final report

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Prototype feed truck auto-delivery system

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Executive summary

Commercial feedlot operations deliver feed to pen bunks daily, usually across two deliveries, and this process can often present safe productivity issues, viz,

- Vehicle operators are required to be trained and skilled to perform multiple tasks concurrently, including locating the feed trucks next to pen bunks, steering, speed control, all while operating the vehicle's feed chute as per delivery consignments.
- Performances across operators are often inconsistent, including feed cycle times, feed application distributions along pen bunks, reversing along bunks to deliver feed deficiencies after forward passes, and manually removing (shovelling) excess delivered feed.
- Inaccurate and irregularly distributed feed delivery may lead to sub-optimal carcase weight gains and contribute to other animal welfare issues.

In response to an opportunity created between MLA and Bindaree Beef Group (BBG), we were engaged to develop, supply, and evaluate a prototype feed truck auto-delivery system, suitable for retrofitting on one of the existing feed trucks at Myola Feedlot. A bespoke solution was engineered and delivered to the donor feedlot, and then demonstrated to the satisfaction of stakeholders.

Through an agreed experimental protocol under normal operating conditions, the prototype feed truck auto-delivery system and human operators were evaluated against several criteria. The experiment outputs objectively demonstrate that the prototype system provided more accurate and more time-effective first pass and final deliveries than humans. In both cases, 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.

Key design features of the prototype 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.

The performances already achieved are very encouraging, and we believe that a pathway to a retrofittable automatic feed delivery system is clear, and with further refinements a production system should be realised very soon. Such an outcome ought to provide a very valuable productivity improvement for the benefit of BBG, Myola feedlot, and all Australian feedlots.

The results of this project also pave the way to full automation of commercial feed trucks. Logical next steps are to implement appropriate auto-steer technology to maintain the feed truck at a consistent parallel distance to the feed bunk. Following that, full automation of driverless trucks could be achieved with appropriate collision control and safety mechanisms. Australian feedlots may be the first in the world to integrate semi-automated or fully automated feed trucks into large scale operations.

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1 Background

Safe productivity improvements are always a significant consideration and goal for any commercial entity, and this includes high-capacity feedlots. Such operations require access to a reliable and skilled labour force for most aspects of daily operation, especially the feed delivery process. Unfortunately, regional aspects of feedlots often mean that their workforce is under-resourced and very transient, often contributing to productivity issues.

At most feedlots, daily feed allocations are delivered to each pen bunk via a manually operated feed truck, and these are usually split across morning (usually 40%) and afternoon (60%) deliveries. The delivery process is very labour-intensive, requiring several parallel activities to be completed with high proficiency, including normal truck controls (steering, throttle, 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 (Digi-Star, Fort Atkinson, WI, USA), nominally ±10kg, and any delivery event outside of this limit is included in a daily exception report for corrective action.

Against this brief background, and in response to an opportunity created between MLA and Bindaree Beef Group (BBG), we have been engaged to develop, supply, and evaluate a prototype feed truck auto-delivery system, suitable for retrofitting on one of the existing feed trucks at BBG's Myola Feedlot. This report briefly introduces the prototype system, and then provides experiment outputs describing its delivery accuracy, evenness, time, and bunk utilisation performances versus human operators under normal operating conditions.

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 a prototype feed truck auto-delivery system and retro-fit it to a feedlot truck at Myola Feedlot
2. Determine the Mean Absolute Error and evenness of delivery distribution for the feed-truck auto-delivery system vs manual feed truck delivery at Myola Feedlot

3 Methodology

The purpose of the research activities described here was to explore safe productivity improvements for feed delivery at commercial feedlots through employment of appropriate automation technologies on a standard feed truck. Our agreed schedule included relevant freedom to operate, prototype system development, delivery, and demonstration, and then evaluation under normal operating conditions. The evaluation involved several assessment criteria to assess performances of the prototype versus humans, and this is described in more detail later in this report.

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 finisher ration; this usually occurs between 0700h and 1430h each day. Myola Feedlot has a total 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.

