FINAL REPORT 2016/954

Sensors for improved harvesting feedback: evaluation of suitability

Final report prepared by:	Eloise Keeffe
Chief Investigator(s):	Eloise Keeffe
Research organisation(s):	Sugar Research Australia, Wilmar Sugar, SCAN Consulting
Co-funder(s):	Department of Agriculture and Water Resources
Date:	23 June 2017
Key Focus Area (KFA):	4 – Farming systems and production

Sugar Research Australia™

Australian Government
Department of Agriculture and Water Resources

wilmar

SCANconsulting

© Sugar Research Australia Limited 2017

Copyright in this document is owned by Sugar Research Australia Limited (SRA) or by one or more other parties which have provided it to SRA, as indicated in the document. With the exception of any material protected by a trade mark, this document is licensed under a Creative Commons Attribution-NonCommercial 4.0 International licence (as described through this link). Any use of this publication, other than as authorised under this licence or copyright law, is prohibited.

http://creativecommons.org/licenses/by-nc/4.0/legalcode - This link takes you to the relevant licence conditions, including the full legal code.

In referencing this document, please use the citation identified in the document.

Disclaimer:

In this disclaimer a reference to "SRA" means Sugar Research Australia Ltd and its directors, officers, employees, contractors and agents.

This document has been prepared in good faith by the organisation or individual named in the document on the basis of information available to them at the date of publication without any independent verification. Although SRA does its best to present information that is correct and accurate, to the full extent permitted by law SRA makes no warranties, guarantees or representations about the suitability, reliability, currency or accuracy of the information in this document, for any purposes.

The information contained in this document (including tests, inspections and recommendations) is produced for general information only. It is not intended as professional advice on any particular matter. No person should act or fail to act on the basis of any information contained in this document without first conducting independent inquiries and obtaining specific and independent professional advice as appropriate.

To the full extent permitted by law, SRA expressly disclaims all and any liability to any persons in respect of anything done by any such person in reliance (whether in whole or in part) on any information contained in this document, including any loss, damage, cost or expense incurred by any such persons as a result of the use of, or reliance on, any information in this document.

The views expressed in this publication are not necessarily those of SRA.

Any copies made of this document or any part of it must incorporate this disclaimer.

Please cite as: Keeffe, E. C. 2017. Sensors for improved harvesting feedback: evaluation of suitability. Sugar Research Australia Limited

ABSTRACT

A feasibility study was conducted to investigate the value and application of sensors in the harvesting environment for improved feedback for quality and loss control. A desktop study, this project (a) investigated the current practices and processes of the harvesting community, including the present use of sensors, (b) Isolated the cause and effect of harvest quality and loss and the issues that are currently preventing change, (c) identified what contractors, growers and millers need and/or wish to achieve from the addition of sensors on harvesters (d) identified and evaluated commercially available sensors and other measurement systems for their suitability to measure certain parameters in the harvesting environment, and (e) identified four sensing systems most likely to succeed in future efficacy testing.

The project was conducted with a strong consultative approach with industry, using surveys, focus groups, presentations and one-on-one meetings to discuss regional issues and potential solutions. Ultimately, industry has prioritised the following quality and loss pathways: (1) extractor losses, (2) basecutter quality (height control), and (3) cane supply quality. Spectral imaging, proximal NIR spectroscopy and radar technologies were favoured solutions.

EXECUTIVE SUMMARY

Poor harvest quality is a critical issue for the Australia sugarcane industry. Despite the development of a harvesting best practice guideline and extension program in 2002, cane loss and poor cane supply quality are still contributing towards an estimated $50 million loss. In part, the lack of adoption of harvest best outcomes (HBO) is due to the payment structure, which does not provide incentive for quality. However, for a revision of the payment system to include quality metrics, robust, rapid methods to measure those metrics are required. Realistically, this can only be achieved on the scale required by implementing sensing technology.

Real-time or rapid sensors in the harvesting environment will improve the quality of the harvesting operation across the board by allowing (a) contractors to adjust harvester settings based on losses and cane supply quality indicators in real-time, (b) growers to monitor contractor’s performance and adherence to HBO, (c) mills to receive feed-forward information on the quality of incoming feedstock, and (d) providing the data for a quality-based payment system.

Recently, there has been significant advancement in the availability of sensing technology and reductions in price. Resource and time constraints prevent real-world evaluation of all sensing options for suitability so a desktop feasibility study was developed that aims to identify those sensors and installation with the greatest likelihood of success and identify strategies for further research in field-based efficacy testing.

The feasibility study was conducted in six parts, including: (1) the Project Scope, which defined the problem and opportunity to be addressed; (2) the Current Analysis, which defined the current harvesting systems and environment; (3) the Requirements, which identified and specified the needs of the end users, who include, contractors, growers, millers, harvester manufacturers and sensor manufacturers; (4) the Approach, which evaluated each of the sensors available in the market at the moment, as well as technologies capable of being used as a sensor, against the Requirements; (5) the Evaluation, which identified a subset of systems presented in the Approach with the greatest likelihood of being efficacious in proof-of-concept, and; (6) the Review, which will be a rigorous assessment of the feasibility study and its recommendations by an independent panel. This project had a strong industry focus and this information was gathered through industry surveys, focus groups and on-on-one discussions.

Project outputs include a completed feasibility study on the efficacy of sensors in the harvesting environment and a selection of four sensors that should be progressed to field trials. They include a mixture of NIR spectroscopic, spectral imaging and radar technologies to measure extractor losses, basecutter height and cane supply quality. This project will deliver outcomes that will benefit the entire industry by providing a plan for targeted research to improve harvesting performance. The direct users of the immediate outputs will primarily be researchers from the sensing and sugar industries. However, the long-term users of the subsequent research’s outputs shall include harvester and sensing manufacturers, harvesting contractors, millers and growers.

Sensing technology in the harvesting environment has the potential to significantly reduce current losses, and improve the cane supply quality, providing a step-change in production with minimal input.

TABLE OF CONTENTS

TABLE OF FIGURES

1. BACKGROUND

Lack of incentives for key parties in the sugarcane supply chain has resulted in low adoption of harvesting best outcomes (HBO) strategies. Poor harvest quality is estimated to cost the industry over $50m annually. A revision of the payment structure is critical to driving practice change; however, there is currently no measurement mechanism available to facilitate a quality-based payment system for the sugarcane supply chain.

Real-time or rapid sensors in the harvesting environment will improve the quality of the harvesting operation across the board by allowing (a) contractors to adjust harvester settings based on losses and cane supply quality indicators in real-time, (b) growers to monitor contractor's performance and adherence to HBO, (c) mills to receive feed-forward information on the quality of incoming feedstock, and (d) providing the data for a quality-based payment system.

Sensing technology must provide meaningful information about actionable issues on-the-go, be easy to implement and use, and have potential to improve productivity by limiting losses and improving cane supply quality. Resource and time constraints prevent real-world evaluation of all sensing options for suitability. Instead, our feasibility study will identify those sensors and arrangements with the greatest likelihood of delivering and identify strategies for further research in field-based efficacy testing.

Harvest quality is an aggregate term used to describe multiple loss, damage and contamination pathways in the harvesting process. Driven by an economic imperative for maximising tonnes/hour, causal factors are dominated by pour rate, ground speed, base cutter parameters and fan speed (2014a). Past research has identified that harvest quality impacts along single pathways can be inferred to some degree from harvester set-up. The following correlations have been identified (2014b, Sandell and Agnew, 2002, Whiteing and Norris, 2002, Whiteing, 2013):

- Fan speed – cane loss
- Pour rate and forward speed – cane loss, ratoonability and billet quality
- Roller and chopper speeds – sugar loss and billet quality
- Pour rate – cane losses, extraneous matter
- Chopper blade sharpness – cane and juice loss
- Base cutter blade sharpness – cane loss, ratoonability
- Elevator flights – billet loss

This information has been captured through harvesting trials, but challenges have always existed in capturing accurate cane loss information. Two commonly used techniques are the mass balance cane loss system (Sandell and Agnew, 2002), which is accurate but very slow and expensive; and the infield sucrose loss measurement system (ISLMS) (Whiteing, 2013), which is a modification of the traditional blue tarp method (Linedale, 1997, Linedale and Ridge, 1996, Sandell and Agnew, 2002). The ISLMS provides an accurate measure of sucrose loss in the field and is considered a rapid test, despite turnaround times between 4 and 24 hours. The process is very manual and requires manning by three highly-skilled operators to minimise analysis errors. These techniques provide strong feedback to the industry about the impact of certain practices on harvest quality, which is recognised and understood. However the lack of immediate visual clues for the contractor, while operating on the run, in addition to economic pressures, result in continuation of poor practice.

Sensors that can operate in the harvesting environment and provide rapid feedback to the harvester operator about loss pathways in real-time will provide information and opportunities for rectification. Sensors exist in many forms (e.g. NIR, IR and Raman spectroscopy, multi-/hyper-spectral cameras, refractometers, acoustic and vibrational monitors) and are used extensively in agricultural (Cozzolino et al., 2015, Gowen et al., 2007, Posudin, 2007, Liang et al., 2015) and production (Gowen et al., 2007, Úbeda et al., 2016) processes. Recently, the grains industry has seen an increase in sensors on combine harvesters measuring grain quality characteristics by techniques such as NIR spectroscopy (Taylor et al., 2005), peizoelectrics (Liang et al., 2015) and electronic noses (Evans et al., 2000) among others.

Currently, sensors are only used in the sugarcane industry to measure physical parameters of the harvester, for example, elevator and engine status, GPS, basecutter height control and processing pressures (2014a). Several groups have investigated yield monitoring sensors (Price et al., 2007, Cox, 2002, Esquivel et al., 2006, Jensen et al., 2013), however Bramley et al. suggested modified GPS systems were required for accurate yield monitoring (Bramley et al., 2008). Only one is commercially available (2015a). Jensen, from USQ has recently finished an SRA-funded project investigating yield monitoring in sugarcane. Cane loss monitors based on acoustics and piezo-electric sensors (Dick and Grevis-James, 1992, Dick et al., 1991, McCarthy et al., 2002) were developed, but failed to directly measure billet hits in the extraction systems. Instead, they measured loss as a function of material flow(Whiteing et al., 2004). Doherty et al. investigated hand-held NIR systems and enzymatic methods; the former failed to achieve appropriate models and the latter was too cumbersome in the field (Doherty et al., 2007). Similarly, Nawi and team investigated in-field NIR for multiple applications (Nawi et al., 2014, Nawi et al., 2013, Nawi et al., 2012).

Previous Sugar Research Australia research investment related to the project includes:

- 2013025 Robson- Evaluation of hyper- and multi-spectral imaging as tools for screening research and breeding trials, as well as measuring canopy nitrogen status.
- 2014028 Jensen- Continued development of yield monitors to improve consignment assignment and reliability as well as assessment of the validity of the generated data.
- 2014035 Plaza- Understanding the feasibility of a non-pneumatic cane cleaning plant
- 2014048 Whiteing- Increasing harvest recovery by addressing harvester set-up, including after-market changes, and operation.
- 2014091 McBean- Improving HBP adoption through engagement with key stakeholders.
- 2014092 Milla- Understanding the impact of harvester speed on ratoon performance.
- AGX001 Crossley- Developing an on-board computer system to monitor operations and provide feedback while harvesting.
- BSS318 Whiteing- Development of a rapid sucrose loss monitoring system for use in the field.
- BSS189 Whiteing- Development of HBP guidelines to reduce EM and cane loss
- CHC002 Rose- Development of SHIRT, the Supply and Harvester Information in Real Time.
- CGT001 Stainlay- Development and implementation of a harvest management tool for Tully district based on CSIRO’s SugarMax (CSE003, CSE005).
- CSE022 Bramley- Developed protocols for yield sensor data manipulation and identified areas requiring future work for yield mapping.
- DPI021 Robson- Evaluation of remote sensing technologies for a variety of applications, such as abiotic and biotic cropping constraints.
- FSA001 Davis- Reviewed the current harvester design and harvesting practice and identified areas of value for future research investment.

- GRF001 Granshaw- Investigated automation of harvester forward movement.
- MSA003 Fleming- Investigated the measurement and feedback for cane quality data.
- HGP004 Markley- Demonstrated the value of implementing HBP and provided a basis for sharing the additional revenue.
- CO02008 Brotherton- Review of harvester performance testing methodology.
- BS81S Ridge- Automation of basecutter speed and height.
- Scholarship McCarthy – Integration of sensory control for primary separation system and toppers.

The Australian sugar industry's investment in harvest activities, yield monitoring and remote sensing is extensive. The proposed project will build on this research by conducting a full review of what has and hasn't been successful and understanding the key barriers to development of suitable technologies. Recently, yield monitors have received a significant amount of attention and funding, and consequently, won't be the focus of the new investigation. Rather, we will attempt to merge factors of existing research to develop new tools. For example, installing remote sensing systems, such as those investigated by Robson and Bramley on the harvester to measure sucrose losses on-the-go.

Several projects aimed to produce products that would provide a ready-made platform to receive and display the data generated from new sensors (AGX001, MSA003). Project MSA003 linked in with Agtrix's CHOMP software to process and display their harvester monitoring and reporting, however this was only ever completed in a desktop study. The project participants of AGX001 were not able to develop the on-board computer system.

This will maximize the industry's benefit from existing investment by using it to coordinate a structured research plan for future investment in the use of sensors to provide feedback about harvesting parameters.

Challenges associate with harvesting are currently of critical interest in the Australian sugar industry. In particular are the issues surrounding payment, cane supply quality and cane and juice losses. For increased adoption of HBO, all parties require motivation via quality-based payment; however, the required measurement and performance monitoring mechanisms do not currently exist. Industry has recognised that sensors on harvesters are part of the solution, but the piecemeal approach to date has not been effective.

The Australian sugar industry will derive several benefits from this project. It will demonstrate the industry's commitment to solving harvesting issues with sensible, clearly defined research pathways, resulting in faster delivery of workable solutions. Additionally, the consultative approach we will use to identify the sensors recommended for efficacy testing has a positive social impact by engaging all parties in developing solutions that will provide financial and practice benefits to each sector.

Once the outputs from this project are used to develop effective sensors to monitor harvest quality and losses, significant additional financial and social benefits accrue. Small improvements in extractor losses, which are currently estimated to be 5-25%, due to immediate feedback could result in an additional $2.6m/annum, adherence to HBO will become easier, and a quality-based payment system becomes feasible.

2. PROJECT OBJECTIVES

This project will undertake a feasibility study to identify the sensing opportunities most efficacious in the harvesting environment. Specific objectives to achieve this include:

a) Investigate the current practices and processes of the harvesting community, including the present use of sensors.
b) Isolate the cause and effect of harvest quality and loss and the drivers currently preventing change.
c) Identify what contractors, growers and millers need and/or wish to achieve from the addition of sensors on harvesters.
d) Identify and evaluate commercially available sensors and other measurement systems for their suitability to measure certain parameters in the harvesting environment.
e) Identify a small sub-set of systems (4 or less) most likely to succeed in future efficacy testing and develop a research strategy to support this development.

3. OUTPUTS, OUTCOMES AND IMPLICATIONS

3.1. Outputs

This project has delivered the following outputs:

- A compilation and critical review of past research on the use of sensors in the harvesting environment.
- A survey describing the participation in and attitudes towards harvesting best practice.
- A feasibility study evaluating sensors for improved harvesting feedback.
- A concise course of action for future research regarding sensors in the harvesting environment that includes: sensor techniques viable for efficacy testing, pathways suitable for testing and proposed sampling points.
- The first step towards developing a system capable of providing real-time quality and loss feedback to contractors, growers and millers which will encourage adherence to HBO and allow quality-based payment.

