Re-engineering of grain grinding/sieving in commercial mills and application of software

Report prepared for the
Co-operative Research Centre for High Integrity Australian Pork

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September 2018

Pork CRC

Australian Government
Department of Industry, Innovation and Science

Business
Cooperative Research Centres Programme

Executive Summary

Rationale

Despite work within program 4B identifying up to 20% improvement in feed efficiency by removing grain particles >1 millimetre in the feed milling process there has been little to no uptake of recommended mill grinding modifications by commercial feed mills. This project completed desktop feed mill grinding re-engineering options for four commercial feed mills. Additionally a grain threshold particle size algorithm developed through project 4B -123 provides an opportunity for the pig industry in having a tool that can be used to monitor grain particle size and the potential impact on growing pig performance.

Outcomes

From the completion of desktop re-engineering reports it was identified that significant costs were involved. Across the four commercial feed mills involved in this project the cost of re-engineering, including equipment and labour ranged from $202,730 to $480,550. While not insignificant amounts the true cost of re-engineering the feed mills is far greater than this amount when you consider the cost of 'mill down-time'. This is the time the mill would not be available to operate. For two of the mills 'mill down time' was estimated to be 5-6 days. For these mills the cost of seeking alternative feed supplies plus additional freight to ship the feed from an alternative site would increase project costs by up to 25%. This is assessment is based on the grinding system being commissioned without further mill downtime.

Sieving of ground grain samples was identified as a limitation when the grain particle size algorithm from project 4B-123 was assessed. The feed industry traditionally measure grain particle size using 5 sieves however to provide enough data 9-10 sieves were needed when using the algorithm. While sieving ground grain, or feed, with 9-10 sieves can be done it was assessed as being a laboratory based assessment due to the complexity of using such a large sieve apparatus. Additionally when using the algorithm a curve of best fit needs to be selected which again was assessed as a technical role.

Relevance

This study has shown that feed mills may not need to be re-engineered in the first instance. Greater focus on monitoring grinding equipment and establishing a base line particle size capability should be the first step. In this study the exact same grinding equipment run using the same parameters such as screen size and RPM's resulted in vastly different particle size results. This illustrated that grinder set up and monitoring will have the largest impact on grain particle size. The data provided by the grain particle size algorithm illustrates an opportunity for the industry to gain 0.60-0.70 MJ DE through reducing or eliminating particles greater than 1mm in growing pig diets.

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1. Introduction

Research within Pork CRC 4B projects has shown that removing grain particles >1 millimetre can improve efficiency of feed use by >20% by minimizing energy loss through microbial fermentation and preventing the ileal brake which reduces feed intake. A survey of commercial and home mixers identified a large proportion of grain particles above 1000 microns following milling. Several methods have been canvassed to re-engineer existing mills to remove large particles without increasing particles <400 microns. These options have not been incorporated in commercial mills to date because the cost and inconvenience of retrofitting mills is unknown. This project comprised two parts: (i) a desktop study of options available and cost/benefit analyses for four stock feed plants in Victoria, NSW & South Australia and (ii) evaluation of software and algorithms arising from two integrated projects through University of Queensland.

2. Methodology

The project had two parts (i) cost/benefit analysis of retrofitting existing feed manufacturing plants and (ii) evaluation of algorithms and software developed in the Associated Projects.

The capacity for commercial companies like Ridley AgriProducts and Rivalea to re-engineer a feed manufacturing plant without a full economic evaluation is remote. Consequently, this project completed a desktop study at two selected Ridley AgriProducts stock feed plants with different layouts, Rivalea Corowa and the SunPork feed mill at Murray Bridge. The study examined the costs and benefits from alternative methods of retrofitting the plants to ensure that grain particle sizes be controlled to have a maximum size cut-off. Alternative strategies to be considered include among others, sieving and regrinding large particles; hammer milling and then passing through roller mills with a maximum size particle gap; and post-mix milling.

The analysis required engineering consultation with mill managers and operators, costing of retrofitting, loss of production during retrofitting and likely benefits to pig producers.

Recommendations for change were made for each plant.

The second and third components of the project evaluated under commercial conditions:

- algorithms for calculating the effects of feed ingredients on feed intake of pigs; and
- threshold particle size calculator; developed as part of the Associated Project 4B 123.

