average of the two.

Decisions are not formally stated as a normative decision problem with actions, uncertainties, outcomes, and consequences. The intention of this part of the research was to gain understanding of how growers spoke about their own understanding of the decision that may include breaking down a single decision into multiple decisions, or interpreting the decision problem differently to other growers due to their context (for example, region, irrigation strategy, farm management, size of operation), for example a grower might say that pest management is easy because they rely heavily on their agronomist's recommendations. This does not mean that the decision is in fact easy, merely that the participant benefitted from the expertise of a trusted consultant acting as a decision analyst.

Therefore, the work reported is descriptive rather than normative. That is, while we have classified decisions, the material presented is not to be interpreted as providing normative grounded guidance on decisions such as how to make decisions or what information or circumstances might be needed to make optimal decisions. This will be part of a subsequent part of the project.

Table 1: The set of 61 decisions representing the Australian cotton production decision space.

Planning (n=17)

- Labour requirements for the upcoming season
- Pest management strategies
- Volume of cotton sold in forward contracts
- Ginning contracts
- Type of crop to plant
- Variety of seed type
- Equipment requirements
- Crop rotation sequence
- Nutrition strategies
- Weed management strategies
- How many hectares to plant
- Layout of paddock relative to water access
- Irrigation strategy
- Planting time
- Insurance
- Which merchant to choose
- Row configuration

In-season (n=13)

- Labour requirements during the season
- Irrigation scheduling
- Nutrition management
- Weed management
- Spray decisions
- Pest management
- Farm machinery supplier relationships
- Take growing areas out of production
- Pre-irrigation timing
- Last application of nitrogen
- Final irrigation
- Defoliation times
- First irrigation

Harvest & post-harvest (n=14)

- Pest management
- Labour requirements at harvest
- Module shape: Round or square models?
- Freight to the gin
- Marketing plan
- Harvest date/time
- Weed management
- When to mulch
- When to bust pupae
- Analysing classing data
- What to do with post-ginning seed?
- Classing method (HVI or visual)
- What time of year to gin?
- Contractor requirements

Business (n=17)

- Banking requirements
- New machinery
- How much income to put into each year?
- Investment in staff and training
- Natural resource management
- Level of off-farm industry engagement
- Term loans and overdraft requirements
- Water agreements
- Participation in myBMP/BCI programs
- Developing new land
- Holidays
- Succession planning
- Debt and tax decisions
- Capital investments
- Re-level fields
- When to get payment
- Marketing plan

The problem context for decisions in cotton production includes questions about structure, complexity, timing, urgency, options, information, uncertainty and the consequences of outcomes. Interviews with growers focused on exploring each of these aspects of decision-making in the context of the set of 61 decisions presented. The ways in which these aspects might be interpreted were left up to the growers. For example, no precise definition for complexity was offered when issues of complexity were raised in relation to a particular decision. Instead, complexity was discussed relative to the grower's own unique conception of where the decision sat on a hypothetical range between simplicity at one end and complexity at the other. **Further detail about the decision-making problem context is included in Milestone report 3.1, section 3.1.3.**

The 61 decisions were analysed in terms of each grower's perception of each decision on two attributes: impact and difficulty of each decision. Each of these attributes have been assigned a discrete level of low, medium, or high. Based on the growers' responses, we then computed the probability of each level for the two attributes considered and taken the most likely value in order to allocate a decision to any of the three-by-three matrix sections. We also show next to each decision the agreement indices. The latter provide an indication of how certain we can be that a decision falls within the right place in the matrix. For example, decisions about irrigation strategy have been classified as medium impact and high difficulty. However, the agreement index about difficulty is low (AI-D 0.06), which shows that some growers may find the impact to across medium and high or medium and low.

Table 2: Matrix of decisions by difficulty, impact and agreement. See Appendix 1 of this report for a larger version of the decision matrix.