3.1 Prototype system brief description

A fit-for-purpose prototype system has been engineered and delivered to Myola Feedlot, and this includes an RTK GNSS reference (base) station (and communications) installed at the administration building, and rover equipment for the host feed truck. The rover equipment is a retrofitted arrangement of GNSS localisation and over-the-air communications, on-board processing, Digi-Star interface, door position feedback, and programmatic control over the mixer bin's rotor and augers, as well as the door and chute. A local human-machine interface (HMI) was also provided in the operator's cabin for basic automation system useability controls and diagnostics.

Key features of the system include:

1. The feed truck's three-axis position and heading are resolved in the world reference frame via rover RTK global navigation satellite system (GNSS); RTK correction information is available over-the-air from an RTK base/reference station. Truck position is used to determine pen attendance, location along bunk, and speed.
2. Feed gate door position is measured with a transducer, and feed chute state (open, vertical/closed, horizontal) via inductive switches.
3. The feed gate door has an interlock system, which will not allow feed-discharge if the feed truck is located at the incorrect pen as determined by the rover RTK global navigation satellite system (GNSS).
4. Control over the feed truck's mixer bin functions, including feed gate door, feed chute, rotor, auger and variable power take-off (PTO), are achieved by parallel interfaces with the manual controls which allow the system to be switched between manual and automatic mode.
5. Feed truck scale head and indicator provide mass and feed plan information.

The original agreement required the system to be ultimately deployed on Myola's new Kenworth truck with Roto-Mix 920-18 feed mixer bin (Roto-Mix LLC, Dodge City, KS, USA). Based on discussions between all stakeholders, this transfer was moved forward in the schedule, so all subsequent development and testing were completed on this preferred platform. This was completed, with the prototype equipment operational under load conditions on the Roto-Mix, forming the basis for the evaluation experiments described in the next section.

3.2 Experiment protocol

Based on approvals from MLA and BBG, we exercised the following experimental protocol for testing and assessment of the prototype system and human performances.

- One diet was considered: steam-flaked white cereal grain finisher ration.
- Assessment occurred on second (PM) daily delivery only.
- Human operator was the nominal resource on that day's shift for the Roto-Mix.

- Prototype operation was monitored in-cabin by project engineer without direct interruption of control system during delivery pass.
- Feed deliveries were assessed on first forward pass and final delivery by prototype and human operator.
- Each day, over five days,
    - A randomly-selected population of pens had feed delivered automatically, employing the prototype system's operating protocol.
    - A randomly-selected population of pens had feed delivered manually, under normal operating conditions. The human operator was blind to the selected pens.
    - At least 50 pens of each population have been assessed.
- 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 previous agreement. The next section provides detailed information about the project process and output results employing the described assessment criteria.

4 Results

The following section introduces some of the statistical analyses employed to assess the outputs of the evaluation experiment, 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.

Delivery evenness has been a very challenging metric to determine effectively. Our original suggestion had been to employ the regression's linear bias and r^2 to describe the variability of the feed delivery along the bunk length, with an ideal result being linear bias = 0kg and r^2 = 1. We have found this metric provides very limited value. Instead, we have preferred to assess delivery evenness by comparing an ideal distribution against actual delivered feed quantities across the length of the nominal bunk. 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.

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

Two humans operated the Roto-Mix feed truck during the feedlot experiment. A total of 69 observations were performed for the prototype system, and 53 for the human operators; these irregular observation numbers were a function of an intermittent communications issues with human staff. Fig. 1 demonstrates the composition of feed delivered masses observed for the prototype system (machine) and humans.