These outputs will primarily be used by researchers to define new projects that will test and develop the sensing systems proposed in this project in the field. Specific research groups capable of continuing these activities have been consulted with during this project.

3.2. Outcomes and Implications

This project will deliver outcomes that will benefit the entire industry by providing a plan for targeted research to improve harvesting performance. The direct users of the immediate outputs will primarily be researchers from the sensing and sugar industries. However, the long-term users of the subsequent research project outputs shall include harvester and sensing manufacturers, harvesting contractors, millers and growers.

The outputs developed in this project will be used by researchers to scope and target future research in the development of sensors in the harvesting environment. This will result in more effective and efficient research with higher adoption and implementation rates.

Sensing technology in the harvester has the potential to significantly reduce current losses and improve cane supply quality, providing a step-change in production, with minimal input. Long-term outcomes of research derived from the outputs of this project could include:

- encouraging the use of HBO through quality monitoring and data collection;
- a measurement framework for a quality-based payment system;
- reduction of losses resulting from improved harvest performance;
- improved cane supply quality
- ability to monitor/map harvesting performance across the industry;
- improved return from growing and harvesting investment by minimising sugarcane losses; and
- increased sugar tonnage industry-wide.

4. INDUSTRY COMMUNICATION AND ENGAGEMENT

4.1. Industry engagement during course of project

There has been significant industry engagement and consultation throughout the course of this project. This has been achieved through workshops, presentations at industry forums, industry-wide surveying, focus groups and one-on-one consultation. Specifically, these include:

- 2016 Herbert Variety Adoption Meeting
- 2016 Harvesting Forum series
- June/July 2016 Contractor Harvesting survey (including text message campaign)
- June/July 2016 Grower Harvesting survey (including text message campaign)
- Winter 2016 CaneConnection Magazine
- 11/6/16 ACFA e-news
- 10/6/16 SRA e-newsletter
- June/July 2016 SRA Website
- Issue 4 MillingMatters Magazine
- 30/9/16 Harvest Research Management Group Meeting
- 21/3/17 Central Region Grower Update
- 8/5/17 Isis/Maryborough Harvesting Forum and Focus Group
- 9/5/17 Bundaberg Harvesting forum and Focus Group
- 15/5/17 Harvest Reference Management Group Update
- 15/5/17 Mulgrave Focus Group
- 15/5/17 South Johnstone and Tully focus group
- 19/5/17 NSW Focus Group
- 22/5/17 Bundaberg/Isis Focus Group
- 26/5/17 Canegrowers working group

Individual consultations were held with:

- Chris and Stuart Norris, Norris ECT
- Darren Reinaudo, Herbert Contractor and Grower
- Richard Zunker, Bundaberg Contractor and Grower
- Alan Cook, Proserpine Contractor
- Troy Jensen, USQ Researcher
- Cheryl McCarthy, USQ Researcher
- Robert Crossley, Agtrix

- Ana Gonzales, Specim Spectral Imaging
- Asger Jensen, NKT Photonics
- Gino Putrino, University of Western Australia
- Tomi Väänänen, Spectral Engines OY
- Lysann Simon, LLA Instruments GmbH
- Marco Snikkers, Ocean Optics
- Chris Pederson, Viavi
- James de Haseth, Light Light Solutions Instruments
- Peter Lewis, Panorama Synergy

Phil Patane, Adoption Officer for Harvesting has been closely involved with this project for its duration. Following his employment at SRA, Anthony Curro, SRA Adoption Officer for Precision Agriculture has also been kept abreast of project activities. The whole SRA Adoption Team were recruited to help advertise and distribute the Harvesting Survey and regional Adoption Officers were used to set up focus groups.

Additional activities will be conducted through the Harvest Reference Management Group for the large, Rural R&D for Profit Project.

4.2. Industry communication messages

There is a strong appetite for the use of sensors in the harvesting environment for the monitoring of quality and loss pathways in real time. Specific focus should be on the measurement of losses, particularly from the primary extractor, automation of basecutter height control and evaluation of cane supply quality entering the bin.

Factors such as topping, feedtrain optimisation and chopper box set up and crop presentation should be managed through continuing education, rather than sensing applications.

5. METHODOLOGY

This feasibility study was broken down into six parts: (1) the Project Scope, which defined the problem and opportunity to be addressed; (2) the Current Analysis, which defined the current harvesting systems and environment; (3) the Requirements, which identified and specified the needs of the end users, who include, contractors, growers, millers, harvester manufacturers and sensor manufacturers; (4) the Approach, which evaluated each of the sensors available in the market at the moment, as well as technologies capable of being used as a sensor, against the Requirements; (5) the Evaluation, which identified a subset of systems presented in the Approach with the greatest likelihood of being efficacious in proof-of-concept, and; (6) the Review, which will be a rigorous assessment of the feasibility study and its recommendations by an independent panel. A detailed breakdown of each step in the feasibility study is provided in Section 5.1.

Much of the required information was collected through literature review, industry-wide paper and online surveys, consultation with industry experts and researchers, consultation with industry service providers (growers, contractors and millers), harvesting manufacturers, sensor manufacturers and method specialists. This consultation occurred by multiple means, including: workshops, face-to-face meetings and teleconferences. A breakdown of the data collection methodologies is provided in Section 5.2.

5.1. Feasibility study

5.1.1. Project scope

The project scope has mostly been developed during the preparation of the project proposal. However, minor revision will be required based on feedback from the Funding Unit and relevant assessors.

5.1.2. Current analysis

Project objectives (a) and (b).

Develop a detailed understanding of the current harvesting systems and environment by:

a) Identifying and defining the harvest quality and loss pathways.
b) Examining why the quality/loss pathways exist (e.g. due to fundamental design flaw, cost pressure, cropping configuration, etc.).
c) Identifying and documenting whether the causal factors of the pathway are controllable and if not, why not.
d) Evaluating the current mechanisms/methods to measure losses and harvest quality.
e) Reviewing the existing research surrounding harvesting sensors and identifying the reasons behind their success or failure.

5.1.3. Requirements

Project objective (c).

Identify what the contractors, growers and millers need from sensors in the harvesting environment by:

a) Prioritising which pathways are the most critical or valuable to control.
b) Identifying what products and constituents will provide the most useful data when analysed.
c) Identifying the level of involvement the end users are prepared to contribute for calibration, analysis, ongoing maintenance etc.
d) Understanding the limits around the value proposition for end users.
e) Receiving feedback on expected barriers and factors to consider for adoption.
f) Evaluating whether the mechanisms/methods used to measure harvest loss and quality are suitable as reference methods for sensing technologies.

5.1.4. Approach

Project objective (d).

Identify and evaluate the systems potentially suited to satisfying the requirements in Section 5.1.3. Each system will be referenced against the following criteria:

a) The product (e.g. extraction material) and analyte (e.g. sucrose) being measured
b) What type of sensor is being evaluated
c) Sample presentation
d) Location of sensor, e.g. on-harvester, in field, or at the mill
e) Installation requirements
f) Cost (sensor and installation)
g) Maintenance needs
h) Calibration efficacy
i) Ease of operation
j) Robustness

k) Practicality
l) Whether it can be retrofitted
m) Whether there will be specific hurdles with implementation
n) Software requirements and whether it can be integrated with a management system
o) Data processing requirements
p) What other system or conditions are required around the sensor
q) This section will be supported by a Patent Landscape Analysis, completed by a specialist IP lawyer, to appropriately identify freedom-to-operate around each system.

5.1.5. Evaluation

Project objective (e).

Deliver a subset of systems presented in Section 5.1.4, with the greatest likelihood of being efficacious in proof-of-concept. The evaluation will involve:

a) Comparing and contrasting the systems presented in Section 5.1.4, evaluating them on their ability to satisfy the requirements defined in Section 5.1.3.
b) Assessing the economics of each system.
c) Developing a proposal outlining the recommendations for future efficacy testing.

5.1.6. Review

A review of the feasibility study and consequent recommendations (Section 5.1.5c) will be conducted in conjunction with the Research Funding Unit.

5.2. Data collection methodologies

Different data collection methodologies were used to populate Section 5.1. These included literature review, interviews, industry surveys and focus groups. Specific methods for each are provided in the following sections.

5.2.1. Literature review

A review of the literature relating to sensors in the Australian sugarcane system was conducted via internet searching and captured in matrix format. Additional literature relating to sensing technologies is captured in the body of the report.

5.2.2. Survey

The survey was developed in consultation with Dr Dominique Greer, an expert in survey design and implementation at Queensland University of Technology. Careful consideration was given to structure the questions in an un-biased manner. Due to the size of the survey, little redundancy was included for cross-question analyses. Questions took the form of single selection (best option), ranking, rating, all options that apply, and written responses. The grower survey was 38 questions and the Contractor survey 42 questions. The survey was reviewed by a grower/contractor, the project team and several SRA staff prior to release.

The survey is composed of three individual surveys, one each for the Harvesting Contractor, Grower and Milling Company Staff. Questions specific to each sector were asked as well as generic questions around harvesting best outcomes (HBO).

The surveys and instructions were made available in paper (Section 9.2) and online (Survey Monkey) formats to encourage all people within the industry to participate. SRA Grower members were sent a paper copy of the Harvesting Contractor and Grower surveys.

Contractors not captured in the Grower mail-out were sent a text message informing them of the survey and providing a link to the SRA website, which contains links to the paper versions as well as a link to the online survey. Text message is generally the best method for communicating with the Contractors as their mill communications are typically managed this way. Milling organisations were contacted first by phone and followed up with an email containing information about the survey. This was then distributed to staff internally.

This process identified that SRA did not maintain a record of harvesting Contractor details, as they are typically not members or levy payers. This made communication directly with contractors difficult, unless they were also growers. Milling groups were used to contact Contractors on our behalf or provide contact details for Contracting Groups.

Prior to release of the survey to industry, communication with ASMC, Canegrowers, ACFA and the SRA Adoption Team occurred to generate support for the survey. Each group was provided with information to assist the industry in completing the survey and all provided support through endorsement and advertisement, particularly through their e-newsletters. The survey was also mentioned at industry events and presentation opportunities.

The majority of respondents completed the surveys in paper format. These were input into Survey Monkey by SRA staff to allow electronic data analysis of the results. The data were exported from Survey Monkey into IBM SPSS Statistics version 24 for data clean up and statistical analysis.

Repeated entries (caused by stopping and resuming data entry in Survey Monkey) were deleted. Additionally, respondents who left the survey prior to answering a minimum number of questions were deleted. Some descriptive terms were adjusted for consistency where similarities were obvious, e.g. *Delegate for SRA* changed to *SRA Delegate*. Where ‘lifetime’ or similar were recorded against farming experience, six years were subtracted from the respondents age and used as farming experience in years. Grouping variables were created to reduce the number of variables for questions such as age and region. The original responses were maintained for traceability. Frequency tables were generated for each question along with minimum and maximum information. Weighted averages were calculated where appropriate.

A summary of the survey results are attached in Section 9.3. The frequency, percent, valid percent and cumulative percent are reported. The frequency describes the number of people that answered that response for a particular question. The percent describes the frequency relative to all survey respondents, even if they didn’t answer the question. The valid percent describes the frequency relative to the people who answered that question only, i.e. the total will add to 100 %. In this report, the percent values have been reported.

5.2.3. Focus groups

The focus groups were conducted as guided discussions, where the facilitator recorded information relating to specific topics. To cover all areas to be investigated in the feasibility study, different focus groups had different key topics, although all focus groups discussed general quality and loss issues and sensors that would be useful. The information has been used to explain the survey results and direct research activities for the project, to ensure that they are industry relevant.

Attendance lists and the information recorded during the focus groups are provided in Section 9.4.

6. RESULTS AND DISCUSSION

6.1. Survey results

The survey was widely distributed and advertised among the Australian sugarcane industry. There were 406 total respondents: 114 who self-identified in the contracting role, 290 who self-identified as growers and 2 who were involved with a milling organisation. It was intended that all respondents currently involved in harvesting operations of any form answer the Contractor survey, but 22 respondents of the Grower survey also identified as harvester or haulout operators or owners. Additionally, 38 % of Growers had operated a harvester in the past and so were able to answer the questions about harvesting from a position of experience. Two respondents for the Miller survey were not enough for a statistically significant sample size and these were removed from the analysis.

Despite the long length of the survey, the responses were mostly complete and the frequent lengthy written responses indicated that the respondents provided considered, honest answers. In particular, this was indicated where respondents self- identified that they could be performing a better job.

Survey responses were used to generate an understanding of the industry's current adoption of HBM and sensing/ automation technology to facilitate HBO and act as a baseline against which, change can be measured. Overall, the survey demonstrated that cane loss and quality was affecting the industry and a positive attitude towards practice change for improvement.

Preliminary questions captured demographic information. This information showed that the respondents captured for each survey showed a distribution of age (Grower survey (G) 20 - 80+ years; Contractor survey (C) 20 - 79 years) and distribution in experience from less than one year to more than 60 years for Growers and less than one year to 59 years for Contractors. All Australian sugarcane growing regions were captured. The survey identified that both Growers and Contractors have a multiplicity of roles in their work. Additional roles ranges from Farm Hands to SRA Delegates and industry Board Members. This suggests that the responses returned were a good cross-section of the industry and should not represent a biased opinion.

There was a general opinion that cane loss is affecting Growers and Contractors equally, with approximately 50 % suggesting the loss was in the range of 0 - 14 %. Both Growers and Contractors identified mechanised harvesting as a large source of cane loss, with 55 % of Contractors and 70 % of Growers indicating that this causes 5 - 19 % loss, on average. On a 36 million tonne crop, such as that experienced in 2016, a conservative 12 % loss equates to 4.32 million tonnes of cane.

Both growers and contractors prioritised the same quality and loss pathways, based on impacts on loss and quality and the ease of adjustment in response to feedback. The priorities were:

1) Primary extractor
2) Pickup (e.g. spirals, basecutter)
3) Chopper system

The survey results demonstrated strong recognition that farming practices strongly affected a Contractors ability to adhere to HBO. Between 50 - 60 % of Growers suggested that at least a portion of their farm was set up for HBO, with features such as large headlands and row profiles matched to basecutter blades. Contractors identified approximately 35 - 40 % of the Farms they encountered were set up to facilitate HBO. Maintenance and overhead costs were an additional factor that both Growers and Contractors felt strongly affected a Contractor's ability to adhere to HBP.

Surprisingly, both parties indicated that the payment structure did not affect a Contractor's ability to adhere to HBO. This was questioned further in the focus groups. And the general consensus was that the grower had to increase profit for it to be shared with the contractor, and that it mostly was shared if bonuses were paid by the mill. There was a mild resistance to change of the payment structure, seemingly based on a fear of needing to be paid less for someone else to get more.

Approximately 55 % of Contractors and 71 % of Growers felt that sensors in the harvesting environment would improve cane supply quality and reduce losses. Approximately 20 % of Contractors had used sensors in the past. On both occasions, there was a diversity in ages of the people who were supportive of new technology and had used it in the past. It is important that extension of new technology does not exclusively focus on 'young and innovative' industry participants.