Agreement Index for Difficulty (AI-D), Agreement Index for Impact (AI-I) and Total Agreement across AI-I and AI-D (ADI) **			
Decisions ordered from most to least agreed in each cell			
IMPACT	DIFFICULTY		
	Low	Medium	High
High	Re-level fields (DEC-BUS-017) [AI-D .26, AI-I .15, ADI .21] Nutrition strategies (DEC-PLN-009) [AI-D .10, AI-I .27, ADI .18] Spray decisions (DEC-ISN-008) [AI-D .20, AI-I .15, ADI .18] Taking growing areas out of production (DEC-ISN-011) [AI-D .16, AI-I .20, ADI .18] Type of crop to plant (DEC-PLN-005) [AI-D .20, AI-I .11, ADI .16] Banking requirements (DEC-BUS-001) [AI-D .17, AI-I .14, ADI .15] Harvest date/time (DEC-HPV-006) [AI-D .15, AI-I .15, ADI .15] Layout of paddock relative to water access (DEC-PLN-012) [AI-D .10, AI-I .19, ADI .14] When to get payment (DEC-BUS-018) [AI-D .21, AI-I .03, ADI .12] How much income to put into each year? (DEC-BUS-003) [AI-D .03, AI-I .17, ADI .10] Insurance (DEC-PLN-015) [AI-D .14, AI-I .06, ADI .10] Contractor requirements (DEC-HPV-003) [AI-D .17, AI-I .00, ADI .09] Investment in staff and training (DEC-BUS-004) [AI-D .10, AI-I .09, ADI .09] Clipping method (HVI or visual) (DEC-HPV-015) [AI-D .17, AI-I .01, ADI .09] Water agreements (DEC-BUS-009) [AI-D .02, AI-I .14, ADI .08] Developing new land (DEC-BUS-012) [AI-D .01, AI-I .10, ADI .06] Analysing classing data (DEC-HPV-012) [AI-D .10, AI-I .01, ADI .05]	Irrigation strategy (DEC-PLN-013) [AI-D .06, AI-I .65, ADI .36] Irrigation scheduling (DEC-ISN-003) [AI-D .06, AI-I .49, ADI .28] Nutrition management in season (DEC-ISN-005) [AI-D .21, AI-I .30, ADI .25] Pest management strategies (DEC-PLN-002) [AI-D .12, AI-I .31, ADI .21] Pest management in season (DEC-ISN-009) [AI-D .05, AI-I .35, ADI .20] Debt and tax decisions (DEC-BUS-015) [AI-D .07, AI-I .33, ADI .20] Time to plant (DEC-PLN-014) [AI-D .04, AI-I .28, ADI .16] Volume of cotton sold in forward contracts (DEC-PLN-003) [AI-D .07, AI-I .26, ADI .16] How many hectares to plant (DEC-PLN-011) [AI-D .04, AI-I .25, ADI .15] Crop rotation sequence (DEC-PLN-008) [AI-D .20, AI-I .10, ADI .15] Final irrigation (DEC-ISN-016) [AI-D .18, AI-I .12, ADI .15] Defoliation times (DEC-ISN-017) [AI-D .19, AI-I .08, ADI .14] Marketing plan (DEC-BUS-008) [AI-D .03, AI-I .21, ADI .12] Capital investments (DEC-BUS-016) [AI-D .02, AI-I .19, ADI .11] Weed management strategies (DEC-PLN-010) [AI-D .04, AI-I .15, ADI .09] Labour requirements for the upcoming season (DEC-PLN-001) [AI-D .06, AI-I .04, ADI .05] Holidays (DEC-BUS-013) [AI-D .01, AI-I .10, ADI .05]	First irrigation (DEC-ISN-018) [AI-D .04, AI-I .39, ADI .21] Succession planning (DEC-BUS-014) [AI-D .04, AI-I .25, ADI .15]
	Ginning contracts (DEC-PLN-004) [AI-D .37, AI-I .13, ADI .25] Seed marketing (DEC-HPV-014) [AI-D .34, AI-I .08, ADI .21] When to pupae bust (DEC-HPV-011) [AI-D .31, AI-I .10, ADI .20] Level of off-farm industry engagement (DEC-BUS-006) [AI-D .26, AI-I .14, ADI .20] Pre-irrigation timing (DEC-ISN-014) [AI-D .21, AI-I .14, ADI .17] Natural resource management (DEC-BUS-005) [AI-D .18, AI-I .14, ADI .16] Weed management harvest/post-harvest (DEC-HPV-009) [AI-D .28, AI-I .03, ADI .16] Term loans and overdraft requirements (DEC-BUS-007) [AI-D .18, AI-I .10, ADI .14] Last application of nitrogen (DEC-HPV-015) [AI-D .14, AI-I .08, ADI .11] Equipment requirements (DEC-PLN-007) [AI-D .14, AI-I .04, ADI .09] Labour requirements harvest/post-harvest (DEC-HPV-002) [AI-D .06, AI-I .09, ADI .07] New machinery (DEC-BUS-002) [AI-D .02, AI-I .05, ADI .04]	Weed management in season (DEC-ISN-006) [AI-D .27, AI-I .16, ADI .21] Which merchant to choose (DEC-PLN-016) [AI-D .36, AI-I .07, ADI .21] Variety of seed type (DEC-PLN-006) [AI-D .20, AI-I .06, ADI .13] Marketing plan at harvest and post harvest (DEC-HPV-007) [AI-D .10, AI-I .10, ADI .10]	
Medium	Freight to the gin (DEC-HPV-005) [AI-D .44, AI-I .10, ADI .27] Pest management harvest and post harvest (DEC-HPV-001) [AI-D .37, AI-I .13, ADI .25] What time of the year to gin (DEC-HPV-013) [AI-D .32, AI-I .10, ADI .21] When to muck (DEC-HPV-010) [AI-D .31, AI-I .10, ADI .20] Module shape: Round or square modules (DEC-HPV-004) [AI-D .25, AI-I .03, ADI .14] Farm machinery supplier relationships (DEC-ISN-010) [AI-D .17, AI-I .01, ADI .09] Row configuration (DEC-PLN-017) [AI-D .16, AI-I .02, ADI .09] Labour requirements during the season (DEC-ISN-001) [AI-D .11, AI-I .01, ADI .06] Participation in myBMP/BCI programs (DEC-BUS-011) [AI-D .02, AI-I .02, ADI .02]		
Low			

* Agreement Index is the degree to which growers agree with one another on impact and difficulty of decisions as measured by predictive probability assessments
 ** The closer the Agreement Index is to 1.0, the more likely growers agree on a particular level of impact or particular level of difficulty of a decision. The closer the index is to 0.0, the less likely growers agree on the impact and difficulty of a decision.

Decisions were allocated within the cells of a three-by-three matrix (see Table 2, above) based on the highest number of responses in each category (low, medium and high) for difficulty and impact.

These nine cells were clustered into three groups and the corresponding cells in the matrix coloured accordingly in temperature map—see Table 3.

Table 3: Temperature map of decisions including Low (Green), Medium (Yellow) and High (Red)

LOW (Green): Low difficulty low impact decisions; Low difficulty medium impact decisions (Number of decisions = 21)
MEDIUM (Yellow): Medium difficulty medium impact decisions; low difficulty high impact decisions (Number of decisions = 21)
HIGH (Red): high difficulty high impact decisions; medium difficulty high impact decisions (Number of decisions = 19)

3.1.1. Agreement analysis

Growers had diverse judgments on the impact and difficulty of decisions producing low agreement indexes on the whole. This means that the location of a decision within the Matrix may not represent a consensus or majority view on the difficulty or impact of decisions; for example, while the decision to

participate in the MyBMP/BCI programs is located in the Low temperature cluster, it was one of the most contentious decisions across the entire set of decisions in terms of difficulty and impact, indicating a wide range of judgments.

While growers expressed a diversity of opinions of the difficulty and impact for many decisions, the following patterns emerged.

- the most agreement on the *impact* of decisions were those rated most frequently as *high* impact (for example, irrigation strategy, irrigation scheduling, first irrigation)
- the most agreement on the *difficulty* of decisions were those rated most frequently as *low* difficulty (for example, when to mulch, freight to the gin and ginning contracts).
- As expected, the least agreement on impact have mixed ratings (for example, analysing classing data, labour requirements during the season, contractor requirements)
- As expected, the least agreement on difficulty have mixed ratings (for example, water agreements, developing new land, holidays)

Decisions with the most agreement are expressed in Table 4 (Decisions with the most consensus on **IMPACT**) and Table 5 (Decisions with the most consensus on **DIFFICULTY**).