This piece of work was undertaken by each mill sending samples of ground grain or mash finished feed to two selected feed mill laboratories for sieve testing. The sieves employed ranged from 4 mm down to the pan. Results were compiled by the project manager and then put into the algorithm developed in project 4B-123. The algorithm is designed to provide energy reduction and threshold particle size data.

3. Outcomes

Mill engineering review

Mill engineering requires specialist skills that are available in Australia through a relatively small number of businesses. For the purposes of this project the engineering group LGPM Process Innovation were contracted to visit each site, Rivalea Corowa, SunPork Farms Murray Bridge, Ridley St.Arnaud and Ridley Mooroonpna and complete a review of particle size management. After completing this particle size review they provided a best cost engineering solution to ensure each feed mill was able to ensure all grain particle were less than 1000 micron.

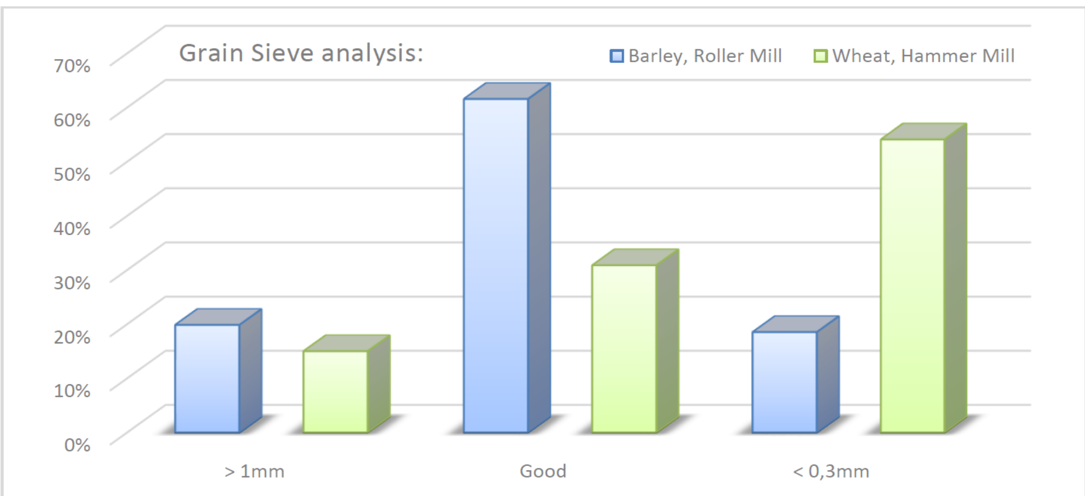
For each mill a full report, including particle size review, re-engineering options, optimal re-engineering option specifications and full financial costings was provided by LGPM. Confidentialities exit between the Pork CRC, LGPM and participating mills so these reports are not attached to this final project report. In order to provide an insight into variation in particle size and feed mill re-engineering costs general graphs and mill engineering feedback is provided below.

