final report

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Prototype feed truck auto-delivery refinements

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Executive summary

Feed delivery to bunks requires consistency, and key indicators include delivery duration, accuracy, and uniformity of feed distribution across the optimal bunk length.

At most feedlots, daily feed deliveries are via a manually operated feed truck, and these are usually split across morning (usually 40%) and afternoon (60%) deliveries; of course, there are exceptions to this protocol, especially for starter cattle. The delivery process is very labour-intensive, requiring several parallel activities to be completed with high proficiency, including normal truck controls (steering, throttle, brakes, environment awareness), feed flow control for even delivery along a pen bunk length, and delivery accuracy. The accuracy of delivery is limited to the on-board scale and indicator, usually ±10kg, and any delivery event outside of this limit is included in a daily exception report for corrective action. Overfeed events can also require shovelling out surplus feed from the bunk.

An enquiry towards improvements in feed truck delivery performances were the genesis of MLA project P.PSH.1079. This precedent project delivered a world first auto-delivery system retrofittable to the mixer bins of commercial grade delivery trucks, and this system was successfully prototyped at Bindaree Beef Group's (BBG) Myola Feedlot. Through an agreed experimental protocol under normal operating conditions, the prototype and human operators were evaluated against several criteria for delivering steam-flaked wheat finisher ration. The precedent project's experiment outputs objectively demonstrate that the prototype system provided more accurate and more time-effective first pass and final deliveries than humans.

Key design features of the prototype system include its high-accuracy positioning solution based on RTK global navigation satellite system (GNSS) technology, it is retrofittable to feed trucks and scale heads that are commercially available, it can be switched between automatic and manual feeding modes, and the feed gate has an interlock preventing feeding errors if the feed truck arrives at the incorrect pen. While other commercial passive (operator assist) systems may already be available, we understand this is the first time an active computer-controlled system has been delivered and validated.

With a view to refining the working prototype as a more robust and commercially viable outcome, several improvements were required for the prototype system at Myola Feedlot. Most significantly, algorithmic refinements were required to enable more robust and reliable feed deliveries under normal operating conditions, and to include all rations, all masses, to all pen lengths, with minimal reversing.

After these control system refinements were completed, and appropriate operational confidence was garnered, an eight-week serialised experiment under normal operations evaluated the prototype system versus human operators. The review process considered performance criteria agreed to be relevant to all stakeholders. The distilled experiment results objectively show that the prototype system outperforms human operators with less reversing and therefore less distance travelled, and achieves higher accuracy in meeting total delivery allocation for target pen. The average travel speeds for each delivery mode were sufficiently different that direct comparison does not appropriately quantify time-based metrics, and it follows that extracting objective performance indicators is very difficult given the multi-variate nature of the problem. After the travel speeds for delivery sequences (i.e. travel within target pens) were normalised to the average human rate of

3.0kmh^{-1}, it was determined that the prototype system enabled 19.2% faster feeding in tons per hour; for clarity, this is a proportional improvement of tons delivered per hour when the truck was in pens and outputting feed. The maximum benefit of this performance improvement was probably not fully visible, as the truck's utilisation (again, time in pen) was only 20.4% of its working day (observed, 16.5% after delivery speeds normalised), so the significant feed rate improvement is diluted by the majority of working time consumed by factors such as travel, reloading at mill and mixing delays, and external operating disruptions.

Based on the results of this project, the prototype auto-delivery system demonstrates exciting promise to improve feed delivery to bunks, with performances superior to human feed truck operators. In the short-term, our results suggest that even inexperienced or unskilled operators should now be able to deliver feed with high performances. The prototype system may also assist or complement future autonomous feed truck possibilities.

While the refinement process for the prototype system will continue, results suggest that an appropriate solution has been achieved, and a commercial outcome is likely for lot feeders very soon. The technology will also be appropriate for alternate delivery arrangements such as mixer/delivery wagons, and ration delivery boxes and will be very transferrable when required.

We believe that while this system solution may be simple enough in principle to ideate, the fact remains that it is very complex to implement, therefore an equivalent product does not seem to exist in the market. It follows that the high performance that has been achieved represents a high-value outcome for the Australian feedlot industry.

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1 Introduction

This final report describes the results of a serialised longer-term experiment to evaluate a prototype auto-delivery system retrofittable to commercial feed truck bins against human operators.

2 Project objectives

The overall project objectives that were agreed in the contract are as per the following sub-section.

2.1 Project objectives as worded in the research agreement

1. Develop refinements to the working prototype feed truck auto-delivery system, and deliver these to Myola feedlot
2. Determine the accuracy, evenness, time, and reversing distance of deliveries for the prototype versus manual (via 100 observations) of either delivery mode
3. Support the prototype for a period of 90 consecutive days when used under normal operating conditions

3 Methodology

The donor site for this project was BBG's Myola Feedlot, located in north-west New South Wales, Australia, approximately 70 kilometres south of Goondiwindi, Queensland. It is a commercial feedlot licenced up to 20,000 standard cattle units (SCUs), which usually operates two feed trucks for all rations; this typically occurs between 0700h and 1430h each day. Myola Feedlot has a total of 135 pens, which are between 8m and 50m long, with most either 25m or 50m, and all feed bunks are on the pens' eastern side, accessible by single-lane roads composed of compacted fine base aggregate.

The outcome of precedent project P.PSH.1079 was a validated prototype auto-delivery system retrofitted on a new Kenworth feed truck with Roto-Mix 920-18 mixer bin. Briefly, this system provided superior feed delivery accuracies, requiring less time and reversing distances than humans for steam-flaked wheat finisher ration.

At the completion of P.PSH.1079, the working prototype system's limitations were recognised (e.g. only suitable for finisher ration, long pen lengths, and large delivery masses), and these were only better understood during its development and assessment in an operational environment. The purpose of the current research activity is to leverage the existing technology-base and refine the working prototype's performances to account for the diversity of deliveries experienced under normal operating conditions, with a focus on additional and more comprehensive field testing for the system at the donor site.