Table 4: Decisions with the most consensus on **IMPACT**

Code	Decision	Impact Agreement Index > .2
DEC-PLN-013	Irrigation strategy	High (AI-I .65)
DEC-ISN-003	Irrigation scheduling	High (AI-I .49)
DEC-ISN-018	First irrigation	High (AI-I .39)
DEC-ISN-009	Pest management in season	High (AI-I .35)
DEC-BUS-015	Debt and tax decisions	High (AI-I .33)
DEC-PLN-002	Pest management strategies	High (AI-I .31)
DEC-ISN-005	Nutrition management	High (AI-I .30)
DEC-PLN-014	Planting time	High (AI-I .28)
DEC-PLN-009	Nutrition strategies	High (AI-I .27)
DEC-PLN-003	Volume of cotton sold in forward contracts	High (AI-I .26)
DEC-BUS-014	Succession planning	High (AI-I .25)
DEC-PLN-011	How many hectares to plant	High (AI-I .25)
DEC-BUS-008	Marketing plan	High (AI-I .21)
DEC-ISN-011	Take growing areas out of production	High (AI-I .20)

Table 5: Decisions with the most consensus on **DIFFICULTY**

Code	Decision	Impact Agreement Index .03 < AI-I < .16
DEC-HPV-010	When to mulch	Low (AI-I .11)
DEC-HPV-005	Freight to the gin	Low (AI-I .10)
DEC-PLN-004	Ginning contracts	Medium (AI-I .13)
DEC-HPV-001	Pest management at harvest and pots-harvest	Low-Medium (AI-I .13)
DEC-PLN-016	Which merchant to choose	Medium (AI-I .07)
DEC-HPV-014	What to do with post-ginning seed?	Medium (AI-I .08)
DEC-HPV-013	What time of year to gin?	Low (AI-I .10)
DEC-HPV-011	When to pupae bust	Medium (AI-I .10)
DEC-HPV-009	Weed management at harvest and post-harvest	Medium (AI-I .03)
DEC-ISN-006	Weed management in season	Medium (AI-I .16)
DEC-BUS-017	Re-level fields	High (AI-I .15)
DEC-BUS-006	Level of off-farm industry engagement	Medium (AI-I .14)
DEC-HPV-004	Module shape: Round or square models?	Low (AI-I .03)
DEC-BUS-018	When to get payment	Medium-High (AI-I .03)
DEC-ISN-005	Nutrition management	High (AI-I .30)
DEC-ISN-014	Pre-irrigation timing	Medium (AI-I .14)
DEC-PLN-006	Variety of seed type	Medium (AI-I .06)
DEC-ISN-008	Spray decisions	High (AI-I .15)
DEC-PLN-008	Crop rotation sequence	High (AI-I .10)
DEC-PLN-005	Type of crop to plant	High (AI-I .11)

The assessment of consequences and impact of decisions provides key information to assist in formulating and prioritising R&D activities for the Australian Cotton Industry.

A complete set of findings into on-farm decision-making is available in Milestone Report 1.3, Section 3.1 and Appendices 2-5.

3.2. Information and data use

Desktop research and feedback from growers during our inception workshops revealed a collection of priority information sources relevant to cotton production, which included industry bodies, research organisations, agricultural and professional consultants, and publicly available resources relevant to agriculture. A total of 56 individual sources was tested with growers and are listed in table 9. These sources were not intended to be an exhaustive set of all possible sources available or in use by growers; rather, the collection of sources tested with growers was intended to represent both known sources of regularly-accessed data and information or representative sources of information.

Table 6: Complete list of data and information sources tested with growers during the information sorting exercise.

Category	Data/information sources
Technology, equipment, software and applications	Farm sensors; Farm machinery; Soil moisture readings; Monsanto; Rainman Streamflow;
Government and water	State government; Federal government; Local water provider
Consultants, advisory services, financial institutions and professional associations	Australian Society of Agronomy; CottonConnect; Association of Australian Cotton Scientists; Crop Consultants Australia (organisation); Australian Cotton Shippers Association (ACSA); Solicitor; Accountant; Financial institution; Cotton Seed Distributors (CSD); Agronomist;
Media, social media and grower networks	Cotton Compass; Twitter; Weekly Times; The Land; Queensland Country Life; Facebook; Other growers; Australian Broadcasting Corporation (ABC);
Own records, family, staff and business partners	Elevation data; Yield map; Predicted water availability; Classing data; My own budget; Family; Business partner; Staff;
Industry programs	Better Cotton Initiative (BCI); ChemCert; myBMP; Short course;
Research, extension and industry advocacy	Extension officer; Grain Research and Development Corporation (GRDC); CottinInfo; Cotton Research and Development Corporation (CRDC); Cotton Australia;
Value chain actors	Classing house; Cotton gin; Merchant; Fabric/apparel producers; Retailers; Mills; Consumers; Merchant brokers
Journals and periodicals	Sourcing Journal; The Agronomist; Australian Cotton Grower magazine;
Meteorological data	Bureau of Meteorology (BOM); Long-range weather forecast

We also defined rates of frequency with which growers might access a specific set of data or information sources. These defined rates are outlined in Table 7.

Table 7: Rates used by growers to indicate how frequently they used certain sources of data or information.

Rate of frequency	Definition
Daily	Source may contribute to decision-making once a day throughout the year or when it is required (for example, predicted water availability during extended periods of hotter than average weather).
Daily-Weekly	Source may contribute to decision-making more frequently than weekly but less frequently than daily (for example, every few days).

Weekly	Source may contribute to decision-making once a week throughout the year or when it is required (for example, checking predicted water availability leading up to planting).
Monthly	Source may contribute to decision-making once a month throughout the year
When Released	Source may contribute to decision-making at the time it is made available to the grower (for example, subscription magazines or emails).
Seasonally	Source may contribute to decision-making once during the season for regular, predictable seasonal activities (for example, harvest time).
Variable	Source may contribute to decision-making on an irregular basis (for example, solicitor's advice).
Rarely	Source rarely makes a contribution to decision-making throughout the year (for example, accessed only a few times a year with no regularity or predictability).
Don't Use	Source is not used by the grower to support decision-making.
Data Not Collected	We were unable to collect data about this particular information source from a particular grower.

3.2.1. Most common responses for all data and information use frequencies

This section presents the top responses for each of the information use frequencies reported by growers.

Importantly, the frequency with which a data or information source is accessed should not necessarily be equated with its value. For example, a data or information source accessed daily may not necessarily be highly valued by the grower. Likewise, a source that is reported by our study as never being accessed at all does not necessarily mean it lacks value. According to one grower, who reported not using Twitter at all in their decision-making, ... *one of my next goals right now is to start using that [Twitter] ... I believe there's a lot of agricultural content coming up that's quite relevant, quite up-to-date, quite topical.*

Table 8 on the following page reveals the most commonly reported data or information sources for each rate of frequency tested with growers. The number of growers who selected each information source is included in parentheses.

Table 8: Most commonly reported sources of data or information selected by growers for each rate of frequency. Each source of information includes the total responses for that frequency (out of 29 growers) in parentheses.