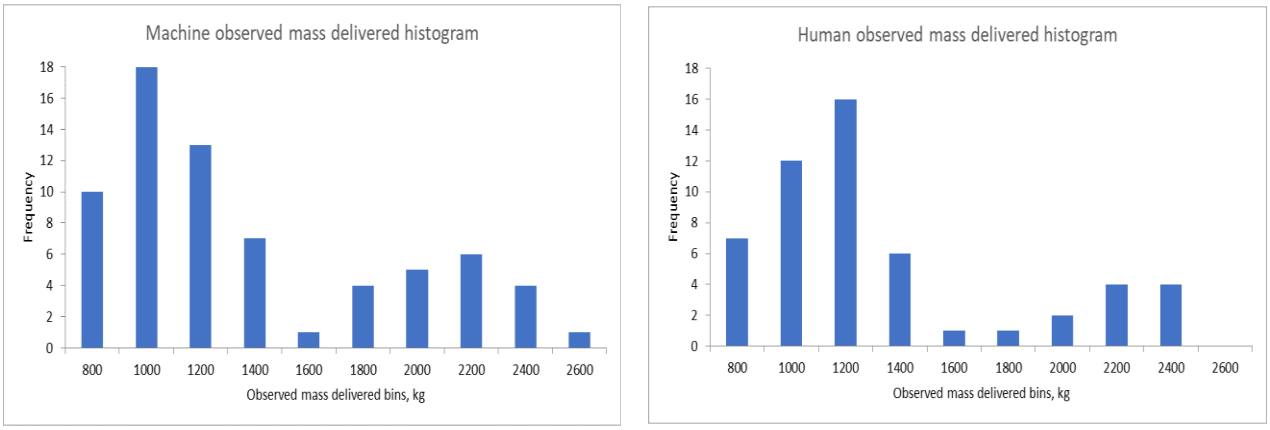

Fig. 1: Histogram of observed feed delivered masses for prototype system (left), and humans (right).

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

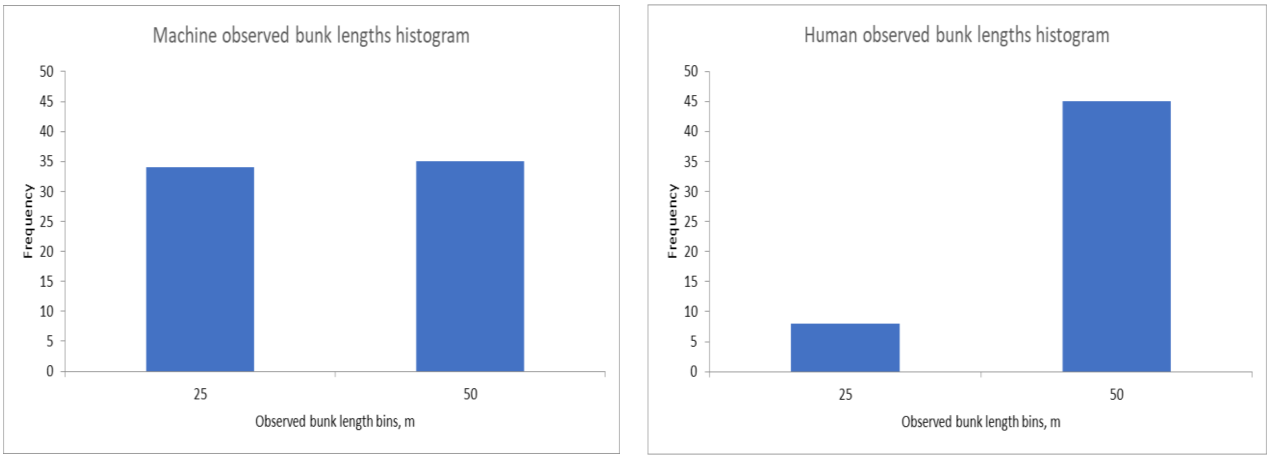

Fig. 2: Histogram of pen lengths fed by the prototype system (left), and humans (right).

Results of the regression of observed on predicted feed delivered and other performance indicators are shown in Table 1.