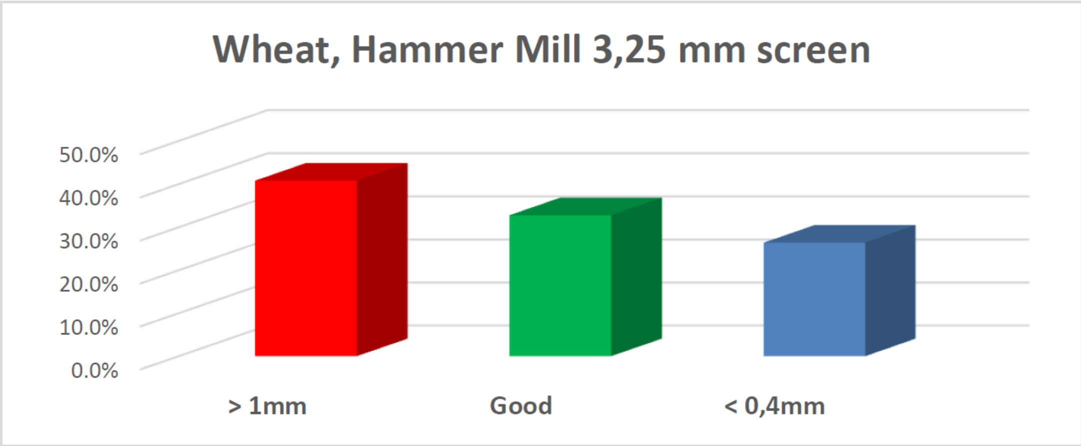
Particle size review

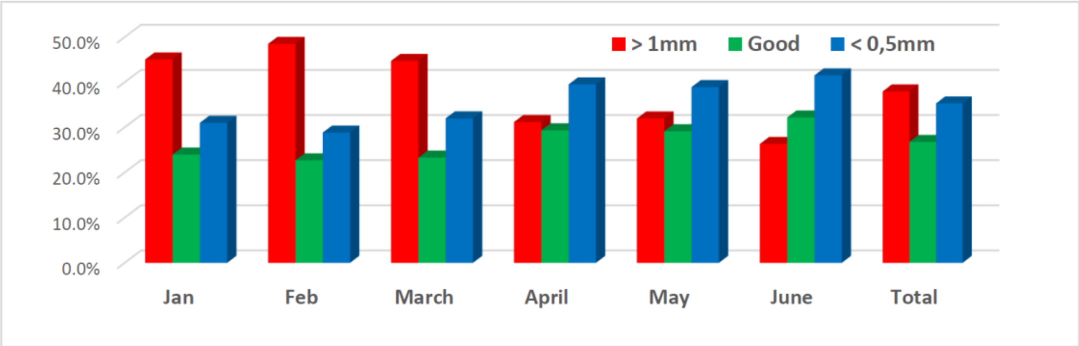
For all mills, the grain particles (including full mix for one mill) above 1000 micron ranged from 20-40%. Optimal particle size ranged between 20-60%. Only for a roller mill did optimal particle size reach 60%. For all other grinder type's optimal particle size ranged between 20-30%. Fine particle size ranged between 20-50%. The results from this review line up closely with the previous trial work completed through Pork CRC.

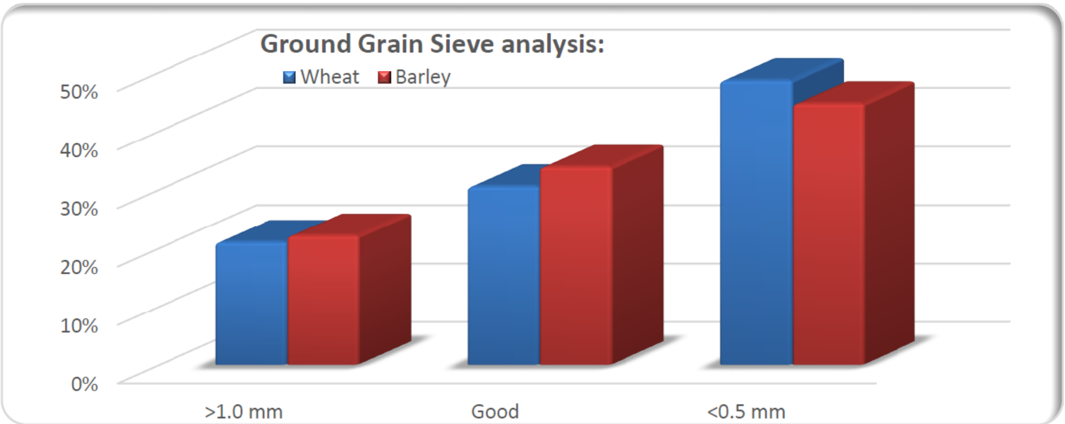
Indicative graphs showing the particle size variation. No specific site reference.

Figures 1-4 – Indicative particle size review from commercial feed mills.









Engineering evaluation

At each site, the engineering review identified a series of opportunities for improvement. A full list of opportunities across all participating sites are described below.

1. Old grinder design. The design of the same grinder today would be expected to provide more consistent grind size and also less particles above 1000 micron.
2. Grinder running at double the specified speed.
3. Hopper too small for the speed of operation.
4. Position of suction point filter is not optimal.
5. Grinding system under dimensioned for the size of plant.

6. No air inlets or control of incoming air.
7. Manual setting of grinder required. Automatic setting equipment would be beneficial.
8. Regular monitoring of grinder performance required.
9. Inclusion of various sensors now available on the market (such as heavy particle sensors) would help monitor and manage grinder performance.

Engineering alternatives and final recommendation

For each site, the full engineering review identified up to three common alternative re-engineering solutions.