Frequency of use	Daily	Weekly	Monthly	When Released	Seasonally	Variable	Rarely	Don't Use
Sources of data or information (number of responses out of 29 in total)	Staff (22)	Agronomist (17)	My own budget (6)	Australian Cotton Grower magazine (17)	Cotton gin (20)	Extension officer (11)	Australian Cotton Shippers Association (13)	Sourcing Journal (27)
	BOM (19)	Other growers (11)	Accountant (4)	Cotton Research and Development Corporation (9)	Classing data (19)	Short course (11)	Solicitor (12)	Mills (24)
	Family (19)	My own budget (10)	Cotton Seed Distributors (4)	Grain Research and Development Corporation (9)	Classing house (18)	Cotton Australia (10)	State government (11)	Fabric/apparel producers (23)
	Business partner (16)	Farm sensors (8)	Extension officer (3)	Cotton Seed Distributors (9)	Monsanto (17)	Solicitor (10)	Queensland Country Life (11)	Retailers (23)
	Farm sensors (15)	Local water provider (8)	Australian Cotton Grower magazine (3)	Cotton Seed Distributors (9)	Yield map (17)	Accountant (9)	myBMP (9)	Consumers (23)
	ABC (14)	Queensland Country Life (8)	Other growers (3)	Cotton Australia (6)		Other growers (9)	Elevation data (8)	Australian Society of Agronomy (23)
						CottonInfo (8)	Federal government (8)	
						myBMP (8)		

3.2.2. Issues and observations regarding data and information use

Growers reported a wide variety of issues in relation to their use of data and information to support on-farm decision-making. This section summarises broader trending issues reported by the participant group. Less frequently reported issues are presented within the context of individual sources of information in *Milestone Report 1.3, Appendix 1*.

- very little direct flows of information from the wider cotton value chain;
- information overload;
- behaviours, attitudes and practices related to data and information management;
- suitability and transfer of information (eg, grower networks, extension information);
- internet and telecommunications reliability;

- uncertainty around the benefits of precision and digital technologies; and
- inconsistent views on the interoperability, security, trustworthiness and independence of data and information sources.

A complete set of findings into on-farm data and information use is available in Milestone Report 1.3, Section 3.2 and Appendix 1.

3.3. Value chain findings

The cotton value chain is the set of activities that add value to the raw commodity, cotton, through development into a product. The cotton value chain comprises the following activities: growing, ginning, marketing, spinning into yarn, textile production, ready-made garment (RMG) or other textile product manufacturing or cut, make, trim (CMT), and retailing, with each step adding value to the final product. Value chain analysis has developed into analysis of global value chains (GVCs) theory developed by Gereffi (1999) to analyse the interactions and linkages between supply chain actors. The cotton value chain is buyer-driven, meaning retailers and brands are the dominant actors, known as lead firms (Gereffi and Fernandez-Stark 2016, 10).

The Australian cotton industry, as upstream suppliers of a raw material, operates as one link in this chain, in which the lead firms downstream typically have greatest power (Gereffi and Lee 2016). Figure 1 identifies the key stages and actors in the Australian cotton value chain. We investigated the following stages of cotton processing activities post farm gate: cotton ginning, classing, marketing, textile production, garment manufacturing and retailing.

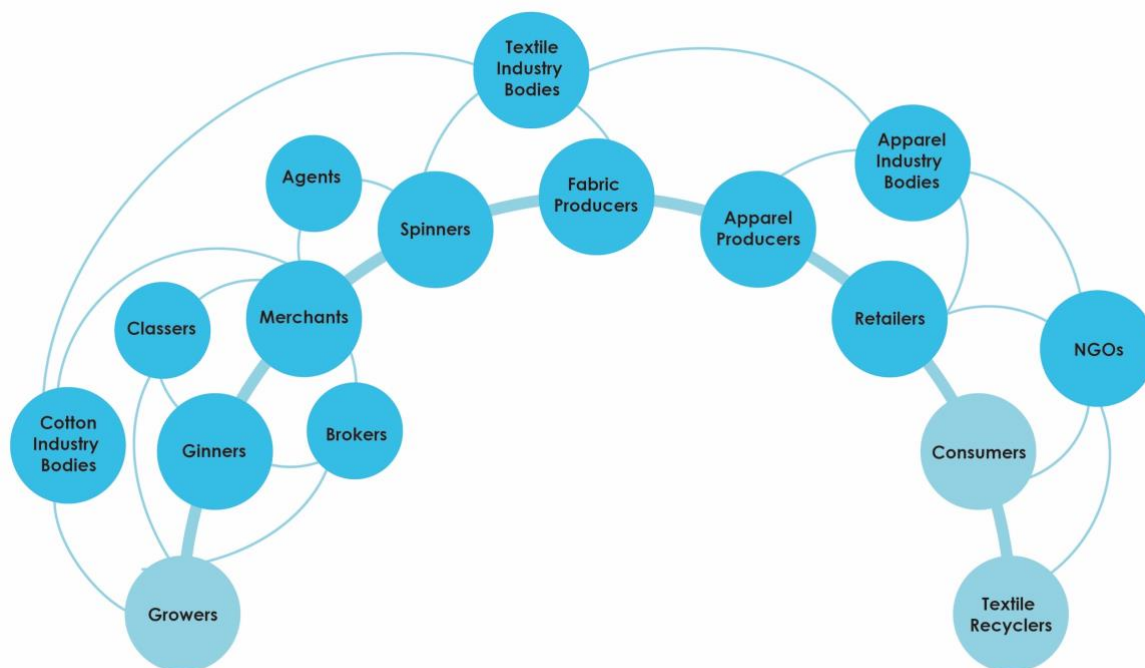


Figure 1: Actors of the cotton value chain (Payne et. al, 2017)

3.3.1. Themes from the value chain

Key themes emerging through the value chain interviews were around sourcing sustainable cotton, particularly the Better Cotton Initiative (BCI)/myBMP relationship, and the need to ensure and communicate fibre quality requirements at each stage of the value chain.

Maintaining fibre quality is of critical importance in ginning. Discussions with ginners highlighted the interconnected issues of ensuring fibre quality while balancing the need for high throughput and managing contamination. Interviewed ginners described close relationships with growers and with the farming community, in which they were able to watch closely the conditions and crop development to help them understand how the season may unfold for ginning. Challenges included communicating issues around moisture and turnout expectations to growers and described occasionally fraught relationships when growers' expectations did not match outcomes.

Classers discussed the relative merits of HVI and manual classing, the perceptions of independent classing, and provided insights into the gathering and uses of classing data.