3.1 Feed delivery strategy improvements

The algorithms of the working prototype have been refined so that the system may deliver all rations, all masses (specifically those <650kg), to all pens lengths at the donor site during morning and afternoon cycles, i.e. normal operational conditions for the feedlot.

Through P.PSH.1079, the significant influence of the human operator's actions on feed delivery performances was recognised. Most significantly, this was their preferred 'start' and 'end' delivery positions along the bunk lengths, as well as the impact of their applied speed and acceleration profiles. In lieu of automatically controlling these vehicular inputs, an additional passive feedback device was provided for the operator, which shows in real-time the required motions via a bespoke truck speed indicator. At this stage the required motions are still manually actuated as 'normal' by the operator; this is probably an opportunity for further consideration when appropriate.

A bespoke truck speed indicator has been manufactured and installed adjacent to the existing feed remaining (Digi-Star, Fort Atkinson, WI, USA) indicator on the driver's side rear vision mirror, and includes a simple high-resolution digital graphical interface containing the target and current speeds and future preferred speed profile.

The truck speed indicator also enables the ranges of travel for the truck along the bunk lengths to be more closely monitored, with a specific focus on the end extent to eliminate reversing. Even though the travel is still to be managed by humans, the original automatic feed algorithm has been updated with a new protocol: the new motion profile along the bunk length will allow feeding of a normal delivery up to 10% below target mass, from the start of the pen bunk to its length less around 10% of bunk length. The remaining delivery will then be finalised with the short bunk length remaining, thus nearly completing the delivery in one pass, and almost eliminating reversing.

3.2 Localisation improvement

Based on operating experience with the precedent system, occasional localisation issues were recognised, so the GNSS antennas were upgraded in this project to a more robust survey-grade technology. The mechanical protection for interconnecting cables between the antennas and cabin junction box has also been significantly improved.

3.3 Experiment methodology

Following the prototype upgrades, the working prototype was assessed via the following experimental process, equivalent to the one exercised in the precedent project, and these were based on approvals from MLA and BBG. Testing and assessment of the prototype system and human performances included:

- All diets were considered: starter (R1 and 1C), intermediates (R2 and 3), and steam-flaked wheat cereal grain finisher ration (R5).
- Assessment occurred on both AM and PM daily deliveries.
- Human operator was the nominal resource on that day's shift for the Roto-Mix.
- Prototype system operation was initiated and monitored in-cabin by operator during delivery pass.
- No direct interruption or manipulation of prototype control system occurred during delivery pass.
- Feed deliveries were assessed on first forward pass and final delivery by prototype system and human operator.
- All data for the experiment were automatically acquired and stored on the prototype system's onboard processor, including, RTK GNSS position, time, speed, pen ID, target delivery, instantaneous mass on Digi-Star scale, and door position.

First passes, final deliveries, and, where appropriate, total experiment metrics for the prototype and humans have been assessed in a generally consistent method to the previous agreement. The next section provides detailed information about the project process and output results, employing the described assessment criteria.

The experiment was undertaken over a longer period (eight weeks) than previously exercised to increase the number of observations for both prototype system and human operators, with a view to including more variabilities experienced under all operating conditions and enabling more comprehensive time-motion analyses and outputs. The eight-week period of human observations was completed through November to December 2018. Two experienced personnel (A and B) operated the truck throughout this period, and they were both blind to the measurement process. The eight-week period of prototype system observations occurred from March to June 2019, and the truck was operated by personnel A and B, as well as two new drivers C and D. This experiment's period was extended because of some minor yet disruptive hardware failures that were experienced early in the campaign and required rectification with new components.

4 Results and discussion

The following section describes the distilled experiment results towards objectively assessing the success of this project. Specifically, statistical analyses employed to assess the outputs of the evaluation experiment are introduced, followed by presentation of the output results.

4.1 Statistical analyses

Observed feed delivered in the first pass and overall for each pen has been regressed on predicted feed deliveries for both the prototype system and human operators. The coefficient of determination (r^2) has been calculated on the line of regression as a measure of the strength of the relationship between observed and predicted feed deliveries.

Evaluation of the prototype and human's delivery accuracy has been calculated via their respective mean absolute error (MAE), once again for both first pass and overall feed deliveries.

Consistent with reporting for the precedent project, delivery evenness has been assessed by comparing an ideal distribution along the length of the nominal bunk against actual delivered feed quantities. In practice, each bunk was discretised into one metre length bins and an average level per bin, in kilograms, was calculated. Based on the final delivery only, residual (observed minus predicted) feed quantities for each bin were calculated, and a single MAE for the bunk was output. The standard deviation for each delivery's MAE across the experiment has also been calculated to demonstrate variability of delivery evenness.

Other metrics have also been determined to report the respective performances, and their calculations ought to be very self-evident and instructive.

4.2 Summary of results

The prototype system was observed for 6,170 deliveries, and human operators were observed for 5,774 deliveries. Fig. 1 demonstrates the composition of feed delivered masses observed for the prototype system (machine) and humans.

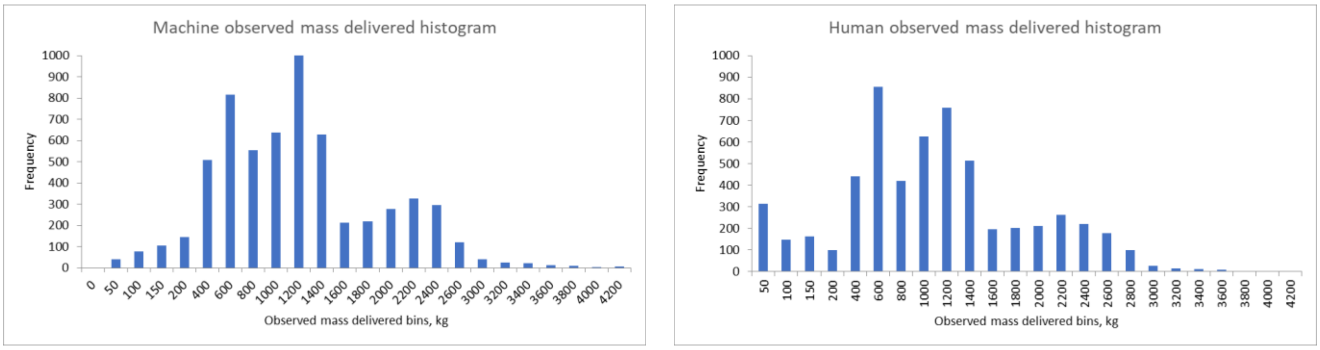

Fig. 1: Histogram of observed feed delivered masses for prototype system (left), and humans (right).