6.2. Focus group discussion

The focus groups were typically fairly small, but the optimal number for good discussion where everyone could contribute. Attendees were a mixture of harvester and haulout operators, co-op managers, mill transport coordinators, harvester manufacturers, researchers and growers. This gave a good cross-section of opinion and discussion. Focus groups were held in Bundaberg, Isis and Maryborough area, Mulgrave, Tully and South Johnstone and NSW. One-on-one discussions were conducted with people from the Herbert and Proserpine. This covered a range of production systems and regional areas to identify local issues.

In all, the attitudes towards sensors in the harvesting environment were very positive. Particular attention was given to cane loss through the primary extractor and basecutter height controllers, which dominated many of the discussions.

Focus groups began by identifying specific challenges for the Miller, Grower and Contractor relating to quality and supply issues to clarify that these were industry-wide issues affecting all.

Some focus groups contained an exercise where the group stepped through the decisions that have to be made by Growers and Operators, what data and information the use to make those decisions and whether there were and points of deficiency in the process. Some issues that were raised very frequently, but are somewhat unrelated to this project include poor communication between Growers, Operators and Millers and multi-user mapping and information storage portals were discussed where Growers could mark potential obstacles for Operators and Operators could mark specific practice adjustments in preparation for the following year to minimise reliance on memory recall. A similar tool is already provided by Agtrix, but isn't well used for this purpose (Robert Crossley, pers. comm.). Another major problem was that of recruiting and keeping decent operators and the lack of training for new Operators. These should be considered for a research program in harvesting.

6.3. Current analysis and requirements

The current analysis and requirements are comprehensively described in full in the Feasibility Study Matrix in Section 9.5. This section describes the highest priority areas flagged in that document in more detail. Initially, potential sensing platforms are described, followed by the Current Analysis and Requirements, broken down by loss pathway. This section was compiled initially through literature searching and discussion with leading industry research experts in harvesting and engineering applications. Once a framework was developed, the survey was compiled and put out to industry.

The results were interpreted by the project team and used to guide the discussion topics of the focus groups.

6.3.1. Sensing technologies

Over the last couple of decades there has been considerable advancement in the development and application of sensors in agriculture, with some fully automated systems now in use (Trapnell, 2016, Aravind et al., 2017). A brief summary of sensing technologies and their application in agriculture are provided.

GPS guidance

Before any new sensing technology is developed or implemented, it is expected that full adoption of GPS technology has occurred. GPS should be standard technology in all tillage and planting operations, haulouts and harvesters.

Discussion at focus groups identified that some harvesters and most haulouts are not on GPS guidance. This is mostly driven by cost or legislative restriction, in particular the fitting of GPS guidance to trucks used as haulouts. This should be a primary imperative for the implementation of sensors in the harvesting environment, as early work at BSES by Robotham and team (Pers. Comm.) determined it was not possible to maintain controlled traffic farming without GPS guidance.

If cost is the major barrier for the implementation of GPS systems, yet the infrastructure is critical for implementation of the modern farming systems, alternative management approaches may provide improved outcomes for the industry. GPS systems typically require base stations for operation, which are an expensive capital component. Base stations can operate in isolation and can provide a working range of several kilometres depending on terrain (although the system accuracy decreases with distance). Options exist for operators to own their own base station, possibly shared with neighbours, or a base station network may be provided by a supplier, e.g. Trimble/ John Deere, or a third party provider, such as a sugar mill or productivity board. Other third party providers may supply a generic correction signal such as CORS, where the user pays an annual licence fee to access the base station network.

Some regions, such as Mackay, have developed a regional-based system that allows multiple RTK platforms to use the base station network, whereas other regions rely on grower-owned or commercially owned infrastructure. It’s proposed that improved adoption of GPS systems could be achieved by facilitating regional multi-system, such as CORS, network implementation across all sugarcane growing areas. This could be co-operatively implemented by commercial suppliers and driven at an industry level by Canegrowers and ASMC, with support from SRA and the Government. The grower costs for implementing GPS guidance on all machinery entering the field would be reduced considerably and giving access to a highly reliable RTK correction signal.

Retrofitting GPS guidance to existing machinery is relatively simple as many harvesters and haulouts either have the wiring and valves required to install autosteer (additional cost at purchase), or are easily installed by a suitably qualified installer. The GPS guidance system for a haulout does not need to be complex, and this can be used to minimise costs. The haulout auto-steering system requires an input device or monitor with limited features, as it will only be required to follow supplied AB lines, rather than create them. In-field operation could be displayed by a simple On/Off dash display.

Implementation of GPS networks are considered essential to allow additional automation as described in the elevator section.

When discussing sensing technologies the systems can typically be divided into two sub-groups: Radar and spectroscopic (often called vision-based) techniques.

Radar

Radar refers to all active sensing systems that collect information in the 300 GHz to 3 kHz region of the electromagnetic spectrum, including microwave sensors, which operate between 300 GHz and 300 MHz. Radar works by sending waves of a certain frequency towards an object and measuring the return signal, which can give information relating to the location, size and speed of an object. The return signal can be measured in scatter, reflection, transmission or interactance (reflectance with minor sample penetration) modes. In agriculture, radar is typically used as a ground-based sensor for weather observations (Doviak and Zrnić, 2006) or a satellite-based sensor for agricultural monitoring, including crop condition, forecasting, area mapping and soil moisture monitoring (Panel, 1995) (Steele-Dunne et al., 2017, Joshi et al., 2016). Radar provides advantages over other sensing techniques as it's not influenced by cloud cover and dust generated in harsh agricultural conditions. Synthetic aperture radar (SAR) can provide 2D or 3D imaging with very fine resolution and a comparatively small antenna by using the motion of the radar platform to extend the aperture of the antenna (Inggs and Lord). Due to the frequency of radar energy, it typically interacts with structural components of vegetation and can, under certain circumstances relating to frequency and penetration depth, pass through vegetation to interact with the soil surface (Panel, 1995).

Satellite-based monitoring is typically conducted at the regional scale due to its large field of view. Alternatively, on-ground radar sensing is often used in agriculture for collision avoidance of robotics and machinery (Rouveure et al., 2004, Ghaffarzadeh and Zervos, 2017, 2015b), rather than for the evaluation of the cropping system. This has mostly been made possible through the developments in frequency modulated continuous wave (FCMW) and chirp radar, which improved radar for short-range applications. Microwave FCMW has been used to measure the height of soil-working implements and the roughness of soil due to its low cost and resistance to dust, rain, mud and turbulence (Rouveure et al., 2002), and also for measuring the distance of a cutting head in forestry, where the lower branches obstruct visual sensing techniques (Rouveure et al., 2014).

Another short-range application of radar in the agricultural environment is ground penetrating radar (GPR), which is used to measure underground features such as objects or changes in the soil profile. Although frequently used in civil engineering (Salucci et al., 2014, Wai-Lok Lai et al.), GPR is used only minimally in agriculture for soil water content(Galagedara et al., 2005, Lunt et al., 2005). Forestry use GPR to measure root presence and formation, although this is not extended to other agricultural crops (Liu et al., 2016).

Radar sensors are sensitive to the dielectric properties, size, shape orientation and texture of the target material (Steele-Dunne et al., 2017). The dielectric permittivity of a material often depends on its water content, as well as salinity and temperature (Steele-Dunne et al., 2017, Cihlar and Ulaby, 1974), and is often different for soil and plant material. While this is challenging for crop canopy monitoring by satellite, where soil is an interference that needs to be avoided, it may be useful for close-rage GPR in the harvesting environment. Ground penetrating radar is used to measure the soil horizons and impaction zones under the soil (Liu et al., 2016), while scatterometers have been used as proximal sensors to measure the soil surface in the presence of crop residues (Boisvert et al., 1998, Major et al., 1994, McNairn et al., 1996, McNairn et al., 2001).

Ultrasound is a technique that is very similar to radar, in that sounds are generated and their reflection off the target is detected and analysed. However, sound is a longitudinal mechanical wave (as opposed to an electromagnetic wave) that needs to travel through a medium such as water or air. Ultrasound waves are typically in the frequency range of 1 to 5 MHz. They have also been used in collision avoidance (AndÚJar et al., 2011), weed discrimination by height analysis (Tillett, 1991, Jeon et al., 2011) and canopy mapping (Tumbo et al., 2002)

Spectroscopic and optical-based systems

Spectroscopic or optical sensors refer to sensors in the ultraviolet (UV) to infrared (IR) range of the electromagnetic spectrum and includes such devices as IR sensors, multi- and hyperspectral cameras, near infrared (NIR) spectroscopy and simple digital camera imaging. Spectroscopic systems can be either passive, which rely on sunlight for illumination or a body's natural emission, or active, where a light source (often at a specific wavelength) is used to illuminate the sample. Spectroscopic systems come in many forms and can be used as remote systems on a satellite, aircraft, or drone; proximal systems in the field; or direct contact systems in the field.

Hyperspectral imaging systems typically collect hundreds or thousands of continuous wavelengths over a spectral region and provides this spectral information in a spatial context, with resolution from tens of centimetres to kilometres, depending on the distance between the sensor and subject (Dale et al., 2013, Cozzolino et al., 2015, Gowen et al., 2007, Govender et al., 2007). Alternatively, multispectral imaging systems collect data over few bulk wavelength bands (e.g. red, green, NIR, UV), typically each band is around 100 nm and has low resolution. Multispectral imaging is also able to provide spatial context in the same fashion as a hyperspectral imager (Cozzolino et al., 2015). The data collection and management for spectral imaging can be slow and computationally demanding, as hypercubes are built to house the spectral and image data in three dimensions. Developments in light-gathering and detection formats has improved the data collection rates and novel data interrogation and analysis methods continue to be developed (Martens and Reberg, 1999, Wu et al., 2013, Nhek et al., 2015, Fortuna and Martens, 2017, Vitale et al., 2017, Noh and Lu, 2007), as well as computer processing capacity, to improve analysis speeds. Hyperspectral and multispectral data is typically presented as an image, much like that provided by a digital camera, but false colours are used to represent variation in the spectral response at each pixel. These systems can provide detailed information on the chemical composition, colour variations, product damage and texture, to some extent (Gowen et al., 2007).

Hyperspectral and multi spectral imaging (along with NIR spectroscopy), can be performed in reflectance, or transmission imaging (Gowen et al., 2007). Additionally, sources such as lasers can be used for illumination, providing very high resolution three dimensional mapping combined with the spectral overlay (LiDAR) (Kurz et al., 2011, Dalponte et al., 2008), or as an excitation source for fluorescence imaging (Noh and Lu, 2007). These techniques are widely used in agriculture. In particular, for distribution crop residue cover (Daughtry et al., 2004), assessment of soil properties (Ben-Dor et al., 2009), plant/soil/crop residue interaction (McCarthy et al., 2010, Meyer et al., 2004), plant/plant discrimination (Zwiggelaar, 1998).

Direct NIR (Pérez-Marín et al., 2010, Marques et al., 2016) and IR (Poblete-Echeverría et al., 2016, Forrester et al., 2015) spectroscopy can also be used in field applications following recent improvements in handheld devices. Direct NIR and IR spectroscopy measures a wide range of spectral data with a fine resolution (e.g. for NIR spectroscopy 950 – 1650 nm at 6 nm resolution). While direct spectroscopy systems are typically point source, with a small sampling area, rapid analysis means many spectra can be collected in a short time and their subsequent predicted values mapped to GPS coordinates for a quasi-spatial analysis (Kerry Walsh, pers. Comm.)(Staunton, 2012).

Direct NIR spectroscopy is frequently used for soils analysis (Shepherd and Walsh, 2002) (Gomez et al., 2008), plant nutrient analysis (Batten, 1998, Keeffe et al., 2015, Liao et al., 2012) and nutrient sources (Millmier et al., 2000, Keeffe, 2013, Saeys et al., 2005). There are also many applications of direct NIR in the Australian sugarcane industry (Staunton et al., 1999, Staunton and Wardrop, 2006, Keeffe, 2014, O'Shea et al., 2013).

Spectral sensors come in a wide variety of formats that range considerably in price based on spectral range, sensitivity and sampling accessories, among other things. Some rugged hyperspectral systems, such as the Specim FX series or the LLS Instruments GmbH uniSPEC series can be purchased as complete units and range from approximately AUD15,000 to AUD80,000. Ocean Optics provide customisable units that range in price from AUD8,000 for a direct NIR unit, up to AUD20,000 or AUD100,000 for an imaging system. Alternatively, fit-for-purpose devices can be built in-house using purchased components, such as combining imaging and detection systems from Hamamatsu with miniature MEMS spectrometers manufactured by Panorama Synergy.

Instrument performance and data use

All sensors considered for use in the harvesting environment must be insensitive to or protected from vibration, moisture and dust. Mostly, systems can be purchased that are rated against these factors as they're designed for use in factory environments. Additionally, advances in technology tend to result in minimising of moving parts and improved cooling systems in equipment to facilitate these properties.

Resolution and speed of data collection varies depending in the instrument and will need to be considered in testing. These are strong influencers of price and developers should aim for a 'just enough' mentality. For example, basecutter height control will need continuous measurement to allow adjustments at the rate the harvester operator prefers. However, loss measurements can probably occur at much lower frequencies, if required. The LLA Instruments GmbH uniSPEC systems are reported to capture data on a conveyer belt operating up to nearly 11 km/hr. These systems should provide sufficient processing speed to operate as pushbroom systems on a harvester, which is optimally moving at 6 - 8 km/hr. The spectral wavelength regions optimal for specific measurements will change based on the analytic target and the sample presentation. Some instrument manufacturers, such as Ocean Optics, lease or loan a filter camera to allow proof-of-concept evaluations and assist in wavelength selection for multispectral cameras. In the absence of this service, researchers or developers may need to complete their investigative work on expensive, high-quality equipment, with the view of reducing the specifications of the eventual commercial system to only those that are required. This should ensure that the appropriate technology is developed, but can be presented in a package that is cost effective for the industry.

Telemetry and mapping of the data that is generated from the sensors may only be required on some occasions. For example, mapping of ground height for basecutter control is probably not useful once the basecutter has passed over the spot. Alternatively, mapping of the sucrose loss may be useful spatial information and could be captured in tools such as Agtrix's Harvest Management Module and capitalise on existing telemetry systems (Robert Crossley, Pers. Comm.).

6.3.2.Toppers

Toppers are responsible for removing the green cabbage from the top of the crop, with the primary motivation of reducing extraneous matter (EM). Tops comprise up to two thirds of EM in a green crop (Hurney et al., 1984). Inclusion of tops in the cane supply results in increased extractor losses due to saturation of the cleaning chamber (Whiteing and Norris, 2002).

If the cane is not cleaned effectively in an attempt to minimise these losses, the mill supply suffers through reduced tonnage and bin weights (Pope, 1998), low CCS (Whiteing and Norris, 2002) and increased fibre (Brotherton, 1980), as well as additional losses due to poor bagasse extraction and molasses exhaustion (Clarke and Player, 1988). Sugar quality is affected through increased ash, colour and RS levels (Ivin and Doyle, 1989).

In an erect crop, topping is a relatively simple exercise and 50 % of contractors identified that they always top erect cane in the survey. The most common reason not to top cane is due to presentation issues such as lodging (56 % of contractors), followed by direction from a grower (16 %). Other minor factors included fuel costs, safety (e.g. wind blowing tops back into windshield) and non-belief in the benefits of topping.