In the cotton marketing segment of the value chain, both cotton merchants and brokers were interviewed as brokers are engaged by growers to offer marketing advice or negotiate contracts (marketing, ginning, seed contracts). Participants discussed the evolution of the Better Cotton Initiative (BCI), and the interconnected aspects of contracts between merchants and growers, and between merchants and mills.

Merchants expressed uncertainty regarding how many growers are BCI accredited, as well as the extent to which BCI attracts a premium, whether for growers or for merchants. Better Cotton operates a mass balance system in which Better Cotton Credit Units (BCCU) are passed through the supply chain. Merchants are currently facing logistical challenges with the BCCU credit system. Other challenges experienced include the negotiation around Premium and Discount schedules (P&Ds) forward contracts versus tendering ex-gin cotton, and the use of HVI or manual classing data.

The textile manufacturing segment of the value chain included participants from vertically integrated companies, producing yarn, textiles and/or garments, as well as standalone spinners producing yarn only. Participants discussed their perceptions of Australian cotton, their fibre quality requirements, and the sustainability issues of concern to their customers, whether retailers or textile manufacturers. The major factor as to why mills purchase Australian cotton is its contamination-free status. Textile manufacturers, particularly those that are vertically integrated firms selling directly to retailers, reported a growing demand for sustainability credentials communicated through accreditation systems, and for BCI cotton in particular.

Discussions with the textile and garment retailing segment of the value chain focused on fibre quality requirements and sustainability issues of concern to retailers. These include sustainable cotton sourcing strategies, of which BCI is a key component, and the need for traceability and supply chain transparency. Lead firms downstream are increasingly focused on demonstrating social and environmental responsibility to consumers, NGOs, and government stakeholders. A consensus definition of 'sustainable' and 'more sustainable' cotton is coalescing around the BCI and niche cotton identity programs Organic, Fairtrade, Cotton Made in Africa and recycled cotton. Globally, Better Cotton is the only mainstream source of sustainable or more sustainable cotton, meaning that the Australian cotton industry, via BMP, is well-placed to maintain market access in an environment in which influential retailers are increasingly committing to 'sustainable cotton'.

Perspectives from retailers included that BCI would be the default cotton in the future, and any other conventional cotton would be avoided. However, retailers noted that currently BCI has low consumer recognition, indicating the push for BCI was primarily from retailers themselves, industry bodies, and NGOs. Regarding sustainability generally, retailers believe that consumers expect sustainable products, but will not pay extra. Retailers believed that traceability was a growing expectation of consumers, and thus many of the interviewed retailers value physical traceability over BCI's mass-balance system.

Perceptions of the quality of Australian cotton was based on intangible qualities as well as the physical characteristics of the fibre. Retailers mentioned that Australian cotton has as a reputation for higher quality than conventional cotton.

3.3.2. Value chain relationships

The interviews demonstrated the close-knit connection of the onshore Australian cotton industry actors, with long term relationships established between ginners, classers, merchants, brokers and growers.

- Merchants described an interconnected industry in which longstanding relationships were established between growers and merchants. Recent changes to the industry, particularly the growth in the cotton industry in the south, has led to a greater number of brokers.
- Spinners had all visited Australia and all had interest in greater connection with growers. Most spinners source cotton through agents, none of whom were interviewed for this study.
- Local retailers reported direct engagement with the Australian cotton industry, largely through the work of Cotton Australia
- Global retailers had strong awareness of Australian cotton and had positive views of the industry

On shore value chain stakeholders provided insight into a close-knit industry that values the contribution the industry can make to Australian farming communities. The majority of Australian participants reported active involvement in cotton industry bodies and/or involvement in the wider cotton community. This finding may be a characteristic of the interviewees, given that those who agree to participate in an industry research project may already be community-minded. However, if borne out more broadly, a connected industry in which grower and value chain stakeholders are actively engaged with industry bodies points to good information flows and less likelihood of information gaps.

3.3.3. Value chain use of data

Data and information flows to and from the value chain are key for the cotton industry. This information includes essential market information such as cotton price and quality expectations (e.g. fibre staple length, strength, colour) as well as qualitative information such as the sustainability expectations of retailers and their end-users. and how requirements around these aspects may vary between value chain stakeholders such as merchants, ginners, spinners and retailers.

Throughout the stages of the cotton value chain, many kinds of data are collected for use whether in value chain processing stage, or for determining price and contracts along the chain. Table 9, below, presents a snapshot of data generation and usage along the value chain, highlighting their value at each stage.

Table 9: Examples of data generation and utilisation through value chain

Data	Ginning	Classing	Marketing	Textile	Retailing
Module no.	Utilised	Utilised			
Module location	Utilised	Utilised			
Bale no.	Generated	Utilised	Utilised	Utilised	Utilised
Gin location	Generated	Utilised	Utilised		
Quality – Manual colour		Generated	Utilised		
Quality - HVI		Generated	Utilised	Generated	
BCCUs	Generated		Utilised	Utilised	Utilised

Key	Data generated at this point in VC	Data are utilised
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For the cotton value chain, classing data and bale / module / farm location data are the most utilised. However, the utilisation of these data is contingent upon the needs of actors immediately after or before

the point of data generation. For example, classing data are important for growers', ginner's' and merchants' decision-making, but less so for mills who will commonly re-class the cotton for their own needs.

In terms of data linking bale to origin, growers can utilise highly specific location data to trace bales from a problem module to one paddock, for example. Bale data are essential for marketing in determining contracts, and then for merchants to fulfill spinners' orders. However, from this point on, the bale data are no longer relevant. Although one retailer reported that receiving bale data afforded him the opportunity to trace bale to farm, he did not appear to be utilising these data to do so.

The majority of retailers require coarse level location information only. For some retailers, this may mean country of origin – or simply 'not Uzbek cotton' – or cotton identity program only. Australian retailers manufacturing Australian cotton goods utilised precise country of origin data through chain of custody certificates showing Australian-grown, but this information need not be down to farm level for their needs.

Better Cotton's BCCUs are an example of data flowing throughout the value chain, however from interviews there was uncertainty regarding the take-up and usage of BCCUs among merchants and brokers (working on behalf of farmers). Although the BCCU is established when the cotton is baled at the ginning phase, the actual gin has no part in the process as the grower manages the system through the Better Cotton Tracer system. Whether or not the baled cotton had BCCUs attached is not recorded in classing processes as the BCCUs operate in a mass-balance system decoupled from the physical baled cotton.

