ADDING NEW PUZZLE PIECES: IMPROVED CATTLE HANDLING FACILITIES FOR IMPROVED FLOW

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ABSTRACT

Well-designed cattle handling facilities play a crucial role in simplifying handling procedures, ensuring smooth flow, and minimising stress for animals, thereby positively impacting their experience and production. However, there remains a challenge in achieving optimal facility designs. In response, this study aims to integrate industrial engineering principles with animal psychology to propose concept designs for cattle handling facilities on case study farms. Through a narrative literature review and a current state analysis, the study identifies key factors such as gentle handling methods, curved passages- and high-solid sides, that enhance overall flow in cattle handling facilities. Concept designs tailored to each farm are presented, emphasizing the importance of optimising facility layouts, equipment locations, and operational procedures to enhance cattle flow. While the study provides valuable insights, further research is needed to assess the feasibility, effectiveness, and potential impact of implementing these concept designs in existing cattle-handling facilities.

Keywords: Cattle, handling facility, Temple Grandin.

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1 INTRODUCTION

Applying industrial engineering principles in agriculture has proven beneficial in enhancing productivity, improving efficiency, and optimising processes [1]. Industrial engineering techniques, such as work research and quality management, offer valuable tools for analysing and improving work processes in various industries, including agriculture. These principles can boost resource utilisation and overall process optimisation by identifying bottlenecks, eliminating waste and optimising workflow [2].

One area in agriculture where industrial engineering principles can be applied is in cattle handling facilities. Cattle handling facilities are structures that are designed and constructed to facilitate the management and movement of cattle in a safe, efficient, and humane manner. These facilities are essential for livestock producers to manage their herds and provide a controlled environment for performing tasks such as weighing, sorting, and medical treatment. The design and layout of cattle handling facilities are critical to their effectiveness. Good facility design considers the natural behaviour of cattle, their movement patterns, and their reactions to stress [3]. These facilities also play an important role in cow-calf operations where effective handling and management practices are essential for maintaining the health and productivity of the herd and the quality of the calves produced [4]. Just as in a factory/manufacturing setting, bottlenecks in cattle handling facilities can hinder the flow of operations, leading to inefficiencies, increased stress for the animals, and reduced productivity.

Understanding the behaviour and temperament of cattle is also important for effective handling and management [5]. Cattle temperament can significantly affect how they react and the level of stress they experience. Calmer cattle tend to exhibit less fear and anxiety during handling, making them easier to manage [6]. Conversely, hyperactive cattle can be more challenging to handle, leading to increased stress for both the animals and handlers.

Cattle experience stress which is caused by various environmental factors, including temperature, lighting, and noise levels [7]. Stress in cattle can affect their behaviour and overall well-being, which, in turn, influences their production [3]. The cattle handling facility, being the primary location where cattle are subjected to handling procedures, represents a significant source of stress for the animals [8]. Therefore, designing handling facilities with a focus on minimising stress is crucial for enhancing animal welfare and optimising production outcomes.

The importance of an efficient layout and flow dynamics in cattle handling facilities is highlighted by Grandin's research [6, 3, 9, 10, 11, 12]. According to Grandin [13], curved or circular designs, as opposed to sharp corners, can promote smoother cattle movement and reduce the risk of animal injury. The width, height, and type of flooring in the chutes can all have an impact on the behaviour and stress levels of the animals during handling [14]. For example, squeeze chutes and head gates can be used effectively to lessen animal suffering and increase worker safety [15]. By considering layout and flow dynamics, chute systems and equipment, lighting and environmental considerations, cattle handling facilities can be improved to provide efficient, secure, and humane handling procedures.

The intersection of cattle handling facilities with industrial engineering principles underscores a significant synergy aimed at optimising the management of cattle and enhancing operational efficiency. Just as in industrial engineering, where methodologies are employed to streamline processes and maximise productivity, the design and operation of cattle handling facilities demand similar attention to detail and systematic planning. The management of cattle through these facilities parallels engineering management, both aiming to achieve efficiency, safety, and the desired outcomes. The key to this connection is found in the idea of facility design, where the positioning of the workflow in the working area—the pens, chutes, and crushes—is mirrored by the layout of the workspace frequently found in industrial

environments. The main idea of process optimisation in industrial engineering is directly aligned with improving the flow in cattle handling facilities. The use of data-driven decisions, as evidenced by the analysis of the case studies, mirrors the empirical approach often taken in industrial engineering to refine and enhance systems. Integrating insights from Temple Grandin's principles further enhances the scalability and adaptability of these facilities, akin to incorporating innovative strategies in industrial processes to ensure continuous improvement. Furthermore, considerations such as space utilisation and equipment placement resonate with facility design principles, ensuring efficient resource utilisation and overall functionality. This convergence underscores the value of applying industrial engineering methodologies to cattle-handling facility design, resulting in streamlined operations, reduced stress for animals, and improved production outcomes.