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

Item	Prototype system	Humans
n	69	53
Total delivered mass, kg	89,130	66,350
Minimum mass delivered, kg	610	660
Maximum mass delivered, kg	2,420	2,300
Total bunk length, m	2,600	2,450
Bunk utilisation, % bunk length	92.4	92.8
Reversing distance, % bunk length	6	21
First pass delivery		
r^2, regression of observed on predicted feed delivered	0.998	0.951
Slope	0.999	0.963
MAE, kg	37.39	119.81
Final delivery		
r^2, regression of observed on predicted feed delivered	1.000	1.000
Slope	1.000	1.000
MAE, kg	1.16	5.09
Prediction average speed		
First pass, ms^{-1} (kmh^{-1})	0.97 (3.48)	1.11 (4.00)
Final delivery, ms^{-1} (kmh^{-1})	0.69 (2.49)	0.80 (2.88)
Feed delivery rate		
First pass, seconds/ton	31.09	36.77
Final delivery, seconds/ton	42.11	46.18
Evenness		
MAE, kg	5.61	5.34
Standard deviation, kg	2.39	2.85
Final delivery exceptions (MAE >= 10kg)	8	26

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 = 37kg and 120kg respectively) and final delivery masses (MAE = 1kg and 5kg respectively). With reference to the daily exception report mentioned earlier, through the experiment the human operators had 26 occasions (out of 53, 49%) when the final feed delivered was more than 10kg, and in contrast the prototype system had 8 out of 69 (11%), and only two of these were over-deliveries. For both first pass and final delivery times, the prototype system was also quicker than humans in seconds per ton, by 18% and 10% respectively. It follows that the significant error at the end of the human deliveries' first passes required much longer reversing distances (21% of bunk lengths compared to prototype's 6%) and time to complete deliveries evenly over bunk lengths.

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 scores were also very similar, and while their magnitudes and deviations are small, we expect that their performances are probably for similar reasons as the utilisation metric. Both the prototype and human deliveries have only subtle changes in their delivery strategies for the same mechanical mixer arrangement (rotor, auger, and PTO controls), and any residual feed to be delivered at the completion of the first pass was then distributed evenly by the human operator with the truck travelling in reverse. On further review, it has also been established that the most significant error contributions for evenness occur outside the utilised delivered bunk lengths.

4.3 Experiment chart results

The first pass observed on predicted feed deliveries for prototype system (machine) and humans are provided graphically in Fig. 3.

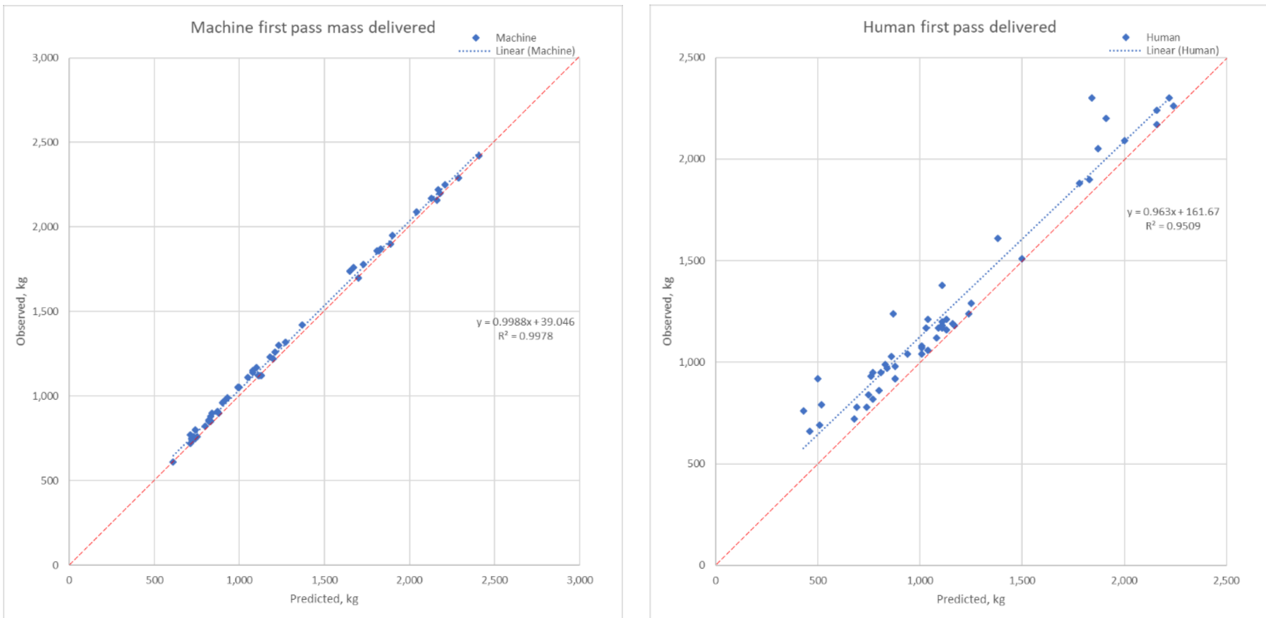

Fig. 3: First pass feed delivered masses observed on predicted for prototype system (machine, left), and human (right).