In conclusion, although every value chain stage collects and utilises data and information, these may not flow back to growers.

A complete set of findings into themes, relationships and data utilisation in the global cotton value chain is available in Milestone Report 1.2, Sections 4-8.

4. Findings: Stage Two

4.1. Mapping the decision space




4.1.1. Synthesis of Stage 1 findings

For each of the 61 decisions, we identified its information sources, its on-farm consequences, and the potential for future information flow from the value chain to farm, based on the identified value chain priorities.

If an on-farm decision results in a consequence for a value chain actor, it follows that the value chain actor experiencing that consequence may be able provide data or information to the grower to enhance the quality of that on-farm decision.

In order to establish consequences experienced within the cotton value chain as a result of on-farm decision-making, we established a matrix that included the groupings of value chain priorities (outlined in Table 10 on the following page) and value chain actors combined into four key segments of ginning, marketing, manufacturing and retailing. By identifying the value chain priorities, we identified whether the decision area has consequences for the value chain. A synthesis of the consequences of these decisions is included in Appendix 2 of Milestone Report 1.5, and the full details of on-farm findings are in the Milestone Report 1.3.

Table 10: Key value chain priorities used to determine consequences experienced by value chain segments as a result of on-farm decision-making.

Value chain key priority	Definition
 Fibre quality	The quality parameters that determine cotton’s commercial value in the marketplace.
 Logistics	How efficiently the cotton moves through the value chain.
 Sustainability	As related to environmental and social sustainability issues in cotton production.

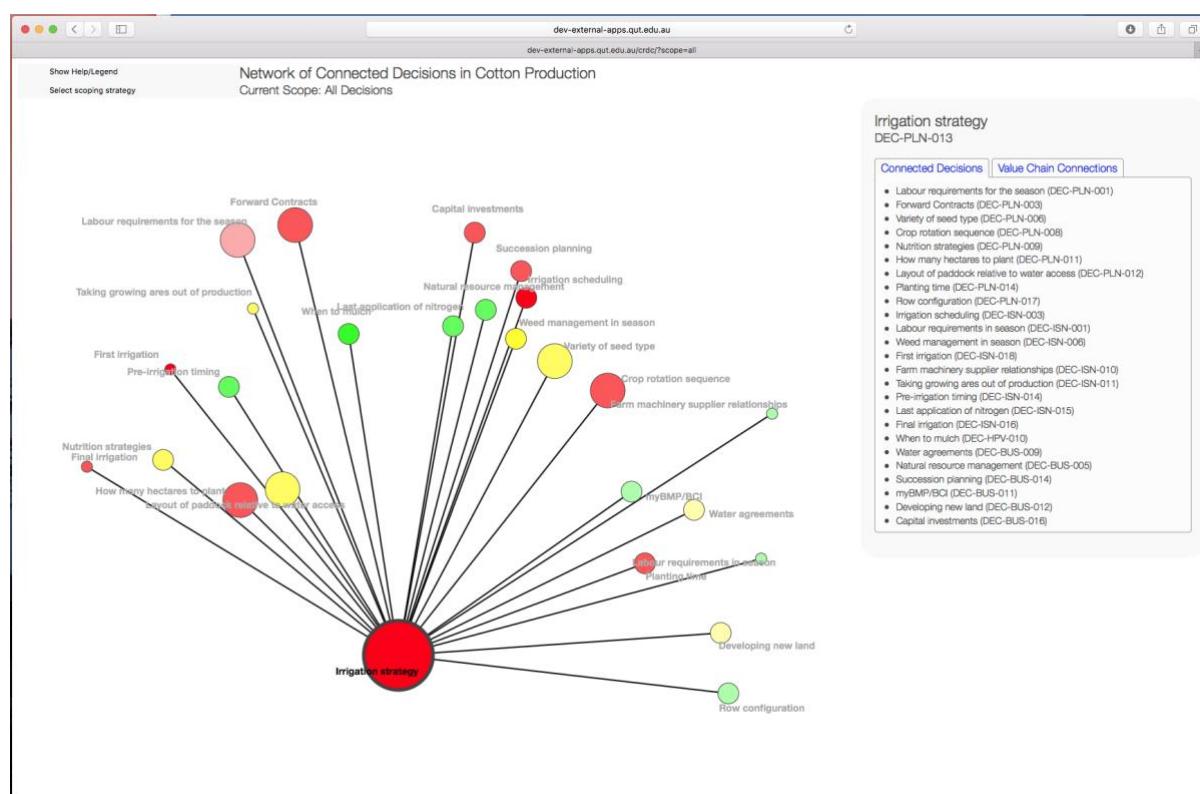


Figure 2. Interactive tool to visualise on-farm cotton decisions as networks. This subnetwork shown focusses on the decisions that relate to irrigation strategy decisions.

We have developed a web-based interactive graphical tool that shows different information about the network and even subnetworks. This tool, which is shown in Figure 2, maps the complexity of decision-making in cotton production.

Access the interactive decision map by visiting <https://external-apps.qut.edu.au/crdc> and entering the username “crdc” and password “qut170115”.

The size of each vertex (circle) associated with a particular decision is representative of the number of edges, and thus the number of decisions to which this decision is related to.

The colors of the vertices refer to a combination of impact and difficulty score Red (high), Yellow (medium), Green (low) – see ***Milestone Report 1.3*** for further details.

The intensity of the colour (bright red vs pink) of the vertices encode information as how much agreement there is in how farmers perceive the combination of impact and difficulty, higher opacity indicates higher agreement and more transparency indicates lower agreement (see ***Milestone Reports 1.3 and 1.5*** for details).

Based on the analysis of connected decisions and the value chain consequences of those decisions, we proposed a set of scoping strategies that would allow the project to pursue an in-depth program of research on a narrow set of decisions. These strategies were designed to adopt different perspectives on decision problems affecting the value chain, and allowed for recommendations to be made based on areas CRDC wished to prioritise.

An outline and justification of project scoping strategies based on the findings from the project's first year are included in Milestone Report 1.5.

4.1.2. Changes to project approach

After the outputs of the project's first year were considered, CRDC asked the research team to reconceptualise the matrix of decisions by the potential investment value they represent to the Australian cotton industry rather than by their collective levels of difficulty and impact. This change in project approach led to the development of one of the project's key outputs: A method for assessing investment opportunities in on-farm digital agricultural solutions. The rationale behind this method with a hypothetical investment analysis is included in section 5 of this report, with a detailed proposal included in ***Milestone Report 2.2.***

5. Key project output: A method for assessing investment opportunities in on-farm digital agricultural solutions

Following from the previous findings, the team developed a method to assist CRDC in evaluating investment opportunities in on-farm digital technologies. The method could help CRDC to select its portfolio of investment research to keep pace with the burgeoning agtech industry and its increasing penetration of Australian cotton producing enterprises. Understanding growers' on-farm decisions is the first step – agri-intelligent solutions should reduce the uncertainty growers face in decision-making, and in so doing, reduce negative consequences on-farm.