Fig. 2 demonstrates the composition of pen lengths fed by the prototype system and humans during the experiment.

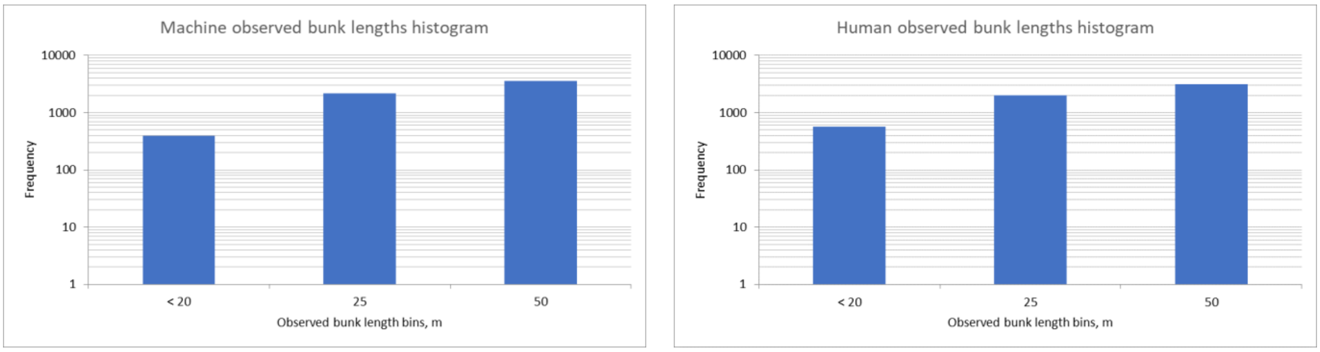

Fig. 2: Histogram of pen lengths fed by the prototype system (left), and humans (right).

Fig. 3 demonstrates the distribution of rations fed by the prototype system and humans during the experiment: the prototype system delivered 84% ration 5, and humans delivered 83% ration 5.

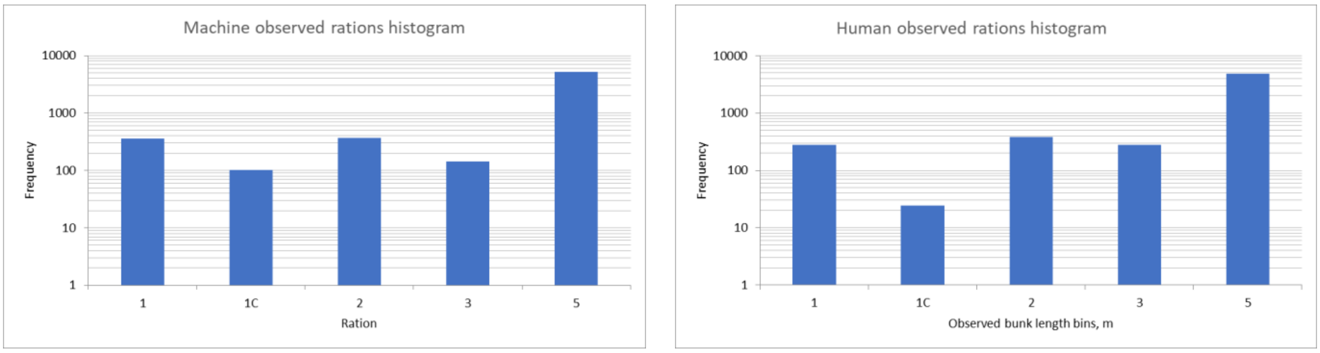

Fig. 3: Histogram of pen lengths fed by the prototype system (left), and humans (right).

Results of the regression of observed on predicted feed delivered and other performance indicators are shown in Table 1 by delivery mode (prototype system versus humans). The more significant performance statistics have also been highlighted in this table to assist reader focus.

Table 1 also includes previously reported prototype performances from the precedent project for reference and benchmarking. Significantly, this demonstrates that the upgraded system now has delivery observations as low as 10kg (previously 610kg) and all rations have been considered, including low rations which have a higher roughage content.

Initial reviews suggested that compiling all rations together probably did not provide adequate resolution for performances across rations. Data reviews and witnessing deliveries strongly indicated that these differing performances were a function of the ration type, with lower rations having significantly lower flow rates (probably due to additional binding and inadequate door opening); it follows that supporting statistics have been calculated by ration, too. For the purpose of simplifying the following analyses, the rations have been segregated as low (R1, 1C, 2, and 3) or finisher (R5).

It can be seen from Table 1 that the prototype system delivered feed more accurately than human operators, and this was the case for both the first pass (MAE = 81kg and 152kg respectively) and final delivery masses (MAE = 2.48kg and 6.43kg respectively). Through the experiment, the human operators had 2,592 delivery events out of 5,774 (44.9%) with an error of more than 10kg, and 531 events (9.2%) more than 20kg. In contrast, the prototype system had 1,097 out of 6,170 (17.8%) with an error more than 10kg, and 368 events (6.0%) more than 20kg. It was also witnessed during both sets of experiments (as well as daily normal operations) that the Digi-Star indicator regularly 'flickers' at its lowest resolution, 10kg, which probably contributed to some of these events in both counts, especially if the operators did not pause sufficiently for the scale to stabilise.

For both first pass and final deliveries, the prototype system may be incorrectly observed as being slower than humans, though this is not a reasonable conclusion as the average travel speed for the human operators was significantly higher for the experiment duration. Similar conclusions may also be drawn from the time in pen metric. These points are discussed in more detail in the following sub-section.