Handling facilities consist of different sizes of sorting and holding pens leading up to a straight or curved chute. The single-file chutes allow cattle to move one-by-one behind each other towards the working area. The working area consists of different types of crushes including head gates, squeeze crushes, box crushes and or scales as indicated in Figure 1.

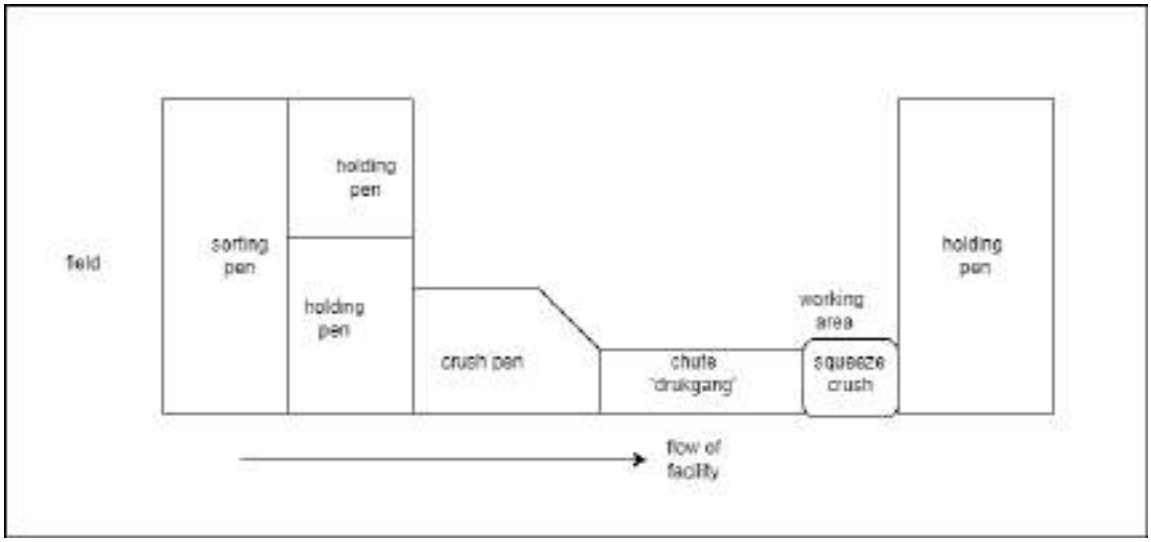

Figure 1: General handling facility layout

The problem is that existing South African cattle handling facilities often lack efficient layouts and flow dynamics, leading to poor handling practices and increased stress on the animals. This results in compromised animal welfare, increased risk of injury for both animals and handlers and reduced overall operational efficiency.

Ten case study farms were chosen at random throughout central South Africa, to examine their handling facilities. These first ten farms form part of a larger study. The goal of the larger study is to improve the design and layout of more facilities throughout South Africa to achieve a more effective and stress-free handling process by integrating insights from industrial engineering and animal psychology. The information gained from the case study farms will be valuable in directing future research (of the larger study) and contributing towards workable solutions to enhance cattle-handling facilities across the entire agricultural sector.

The aim of this study is to investigate how many of the theoretical principles are applied on the case study farms and then to apply industrial engineering principles together with animal psychology principles to provide improved concept facility designs for these farms.

The next section will provide relevant literature on the subject and Section 3 explains the research method that was followed. Section 4 provides the current state of analysis and Section 5 stipulates the design requirements. Section 6 provides the improved concept designs

for which verification is provided in Section 7. Conclusions and recommendations for future research are provided in Sections 8 and 9, respectively.

2 LITERATURE REVIEW

The relevant literature on facility design principles for cattle handling facilities is presented in this section.

2.1 Best Practices

One area of focus in recent research is the impact of handling techniques on animal behaviour and stress levels. Researchers found that using low-stress handling techniques, such as visual cues and maintaining consistent pressure [9], can significantly reduce animal stress and improve animal behaviour [11, 16, 7, 6, 9]. Other studies have explored the impact of facility design, such as the use of curved chutes and solid walls, on reducing animal stress and improving flow [13, 10, 14, 8].