- **Alternative 1 -** Replace old grinders with new generation grinders of the same type.
- **Alternative 2 -** Replace grinders with new two stage roller mills – which are designed to be more energy efficient while also providing greater grain particle size consistency. For roller grinders it must be noted however that it is particularly difficult to grind all coarse grains and pulses. Alternative grinding options may be needed for these ingredients.
- **Alternative 3 -** Sieve and re-grind grain.

Each of the alternative engineering solutions were reviewed in terms of cost benefit to the feed mill and therefore pig feed customers. In all cases this analysis included reviewing the cost of equipment, structural changes required in the mills, cost of commissioning, cost of accommodation and travel for the team of mill engineering specialists completing the work and the amount of time each mill would need to be stopped ('down time') so as to complete the work.

For all mills the costs associated with alternatives 1 and 2 where deemed by the engineers as cost and time prohibitive. The scale of these alternatives for each site would require up to 6-7 days of 'down time' which given the nature of feed milling is not tenable, as alternative feed supply for not only the pig feed being manufactured but also a range of alternative commercial feeds, could not be found for each mill reviewed. Additionally an amount of disruption in each mill would be required to structurally prepare the mills prior to commissioning. This would need to occur while the mills were still operating and would mean the capacity of each mill would be substantially reduced requiring the sourcing of some feed from an alternative mill on an as needed basis. The largest cost in this scenario was the cost of freight from the alternative supply mill to the customer.

For each mill in this review, the most cost effective engineering solution for all grinders (excluding a single roller grinder that is in place at one mill) was deemed to be alternative 3 above. This alternative would require a relatively cost effective sieve placed immediately after the grinder to sieve off particles above 1000 micron and place them immediately into the grinder line again. The cost of this alternative by mill ranged from just over $200k to just under $500k. Table 1 below identifies the specific equipment and engineering costs. Those mills with multiple grinders have higher equipment costs. The costs not included are those for downtime when commissioning the new sieving equipment. The expected downtime for this solution ranged between 2-6 days. For two mills where commissioning could be completed in 2 days it is expected this work could be completed over a weekend and therefore not incur mill downtime. For the mills where commissioning is expected to take 5-6 days mill downtime is expected to be a significant cost and could well make this alternative (in the form recommended by the engineers) unpractical due the length of commissioning. Such a review would need to be undertaken by each of the mills in question.

For the single roller grinder the recommended solutions was to look at increasing the capacity of this grinder so it could grind greater volumes of grain while also installing some automation around roller settings. Additionally the opportunity to look at different fluting for the rollers would improve grinding efficiency. While not every particle could be guaranteed to be below 1000 micron, the engineers believe close monitoring would deliver the required grain particle size through a roller grinder.

Table 1 provides a snap shot of equipment, steel and engineering costs associated for the mills in the review. The mills have not been identified to ensure confidentiality is retained. For mill 3 two alternatives options were provided given the design of that mill. In all cases, the costs are substantial when compared to the quantity of commercial pig feed manufactured. Further to this, not all animal species are seeking the same particle size settings. The ability of commercial feed mills to provide a range of particle sizes depending on animal species and stage of production requires further investigation by each individual feed mill. The alternatives presented in this project provide an insight into how particle size management can be practically managed when retrofitting commercial feed mills.

Table 1: Cost ($A) of selected engineering recommendations by mill (cost of labour, travel and accommodation is the difference between totals and individual mill items)

Mill	**1**	**2**	**3a**	**3b**	**4**
Sieving equipment	$121,180	$51930	$191280	$62730	$195,400
Steel	$21070	$21070	$66390	$41330	$32070
Engineering /commissioning	$41610	$39490	$65250	$51840	$64040
Total	**$291920**	**$202730**	**$480550**	**$272030**	**$464820**

Application of particle threshold algorithm

The second and third parts of this project centered on the application of an algorithm calculating the reduction in energy available from grain due to particle size and the threshold particle size. The algorithm tested was developed as part of project 4B 123 through the University of Queensland.

In order to provide the level of particle size detail required for the algorithm additional sieves where required to be used when sieving grain or finished feed samples. Traditionally the feed industry utilizes up to 5 sieves when completing a sieve test in the mill environment. For the purposes of this review 9-10 sieves where required which meant that all mills included in the trial were unable to complete the test in the mill environment – based on the physical sieve deck height and the skills and capabilities of the mill operators. The sieve deck is so high and difficult to manage that the task of completing the sieve test was given to trained laboratory or nutrition professionals. Even with these professionals completing the test variation in results occurred between practitioners and further development of a specific sieving protocol when using 9-10 sieves is required.