The significant delivery MAE at the end of the human deliveries' first passes required much longer reversing distances (27.7% of bunk lengths compared to prototype system's 9.6%) to complete deliveries evenly over bunk lengths. Interestingly, these reversing performances are very significantly influenced by ration type, and with the more freely flowing (i.e. lower roughage) finisher ration (R5), the prototype system only required reversing on 5.0% of bunk lengths, compared with 22.2% for humans.

The inherent requirement for humans to manage the feed truck steering and speed led to two experiment outputs with limited differentiation: bunk utilisation and evenness. Regarding the former, the human operator initiated the feed deliveries for both manual and prototype system, and these were from the same approximate position along the bunk. In all cases, the feed truck travelled at similar constant forward speed, stopping at operators' 'normal' finishing positions, thereby resulting in very similar (and high) bunk utilisations.

The evenness evaluations showed superior performance by the prototype system for finisher diet only, with a smaller MAE and larger standard deviation. This indicates that across the bunk lengths, the human deviations from an even spread were larger and more varied. The prototype system's delivery of lower rations was marginally worse than humans, and we understand a minor limitation with our current control strategy resulting in a bias at the end of the bunk. In all cases, the significant contributor for both evenness measures was that residual feed to be delivered at the completion of the first pass was then distributed (until exhausted) with the truck travelling in reverse, and so was biased towards one end of the bunk length.

Table 1: Evaluation statistics of feed deliveries during the feedlot experiment.

Item	**Prototype system**				**Humans**			
	Orig.(R5)	**R1,1C,2,3**	**R5**	**ALL**	**Orig.(R5)**	**R1,1C,2,3**	**R5**	**ALL**
n	69	976	5,194	6,170	53	963	4,811	5,774
Total delivered mass, kg	89,130	1,231,650	5,726,590	6,958,240	66,350	1,020,940	4,988,690	6,009,630
Minimum mass delivered, kg	610	10	10	10	660	10	10	10
Maximum mass delivered, kg	2,420	4,190	3,190	4,190	2,300	3,960	3,170	3,960
Total bunk length, m	2,600	32,689	206,277	238,966	2,450	33,552	181,928	215,480
Bunk utilisation, % bunk length	92.4	92.9	93.8	93.6	92.8	84.3	89.0	88.2
Reversing dist., % bunk length	6	34.4	5.0	9.6	21	55.4	22.2	27.7
First pass delivery								
r^2, regression of observed on predicted feed delivered	0.998	0.894	0.996	0.936	0.951	0.867	0.944	0.905
Slope	0.999	1.284	1.013	1.064	0.963	1.268	1.019	1.054
MAE, kg	37.39	289.13	41.91	81.02	119.81	314.79	119.47	152.05
Final delivery								
r^2, regression of observed on predicted feed delivered	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Slope	1.000	0.999	0.999	0.999	1.000	0.999	0.999	0.999
MAE, kg	1.16	2.56	2.46	2.48	5.09	6.22	6.47	6.43
Prediction average speed								
First pass, ms^{-1} (kmh^{-1})	0.90 (3.24)	0.75 (2.71)	0.79 (2.84)	0.78 (2.82)	1.03 (3.71)	1.00 (3.61)	0.95 (3.42)	0.96 (3.46)
Final delivery, ms^{-1} (kmh^{-1})	0.68 (2.47)	0.60 (2.17)	0.66 (2.38)	0.65 (2.34)	0.89 (3.22)	0.84 (3.01)	0.84 (3.01)	0.84 (3.01)
Feed delivery rate								
First pass, seconds/ton	31.09	45.60	44.97	45.06	36.77	48.56	39.40	40.68
Final delivery, seconds/ton	42.11	58.58	53.96	54.78	46.18	62.50	48.34	50.75
Final delivery, tons/h	-	-	-	65.60	-	-	-	70.99
Truck utilisation, % (time in pen/total time)	-	-	-	20.4	-	-	-	21.3
Evenness								
Average MAE, kg	5.61	7.11	5.01	5.34	5.34	5.69	6.54	6.40
Standard deviation, kg	2.39	4.64	2.93	3.35	2.85	4.85	4.05	4.20
Final delivery exceptions								
MAE >= 10kg (% total)	8 (11.6)	188 (19.3)	909 (17.5)	1,097 (17.8)	26 (49.1)	397 (41.2)	2,195 (45.6)	2,592 (44.9)
MAE >= 20kg (% total)	0 (0.0)	49 (5.0)	320 (6.2)	368 (6.0)	1 (1.9)	78 (8.1)	453 (9.4)	531 (9.2)
Time in pen (s)								
< 20m	N/A	42.84	30.54	36.71	N/A	34.28	29.26	30.77
25m	41.86	58.80	46.20	48.24	45.38	54.33	39.63	42.00
50m	66.62	100.43	68.95	72.71	60.01	86.16	59.69	63.57

4.2.1 Impact of observed truck travel speed

The feed delivery rate and time in pen metrics are functions of time, and so dissimilar truck travel speeds will have a direct influence on their performances. The experiment's average travel speeds for human deliveries were observed 29% faster than those delivered with the prototype system. This is not a requirement for the prototype system, and in fact, its performances will be better at the nominal 3.0kmh^{-1} as the mixer bin machinery also operates faster, leading to improved flows; the door control algorithms will be equivalent, independent of truck speed.

With a view to providing a more reasonable description of the prototype system's time-based metrics, relevant predictions have been scaled as a function of the average final speed over the human's average speed across all observations, and Table 2 summarises the relevant adjustments. After applying this correcting factor, for both first pass and final deliveries, the prototype system was faster than humans by 9.6% (40.68s/t over 36.78s/t) and 16.1% (50.75s/t over 42.59s/t) respectively.

It also follows that the feed truck's time in pens was improved with auto-delivery, after the delivery sequences' elapsed times were normalised to the average human speed of 3.0kmh^{-1}. This is most obvious with the lower rations, though significant improvements were also observed for finisher ration. For example, finisher ration for 50m pens required an average of 56.53s for auto-delivery versus 63.57s for humans, which represents a 11.1% reduction.

Table 2: Evaluation statistics of relevant feed deliveries during the feedlot experiment AFTER truck travel speeds have been normalised to average human speed of 3.0kmh^{-1}.