These plots demonstrate the prototype system's results are very close to the ideal unity gradient with insignificant mean offset (based on y-intercept), suggesting a very low MAE for the first-pass delivery. Conversely the human operators are almost always 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. 4. In both cases it may be observed that final deliveries were accurate and precise, and in these cases these metrics are independent of delivery time.

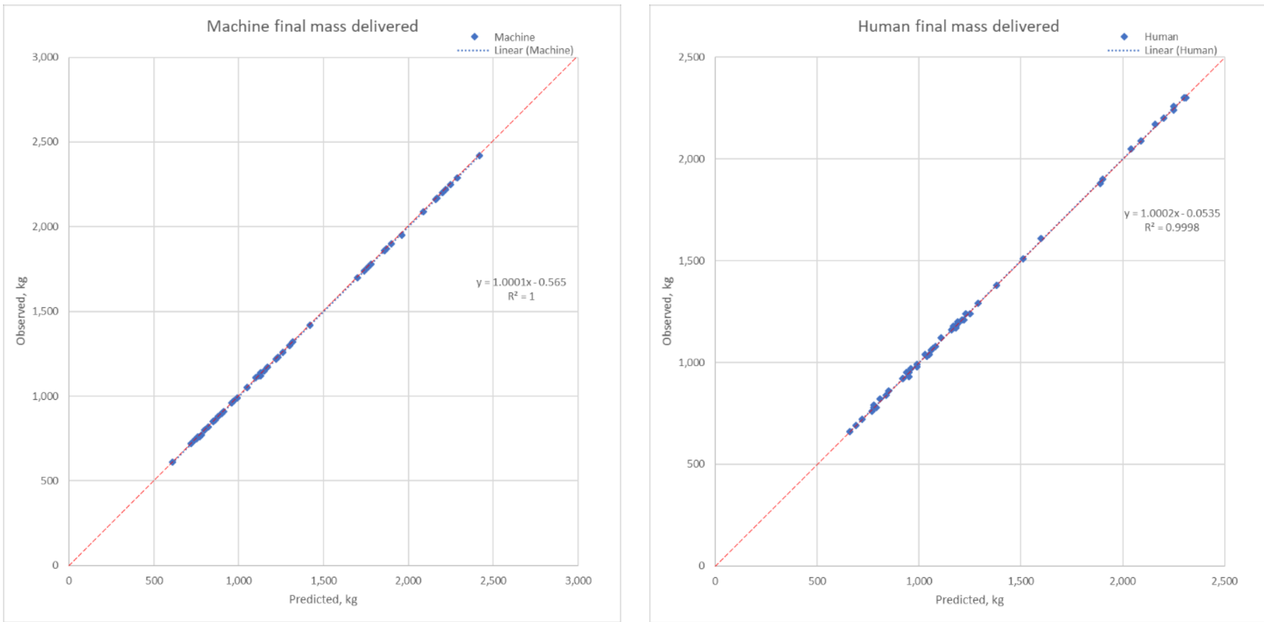

Fig. 4: Final delivery feed masses observed on predicted for prototype system (machine, left), and human (right).

Total feed delivery travel distances observed on predicted masses for both systems are provided graphically in Fig. 5. The occurrences of the two feed bunk lengths (25 and 50m) is simply observed, and these charts reinforce the significant travel distances sometimes required by the human operators to complete the feed deliveries; these include the outliers greater than 100m for a 50m bunk length.