Both the growers and the contractors ranked topping poorly for impact on cane loss, quality and yield, however, contractors identified that it was a parameter that is easy to adjust in the harvester. Neither growers (rank 12 - 14) nor contractors (rank 14), felt that sensors to assist in the measurement of automation of topping would be useful or valuable to the industry. This was in direct disagreement with industry researchers, who felt that the losses and quality impacts were significant and easily minimised through practice change, with little or no cost to any party.

This disconnect was discussed during the workshops and the issue of crop presentation was frequently cited as the reason for the lack of interest. In general, the appetite for sensing in this area remained low. Most contractors felt their crops were not able to be topped. Instead of automation in this area, further research is required into better feeding or crop presentation mechanisms to allow some level of topping in lodged crops.

Due to the industry feedback, it is suggested that sensors for toppers are not developed at this point in time, but continued education in the value of topping where possible is critical to reducing the EM levels at the mill.

6.3.3. Feeding system

The feeding system for a sugarcane harvester is a complex mixture of spirals, and rollers designed to gather the cane and align it for cutting and transition through the harvester. The base cutters are also considered to be part of the feeding system, but will be discussed further in the next section. Research indicated that the feeding system impacts the quality of the cane supply and results in losses in the field of up to 5 t/ha in poor conditions (2014a). Key losses are associated with cane stalks left in the field, impacts on machine performance through glut/ starve feeding and poor ratooning due to compression and stool damage (cane snapping and tear-out)(Norris et al., 1998, Kroes and Harris, 1996). The position of the floating sidewalls and croplifter spirals also have an impact on the dirt levels in the cane supply (Ridge and Dick, 1992).

Several factors influence the quality and loss impacts of the feeding system and are a mixture of faming practice, poor communication, harvester design issues and social pressures. The crop presentation has a significant impact on how well the crop feeds into the harvester. Highly lodged crops, with poor filling in and inappropriate mound shape will results in higher losses and significant damage to the ratooning crop. This is further affected by the harvester design which operates with a fundamental mismatch between the speeds and positions of the feeding elements of the harvester, ground speed and the crop (Davis and Norris, 2002).

Pickup losses (which included basecutters) were ranked as the number 1 impact on yield by 52 % of growers and 75 % of growers ranked it between 1 and 3.

Poor pickup is a very visible loss for the grower, but there is little data to reflect the true yield loss associated with whole sticks and high stubble left in the field. Similarly, there is an anecdotal recognition that poor basecutter height optimisation causes poor ratoonability and stool rip-out, reducing the yield in subsequent seasons. Approximately 70 % of growers ranked the pickup system 1 to 3 for the impact on losses. Eighty percent of growers ranked the pickup system 1 to 4 (2 by weighted average) for its impact on cane quality. However, the research shows that the pickup system is a significant cause of billet damage, followed by the feedtrain/ chopper interaction (2014a).

Contractors prioritised the crop pick up slightly differently to growers for their impact on losses, with 20 % ranking them 3. However, similar to the Growers, approximately 46 % ranked it as 1 to 4 for impact on cane quality. The contractors also identified that the feeding systems were relatively easy to control or adjust for improvements to cane quality and reduction in yield.

In the past, engineering adjustments to the crop dividers and rollers have been attempted to improve the feeding and reduce pickup losses, but these are often retrofits by local contractors or on-farm adjustments. Despite this, a large number of survey respondents reported their harvesters were fitted with trimming saws (71 %), adjustable fronts (41 %) and hydraulically adjustable knockdown rollers (57 %). Recently, a project has been funded through SRA's Rural R&D for Profit project 1502020 *"Enhancing the sugar industry value chain by addressing mechanical harvest losses through research, technology and adoption"* that investigates matching the forward feeding elements with ground speed. Until this project has concluded and been implemented in industry, the development of sensors and systems to automate these components is not appropriate.

From the information in the survey relating to the impact of the feeding system on the cane quality and harvest losses and the ease of control for the feeding components, the feeding system was ranked second priority for development of sensing technology. Further interrogation of this through the survey and workshops identified that sensing and automation around the basecutters was the driving requirement from industry.

6.3.4. Basecutters

Basecutters are a component of the feeding system, but are well recognised as a critical quality and loss pathway with unique issues, and therefore, will be discussed separately. Losses associated with basecutter blades are difficult to quantify, however they are recognised to exist both immediately, in juice and stalk loss into the field with each cut, and long-term, through poor ratooning due to stool tear-out, shattering and biological/disease damage (da Cunha Mello and Harris, 2000). Biological damage also impacts the sugar content of the shattered cane sent to the mill. Damaged and mutilated billets are much more susceptible to biological breakdown of sucrose because of the greater surface area of the entry points.

Whiteing reports direct cane loss associated with basecutters to be in the order of 2% (Whiteing, 2013), whereas Kroes and Harris estimated the losses due to splits and partial cuts of bent stalk to be as high as 4 % (Kroes and Harris, 1997). Da Cunha Mello and Harris quantified losses due to basecutter blades to be in the order of 280 kg/ha, under standard operating conditions (da Cunha Mello and Harris, 2000).

During the 1990s, significant research was conducted by Queensland organisations into the causal factors of cane supply quality and loss associated with basecutter blades.

Primarily, they include basecutter RPM, which splits the billets and shatters the stool due to excessive blade contact at low RPM or tearing at high RPM (Kroes and Harris, 1994, Ridge and Linedale, 1997); basecutter feedrate, which causes stepped and partial cutting leading to splitting as well as stool knockdown due to stool-disk contact (Kroes and Harris, 1997, Kroes and Harris, 1994), basecutter angle (Kroes and Harris, 1994, Ridge and Linedale, 1997); blade thickness, which influences the cutting capacity of the blade and causes cane and stool shattering at high levels (2014a, Kroes and Harris, 1994, da Cunha Mello and Harris, 2001); blade shape, which influenced the quality of the cut, often shattering or splitting the cane or stool (Kroes and Harris, 1994, da Cunha Mello and Harris, 2000, Harris and da Cunha Mello, 1999, da Cunha Mello and Harris, 2001, Ridge and Linedale, 1997, Ridge and Dick, 1992); basecutter depth, which influences the amount of soil in the cane supply and can cause stool damage at deep settings or cane loss and stool shattering when set high (Henkel et al., 1979, Ridge and Dick, 1992, Ridge and Linedale, 1997); basecutter blade wear, which allows the cane to be pushed aside instead of an efficient cut (Kroes and Harris, 1994, Ridge and Linedale, 1997); and the relationship between the basecutters and the knockdown roller, which influences cane snapping and splitting (Kroes and Harris, 1994, Kroes and Harris, 1996, Ridge and Dick, 1992).

It is also well recognised that the row profile, row spacing and degree of lodging are intricately involved in the performance of the basecutters in guarding against losses and quality issues (Ridge and Linedale, 1997, 2014a).

The methods for evaluating cane loss and cane quality have been fairly consistent throughout the research activities. Kroes and Harris also developed a testing rig that allowed research on the basecutters and knockdown roller, as well as their interactions, in a controlled environment (Kroes and Harris, 1994). Following this, they visually evaluated stalk damage and developed a rating system based on the degree of splitting and the quality of the cut (Kroes and Harris, 1994), this approach became standard (da Cunha Mello and Harris, 2000). Modifications to the rig were made to investigate additional interactions, as required (Kroes and Harris, 1996, da Cunha Mello and Harris, 2000, da Cunha Mello and Harris, 2001). Where losses due to cutting, smashing and splitting were evaluated in the laboratory, mass difference before and after cutting was typically used (da Cunha Mello and Harris, 2000). Field-based testing occurred frequently under research conditions and commercial operations. Stool damage was often assessed by counting the number of stools easily removed by hand (da Cunha Mello and Harris, 2001), or by counting stool populations, gaps and final yields (Braunack and Hurney, 2001). When evaluating cane loss and the impact of dirt in cane, stalk frequency and height were typically measured and an assessment of CCS made, which included an evaluation of EM (dirt) (Henkel et al., 1979, Esquivel et al., 2008, Schembri et al., 2004). Laboratory methods to evaluate EM and cane quality often involved hand sorting of the different components and washing, fibre by disintegration, and estimation of mud solids (Bobbermein et al., 1983, Schembri et al., 2004, Henkel et al., 1979).

The causal factors for cane supply quality and loss associated with the basecutters are typically controllable. In the Contractor survey, 40% of respondents ranked the pickup system 1 to 3 for ease of control to minimise loss and 38% responded the same for maximising quality. The skill in harvesting involves balancing these causal factors with throughput requirements and cane cleaning. Under no conditions will they all be zero. Control comes in many forms. Easy, push-button adjustments like basecutter height can be made frequently, as can forward speed (dependent on yield). Despite being a manual adjustment, basecutter blades can be changed relatively easily. Basecutter RPM is not typically able to be controlled, but changes based on machine load or the number of blades on the disc.

Basecutter angle is adjustable with significant effort and so is typically set to an average row profile for the entire season by the contractor. It is SRA's opinion that growers should match their row profile to that of their harvester, rather than vice versa. However, the focus group in NSW identifies a regional preference for the grower to plant into a flat block and allow the harvester to create a 'row profile' on the first pass harvesting of the plant crop. This was thought to achieve the best match between the harvester basecutter setup and row profile. Indeed, anecdotally, many growers suggest that the harvester is the most efficient mechanism for filling in or generating the appropriate row profile. Growers in all discussion groups mentioned that it was difficult to create the appropriate row profiles due to equipment deficiencies, weather and timing.

Discussion around operational activities during the focus groups identified that basecutter height adjustment to minimise dirt in cane and losses associated with high cuts are one of the most frequent adjustments a contractors makes in the field. To make these adjustments on the go, they rely on visual observation of the quality of the job on the row beside them and a visual assessment of the amount of stool going into the bin. Occasionally during stoppages and rest breaks they will remove the trash blanket for additional confirmation. Basecutter pressure can give an indication of cutting depth and blade wear. Many experienced operators rely on 'the feel of the vibrations through their seat' to determine basecutter height, although this is becoming more difficult as the cabs modernise and driver comfort has a higher focus. Some regions receive feedback from the mill regarding the ash levels in the cane, but this is typically 12 - 24 hours later and consequently, not particularly useful.

As described in the previous section, basecutters were identified as a priority area during the focus groups. This reflected the survey outcome, which showed 20 % of contractors ranked basecutter height control as the most useful sensor for automation or feedback purposes. Basecutter height control frequently dominated the conversation during the focus groups, only surpassed by a general measure of cane loss. Many survey and focus group participants had trialled basecutter height controllers or had them on their harvesters, but few were in routine use. Typically, the systems were not used due to a belief that they did not work. Response times being too long were most frequently cited. Despite this, there was a strong appetite for research to continue in this area. An exception to this is a Proserpine contractor who routinely uses the height controller on his Case New Holland machine and believes it works well. To achieve a consistently-working sensor he spent a lot of time experimenting with the sensor to learn how to appropriately calibrate and use it for different fields and soil types. Unfortunately, the harvester supplier's sales and training staff were not appropriately educated in the operational characteristics. This highlights the importance of the appropriate training and support of any new technology in the harvesting environment, as well as the lack of knowledge in the machinery supplier sector as to how to effectively use the technology in the machines they sell.

Research on automation of basecutter height has focussed on the development of hydraulic (Esquivel et al., 2008, Garson, 1992), ultrasonic (Garson and Armstrong, 1993, Garson, 1992), acoustic (Pandey et al., 1998) and microwave sensors (Page, 2006). Each suffered from the interference of the trash blanket and harsh environment of the cutting zone. Although, this was minimised in later trials by mounting sensors on the outside of the crop dividers (Schembri et al., 2004). Variance in operation on different soil types was also frequently observed. The technology used by CaseIH and John Deere is proprietary and little specific information is provided. Typically, all of these sensors rely on some kind of field-based calibration where the minimum and maximum levels of the basecutter height are evaluated and the Contractor sets a preferred cutting height as zero point.

The height control system then aims to cut within a specific tolerance of the zero point. Most modern commercial harvesters also come with start/end of row functionality where the basecutters lift up and return to their starting point between rows. This was highly regarded by Contractors and considered an effective and functional system.

A key observation regarding the design and implementation of basecutter height controllers is the location of the sensor. The sensors are typically extremely sensitive instruments and cannot withstand the harsh environment in the throat of the machine. Additionally, they cannot impede the material flow through the harvester. To overcome this in recent times, most sensors have been mounted on the outsides of the harvester throat and measure the bottom of the furrow (Schembri et al., 2000). This relies on the assumption that the difference in height between the furrow and the top of the bed is consistent across a paddock, which it rarely is, and the movement of the front-end components of the harvester are consistent and related, which they are not. This was improved upon by the prototype microwave method which measured across the row profile, from one side of the skid to the other. They recognised that this was not measuring the same height and movement that the basecutter saw, as the skids are independent of the chassis, but the principle was effective because the top of the soil profile of the row was being measured.

A simple and effective sensor that is used in some locations throughout the industry is a basic video camera mounted to the rear of the harvester and pointed at the ground. Using this, a Contractor can relatively easily see the quality of the ground job, in a cost-effective way. Dry conditions can create a very dusty environment that blocks the view for these systems so their application can be limited for some users.

There are several potential options for the development of new sensors to improve the basecutter automation or feedback for height control. The key is to appropriately distinguish between living plant material, dead plant material and soil so that the crop/soil interface can be determined. In particular, the sensor also needs to be able to distinguish between material on the surface of the ground (e.g. horizontal stalks and trash build-up) and the soil level, as these are easily misinterpreted as ‘ground level’, causing the autonomous height systems to raise the basecutter prematurely. One way to avoid this is to smooth (average) the signal across a set distance to avoid cycling of the height controller due to minor fluctuations in sensor signal output. This will delay the response of the sensor slightly, but could be achieved well within the desired response time of the contractors, which was determined at approximately 10 meters during the focus groups.

Both spectral and radar technologies will provide solutions for evaluating the crop/ soil interface and the topography or the distance between the row profile and the harvester chassis. Advancement in technology means that some of the techniques that have already been tested may be worth revisiting. Possibly the most variable aspect is the presentation of the sample to the sensor, or rather, what is to be measured and how. Variation in measuring angle can be used to optimise different techniques or improve on existing research.

Side-view reflectance imaging of the crop/soil interface, similar to that proposed by Page (Page, 2006), is likely to be useful for both types of technique, by allowing clear delineation between the soil bed and the plant, as described in **Figure 1**. Even highly lodged or bendy cane cannot rest lower than the soil, although may travel down the edge of the row profile. This is typically cut using deeper and more angled basecutter blades to minimise pickup losses, so a sensor measuring this height would still be appropriate.

The ‘cut height’ (dotted line in **Figure 1**) either be used as a signal for the contractor to manually adjust the basecutter height against (feedback), or the response input against which the analytics determine the output for automation of basecutter height. If the positioning of the sensor obstructs the flow of material or is not feasible due to sensor robustness, the same technology could be used on the outside of the harvester to measure the next row, mapping the variation spatially in preparation for cutting.