Item	**Prototype system**				**Humans**			
	Orig.(R5)	**R1,1C,2,3**	**R5**	**ALL**	**Orig.(R5)**	**R1,1C,2,3**	**R5**	**ALL**
Feed delivery rate, normalised truck travel speed								
First pass, seconds/ton	31.09	34.31	37.28	36.78	36.77	48.56	39.40	40.68
Final delivery, seconds/ton	42.11	42.31	42.65	42.59	46.18	62.50	48.34	50.75
Final delivery, tons/h	-	-	-	84.75	-	-	-	71.08
Truck utilisation, % (time in pen/total time)	-	-	-	16.5	-	-	-	21.2
Time in pen (s) normalised truck travel speed								
< 20m	N/A	30.95	24.14	28.54	N/A	34.28	29.26	30.77
25m	41.86	53.78	36.52	37.50	45.38	54.33	39.63	42.00
50m	66.62	91.87	54.50	56.53	60.01	86.16	59.69	63.57

Attention should also be drawn to the very significant productivity improvement for the auto-delivery system during the feeding sequence when considering tons per hour, i.e. when the truck was in pens and outputting feed into bunks. During this process, the prototype system enabled 19.2% faster output of feed, based on 84.75 over 71.08 tons/h. The maximum benefit of this performance improvement was probably not fully visible as the truck's utilisation (again, time in pen) is only 16.5% of its working day (after delivery speeds are normalised), so the significant feed rate (productivity) improvement is diluted by factors such as travel around the yard and feedlot operating conditions and disruptions.

4.3 Experiment chart results, overall

The first pass observed on predicted feed deliveries for prototype system (machine) and humans are provided graphically in Fig. 4.

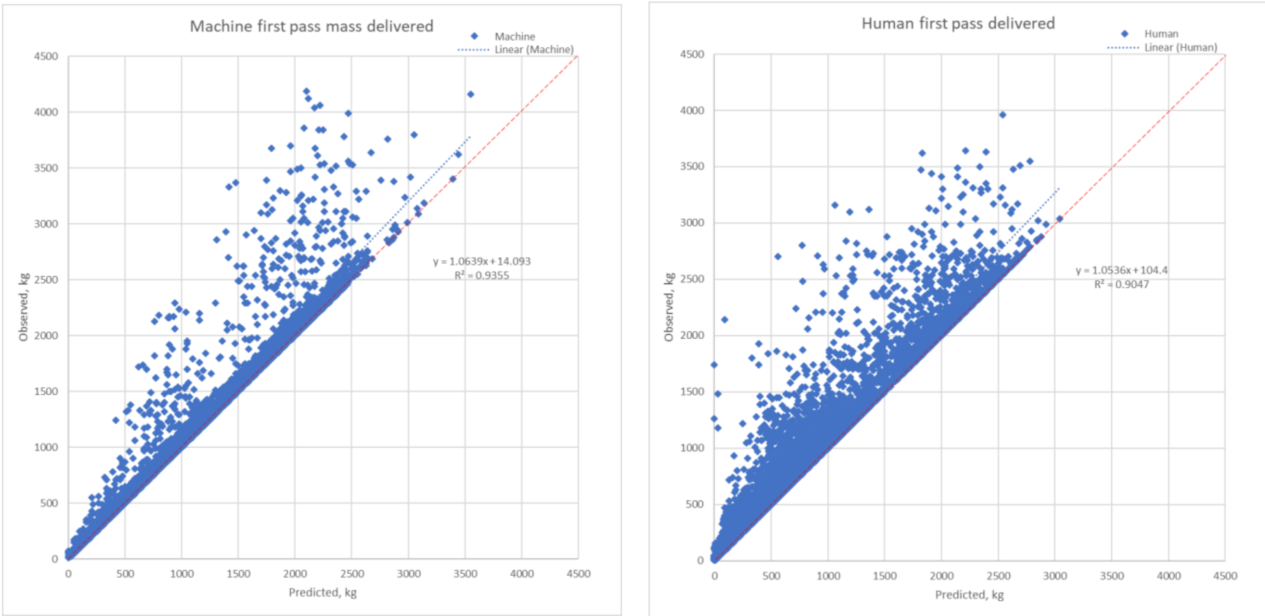

Fig. 4: First pass feed delivered masses observed on predicted for prototype system (machine, left), and human (right).

These plots demonstrate that the prototype system's results are very close to the ideal unity gradient with a small mean offset (based on y-intercept), suggesting a very low MAE for the first-pass delivery, and limited requirement for reversing. Conversely, the human operators are very consistently under the nominal delivery mass on the first pass, and this accounts for the larger masses required to be delivered through reverse travel.

Final delivery observed on predicted masses for both systems are provided graphically in Fig. 5. In both cases it may be observed that final deliveries were accurate and precise; some occasional exceptions are visible in both charts. Please note that these mass-based metrics are all independent of delivery times, which have been calculated and published in Table 1 and Table 2.