The project manager compiled the results for each sample that was sieved and then used the algorithm from project 4B 123 to assess threshold particle size and the energy reduction based on the percentage distribution of the particles in each sample.

In total 35 samples of ground grain (wheat and barley) or finished feed were sieved. At the time of writing this report, the algorithm still required some development, as the threshold particle size could not be consistently calculated. Curve type needs to be selected to ‘best fit’ the percentage particle size curve. Again this was deemed to be a technical task rather than an in mill application. There was however good data generated for energy reduction as detailed below in table 2. At the time of writing this report, there was a problem with getting the roller grinder data recognized by the algorithm so the results for those samples remain blank.

Table 2: Threshold particle size and energy reduction* (%) from grain for feed ground using different grinding equipment.

Sample #	Sample Type	Grinder type	Threshold particle size (Micon)	Curve type selected	Energy reduction (%) *
1	Wheat	Hammer Mill	682	Skewed Normal	4
2	Wheat	Hammer Mill	682	Skewed Normal	4
3	Wheat	Hammer Mill	682	Skewed Normal	2
4	Wheat	Hammer Mill	682	Skewed Normal	3.8
5	Wheat	Hammer Mill	682	Skewed Normal	4.6
1	Barley	Hammer Mill	682	Normal	5
2	Barley	Hammer Mill	682	Normal	1.4
3	Barley	Hammer Mill	682	Normal	3.1
4	Barley	Hammer Mill	682	Normal	3.7
5	Barley	Hammer Mill	682	Normal	4.8
1	Feed	Disc Mill	682	Skewed Normal	8.4
2	Feed	Disc Mill	682	Skewed Normal	9.8
3	Feed	Disc Mill	682	Skewed Normal	7.6
4	Feed	Disc Mill	682	Skewed Normal	9.5
5	Feed	Disc Mill	682	Skewed Normal	9
1	Feed	Disc Mill	682	Skewed Normal	9.4
2	Feed	Disc Mill	682	Skewed Normal	8.9
3	Feed	Disc Mill	682	Skewed Normal	9.2
4	Feed	Disc Mill	682	Skewed Normal	9.7
5	Feed	Disc Mill	682	Skewed Normal	9.1
1	Wheat	Hammer Mill	682	Normal	7.3
2	Wheat	Hammer Mill	682	Normal	5.4
3	Wheat	Hammer Mill	682	Laplace	12.5
4	Wheat	Hammer Mill	682	Laplace	7.2
5	Wheat	Hammer Mill	682	Normal	5.1
1	Wheat	Roller Mill			
2	Wheat	Roller Mill			
3	Wheat	Roller Mill			
4	Wheat	Roller Mill			
5	Wheat	Roller Mill			
1	Barley	Hammer Mill	682	Laplace	11.8
2	Barley	Hammer Mill	682	Laplace	12
3	Barley	Hammer Mill	682	Laplace	11.8
4	Barley	Hammer Mill	682	Laplace	11.8
5	Barley	Hammer Mill	682	Laplace	11.7

***Energy reduction relates to the amount of energy the pig is unable to extract from the ground grain or feed due to the proportion of particle greater than 1mm.**

It is the view of the project manager and feed mill participants that the algorithm definitely has merit as a further monitoring tool associated with feed manufacture. The complexity of completing the sieve test means that it is not likely it will be an in mill test but rather a test completed in either an internal feed mill laboratory or a commercial laboratory. To this end, further work is required to review and formalize the actual sieving protocol due the complex nature of using such a large number of sieves. The project manager is aware that automatic sieve machines are available for this number of sieves, which would help reduce the effect of individual operator on the sieve results. That said the nature of the grain or feed sample being sieved can sometimes lead to sieve blockages, which does require manual intervention by a trained laboratory operator.

4. Application of Research

This project has identified alternatives to retrofit conventional feed mills to better manage grain and feed particle size. In all circumstances, the costs of completing this work are considerable and for alternative options such as replacing grinding equipment, are cost prohibitive from both an equipment (capital) and mill down time for the work to be completed. The cost benefit analysis for the mills included in this project also relates to the volume of pig feed manufactured and the volume of alternative species feeds manufactured. Each mill included in the project are best placed to complete this assessment.