This method is based on the deep analysis of growers' on-farm decision-making and connection to value chain, summarised briefly in Section 3 of this report, and captured in depth in the Milestone Reports 1.2, 1.3 and 1.5. The method we have designed can ensure that any investable ag-tech solutions are assessed based on evidence of market opportunity and feasibility. This six-step method allows for two or more solution requirements to be developed, scored and then compared by an expert panel. Each solution requirement is developed based on an on-farm decision area.

This section provides a brief summary of the six steps of the method. The full method and supporting workshop materials was submitted to CRDC in Milestone Report 2.1.

The proposed method is illustrated in Figure 3 on the following page. The method is organised into a series of steps that could allow the CRDC to:

1. articulate decision problems from the perspective of on-farm end users
2. consider issues, uncertainties and consequences (especially as they relate to the global cotton value chain) in relation to those decisions
3. develop a set of solution requirements (but not the solutions themselves) for improving decision-making with the input of an arms-length Industry Reference Panel
4. determine an investability score that quantifies an investment potential of any given set of resulting agri-intelligent digital solutions based upon their market opportunity and feasibility.

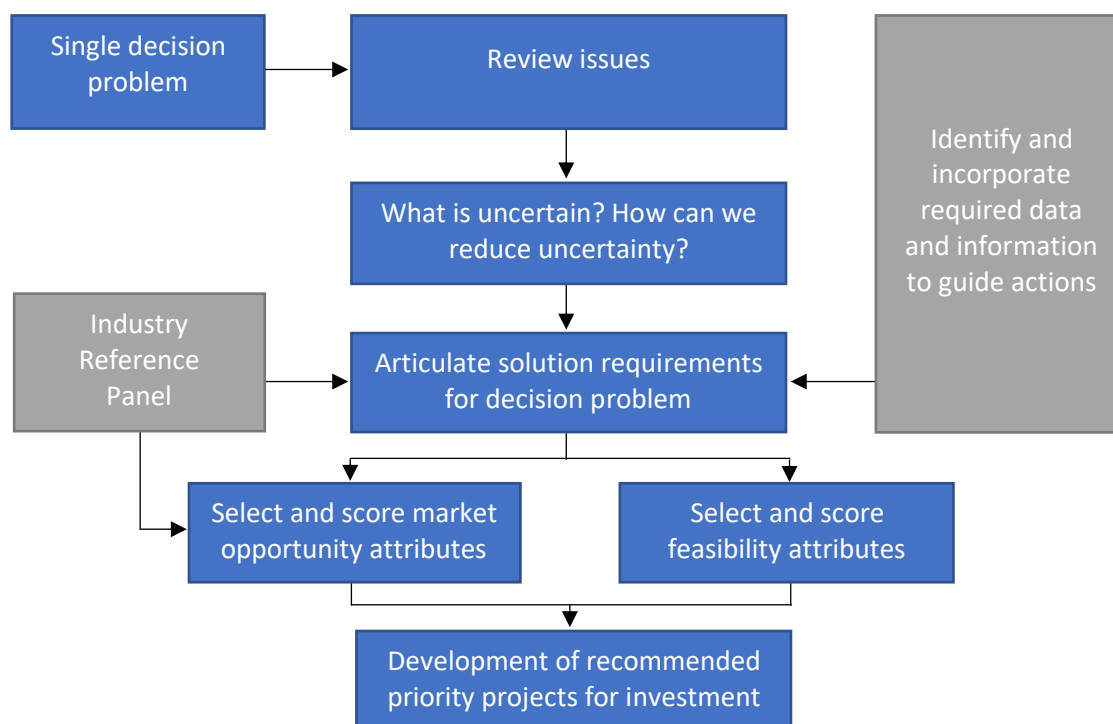


Figure 3: Process for formulating and evaluating investment opportunities.

Industry Reference Panel

The input of an Industry Reference Panel is assumed in order to extend the capabilities of CRDC and the research/development team. The role of the Industry Reference Panel is to provide expert, arms-length guidance around the specification of solutions requirements once issues, uncertainties and consequences for each decision problem under consideration have been defined.

The panel's main function is to:

- help co-design solution requirements that present the most compelling investment opportunity and provide a clear pathway to commercialisation;
- assess the potential impact of the solution on the Australian cotton industry; and
- determine the expected degree of difficulty in developing and deploying the solution.

The composition of the Industry Reference Panel can be tailored to suit the types of decision problems under consideration but would ideally be kept to as small a group as possible. Members of the panel should include a diverse range of perspectives from across the industry, and may include:

1. research providers
2. technology analysts
3. agronomists
4. selected technology developers
5. growers
6. extension officers
7. financiers.

5.1. Step 1: Articulating decision problems from the perspective of on-farm end users

Through our work in the first part of the project submitted as part of Milestone Report 1.3, issues were identified and summarised from discussions with growers about their experiences with on-farm decision-making processes. Issues in relation to each decision problem under consideration can be collated from the compiled Cotton Decision Compendium (see Appendices, Milestone Report 1.3) developed as part of this project. The detailing of these issues for consideration by the Industry Reference Panel, who will be required to develop requirements for potential solutions to the decision problem, should be high-level points to prompt discussion and reflect the experiences outlined by growers during the study.

5.2. Step 2: Considering issues, uncertainties and consequences of on-farm decisions

One of the key characteristics of any decision problem is its inherent **uncertainty**. The outcomes of a decision are determined not only by the actions of the decision maker, but also by the state of external attributes of which the decision maker is often uncertain about. Different decisions carry different degrees of uncertainty, the sources of which may include a deficit of timely, trusted, accurate, purposefully-collected data and information. Defining the uncertainties inherent in each decision problem lays the foundation for developing a solution to reduce uncertainty, thereby providing a means of improving decision-making.

Each decision will select action, which then combined with the state of the external attributers will result in outcome with **consequences** for a grower. Defining the consequences of each decision can help to convey the extent to which a potential solution may positively impact the farming enterprise.

Potential uncertainties and consequences for each decision problem are summarised in Appendix 3 of Milestone Report 1.5. These should be drawn from and elaborated on by the Industry Reference Panel and inform solution requirements in Step 3.