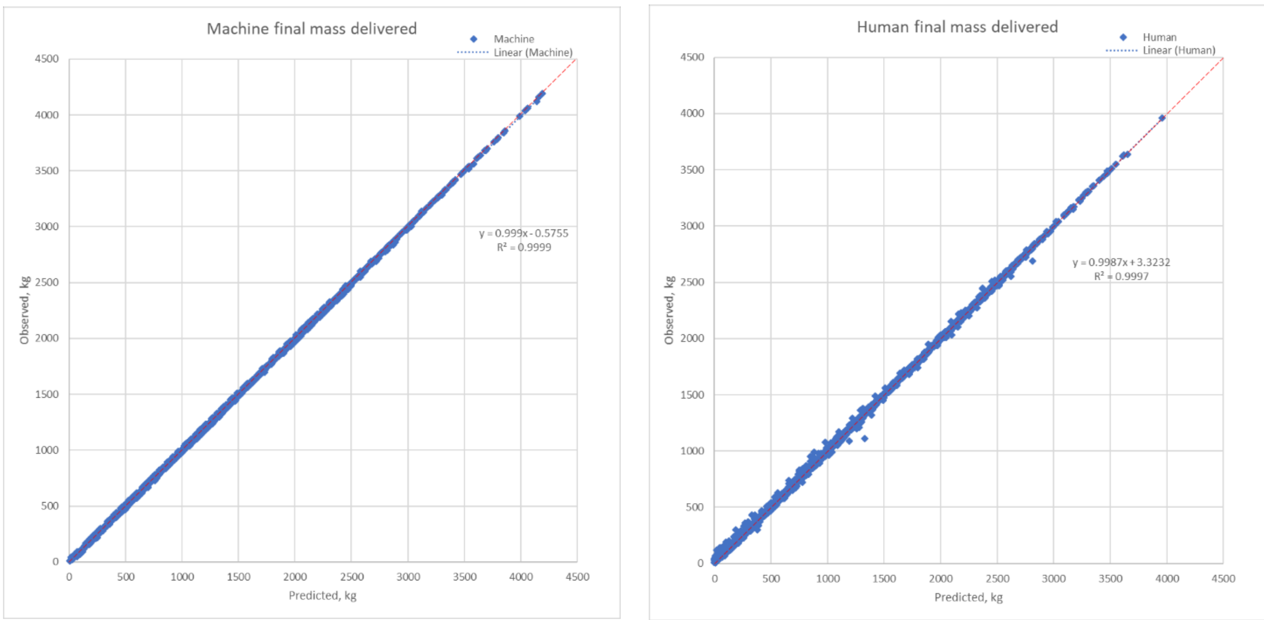

Fig. 5: Final delivery feed masses observed on predicted for prototype system (machine, left), and human (right).

Total feed delivery travel distances observed on predicted masses for both systems are provided graphically in Fig. 6. The occurrences of the generally discrete feed bunk lengths (<20, 25, and 50m) are easily recognisable, and these charts reinforce the significant travel distances sometimes required to complete the feed deliveries; these include outliers greater than 200% for some bunk length and ration combinations.

Fig. 6 demonstrates the general overtravel events occurring. These charts may be difficult to interpret without further investigation, though it could be suggested that the prototype system has a higher level of repeatability (precision, r^2 = 0.63 versus 0.32), complete with a nominal line-of-best-fit that is closer to unity gradient and zero y-offset.

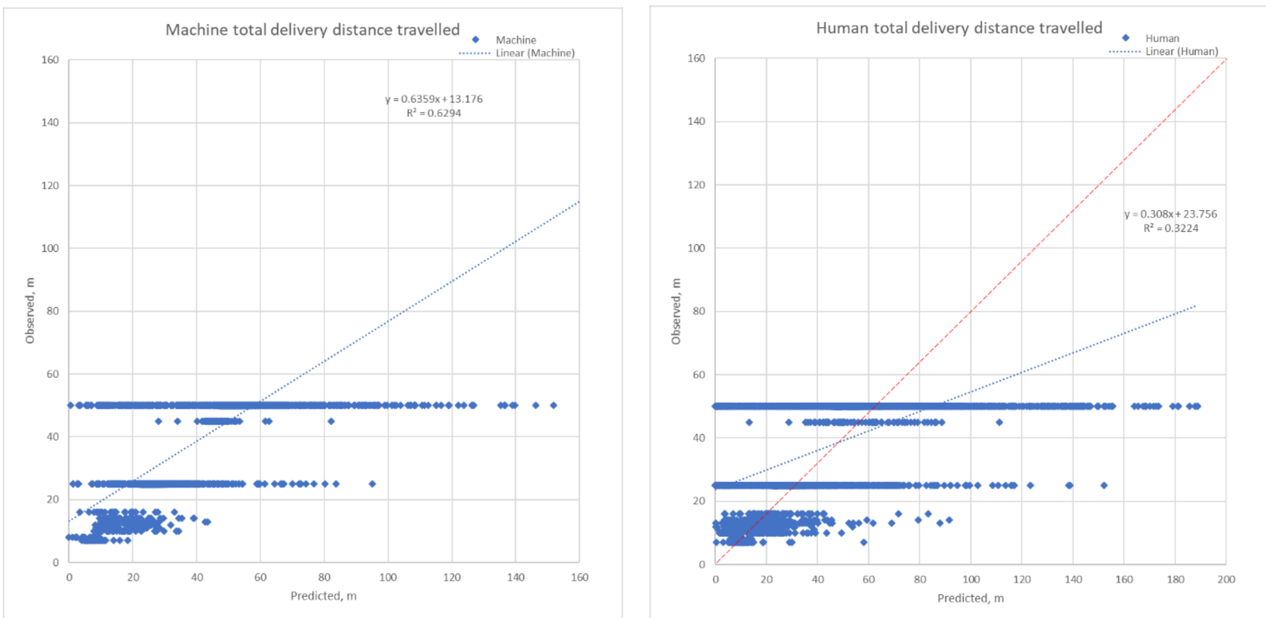

Fig. 6: Total feed delivery travel distances observed on predicted for prototype system (machine, left) and humans (right).

After further investigation it has been understood that several observations for both delivery modes were small or split deliveries, low rations, small pens, or a combination of these factors. Removing these data ‘irregularities’ (even though they are normal operating conditions in a feedlot) may significantly improve both the accuracies and precisions of deliveries, though this treatment may not sufficiently describe normal operating conditions. With a view to improving understanding of diet impacts on performances, especially outliers, the next subsection provides further insight of both delivery modes by ration.

4.4 Experiment chart results, by ration

The experiment’s measurements were observed under normal operating conditions for extended periods. In this sub-section, additional charts visually demonstrate experiences with first pass and final deliveries, as well as distance travelled, by low rations and high rations. The first pass observed on predicted feed deliveries for prototype system (machine) and humans are provided graphically in Fig. 7.

These plots demonstrate that for both delivery modes, the large masses (e.g. >1,000kg, a function of bunk length) of lower rations (R1, 1C, 2, and 3) consistently underdeliver in the forward pass of the feed truck. Through review of historian data, it has been confirmed for these deliveries (both modes) the truck was regularly operating at its lowest speed with its door 100% open and PTO set at maximum (as per normal operating procedures). In other words, the maximum feed throughput of the truck was being achieved with its current arrangement.