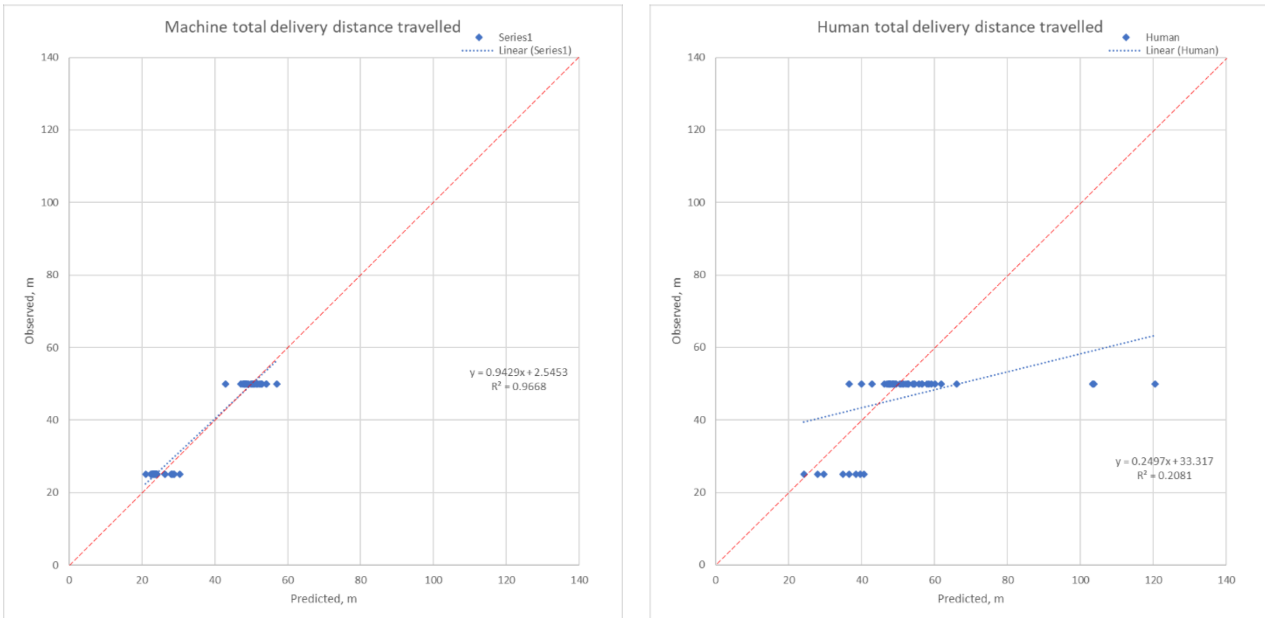

Fig. 5: Total feed delivery travel distances observed on predicted for prototype system (machine, left) and humans (right).

5 Conclusions/recommendations

Against the results presented in this report, the prototype feed truck auto-delivery system provided more accurate and more time-effective first pass and final deliveries than humans under normal operating conditions in a commercial feedlot. In both cases, 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 from anecdotes at other feedlots that bunk utilisations are usually significantly lower than we have recorded during the experiment. We suggest that the human operators at Myola Feedlot were very proficient, especially with the new feed truck, and we believe that while the differentiation between the prototype system and human operators is objective and clear, it was also probably limited during the execution of this experiment.

Our immersive experiences at the operational feedlot through the prototype's delivery and evaluation has enabled us to identify opportunities for further system enhancements. An immediate and possibly obvious improvement will be to eliminate reverse travel all together, and we have a clear view of options to achieve this outcome, as well as the scope of implementing other necessary system refinements and algorithm tuning. We will be very pleased to discuss this with stakeholders very soon with a view to exploring and evaluating improvements.

6 Key messages

We are very excited about the potential benefits that the red meat industry should garner through our technology solutions partnership. This report confirms that a fit-for-purpose retrofittable prototype for auto-delivery has been achieved on Myola Feedlot's Roto-Mix feed truck, and in the very near-future a production system should be realised, providing very significant productivity improvement opportunities. We have been pleased with the establishing relationship between ourselves, MLA, and BBG, and look forward to further refinements and assessments of the working prototype system to achieve a suitable outcome for all stakeholders.