5.3. Step 3: Specify solution requirements

With the input of the Industry Reference Panel, a set of key solution requirements that may guide development of a potential solution should be developed across the following dimensions:

Digital technologies: Solution requirements that make use of either new or existing digital technologies and infrastructure.

Informatics: Solution requirements that include a data analytics, optimisation, or any other computational element. This dimension might include a provision for the analysis, interpretation and presentation of data collected using digital technologies as well as information extracted from these data.

Business and social intelligence: The integration of data or information from the collective intelligence of commercial or social groups.

Findings from the exploration of growers' use of data and information to support production decisions should be also be incorporated into this step.

Example solution requirements

Using irrigation scheduling as an example, the **digital technology** component of a solution would include the sensing and telemetry infrastructure deployed on-farm to collect and transmit data related to soil moisture content, local weather conditions, solar radiation, and volumetric flow of water applied. This infrastructure also includes controlled devices that regulate the applied amount of water on the paddock over time and location. The **informatics** component would include the algorithms and methods to extract and forecast information from sensor data and provide insights to assist with either decision support or generate actions for automated decision-making based on sequential optimization over time and space. The **business and social intelligence** component would incorporate real-time intelligence about the social license impacts of reduced water use through precise irrigation and, over time, community-driven changes to water management policy.

5.4. Step 4: Quantify the market opportunity for a potential solution

The method recommends that the market opportunity for the potential solution be scored using a weighted system that considers each of the following attributes:

- *m1*: Impact on-farm of the decision problem
- *m2*: Difficulty on-farm of the decision problem
- *m3*: Competitive advantage
- *m4*: Degree of required on-farm practice change
- *m5*: Applications beyond the intended problem
- *m6*: Social license
- *m7*: Adaptation of the workforce
- *m8*: Market license to operate.

Each attribute should be scored according to the scoring guide for each attribute outlined in Milestone Report 2.1, section 2.6.

Market opportunity attributes *m1* and *m2* relate to the potential size of the market for the solution requirements under consideration. The assessment of these attributes is facilitated by the results in our previous work outlined in milestone reports 1.2, 1.3 and 1.5. Attributes *m3-m7* relate to potential barriers to adoption within the potential market for the solution, and are thus related also to market-size attributes. The attribute *m8* is a threshold – or “stop-go” – attribute that determines whether the solution can be implemented at all or there may regulatory or other barriers that would deem a solution non-compliant with current regulatory, legal and social environments.

5.5. Step 5: Identify the feasibility of a potential solution

The method recommends that the feasibility of the potential solution be scored using a weighted system that considers each of the following attributes:

- *f1*: Leveragability
- *f2*: Technological sophistication
- *f3*: Development process complexity
- *f4*: Pace of development
- *f5*: Regulatory environment
- *f6*: Partnership potential
- *f7*: Liability/litigation risk

Feasibility attributes broadly address the costs, risks and other external factors that may impact research and development activities associated with meeting the proposed solution requirements.

Each attribute should be scored according to the scoring guide for each attribute outlined in Milestone Report 2.1, section 2.7.

5.6. Step 6: Calculate scored attributes

A method of calculating the market opportunity and feasibility of a particular investment opportunity has been devised to provide a single score for each set of attributes per solution, which can be combined to provide a single weighted score for the investment opportunity under consideration. Each attribute is individually weighted to emphasise investment priorities across the set. These weightings are adjustable to accommodate changes in investment priorities over time.

Milestone Report 2.1 includes an Investment Assessment Calculator to assist with calculating a single weight score for a potential investment opportunity based on the scored results for each set of market opportunity and feasibility attributes.

The solution requirements with the highest score can be considered to be the most investable.

6. Conclusions and recommendations

This report is the final summary report of the 'Agri-intelligence in cotton production systems' project. We have delivered four key artefacts:

5. Cotton Compendium describing grower perceptions of the impact and difficulty of decision-making on farm;
6. Interactive decision map, showing interconnected production decisions;
7. Report on grower information use; and
8. Value chain state of knowledge report, including identified value chain priorities and consequences of grower decision-making.

These outputs can provide current contextual knowledge to the cotton industry including growers, agronomist, extension officers and other researchers.

Drawing on these artefacts, a major output of the project is an evidence-based method for developing and evaluating a portfolio of potential investment opportunities based on analysing the issues, uncertainties and consequences of on-farm decision-making with the input and assistance of an arms-length Industry Reference Panel. Our method can provide CRDC with a robust approach to identifying investment opportunities and developing a portfolio of prioritised investments, with an emphasis on the needs and perspectives of Australian cotton growers.

The method is also being investigated for integration within CRDC's developing research commercialisation framework, with initial discussions resulting in a commitment to repurpose aspects of the method outlined in this report for immediate implementation with industry.

6.1. Recommendation 1

Our first recommendation is that CRDC makes the four project milestone reports and interactive decision map available to industry at their discretion:

1. Payne, Alice, Zoe Mellick, Andrew Simpson, S. Kate Devitt, and Tristan Perez. 2017. Milestone Report 1.2 Value Chain State of Knowledge. QUT-IFE, December.
2. Perez, Tristan, S. Kate Devitt, Alice Payne, and Andrew Simpson. 2018. Milestone Report 2.1 "A method for assessing investment opportunities in on-farm digital agricultural solutions". QUT-IFE. Report for CRDC, 30 November.
3. Perez, Tristan, S. Kate Devitt, Alice Payne, Andrew Simpson, and Alan Woodley. 2018. Milestone Report 1.5 Identification of the current state of agri-intelligence within the Australian cotton industry. QUT-IFE. Report for CRDC, April.
4. Simpson, Andrew, S. Kate Devitt, Zoe Mellick, Alice Payne, and Tristan Perez. 2017. Milestone Report 1.3 Difficulty and impact of decision areas and identification of information use in cotton production. QUT-IFE, December.

Access the interactive decision map by visiting <https://external-apps.qut.edu.au/crdc> and entering the username "crdc" and password "qut170115".

6.2. Recommendation 2

Our second recommendation is for CRDC to test the digital agricultural investment assessment method outlined in report Milestone Report 2.1 to prove its effectiveness in a real-world scenario and with a view to incorporating it into its internal innovation pipeline.

7. References

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- Simpson, Andrew, S. Kate Devitt, Zoe Mellick, Alice Payne, and Tristan Perez. (2017). *Milestone Report 1.3 Difficulty and impact of decision areas and identification of information use in cotton production*. QUT-IFE, December.