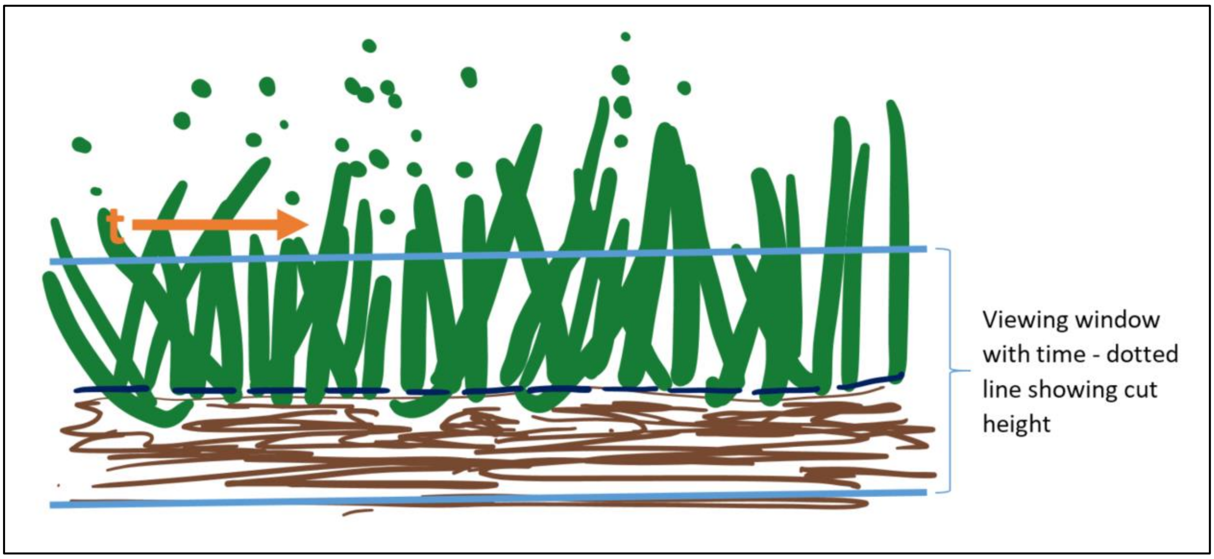

Figure 1. Image showing the viewing window of a side-view installation of sensor observing soil and base of cane plant

Radar technology could be used in this instance to measure textural variation between the plant and soil/ trash blanket, and spectral imaging could be used to map the various chemical differences between the living, photosynthetic plant stalk, non-photosynthetic trash residues and inorganic soil, which all have different spectral profiles. This discrimination, for a different application, has been used previously (Roberts et al., 1993) and is a promising solution. Potentially, even a simple smartphone-type camera system can be used for basic red, green, blue imaging in the same ways our eyes can detect the most appropriate cut height (Gino Putrino, Pers. Comm.). Combined spectral and LiDAR analysis could provide comprehensive 3D mapping of the row profile, trash layer and base of the stalks. However, the technique is very expensive and the additional resolution provided is not likely to be required.

For a side-view analysis the sensor could be located in many different positions. Ideally, it would be located in front of the basecutters, in the throat of the harvester and attached to the main chassis to avoid differential movement between the sensor and the basecutters. Alternatively, a more suitable position as far forward as possible on the crop divider to image the cane before it has been influenced by the harvester. The signal would require tracking from collection to basecutter and the height differential between the crop divider and the basecutter would be required. It would need to be installed relatively low, approximately the same height as the plant/ soil interface and mounted flush with the internal wall. Where its absorbance did not cause issues, sapphire glass would be a suitable viewing window as it’s extremely resistant to scratching and damage. Dust can interfere with spectral measurements so this should be considered in mounting and sensor evaluation.
An illumination source would be required, as any sunlight penetrating the read area would be highly variable.

An alternative orientation for monitoring basecutter height control is the more traditional top-down approach, but using the newer, microwave FCMW radar technologies and GPR technology.
The transmission depth of microwave-based radar could be tuned over short range to provide 3D mapping (vertical and horizontal) of crop layer, trash layer and soil surface and sub-surface layers as each will have a vastly different dielectric permittivity. If a sensor were mounted immediately in front of or behind the knockdown roller on the upper cavity of the chassis (or on a mounting block, if exposed), it will be protected slightly by the base of the topper and will have a fairly structured bed of cane pass under it at a uniform height and orientation (or as uniform as possible). This location would also allow the centre of the row profile to be measured, where the cane is cut by the basecutters, rather than inferring a height from the side of the row profile of the bottom of the wheel tracks. This application would take advantage of the interference from soil that is typically experienced when trying to measure crop coverage with microwave technology. Microwave radar operates very well in dusty and wet environments and often considered superior to spectroscopic techniques in this respect. Potentially, this technology could also be used to monitor a reduction in compaction long-term as growers move to the modern farming systems and full GPS guidance.

Another sensor that was discussed for basecutters was a device to show blade wear. In the survey, 23 % of growers ranked this number 2 in usefulness, whereas Contractors suggested it had mixed value. This was supported in focus groups with the reasoning that they're easy to check during breaks and down-time. A majority of contractors identified that they change their basecutters either multiple times a day (35 %), or daily (34 %). The main factors informing this decision were visual assessment (72 %), after or for cutting on a particular soil type (21 %) and feel or sound triggers while driving (19 %). Typically, both contractors and growers were amenable to a cheap and easy image-based system to monitor basecutter blades, such as a simple R, G, B still camera to take an image at the end of each row. An extension of this would be to use image analysis to map the shape of the blades and provide an alarm when the cutting edge became too short (Stegmann and Gomez, 2002, Costa and Roberto Marcondes Cesar, 2000).

6.3.5. Feedtrain and chopper system

The feedtrain and chopper system are closely linked apparatus and will be discussed as a single unit. The feedtrain comprises the butt-lifter, which is responsible for guiding the cane into the feedtrain, butt first, following cutting by the basecutters; and the roller train, a series of 9 - 10 additional rollers designed to feed the cane to the chopper box in a single, consistent mat (2014a). The chopper system comprises two parallel drums fitted with a fixed number of blades, although the number of blades can vary between machines (2014a). The blades experience wear with use and the chopper drums are designed to allow easy blade replacement.

The feedtrain controls the rate at which cane moves through the harvester body and is delivered to the choppers, which is ideally faster than it is cut by the basecutters, and 55 - 60 % of the tip speed of the chopper system. In the past, rollers in the feedtrain have been run at different speeds to facilitate cleaning (Ridge and Dick, 1988, Davis et al., 2009), but in modern harvesters this is not achieved due to high pour rates (2014a). Davis *et al.* (Davis et al., 2009) report that Norris *et al.* (Norris et al., 1998) demonstrated splitting and crushing is occurring in the feed train. Instead of improving cane supply evenness, as previously thought (Ridge and Dick, 1992), research by Hockings *et al.* on the chopper test rig identified that performance was improved with all rollers operating at the same speed (Hockings et al., 2000).

The number of blades on a chopper drum is the primary influencer of billet length (2014a), followed by feedtrain roller tip speed (Norris et al., 2000) compared to the chopper tip speed (Agnew et al., 2002, 2014a).

Early research into chopper knife sharpness showed an increase in damaged billets with knife age (Fuelling and Henkel, 1979) and Mason *et al.*, saw large increases in the percentage of damaged and mutilated billets where blunt chopper blades were used in field tests (Mason et al., 1978). Blunt knives have been demonstrated to increase juice loss from 3.5 % to 8.7 % in the chopper test rig (Hockings et al., 2000). It is expected that losses would be higher in a commercial system. Norris *et al.*, demonstrated an increase in percentage loss by weight from 2.5 % to 8.5 % using blunt chopper blades (2014a).

A significant influencer in the move towards higher blade numbers in chopper drums, resulting in shorter billets has been feedback between the mill and contractors associated with cane bin weights. General opinion throughout the focus groups was that there was an expectation to maintain burnt cane bin weights when harvesting green cane. Research by James, (in (Agnew et al., 2002)), indicates that billets of 204 mm instead of 175 mm decreased bin weights slightly but this was countered with an increase in CCS and sugar yield. Billet loss through the extractors also becomes an issue with small billets and will be discussed in Section 6.3.6.

An overarching contributor to billet and juice loss as well as billet quality for the feedtrain and chopper systems is pour rate (Agnew et al., 2002, Hockings et al., 2000, Norris et al., 2000). Essentially, the system is being overloaded and cannot operate as designed.

Ultimately, many of the factors that impact quality and loss in the feed train and chopper system are controllable and relatively static. Maintaining sharp chopper blades, reducing the number of blades per drum (or possibly, using EHS chopper drums, which anecdotally reduce billet damage), optimising feedtrain roller tip speed to chopper tip speed and maintaining a low pour rate, where possible.

There was strong recognition from Growers and Contractors about the considerable losses, quality issues and yield impacts associated with choppers, with it typically ranking 1 to 3 for Growers and 1 - 4 for Contractors. However, both Growers and Contractors consistently ranked the feedtrain mid-range for the same questions. This shows a lack of understanding between the fundamental relationship between the feedtrain and the chopper systems. The feedtrain and chopper systems were ranked mid-range when questioned about the ease of adjustment. The survey identified there was a moderate appetite for sensors around billet damage and cane loss at the chopper system, but discussions during the focus groups identified that this would not be particularly useful as minimal action can be taken once the harvester set up is optimised.

Sensing options suggested around blade health monitoring was received similarly to that of basecutters. They're fairly easy to check during breaks, but an image-based system would be useful if provided at low enough cost.

Due to the industry feedback, it is suggested that sensors for the feedtrain and chopper systems are not developed at this point in time, but continued education in the value of optimising the harvester set up to improve cane flow and reduce the number of cuts will be critical to minimising the significant quality and loss issues caused by this processes. Removing or relabelling the 'billet length' dial in the cabin would also be advantageous.

6.3.6. Primary extractor

It is well accepted in the industry that there is a strong need to redesign the harvester due to deficiencies in the cleaning mechanism. This was raised several times during the survey and focus groups. Approximately 52 % of contractors ranked the primary extractor 1 or 2 for its impact on losses in the harvester. Similarly, 46 % of Growers ranked it number 1.

The current cleaning system design operated such that a large fan, placed above the mat of cane exiting the chopper system, sucks a stream of air through the cane. Ideally, this uses the dimensionality of the cane and trash particles to extract trash and other extraneous matter (EM) from the system and leave the intact billets behind. This extraction method is high powered and very effective at removing material from the mat (Davis et al., 2009). However, increasing pour rates has resulted in very large cane mats and saturation of the cleaning chamber (Davis et al., 2009). This results in the removal of all types of cane material through the extraction system (Whiteing and Norris, 2002) in an attempt to provide clean cane for the mill. For many years, this was not recognised as a significant source of cane loss as a majority of the losses are 'invisible'. Whole billets are disintegrated following collision with the fan blades and shroud prior to exiting the cleaning chamber (Davis et al., 2009).

Research trials conducted by Agnew *et al.* illustrated that the current application of extractor fans was not well suited for reducing EM, and instead, increased cane loss significantly. A 150 rpm increase in fan speed resulted in a financial loss of $263 between the grower and contractor, as a result of cane loss measured by mass balance (Agnew et al., 2002). This research also demonstrated that there was a link between pour rate and fan speed, illustrating the financial gains by reducing both (Agnew et al., 2002). This was supported by Whiteing and Norris, who illustrated that fan speed has limited impact on EM levels, but strongly affected cane loss (Whiteing and Norris, 2002). Research by Stainlay indicated that reducing pour rates to minimise extractor losses returned financial gains to the industry, but left the contractor out of pocket due to the additional labour hours (Agnew et al., 2002).

With the current pressures on the industry to harvest the current crop size in the time period allowed and with the existing number of contractors, cane loss from the extractor system will never be removed completely. Instead, the Contractor must balance the EM in the cane supply and acceptable levels of cane loss. Pour rate, the major factor in extractor loss is controllable to some extent to reduce extractor losses and EM in the cane supply. Fan speed is easily controlled in the cab. In the survey, Contractors identified that the primary extractor was easy to control to minimise loss (45 % ranked 1 to 3) and quality issues (34 % ranked 1 to 3).

The ISLMS is the only mechanism for contractors to obtain feedback on how their practices are affecting losses. Quality indicators are received from some mills who have recently reinvigorated quality sampling in response to high fibre rates across the industry. As feedback is only received regarding one side of the equation, it's not surprising that during recent trials, extractor losses are regularly measured at 10 - 15 % (Whiteing, 2013) and periodically up to 30 % (Phil Patane, pers. comm.). Cane loss sensors for the primary extractor were ranked as the most valuable sensor and highly useful by Contractors in the survey. This was reinforced very strongly during the focus groups where loss monitors were frequently identified as the most important application for sensors in the harvesting environment.

As a consequence of the disintegration of cane lost through the extractor, one of the early measurement systems for extractor loss, the Blue Tarp Method (Linedale, 1997, Linedale and Ridge, 1996) significantly underestimated cane loss, by evaluating only whole pieces of cane and multiplying by an 'invisibility' correction factor (Whiteing, 2013). This method should no longer be used for industry research, instead the infield sucrose loss measurement system (ISLMS) (or sugar loss trailer) should be used. This system takes a large sample of trash and extracts the sugar through a mulching and washing procedure.

The brix of the extract is then evaluated and have been correlated to a sucrose value generated by high performance liquid chromatography (HPLC) (Sichter et al., 2005). Alternatively, mass balance trials should be used, where the experimental protocol allows for the personnel and time investment.

Many systems have been developed in the past with the intention of measuring extractor losses. Vibration (Dick et al., 1991, Dick and Grevis-James, 1992) and acoustic sensors (Harris, 2001, McCarthy et al., 2002) were mounted on the extractor hood or fan and measured impacts from billet hits. While neither of these systems were effective for measuring cane loss, they were suitable measures for mass flow through the extraction hood (Whiteing et al., 2004). Signal to noise discrimination was a key issue for the fan-mounted sensors. Hood mounted sensors suffered because few billets were still intact to generate a strong enough impact to register as a billet hit. The hood mounted sensors on metal hoods were fairly well regarded in industry and some are still in use, as recorded in the survey.

There are several possible sensors that could be used to measure extractor losses. To avoid some of the placement issues experienced in past sensor development, direct measure of sucrose will avoid the need to evaluate whole billets that pass through the extractor fan. Previous research has shown that sucrose levels in trash correlates well with cane loss (Sichter et al., 2005, Whiteing, 2013). Four novel sensors are proposed: handheld direct NIR spectroscopy, transmission NIR spectroscopy, proximal NIR spectroscopy and multi- or hyperspectral imaging.

Near infrared spectroscopy has been used to measure sucrose (or pol) in sugarcane products for decades. The Australian sugar industry routinely analyses pol on prepared cane for cane payment (Staunton et al., 1999) and factory control (Staunton et al., 1999, Keeffe, 2016) by diffuse reflectance. We also measure pol in juice by transflectance (Keeffe, 2016). The South African sugar industry regularly use benchtop transmission NIR spectroscopy for analysis of sucrose in juice (Simpson and Oxley, 2008)(Stephen Walford, Pers. Comm.).