Fig. 7 also shows that smaller masses (<1,000kg) were delivered with moderate accuracy by the auto-delivery system in one pass.

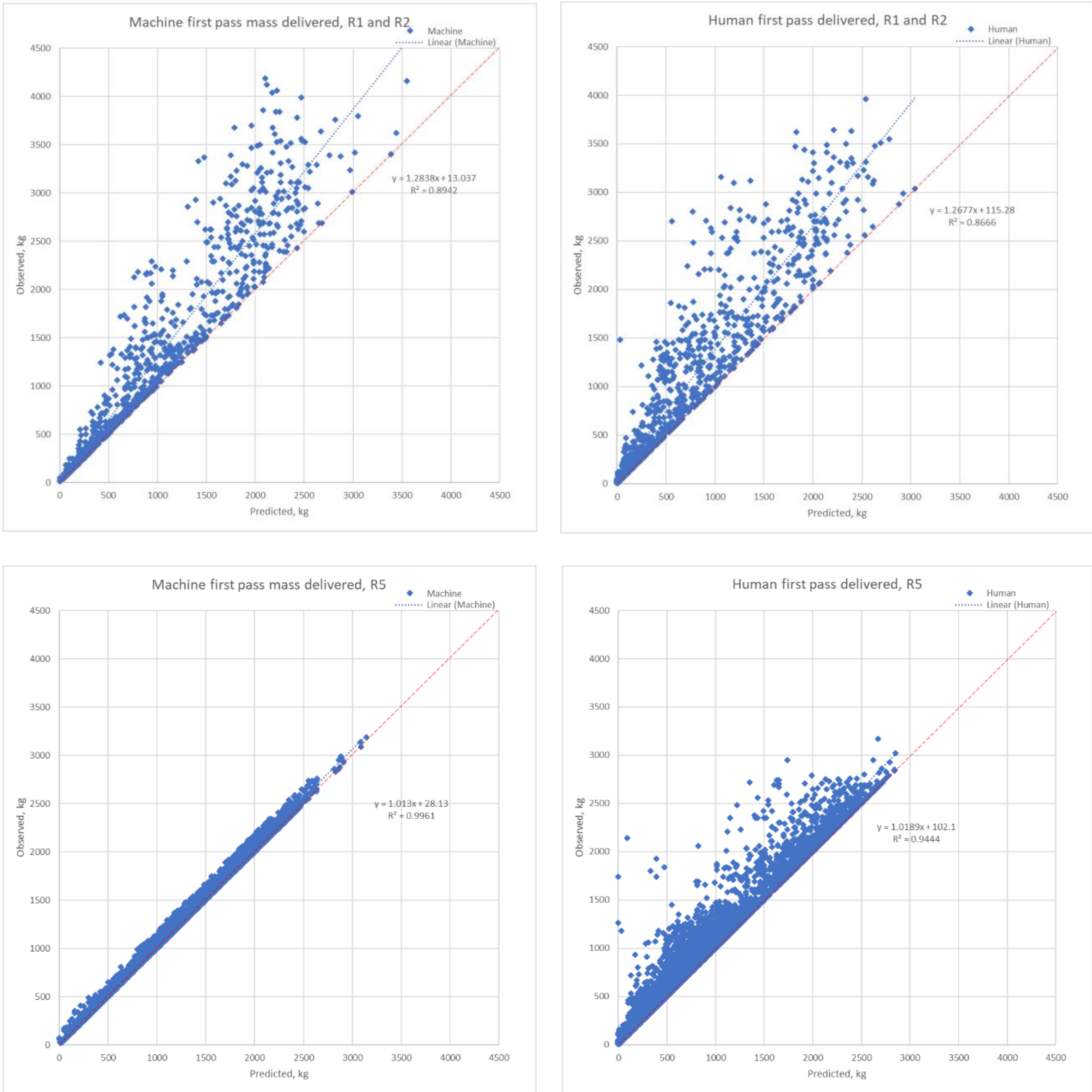

Fig. 7: First pass feed delivered masses observed on predicted for prototype system (machine, top-left, rations 1 and 2, bottom-left, ration 5), and human (top-right, rations 1 and 2, bottom-right, ration 5).

More obviously from the charts of Fig. 7, finisher ration (R5) results for the prototype system are consistently more accurate and precise as per metrics provided within the chart figures and summarised in Table 1.

Final delivery observed on predicted masses have not been repeated in this sub-section as they are generally accurate and precise, independent of delivery time.

Total feed delivery travel distances observed on predicted masses for both systems are provided graphically in Fig. 8. It can be seen from these charts that the lower rations (R1, 1C, 2, and 3), when delivered by either mode, had travel distances that far exceeded bunk lengths, though the auto-delivery system still required less travel.

Ration 5 travel distances demonstrate the most significant performance improvement and safe productivity opportunities for auto-delivery over humans, especially considering that most deliveries (>80%) are this ration type. By reducing the travel distances the prototype system delivers feed faster across bunk extents, and by reducing/eliminating reversing manoeuvres, additional feedlot hazards are proportionately reduced. Once again, after more detailed investigation, it is understood that several ration 5 outlier observations for both delivery modes were small or split deliveries, thereby reducing the precision and accuracy of the reported results.