Another area of research is the use of technology to improve cattle handling [4, 17, 18]. Technologies, such as automated sorting systems, remote-controlled gates, and virtual fences, have been developed to reduce the need for human intervention and improve animal handling. These technologies have shown promising results in reducing stress on animals and enhancing worker safety.

2.2 Review of Temple Grandin's Principles and Their Application

Temple Grandin's principles have revolutionised the design and management of cattle handling facilities [3, 6, 13, 14, 7, 11, 19]. Grandin, a renowned animal behaviour expert and autism advocate, developed principles and guidelines for designing and operating cattle handling facilities based on her extensive knowledge of animal behaviour [19, 20]. According to the literature, Temple Grandin is the leader in the field of animal handling facilities. The collection of her principles served as a useful tool for directing the redesign of the facilities. These guidelines emphasised the significance of reducing stress and fear in cattle, encouraging gentle handling methods, and improving the physical environment to allow for fluid and effective movement. The suggested redesigns provided potential answers to problems in cattle handling facilities.

The main objective of Grandin's design philosophy is reducing animal stress [3]. Furthermore, Grandin's principles aim to improve animal welfare and reduce injuries to both animals and handlers [6, 7]. Grandin also stresses the importance of worker safety in cattle handling facilities [10]. She recommends designing facilities that minimise the need for human intervention, using remote-controlled gates and other technologies to reduce the risk of accidents and injuries [9].

The application of Grandin's principles has been widely adopted in the cattle industry, with many facilities adopting her design principles to improve animal welfare, worker safety, and efficiency [7, 13, 11]. The use of solid walls and curved chutes have been shown to reduce animal stress and improve flow, while the use of visual cues and remote-controlled gates has reduced the need for human intervention and improved worker safety [6, 3, 9].

A summary of principles developed by Grandin is provided in Table 1.

3 METHODOLOGY

The engineering design process was used to develop concept designs of cattle handling facilities for the ten case study farms in the central Free State:

1) Current state analysis and problem identification
2) Literature review

3) Design requirements
4) Final design
5) Verification

3.1 Current State Analysis and Problem Identification

To gain a comprehensive understanding of the existing cattle handling facilities, each farm included in the study was visited. These visits served as an opportunity to gather accurate information about the facility layouts and to observe their operations first-hand. An evaluation of the facilities was done using a checklist based on Temple Grandin's design principles (Refer to the left column of Table 1 for the checklist).

By systematically documenting these aspects, a detailed analysis of the facility layouts was conducted. This analysis aimed to identify problem areas that hindered the efficient flow of cattle and contributed to operational inefficiencies.

The flow of cattle through the facilities, the presence of potential bottlenecks, inefficient equipment placement and other design-related issues were among the main factors considered during the analysis. By closely examining these aspects, specific problems that impeded the smooth handling and movement of cattle, were pinpointed.

The current state analysis is captured in Section 4.

3.2 Literature Review

A narrative literature review (Section 2) was conducted using various search databases such as ScienceDirect, Scopus, and Web of Science. Specific keywords such as “handling facilities”, “cattle psychology”, and “facility design” were used. To ensure the selection of relevant research papers, a set of inclusion and exclusion criteria was applied. The inclusion criteria encompassed research papers that focused on facility layout, handling facilities in a corral set, beef cattle flow and crush/chute systems. On the other hand, the exclusion criteria aimed to filter out non-English literature, topics unrelated to cattle handling facilities (such as slaughter, abattoirs, non-cattle facilities, handling raw meat, rodeo, auction facilities, and flow of blood), transportation handling, and discussions primarily cantered on the human factor with regards of the handling of cattle.

Following the application of these criteria, 58 research papers underwent a thorough quality assessment to ensure their reliability and credibility. This assessment process involved the removal of any duplicate papers and a further narrowing down to 20 research papers. These studies focused specifically on cattle-handling improvements within the corral, emphasising the design aspects of handling facilities rather than the human factor.

The selected 20 research papers were analysed to extract valuable insights and findings related to facility design and cattle handling. This analysis involved comparing and synthesizing the information from different studies to identify common themes, trends, and best practices.

3.3 Design Requirements

Design requirements were established based on the client’s needs and design principles identified from the literature. Refer to Section 5 for the list of design requirements.

3.4 Final Designs

Based on the client requirements and design principles from the literature, the improved concept facility layouts were designed. Refer to section 6 for these concept designs.

3.5 Verification

The concept designs for the handling facilities can be seen in Figure 2-11. The original Temple Grandin checklist was used again to verify that the new concept design of the facilities met the requirements. Refer to the right-hand side of Table 1 for the verification that each principle was addressed in the new concept designs.