Until recently, sample presentation has been a significant issue for measuring agricultural samples by reflectance NIR, a consistent flat surface was required. The advent of new instrumentation, such as the Light Light Solutions Inc. ReSpect 4πr, avoids this by taking advantage of a large scanning area of approximately 30 cm in diameter and an infinite depth of field, allowing measurement of variable height products, from a short distance. This system has been used to measure small concentrations of sugars on cotton bales in the gin (Franklin E. Barton II, Pers. Comm), which is a very similar application to the analysis of sugars on trash, as the host substrates are both primarily cellulosic. The ReSpect 4πr is a ruggedized instrument and could be mounted to the chassis of a haulout in the fleet, near the underside of the prime mover. The instrument read head should be pointed directly downward towards the trash blanket left by both the primary and secondary extractors of the harvester. As the haulout moves through the row, the instrument can automatically gather scans at fixed time intervals and provide predictions for short row portions, of around 5 - 10 metres. These measures can be provided to the contractor and mapped spatially as a % sucrose or loss measure. The position on the haulout, as opposed to the harvester will mean there will be gaps in the information to the harvester operator along with a slight delay in feedback, but discussions in the focus groups felt this was preferable if it meant all extractor losses could be captured, instead of just the primary. A single ReSpect 4πr instrument costs approximately AUD120,000, including delivery and landing costs in Australia. The cost would probably limit the installation of the sensor to a single unit per harvester, or possibly per group. However, a reduction in cost could probably be negotiated if many systems were going to be purchased across the industry.

A similar application, but lower cost option would be the use of hand-held direct NIR spectrometers for manual measurement of sucrose on trash. Due to the small scanning area of hand-held instruments, a thorough sampling methodology will be required to ensure appropriate sample representation. Some sample preparation may also be required. This type of technology would be particularly useful as a tool on the ISLMS with the aim of avoiding the manual weighing, mulching and pressing procedures for the sucrose estimate by refractometer brix. A handheld Viavi MicroNIR ranges in price from AUD8,000 for a standard device to AUD40,000 for a stainless steel process device. This type of handheld system could be value-added with maturity calibrations for cane stalks to facilitate harvest scheduling due to its portable nature and ease of use.

Calibration of both NIR spectroscopic systems would be fairly routine and there is potential that calibration models could be bolstered by the plethora of online NIR spectral data collected at the mill. Completing this activity in conjunction with the field trials being conducted for the Rural R&D for Profit project will minimise the associated trial costs.

A multi or hyperspectral sensor may be another alternative for measuring sucrose directly on the trash blanket. As they are effective at scanning over a large distance, the sensor could be mounted to the top of the harvester and look down at an angle to an area where the primary and secondary extractor outputs have settled as a trash blanket. Alternatively, this may be attached to the haulout as previously. Multi and hyperspectral sensors naturally sample a large surface area and will be effective at managing the heterogeneity of the trash blanket. Depending on the wavelength requirements, a low cost multispectral system may be feasible.

Transmission measurements by NIR spectroscopy are typically performed using a cell with a specific pathlength. This forms part of the linear equation against which concentration is measured. The pathlength is typically quite narrow, in the millimetre range, to avoid detector saturation. Cane and juice passing through the extraction hood will be a combination of solids and liquids as a fine vapour or aerosol. This may allow the extractor hood to be used as a transmission cell. By mounting the source on one internal side of the hood and the detection system directly opposite, also inside the hood, all material that flows out of the extractor hood can be measured and quantified for sucrose, and potentially fibre. This type of system does not exist commercially, but could be built fairly easily with off-the-shelf components. The most challenging parts would be optimising the focussing lenses for the detector. The likelihood of success for a sensor such as this is challenging to estimate, as is the potential cost. If this were to be developed as a research project, a commercial provider of the technology should be involved to ensure rapid deployment to industry if successful.

These sensor were discussed during many of the focus groups and were well received. Due to the high priority of this measurement, these should be the first sensors investigated.

6.3.7. Elevator

The elevator is the final passage out of the harvester. At this point the cane should be cut into consistent billets and be mostly free of EM. The elevator comprises an angled conveyor with flights at consistent intervals for the cane to rest in. AT the top of the elevator, the final cleaning stage occurs via the secondary extractor, discussed briefly in Section 6.3.8.

The elevator is not recognised as having a high impact on cane supply quality 38 % of Contractors ranked 6 to 7) or cane loss (42 % of Contractors ranked 5 to 7) and it is difficult to control or adjust. Consequently, it was not surprising that it was consistently ranked as a low priority for sensing and automation opportunities.

Although, regions that use truck-based transport mentioned the value of accurate mass sensors for bin filling during the focus groups. This was to better achieve bin weights that were as high as possible for the mill, without going over local Government road haulage thresholds. Bin filling was raised at a number of the focus groups. If all transport units are fitted with GPS guidance, slaving (leader-follower) technology can easily be implemented for automating the speed and location of the haulouts, relative to the harvester. Including additional sensors such as radar for collision avoidance means these systems can be fully automated while in the field. This technology is now widely used in the mining industry (Matrix, 2012), although still relatively new in Agriculture (Zhang and Noguchi, 2016). A focus group participant mentioned the availability of new technology where the GPS signal of harvester or (main transponder) could be shared with equipment in close proximity that didn't have dedicated GPS transponders, but instead other, low cost transponders. Investigation of this technology did not identify any commercial systems that could achieve this.

Despite not being a cause of cane supply quality issues and cane loss, the elevator is potentially a good site for sensors to monitor EM and general cane supply quality. The elevator has been used frequently in the past as a measurement point for yield, with weigh cells elevator pressure signals and elevator on/off signals being used (di Bella et al., 2009, Harris, 2001, Jensen et al., 2010, Cox et al., 1996, Cox, 2002). One challenge of using the elevator as a measurement site is the secondary extractor. If the sensor is prior to the extractor, any changes to the cane supply at cause by the secondary extractor would not be captured. However, there is little space after the secondary extractor to mount a sensor that looks at the cane on the flights. Alternatively, a sensor that looks at the falling stream of cane would be possible.

Tulip conducted a series of studies on machine vision with multispectral imager to evaluate EM in manufactured cane samples (Tulip and Moore, 2004). Unfortunately, this analysis suffered from colour resolution in the camera's pixels and long processing times. Soon after, he used UV-Vis spectroscopy and spectral unmixing to evaluate the different components in a laboratory-made cane sample (Tulip and Wilking, 2005) and identified that the different components were spectrally separable. Where cane weight fractions were over 80 %, accurate estimates of component mass fractions were achieved (Tulip and Wilking, 2005). He then used a colour camera to distinguish trash tops and billets based on texture and hue, using machine vision (Tulip and Moore, 2008). This was approaching the accuracy required of an analysis sensor, but no further work was reported.

Elevator pour rates or yield estimates could be provided by imaging and some novel data analytics. Martens and Reberg describe depth modelling of moving objects by occlusion, meaning specific depth information about the cane bundle on the flight is not required (Martens and Reberg, 2001).

Improvements in multi and hyperspectral imaging since the work by Tulip was conducted could allow effective online monitoring of EM in the cane supply by combining textural, shape and spectral analysis of the cane supply. The sensor could either be mounted in the elevator or on the underside of the secondary extractor hood measuring the stream of cane as it's flipped into the bin. If it's measured at the elevator, an assessment of what's lost through the secondary extractor will be required, or the output could be used as a guide only.

There was little appetite in the focus groups to monitor cane supply quality with sensors at the mill.

6.3.8. Secondary Extractor

The secondary extractor operates under similar principles to the primary extractor. There is little research into cane loss specifically from the secondary extractor, Whiteing *et al.* indicated that under optimal conditions, cane loss was less than 0.5 T/ha, but in high EM conditions and high pour rates, losses up to 7 t/ha were experienced (Whiteing, 2002). The secondary extractor removed approximately 20 % of EM (Whiteing, 2002). It is common practice to run large fan blades at high speeds to compensate for saturation of the cleaning chamber.

Sensing opportunities for cane loss in the secondary extractor can be captured in the same was as those for the primary extractor in Section 6.3.6.

6.3.9. Additional factors

Discussions in the focus groups and project meetings raised some additional factors that need to be considered when developing sensors in the harvesting environment, or applied to all of the topics discussed in Sections 6.3.2 to 6.3.8.

Barriers to adoption

Basecutter height control was flagged as a sensor of critical importance in the industry. It is often described as 'the holy grail'. Consequently, many sensors have been investigated and both of the major harvester manufacturers offer automatic basecutter height control systems. Unfortunately they are rarely used and the general consensus is that they don't work. However, investigations around this point more towards the fact that they're not working because they're not being set up and used properly. This is occurring because the resellers do not have appropriate technological understanding of their use and provide little or no support to Operators by way of training or set-up support. It is vital that any sensors that are developed are commercialised in concert with a rigorous and long-tern extension program. The commercial group must also continue after-sales support.

Sensors are typically technical and sensitive devices and need to be calibrated and checked fairly routinely. Research associated with development of these sensors must be realistic under commercial operating conditions. Typically this is achieved by asking contractors to run trials during their commercial operation. Concerns were raised about how this affects their ability to meet daily targets. Trials need to be conducted primarily on SRA research harvesters under semi-commercial conditions. Final assessments can be conducted under commercial operating environments to define the final value proposition.

Contractors were not able to commit to involvement around calibration development and maintenance commitments, but throughout the conversations it was clear that if it was easy (i.e., they clearly understood how to complete the process and why) and returned financial or productivity gains, they would do what was required.

Similarly, participants in the focus groups were hesitant to apply a specific value when asked about sensor costs. Instead they requested that realistic value propositions were presented and cautioned against overly large returns as they are often not believable.

Experimental data collection

Any experimental work or field trials that are conducted to evaluate the efficacy of sensors in the harvesting environment must be conducted using appropriate experimental design to allow statistically significant results to be reported. As most trials investigating sensors will likely be simple and dichotomous, comparing a particular parameter (such as cane loss) with and without the sensor, randomised complete block designs will probably be appropriate.

This controls the error for a precise estimate of the treatment effect. It is recommended the SRA Biometrics team are included in all projects developed in this area to ensure appropriate data is generated.

Additionally, the appropriate reference method must be used when collecting data to calibrate sensors. The SRA Harvesting and Engineering team should be consulted to ensure the latest techniques are being used.

SCHLOT

Norris and Norris have recently developed a comprehensive decision making tool for use by growers and contractors offline (not in real time) (Norris and Norris, 2016). SCHLOT uses complex algorithms based on world-wide harvest performance data collected over several decades, to provide scenario comparisons with financial impact assessments. It's possible that the outputs of real-time sensors in the harvester could be used as inputs for SCHLOT. This would give the contractor a wealth of inferential information based on a small amount of measured data.

Payment systems

If sensors are to be used to reward Operators for high quality cane supply and minimal losses there needs to be an allowance for the crop presentation. For example, an Operator who regularly cuts lodged cane in red soil will have consistently higher EM and higher losses, simply due to the conditions he is cutting in. It would not be appropriate for this Operator to be excluded from a bonus if the losses and cane supply quality were of an acceptable standard, given the crop. To achieve this, benchmarking systems between Operators in a similar area may be appropriate, or a rating system where the contractor and grower both rate the presentation attributes of the field and the average is used as a correction factor for the sensor output. This will need to be negotiated and decided at a regional level before sensors are used to inform payment.

6.4. Approach

The specific criteria defined in the Approach section of the proposal documentation was not used as written. This was due to the challenges in gathering this information from suppliers and evaluating things like maintenance needs in a theoretical framework. Instead, some of these controlling factors were discussed in the Current analysis and Requirements sections previously.

Spectral imaging and radar techniques will always be better equipped to deal with sample heterogeneity due to their large sampling area. Direct spectroscopic applications, are susceptible to presentation issues as particle size, compression, and composition all affect the scattering properties of the sample. This can be overcome by user training and increased sampling frequency if sample preparation processes are to be avoided.

Calibrations are required for all sensors and the monitoring and maintenance of calibrations will vary from system to system. Typically, spectral calibrations are very labour intensive to develop and can require years of dedicated data collection, however, once robust enough, are typically stable for long periods. Spectral imaging and radar technology for interface mapping may not require complex calibrations to be developed as such, but rather, confirmation that there is distinction between the two target products/ analytes under various in-field conditions and training of an algorithm to detect this difference and allow an automated response. The cost of this development should be realised through competitive research funding, but ongoing calibration and maintenance of the system will need to be transferred to a commercial provider. This should be integrated into the research project.

In theory, all sensors that have been discussed are able to be retrofitted to existing machinery.

An IP Landscape Search was initiated with TechMAC Pty. Ltd. For the following topics:

1. In line harvester sensors
2. Ground material sensors
3. Specific methods - defined sensors and data classification methods

However, the significant variability in applications and possible sensors meant that analysis was significantly higher cost than was budgeted. In consultation with the Research Funding Unit this activity was put on hold. Freedom to operate will be reviewed during the first stages of a subsequent, more specific, project as a stage-gate activity.

6.5. Evaluation

As described in the matrix in Section 9.5, several sensing opportunities were presented. Based on the priorities captured in the industry survey and the feedback from the industry focus groups, sensors for only a selection of quality and loss pathways were discussed and evaluated in detail. The shortlist is provided:

6.5.1. Extractor losses with ISLMS

Development of handheld direct NIR spectroscopic systems to support the ISLMS is low-hanging fruit that should be initiated while the extensive adoption trials are being conducted. This will minimise the calibration costs and provide an easy platform for proof-of-concept and efficacy testing. Additionally, the sensor cost is minimal. This technique is likely to be successful because NIR spectroscopy is routinely used for similar applications. Care will need to be taken to appropriately evaluate sampling issues and sample presentation.

6.5.2. Extractor losses by online analysis

Either proximal NIR spectroscopy with the LLSi ReSpect 4πr or spectral imaging should be evaluated for measuring sucrose direct on the trash blanket, in real time. The proximal NIR spectroscopic analysis is likely to be successful, but has a high capital cost with regards to the instrument. Conducting this research with a hyperspectral camera, with a view towards spectral feature selection and reduction of wavelength ranges to minimise instrument costs will be the most effective path forward. It is unknown how well the spectral imaging systems will detect sucrose levels on cane. This technique may be matched with a material flow meter at the extractor to give an indication of depth and therefore, total loss. Universities typically have access to many different multispectral and hyperspectral sensors. Conducting this research in an environment with this kind of resourcing would allow refinement of the sensor to fit the purpose and will provide the highest likelihood of identifying a viable, cost-effective sensor.

6.5.3. Basecutter height control

Top-down microwave GPR sensing and side-view imaging sensors were suggested as sensors to facilitate automatic height control. The two approaches are very different and the likelihood of success is challenging to estimate for both systems. The spectral imaging approach would provide the most comprehensive interpretation of ground/crop/basecutter interactions if successful, however microwave radar technology is more robust to the harsh environment of the cutting zone. Despite being tested previously, developments in radar technology and the proposed adjustments to installation sight, microwave GPR sensors are recommended for evaluation of basecutter height control sensors.

6.5.4. Cane supply quality

Spectral image analysis of the stream of cane falling into the bin from the elevator is likely to provide an effective measure of EM in the cane supply. Previous work by Tulip and colleagues with simple RGB cameras and NIR spectrometers showed distinction of the different trash components, but they were limited by their sensing equipment and computer processing power. It is unknown why this research did not continue after the promising outcomes. As with the sensors described in Section 6.5.2, research should be conducted with a high end imaging system, with the aim to reduce the complexity for implementation on the harvester.

7. PUBLICATIONS

No publications have been generated for this project.

8. REFERENCES

2014a. Harvesting Best Practice Manual. Brisbane, Australia: Sugar Research Australia.

2014b. A vision for the sugar industry in 30 years. *Australian Canegrower,* 36, 11.

2015a. Precision agriculture for the sugarcane industry. Brisbane, Australia: Sugar Research Australia.