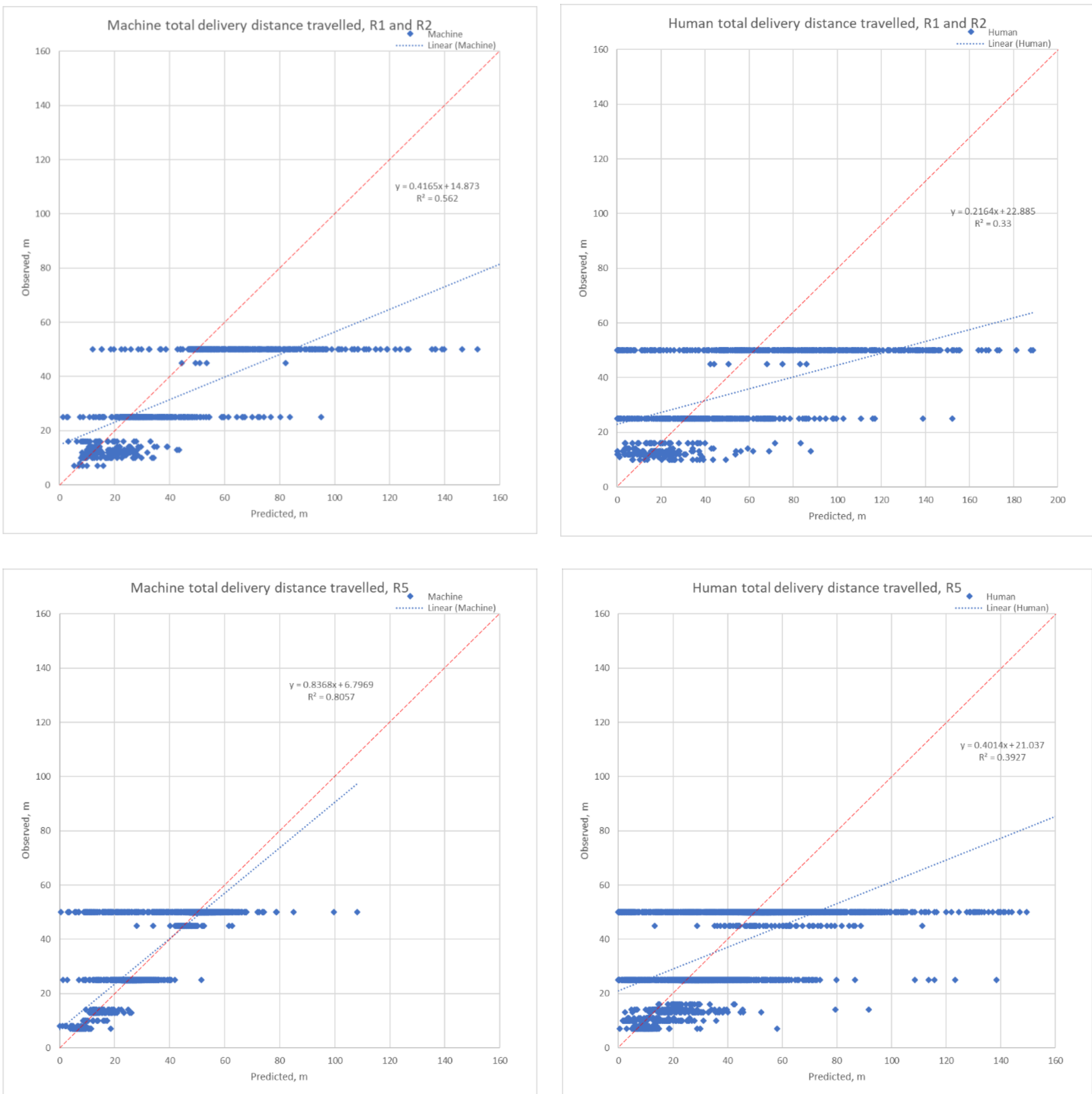

Fig. 8: Total feed delivery travel distances observed on predicted for prototype system (machine, top-left, ration 1 and 2, bottom-left, ration 5), and human (top-right, rations 1 and 2, bottom-right, ration 5).

5 Conclusions

We strongly believe that this project has been very successful improving the safe productivity of the host site's feed truck via tactful and bespoke integration of appropriate technologies. From the outset, the project's strategy has been to explore opportunities for a retrofittable automatic mixer bin control system suitable for the host site. At a higher level, this capability could also be considered a fundamental for the pursuit of an unmanned feed truck, especially as the topic of autonomous (host) vehicles are increasingly understood and accepted.

Based on the results of the extended testing campaign, we suggest that the prototype auto-delivery system is fit-for-purpose and provides appropriate performances to meet the rigorous requirements of the industry. Objective performance metrics are segregated in Table 1 and Table 2, and it can be seen that the auto-delivery performances are more accurate, more consistent, faster, and require less travel (including reversing) than human deliveries.

Under both delivery modes, the feed evenness and bunk utilisation were very equivalent, and we suggest that this is most likely a function of the human factors imposed over feed truck operation during the experimental protocol. We understand anecdotally from other feedlots that bunk utilisations are usually significantly lower than we have recorded during the experiment. We suggest that the experienced human operators (A and B) at Myola Feedlot were very proficient during the human measurements, especially with the new feed truck.

The time metrics analyses and comparisons presented in this report indicate the significant productivity improvements possible via the prototype auto-delivery system. If additional validation experiments were to be repeated at a later stage, a more rigorous campaign should be employed (e.g. day on, day off with operators) to prevent possible biases due to operator experience level and truck operating speed. It will probably be pragmatic to attempt this campaign at an alternate site so normal feeding is not disrupted at the current host's operation.

We believe that this exciting research outcome enables subsequent additional valuable research pursuits, and any future activities must be considered carefully with an intimate understanding of the multi-variate problem. For example, based on our experience we suggest that additional productivity increases ought to be achievable for the auto-delivery system via adjustments to the feed door dimensions to increase discharge of low flow rate rations, as well as provision of a more precise door control arrangement. It is feasible that very soon the industry will require explorations of increased operator assistance facilities such as automatic steering and throttle control: features and capabilities that should soon enable driverless trucks to be realised for the benefit of lot feeders.

6 Key messages

The prototype auto-delivery system has been demonstrated to deliver feed into bunks with performances superior to human operators. We believe this system to be a world first integration of appropriate technologies retrofittable to feed trucks enabling active adaptive control of all rations from mixer bins. The technology will also be appropriate for alternate delivery arrangements such as mixer/delivery wagons and ration delivery boxes, and will be very transferrable when required.

With MLA and BBG's support, we have delivered a solution that ought to have significant potential benefit to Australian lot feeders. We suggest that a commercially viable product should be available in the near term based on the successful outcomes of this project.