Completing the review of particle size identified that there is benefit to the pig industry through feed suppliers or home mixers being able to better manage particle size depending on the stage of pig production. The reduction in energy available to the pig ranged from 1 – 12% depending on the type of grinder and distribution of particles above 1000 microns. At this higher end of this range (where many samples sit) there is potential to halve the reduction in energy through reducing the quantify of large particle above 1mm. Factoring in a reduction from 10% to 5% improves energy availability from the grain component of creep through grower feeds by 0.60 to 0.70 MJ of DE.

Further, the variation in grinding results from this analysis identifies that from the same grinding equipment, operations management (grinder set up and monitoring) strategies can substantially influence the level of energy reduction. Do feed mills need to change equipment, add in additional sieving or adjust current equipment to better manage grain or feed particle size? The results from the ground grain analysis indicates that grinding equipment set up and monitoring provide the quickest and most cost effective method for improving pig performance. Feed manufacture is a specialized skill and should be considered a technical aspect of all pig production systems be they internal or external suppliers. Pig producers are encouraged to have a close working relationship with their feed supplier or look more closely at their own grinding systems set up and monitoring if they home mix their feed.

5. Conclusion

In summary, it has been identified that (a) thorough engineering reviews at selected commercial feed mills illustrate that reengineering the grinding capabilities of commercial feed mills is largely cost prohibitive when compared to maximizing the capabilities of grinders already available. This considers individual mill setups, by species feed supply mix requirements and also the mill down time that would be needed to make the necessary changes; (b) robust monitoring of feed mill grinding capabilities and establishing standards that reduce/minimize grain particle above 1mm for growing pig feed are achievable in feed mills; (c) the application of project 4B-123 threshold particle size calculator has merit as a particle size and grain energy availability monitoring tool for feed mills, and (d) further work to establish a sieving protocol using 9-10 sieves and selection of the curve of best fit is required.

Acknowledgements

I would like to thank the team at LGPM headed by Errol Shaw for the engineering reviews at each site. Thanks also to Andrew Philpotts and David Henman at Rivalea, Sally Tritton and Bjorn Ludvigson at SunPork Farms Murray Bridge and Louise Edwards, Ian Fairbairn and Mark Morrissey at Ridley.

In relation to project 4B 123 thanks go to the UQ team, John Black and Simon Diffey.

6. Limitations/Risks

The most compelling limitation identified from this process is on the cost of alternative mill grinding equipment and also the cost of mill down time to complete the most cost effective engineering solution recommended. The costs are at a magnitude that all participants in the project have identified that return on capital is prohibitive without a significant offset to the cost of feed. An alternative approach could be feed mills and the feed customers establishing a process for sharing the costs based on, amongst other factors, improvements in pig performance. Measurement of pig performance pre and post completion of the mill re-engineering would need to be discussed and agreed between the feed mill and the customer.

Other limitations include the amount of structural work needed at two of the sites prior to the alternative engineering strategies being able to start. The feed mills included in this project run continuously through the week and into the weekend. Any structural work would require mill downtime for periods of up to 5-6 days, which is not practical for these mills.

This project has identified that not all equipment of the same class generates the same results. Manufacturing setup and monitoring has a major impact on particle size and for that reason the skills and capabilities of feed mill operators is both an opportunity and risk.

Finally, and linked to the risk above, is the variability within and between ingredients observed in Australia. Depending on varietal, climatic and agronomic factors, grain size, for example, can vary considerable. This has a direct effect on grain grinding efficiency and may be a risk unless robust procurement and receival procedures are in place to help manage this risk, such as monitoring grain size.

7. Recommendations

Because of the outcomes in this study, the following recommendations are:

1. Establish an industry protocol for sieving raw materials / finished feeds using 9-10 sieves.
2. Commercial feed millers and home mixers should monitor grinding performance to initially establish a base line grinding capability. Following the establishment of a baseline implement actions to reduce/minimize the number of particles greater than 1 mm in feed for creep, weaner and growing pigs. Such a base line should consider grain receival data such as particle size.
3. Further work should be carried out to ensure the particle size algorithm works consistently.

Appendices

Appendix 1: Engineering reports –These are confidential and have been removed from the public version of the report