2015b. *Radar sensor technology for agricultural, construction and freight vehicles* [Online]. InnoSenT. Available: http://www.innosent.de/en/company/news/view/date/2015/10/radar-sensor-technology-for-agricultural-construction-and-freight-vehicles/ [Accessed 18/6/17].

AGNEW, J. R., SANDELL, G., STAINLAY, G. T. & WHITEING, C. 2002. Increased sugar industry profitability through harvesting best practice. *Proceedings of the Australian Society of Sugar Cane Technologists,* 24, 8 pp.

ANDÚJAR, D., ESCOLÀ, A., DORADO, J. & FERNÁNDEZ-QUINTANILLA, C. 2011. Weed discrimination using ultrasonic sensors. *Weed Research,* 51, 543-547.

ARAVIND, K. R., RAJA, P. & PÉREZ-RUIZ, M. 2017. Task-based agricultural mobile robots in arable farming: A review. *Spanish Journal of Agricultural Research,* 15, 2171-9292.

BATTEN, G. D. 1998. Plant analysis using near infrared reflectance spectroscopy: the potential and the limitations. *Australian Journal of Experimental Agriculture,* 38, 697-706.

BEN-DOR, E., CHABRILLAT, S., DEMATTÊ, J. A. M., TAYLOR, G. R., HILL, J., WHITING, M. L. & SOMMER, S. 2009. Using Imaging Spectroscopy to study soil properties. *Remote Sensing of Environment,* 113, S38-S55.

BOBBERMEIN, B. C., ELKINGTON, I. & FUELLING, T. G. 1983. Dirt in cane - Assessment and incentives for clean cane. *Proceedings of the Australian Society of Sugar Cane Technologists*, 1-5.

BOISVERT, J., XU, Q., BONN, F., BROWN, R. & FUNG, A. 1998. Modelling backscatter in bare organic soils. *Proceedings of the 1998 IEEE International Geoscience and Remote Sensing Symposium.*

BRAMLEY, R. G., BAILLIE, C. P. & SCHROEDER, B. 2008. Project CSE022: A Coordinated Approach to Precision Agriculture RDE for the Australian Sugar Industry. Sugar Research and Development Corporation

BRAUNACK, M. V. & HURNEY, A. P. 2001. The position of harvesting traffic does not affect yield. *Proceedings of the Australian Society of Sugar Cane Technologists,* 22, 126-132.

BROTHERTON, G. A. 1980. The influence of extraneous matter on CCS. *Proceedings of the Australian Society of Sugar Cane Technologists*, 7-12.

CIHLAR, J. & ULABY, F. T. 1974. Dielectric properties of soils as a function of moisture content. National aeronautics and space administration.

CLARKE, W. B. & PLAYER, M. R. 1988. Effect of extraneous matter on millers' and growers' costs. *Proceedings of the Australian Society of Sugar Cane Technologists*, 39-46.

COSTA, L. D. F. D. & ROBERTO MARCONDES CESAR, J. 2000. *Shape Analysis and Classification: Theory and Practice*, CRC Press, Inc.

COX, G. J. 2002. *A Yield Mapping System for Sugar Cane Chopper Harvesters* PhD, University of Southern Queensland.

COX, G. J., HARRIS, H., PAX, R. A. & DICK, R. G. 1996. Monitoring cane yield by measuring mass flow rate through the harvester. *Proceedings of the Australian Society of Sugar Cane Technologists*, 152-157.

COZZOLINO, D., PORKER, K. & LAWS, M. 2015. An Overview on the Use of Infrared Sensors for in Field, Proximal and at Harvest Monitoring of Cereal Crops. *Agriculture,* 5, 713-722.

DA CUNHA MELLO, R. & HARRIS, H. 2000. Cane damage and mass losses for conventional and serrated basecutter blades. *Proceedings of the Australian Society of Sugar Cane Technologists,* 22, 84-91.

DA CUNHA MELLO, R. & HARRIS, H. 2001. Angled and serrated blades reduce damage, force and energy for a harvester basecutter. *Proceedings of the Australian Society of Sugar Cane Technologists,* 23, 212-218.

DALE, L. M., THEWIS, A., BOUDRY, C., ROTAR, I., DARDENNE, P., BAETEN, V. & PIERNA, J. A. F. 2013. Hyperspectral Imaging Applications in Agriculture and Agro-Food Product Quality and Safety Control: A Review. *Applied Spectroscopy Reviews,* 48, 142-159.

DALPONTE, M., BRUZZONE, L. & GIANELLE, D. 2008. Fusion of Hyperspectral and LIDAR Remote Sensing Data for Classification of Complex Forest Areas. *IEEE Transactions on Geoscience and Remote Sensing,* 46, 1416-1427.

DAUGHTRY, C. S. T., HUNT, E. R. & MCMURTREY III, J. E. 2004. Assessing crop residue cover using shortwave infrared reflectance. *Remote Sensing of Environment,* 20, 126-134.

DAVIS, R. J. & NORRIS, C. P. 2002. Improving the feeding ability of sugarcane harvesters. *Proceedings of the Australian Society of Sugar Cane Technologists,* 24, 13pp.

DAVIS, R. J., NORRIS, C. P. & C., W. 2009. A review of opportunities to improve the performance of sugarcane harvesters. Towoomba, Australia.

DI BELLA, L. P., SEFTON, M., MARRERO, S., PONCE, E., FERNANDES, F. A. N., ESQUIVEL, M. & COVENTRY, R. 2009. Sugarcane yield monitoring in the herbert river district. *Proceedings of the Australian Society of Sugar Cane Technologists,* 31, 8 pp.

DICK, R. G. & GREVIS-JAMES, I. W. 1992. The Electronic Cane Loss Monitor. *Proceedings of the Australian Society of Sugar Cane Technologists,* 14, 151-155.

DICK, R. G., GREVIS-JAMES, I. W. & HANCOCK, N. 1991. Development of an Electronic Cane Loss Monitor for Harvesters. *Proceedings of the Australian Society of Sugar Cane Technologists,* 13, 32-37.

DOHERTY, W. O. S., WALSH, K. & SUBEDI, P. 2007. Project SRI141 A preliminary assessment of methods to measure in-field sugar loss. Sugar Research and Development Corporation: Sugar Research Institute.

DOVIAK, R. J. & ZRNIĆ, D. S. 2006. *Doppler Radar and Weather Observations,* Mineola, New York, Dover Publications, Inc.

ESQUIVEL, M., CABEZAS, L., HERNANDEZ, B., MARRERO, S., FERNANDEZ, F., PONCE, E., QUINTANA, L. & GONZALEZ, L. 2006. Harvester Automation and Precision Agriculture Trials in Queensland 2006. *Proceedings of the Australian Society of Sugar Cane Technologists.*

ESQUIVEL, M., MARRERO, S., PONCE, E., GUERRERO, A., STAINLAY, T., VILLARUZ, J., WOOD, A. W. & DI BELLA, L. P. 2008. Evaluation of the automatic basecutter control system in the australian sugarcane industry. *Proceedings of the Australian Society of Sugar Cane Technologists,* 30, 322-327.

EVANS, P., PERSAUD, K. C., MCNEISH, A. S., SNEATH, R. W., HOBSON, N. & MAGAN, N. 2000. Evaluation of a radial basis function neural network for the determination of wheat quality from electronic nose data. *Sensors and Actuators B: Chemical,* 69, 348-358.

FORRESTER, S. T., JANIK, L. J., SORIANO-DISLA, J. M., MASON, S., BURKITT, L., MOODY, P., GOURLEY, C. J. P. & MCLAUGHLIN, M. J. 2015. Use of handheld mid-infrared spectroscopy and partial least-squares regression for the prediction of the phosphorus buffering index in Australian soils. *Soil Research,* 53, 67-80.

FORTUNA, J. & MARTENS, H. 2017. Multivariate data modelling for de-shadowing of airborne hyperspectral imaging. *Journal of Spectral Imaging,* 6, 1-6.

FUELLING, T. G. & HENKEL, C. R. 1979. Harvester test - Chopper knife life studies. *Proceedings of the Australian Society of Sugar Cane Technologists*, 75 - 79.

GALAGEDARA, L., PARKIN, G., REDMAN, J., VON BERTOLDI, P. & ENDRES, A. 2005. Field studies of the GPR ground wave method for estimating soil water content during irrigation and drainage. *Journal of Hydrology,* 301, 182-197.

GARSON, C. A. 1992. Control of harvester basecutter height. *Proceedings of the Australian Society of Sugar Cane Technologists*, 156-162.

GARSON, C. A. & ARMSTRONG, M. 1993. Ultrasonic base cutter ehigth control - A report n 1992 season experiments. *Proceedings of the Australian Society of Sugar Cane Technologists*, 52-59.

GHAFFARZADEH, K. & ZERVOS, H. 2017. *Agricultural Robots and Drones 2017-2027: Technologies, Markets, Players*, IDTechEx.

GOMEZ, C., VISCARRA ROSSEL, R. A. & MCBRATNEY, A. B. 2008. Soil organic carbon prediction by hyperspectral remote sensing and field vis-NIR spectroscopy: An Australian case study. *Geoderma,* 146, 403-411.

GOVENDER, M., CHETTY, K. & BULCOCK, H. 2007. A review of hyperspectral remote sensing and its application in vegetation and water resource studies. *Water SA,* 33, 145-151.

GOWEN, A. A., O'DONNELL, C. P., CULLEN, P. J., DOWNEY, G. & FRIAS, J. M. 2007. Hyperspectral imaging – an emerging process analytical tool for food quality and safety control. *Trends in Food Science & Technology,* 18, 590-598.

HARRIS, H. 2001. Development of an improved method of harvester performance testing - in association with the jet-clean system project. Brisbane, Australia: Sugar Research and Development Corporation.

HARRIS, H. & DA CUNHA MELLO, R. 1999. Kinematics, blade shapes and edges for alternative basecutter confihurations. *Proceedings of the Australian Society of Sugar Cane Technologists,* 21, 185-190.

HENKEL, C. R., FUELLING, T. G. & RIDGE, D. R. 1979. The effect of harvester basecutter setting on dirt in the cane supply and cane left in the field. *Proceedings of the Australian Society of Sugar Cane Technologists*, 19-25.

HOCKINGS, P. R., NORRIS, C. P. & DAVIS, R. J. 2000. Chopper systems in cane harvesters, B: Results of a test program. *Proceedings of the Australian Society of Sugar Cane Technologists,* 22, 250-255.

HURNEY, A. P., RIDGE, D. R. & DICK, R. G. 1984. Evaluation of the efficiency of cane harvesters in removing extraneous matter, and in limiting cane losses during the cleaning process. *Proceedings of the Australian Society of Sugar Cane Technologists,* 6, 11-19.

INGGS, M. R. & LORD, R. T. *Applications of satellite imaging radar* [Online]. Online: Department of Electrical Engineering, University of Cape Town. Available: http://www.rrsg.uct.ac.za/applications/applications.html [Accessed 19/6/17].

IVIN, P. C. & DOYLE, C. D. 1989. Some measurements of the effect of tops and trash on cane quality. *Proceedings of the Australian Society of Sugar Cane Technologists,* 11, 1-7.

JENSEN, T., BAILLIE, C., BRAMLEY, R., DI BELLA, L., WHITEING, C. & DAVIS, R. J. 2010. Assessment of sugarcane yield monitoring technology for precision agriculture. *Proceedings of the Australian Society of Sugar Cane Technologists,* 32, 14 pp.

JENSEN, T. A., BAILLIE, C., BRAMLEY, R. G. V. & PANITZ, J. H. 2013. An assessment of sugarcane yield monitoring concepts and techniques from commercial yield monitoring systems. *International Sugar Journal,* 115, 53-57.

JEON, H. Y., ZHU, H., DERKSEN, R., OZKAN, E. & KRAUSE, C. 2011. Evaluation of ultrasonic sensor for variable-rate spray applications. *Computers and Electronics in Agriculture,* 75, 213-221.

JOSHI, N., BAUMANN, M., EHAMMER, A., FENSHOLT, R., GROGAN, K., HOSTERT, P., JEPSEN, M., KUEMMERLE, T., MEYFROIDT, P., MITCHARD, E., REICHE, J., RYAN, C. & WASKE, B. 2016. A Review of the Application of Optical and Radar Remote Sensing Data Fusion to Land Use Mapping and Monitoring. *Remote Sensing,* 8, 70.

KEEFFE, E. C. 2013. *Rapid nutrient determination of sugarcane milling by-products using near infrared spectroscopy.* Master of Applied Science (Research), Queensland University of Technology.

KEEFFE, E. C. 2014. 2012352 Final Report: Developing measurement tools for nutrients and heavy metals in mill by-products. Sugar Research AUstralia.

KEEFFE, E. C. 2016. Improving mill efficiencies through rapid analysis methodologies. Brisbane, Australia: Sugar Research Australia.

KEEFFE, E. C., OSTATEK- BOCZYNSKI, Z. A., DONNAN, L. J. & O'SHEA, M. 2015. Using rapid analytical methods to quantify nutrients in sugarcane leaf tissue. *International Sugar Journal,* (in press).

KROES, S. & HARRIS, H. 1997. The optimum harvester forward speed. *Proceedings of the Australian Society of Sugar Cane Technologists*, 147-154.

KROES, S. & HARRIS, H. D. 1994. Effects of cane harvester basecutter parameters on the quality of cut. *Proceedings of the Australian Society of Sugar Cane Technologists*, 169-177.

KROES, S. & HARRIS, H. D. 1996. Knockdown causes major damage to cane during harvesting. *Proceedings of the Australian Society of Sugar Cane Technologists,* 18, 137-144.

KURZ, T. H., BUCKLEY, S. J., HOWELL, J. A. & SCHNEIDER, D. 2011. Integration of panoramic hyperspectral imaging with terrestrial lidar data. *The Photogrammetric Record,* 26, 212-228.

LIANG, Z., LI, Y., ZHAO, Z. & XU, L. 2015. Structure Optimization of a Grain Impact Piezoelectric Sensor and Its Application for Monitoring Separation Losses on Tangential-Axial Combine Harvesters. *Sensors (Basel, Switzerland),* 15, 1496-1517.

LIAO, H., WU, J., CHEN, W., GUO, W. & SHI, C. 2012. Rapid diagnosis of nutrient elements in fingered citron leaf using near infrared reflectance spectroscopy. *Journal of Plant Nutrition,* 35, 1725-1734.

LINEDALE, A. I. 1997. An Industry Campaign to Reduce Harvesting Losses. Brisbane, Australia: Sugar Research and Development Corporation.

LINEDALE, A. I. & RIDGE, D. R. 1996. A Successful Campaign to Minimise Harvesting Losses within the Queensland Sugar Industry. *Proceedings of the Australian Society of Sugar Cane Technologists,* 18, 1 - 5.

LIU, X., DONG, X. & LESKOVAR, D. I. 2016. Ground penetrating radar for underground sensing in agriculture: a review. *International Agrophysics,* 30, 533-53.

LUNT, I. A., HUBBARD, S. S. & RUBIN, Y. 2005. Soil moisture content estimation using ground-penetrating radar reflection data. *Journal of Hydrology,* 307, 254-269.

MAJOR, D., SMITH, A., HILL, M., WILLMS, W., BRISCO, B. & BROWN, R. 1994. Radar backscatter and visible infrared reflectance from short-grass prairie. *Canadian Journal of Remote Sensing,* 20**,** 47-61.

MARQUES, E. J. N., DE FREITAS, S. T., PIMENTEL, M. F. & PASQUINI, C. 2016. Rapid and non-destructive determination of quality parameters in the 'Tommy Atkins' mango using a novel handheld near infrared spectrometer. *Food Chemistry,* 197**,** 1207-1214.

MARTENS, H. A. & REBERG, J. O. 1999. *Method and apparatus for data analysis*. United STates of America patent application.

MARTENS, H. A. & REBERG, J. O. 2001. *Method and apparatus for depth modelling and providing depth information of moving objects*. United States of America patent application.

MASON, V., ALLEN, J. R., FOSTER, D. H., JAMES, R. A., CULLEN, R. N. & MENG, K. J. 1978. An evaluation of cane harvester performance. *Proceedings of the Queensland Society of Sugar Cane Technologists,* 45**,** 217-228.

MATRIX 2012. Automation & Remote Minimg. *International Mining.* Online: International Mining.

MCCARTHY, C. L., HANCOCK, N. H. & RAINE, S. R. 2010. Applied machine vision of plants: a review with implications for field deployment in automated farming operations. *Intelligent Service Robotics,* 3**,** 209-217.

MCCARTHY, S. G., BILLINGSLEY, J. & HARRIS, H. D. 2002. Development of an Advanced Cane Loss Monitoring System. *Proceedings of the Australian Society of Sugar Cane Technologists,* 24**,** 180-183.

MCNAIRN, H., BOISVERT, J., MAJOR, D., GWYN, G., BROWN, R. & SMITH, A. 1996. Identification of agricultural tillage practices from C-band radar backscatter. *Canadian Journal of Remote Sensing,* 22**,** 15-163.

MCNAIRN, H., DUGUAY, C., BOISVERT, J., HUFFMAN, E. & BRISCO, B. 2001. Defining the sensitivity of multi-frequency and multi-polarized radar backscatter to post-harvest crop residue. *Canadian Journal of Remote Sensing,* 27**,** 247-263.

MEYER, G. E., CAMARGO NETO, J., JONES, D. D. & HINDMAN, T. W. 2004. Intensified fuzzy clusters for classifying plant, soil, and residue regions of interest from color images. *Computers and Electronics in Agriculture,* 42**,** 161-180.

MILLMIER, A., LORIMOR, J., HURBURGH JR., C., FULHAGE, C., HATTEY, J. & ZHANG, H. 2000. Near infrared sensing of manure nutrients. *Transactions of the ASAE,* 43**,** 903-908.

NAWI, N., CHEN, G. & JENSEN, T. 2014. In-field measurement and sampling technologies for monitoring quality in the sugarcane industry: a review. *Precision agriculture,* 15**,** 684-703.

NAWI, N. M., CHEN, G. & JENSEN, J. P. Visible and shortwave near infrared spectroscopiy to predict sugarcane quality from clear and raw juice samples. *In:* NOOR, M. M., RAHMAN, M. M. & ISMAIL, J., eds. 3rd Malaysian Postgraduate Conference, 2013 Sydney NSW, Australia. 167-174.

NAWI, N. M., JENSEN, T. & CHEN, G. 2012. The application of spectroscopic methods to predict sugrcane quality based on stalk cross-sectional scanning. *Journal American Society of Sugar Cane Technologists,* 32**,** 16-27.

NHEK, S., TESSEMA, B., INDAHL, U. G., MARTENS, H. & MOSLETH, E. F. 2015. 2D electrophoresis image segmentation within a pixel-based framework. *Chemometrics and Intelligent Laboratory Systems,* 141**,** 33-46.

NOH, H. K. & LU, R. 2007. Hyperspectral laser-induced fluorescence imaging for assessing apple fruit quality. *Postharvest Biology and Technology,* 43**,** 193-201.

NORRIS, C. P., DAVIS, R. J. & POULSEN, L. S. 1998. An investigation into the feeding of lodged green cane by harvesters. *Proceedings of the Australian Society of Sugar Cane Technologists,* 20**,** 224-231.

NORRIS, C. P., HOCKINGS, P. R. & DAVIS, R. J. 2000. Chopper Systems in Cane Harvesters, A: Development of a Test Facility. *Proceedings of the Australian Society of Sugar Cane Technologists,* 22**,** 244-249.

NORRIS, S. & NORRIS, C. P. 2016. Modelling the sugarcane value chain: A real time decision making tool. *Proceedings of the Australian Society of Sugar Cane Technologists,* 38**,** 10 pp.

O'SHEA, M., DONALD, D., SIMPSON, J., KEEFFE, E. & STAUNTON, S. Development of laboratory near infrared (NIR) spectroscopy systems for sugar mill and refinery applications. Proceedings of the XXVII ISSCT Congress, Sao Paulo, Brazil, 24-27 June, 2013., 2013. (USB), 28: 9p.

PAGE, R. L. 2006. *Ground detection sensor for cane harvester base-cutter height control.* Masters (Research), James Cook University.

PANDEY, N., HANCOCK, N. & BILLINGSLEY, J. 1998. Basecutter height control and automatic steering of sugar cane harvesters. *International Conference of Engineering in Agriculture.* Perth, Australia.

PANEL, E. S. 1995. Satellite radar in agriculture: Experience with ERS-1. *In:* GUYENNE, T. (ed.). Noordwijk, The Netherlands: European Space Agency.

PÉREZ-MARÍN, D., PAZ, P., GUERRERO, J.-E., GARRIDO-VARO, A. & SÁNCHEZ, M.-T. 2010. Miniature handheld NIR sensor for the on-site non-destructive assessment of post-harvest quality and refrigerated storage behavior in plums. *Journal of Food Engineering,* 99**,** 294-302.

POBLETE-ECHEVERRÍA, C., SEPULVEDA-REYES, D., ORTEGA-FARIAS, S., ZUÑIGA, M. & FUENTES, S. 2016. Plant water stress detection based on aerial and terrestrial infrared thermography: a study case from vineyard and olive orchard. *Acta Horticulturae,* 1112**,** 141-146.

POPE, G. M. 1998. The effect of cane factors on bin weights. *Proceedings of the Australian Society of Sugar Cane Technologists,* 20**,** 22-27.

POSUDIN, Y. I. 2007. *Practical spectroscopy in agriculture and food science,* Enfield, Science Publishers, Inc.

PRICE, R., LARSEN, J. & PETERS, A. 2007. Development of an optical yield monitor for sugar cane harvesting. *ASABE Annual International Meeting.* Minneapolis, Minnesota: ASABE.

RIDGE, D. R. & DICK, R. G. 1988. Current research on green cane harvesting and dirt rejection by harvesters. *Proceedings of the Australian Society of Sugar Cane Technologists***,** 19-25.

RIDGE, D. R. & DICK, R. G. 1992. Soil intake with cane during chopper harvesting - minimising the problem. *Proceedings of the Australian Society of Sugar Cane Technologists***,** 24-30.

RIDGE, D. R. & LINEDALE, A. I. 1997. Targeting high soil levels in cane. *Proceedings of the Australian Society of Sugar Cane Technologists***,** 44-50.

ROBERTS, D. A., SMITH, M. O. & ADAMS, J. B. 1993. Green vegetation, nonphotosynthetic vegetation, and soils in AVIRIS data. *Remote Sensing of Environment,* 44**,** 255-269.

ROUVEURE, R., FAURE, P., MARIONNEAU, A., RAMEAU, P. & L., M.-A. 2014. A new radar sensor for cutting height measurements in tree harvesting applications. *2nd International Conference on*

Robotics, Associated High-Technologies and Equipment for Agriculture and Forestry (RHEA). Madrid, Spain.

ROUVEURE, R., MONOD, M. O. & FAURE, P. 2004. Multiple targets detection with a FMCW radar dedicated to mobile robotics. *International Conference on Radar Systems (RADAR 2004).* Toulouse, France.

ROUVEURE, R., MONOD, M. O., FAURE, P. & CHANET, M. 2002. A microwave sensor for agricultural implements. *Geoscience and Remote Sensing Symposium.*

SAEYS, W., MOUAZEN, A. M. & RAMON, H. 2005. Potential for Onsite and Online Analysis of Pig Manure using Visible and Near Infrared Reflectance Spectroscopy. *Biosystems Engineering,* 91**,** 393-402.

SALUCCI, M., TENUTI, L., NARDIN, C., OLIVERI, G., VIANI, F., ROCCA, P. & MASSA, A. Civil Engineering Applications of Ground Penetrating Radar Recent Advances @ the ELEDIA Research Center. EGU General Assembly Conference Abstracts, 2014. 1945.

SANDELL, G. & AGNEW, J. R. (eds.) 2002. *The Harvesting Best Practice Manual for Chopper-Extractor Harvesters,* Brisbane, Australia: BSES Limited.

SCHEMBRI, M. G., DAVOS, R. J. & WHITEING, C. 2004. Measuring the benefits of the SRI base cutter height control system and the floating base cutter system. *Proceedings of the Australian Society of Sugar Cane Technologists,* 26**,** 10pp.

SCHEMBRI, M. G., MCKENZIE, N. J., CONNOR, A. & EVERITT, P. G. 2000. Further advances in automatic base cutter height control. *Proceedings of the Australian Society of Sugar Cane Technologists,* 22**,** 92-97.

SHEPHERD, K. D. & WALSH, M. G. 2002. Development of Reflectance Spectral Libraries for Characterization of Soil Properties. *Soil Science Society of America Journal,* 66**,** 988-998.

SICHTER, N. J., WHITEING, C. & BONAVENTURA, P. 2005. Estimation of harvester losses by determination of sugar in harvest residue. *Proceedings of the Australian Society of Sugar Cane Technologists,* 27**,** 8 pp.

SIMPSON, R. & OXLEY, J. Routine analysis of molasses and mixed juice by NIR spectroscopy. Proceeding of the South African Sugar Technologists' Association, 2008. 245-265.

STAUNTON, S. 2012. Agriculture workshop A: Spatial Mapping of Sugarcane Composition using Infield Telemetry. Australian Society of Sugar Cane Technologists.

STAUNTON, S. P., LETHBRIDGE, P. J., GRIMLEY, S. C., STREAMER, R. W., ROGERS, J. & MACKINTOSH, D. L. On-line cane analysis by near infra-red spectroscopy. Proceedings of the Australian Society of Sugar Cane Technologists, 1999. 20-27.

STAUNTON, S. P. & WARDROP, K. Development of an online bagasse analysis system using NIR spectroscopy. Proceedings of the Australian Society of Sugar Cane Technologists, 2006.

STEELE-DUNNE, S. C., MCNAIRN, H., MONSIVAIS-HUERTERO, A., JUDGE, J., W. LIU, P. W. & PAPATHANASSIOU, K. 2017. Radar Remote Sensing of Agricultural Canopies: A Review. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing,* 10**,** 2249-2273.

STEGMANN, M. B. & GOMEZ, D. D. 2002. A Brief Introduction to Statistical Shape Analysis. Lyngby, Denmark: Informatics and Mathematical Modelling, Technical University of Denmark.

TAYLOR, J., WHELAN, B., GILBERTSSON, M., HASSALL, J. & THYLEN, L. Monitoring wheat protein content on-harvester: Australian experiences. *In:* STAFFORD, J. V., ed. Proceedings of the 5th European Conference on Precision Agriculture, 2005 Uppsala, Sweden.

TILLETT, N. D. 1991. Automatic guidance sensors for agricultural field machines:A review. *Journal of Agricultural Engineering Research,* 50, 167-187.

TRAPNELL, R. 2016. Agbot the robotic weed slayer. Queensland University of Technology.

TULIP, J. R. & MOORE, W. E. 2004. Non-invasive estimation of trash blevels in billet cane using image analysis. *Proceedings of the Australian Society of Sugar Cane Technologists,* 26, 8 pp.

TULIP, J. R. & MOORE, W. E. 2008. Identification of trash in cane using machine vision. *Proceedings of the Australian Society of Sugar Cane Technologists,* 30, 464-476.

TULIP, J. R. & WILKING, K. 2005. Application of spectral unmixing to trash level estimation in billet cane. *Proceedings of the Australian Society of Sugar Cane Technologists,* 27, 387-399.

TUMBO, S. D., SALYANI, M., WHITNEY, J. D., WHEATON, T. A. & MILLER, W. M. 2002. INVESTIGATION OF LASER AND ULTRASONIC RANGING SENSORS FOR MEASUREMENTS OF CITRUS CANOPY VOLUME. 18, 367-372.

ÚBEDA, M. A., HUSSEIN, W. B., HUSSEIN, M. A., HINRICHS, J. & BECKER, T. M. 2016. Acoustic sensing and signal processing techniques for monitoring milk fouling cleaning operations. *Engineering in Life Sciences,* 16, 67-77.

VITALE, R., ZHYROVA, A., FORTUNA, J. F., DE NOORD, O. E., FERRER, A. & MARTENS, H. 2017. On-The-Fly Processing of continuous high-dimensional data streams. *Chemometrics and Intelligent Laboratory Systems,* 161, 118-129.

WAI-LOK LAI, W., DÉROBERT, X. & ANNAN, P. A review of Ground Penetrating Radar application in civil engineering: A 30-year journey from Locating and Testing to Imaging and Diagnosis. *NDT & E International*.

WHITEING, C. 2002. Facilitation of best practice to reduce extraneous matter and cane loss. Brisbane, Australia: Sugar Research and Development Corporation.

WHITEING, C. 2013. SRDC Final report project BSS318 Measurement of in-field sucrose loss by mobile refractometry. Sugar Research Australia.

WHITEING, C., DAVIS, R. J. & SCHMIDE, E. J. 2004. Evaluation of Cane Loss Monitoring Systems. *Proceedings of the Australian Society of Sugar Cane Technologists,* 26, 12pp.

WHITEING, C. & NORRIS, C. P. 2002. BSS189 Facilitation of best practice to reduce extraneous matter and cane loss. Sugar Research and Development Corporation.

WU, T., MARTENS, H., HUNTER, P. & MITHRARATNE, K. Estimating muscle activation patterns using a surrogate model of facial biomechanics. 2013 35th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), 3-7 July 2013 2013. 7172-7175.

ZHANG, C. & NOGUCHI, N. 2016. Cooperation of Two Robot Tractors to Improve Work Efficiency. *Advances in Robotics & Automation,* 5, 11 pp.

ZWIGGELAAR, R. 1998. A review of spectral properties of plants and their potential use for crop/weed discrimination in row-crops. *Crop Protection,* 17, 189-206.

9. APPENDIX

9.1. Appendix 1 METADATA DISCLOSURE

Table 1 Metadata disclosure 1

Data	Survey results
Stored Location	Sugar Research Australia
Access	Restricted access to SRA employees
Contact	Eloise Keeffe Senior Researcher, SRA

Table 2 Metadata disclosure 2

Data	Focus group records
Stored Location	Sugar Research Australia
Access	Restricted access to SRA employees
Contact	Eloise Keeffe Senior Researcher, SRA

9.2. Appendix 2 SURVEY INSTRUCTIONS AND PAPER SURVEYS FOR CONTRACTORS, GROWERS AND MILLERS

See folder Appendix 2.

9.3. Appendix 3 SURVEY RESULTS

See folder Appendix 3.

9.4. Appendix 4 FOCUS GROUP RECORDS

See folder Appendix 4.

9.5. Appendix 5 FEASIBILITY STUDY MATRIX

See folder Appendix 5.