4 CURRENT STATE ANALYSIS

During the current state analysis, each facility was visited, drawn, and evaluated against Temple Grandin's principles. The drawings of the current facility layout can be seen on the left-hand side of Figures 2-11.

A checklist of facility design principles was created, based on the important principles found in the literature review. The focus was on investigating the layout of the facilities, specifically the pens, chute, and crushes, to align with best practices for cattle-handling.

During the evaluation, each farm was evaluated against each principle (refer to the middle column of Table 1). If a farm adhered to the principle it was marked with "Y" denoting "yes". When a particular principle was not upheld, an "N" was recorded, denoting "no". If the principle did not apply to the facility a "- "was inserted in the table. The evaluation of the current handling facilities is represented in the middle column of Table 1.

The design of cattle handling facilities varies, but some common features include pens, chutes, and working areas. The designs range from traditional layouts to more modern designs that incorporate Temple Grandin's principles. However, some facilities have insufficient layouts, little room for movement, misplaced equipment and gates, or other design flaws. Congestion, unpredictable cattle behaviour, and elevated stress levels during handling can result from these design flaws.

Several variables were noted in the construction material used for the current cattle handling facilities. Due to their strength and durability, combinations of cables, wood bulks, and steel these materials are frequently employed in the construction of cattle handling facilities While some of the facilities have been constructed from scratch, others have been passed down through generations of farmers or handed over from previous owners, with only simple renovations made over time.

It was noted how the arrangement of cattle handling facilities affect how the handlers and animals move around during the procedure. The configuration of the pens, squeeze crushes, and chutes may present difficulties in their current state. Some facilities have bottlenecks, sharp angles, or dead ends that obstruct smooth movement and add to delays. The quality, accessibility, and usefulness of equipment varied in each facility. The handling process might have been hampered by out-of-date or malfunctioning equipment, a lack of tools, or inappropriate sizes for a certain activity.

In summary, despite the variations in their design and histories, all the facilities of the case study farms had similar flow problems. These difficulties included bottlenecks at the chute's entrance, where cattle may have trouble or be reluctant to enter the designated area. The facilities also experienced cattle crowding in corners, which can obstruct the easy movement of animals inside the facility. The inability of cattle to move through the chute, which could be brought on by things like fear, stress, or discomfort, is another issue that has been observed.

These flow problems in the current state of the facilities hinder efficient cattle handling, compromise worker safety, and may negatively impact animal welfare. Addressing these issues is crucial to improving the overall effectiveness and functionality of cattle handling facilities.

Table 1: Design principles checklist

Design principles	A current state analysis of handling facilities										Verification of the concept design layouts.
	A	B	C	D	E	F	G	H	I	J	
1) The contact surface is smooth, at the chute.	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Earth ground fillers are incorporated into the designs.
2) Sharp corners are padded.	N	N	N	N	N	N	N	N	Y	N	All the sharp corners are removed or padded.
3) Gates had tiebacks.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Each gate has its tie-back on both sides.
4) The indoor facility has nonslip floors.	-	-	Y	-	N	-	-	-	-	-	Diamond groves are designed on concrete surfaces.
5) Is illumination even?	Y	Y	N	Y	N	N	Y	N	Y	Y	The crush is placed North or South in the design, if not cattle should be handled at certain times of the day.
6) No sudden changes in floor level/texture.	Y	Y	N	Y	N	Y	Y	Y	Y	Y	Yes, no sudden changes.
7) No banging metals.	N	N	Y	N	Y	Y	Y	N	Y	Y	Yes, all banging metals were removed.
8) Is loud machinery far away?	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Yes, no loud machinery is near.
9) Can cattle make 180-degree turns inside the pen?	Y	N	Y	Y	Y	N	Y	N	Y	Y	Yes, the pen is enlarged for it.
10) Are the curve pens' inside radii between 3,5 and 6 meters?	N	-	-	N	Y	-	Y	-	N	-	Yes, the radius is changed to match the requirement.
11) Is the crowd gate between 2,44-3,66 meters?	Y	Y	Y	-	N	Y	Y	Y	N	Y	Yes, all the gates are between those dimensions.
12) Is the junction of the crowd pen and single-file non-sharp?	Y	N	N	Y	N	N	N	N	Y	Y	Yes, the junction was changed to ensure smooth flow.
13) Can the cattle see 2 body lengths up the single file?	N	N	Y	Y	Y	N	Y	Y	Y	Y	Yes, chutes are changed to elongate cattle sight.
14) Is the race width between 66-71 cm?	Y	Y	Y	Y	Y	N	Y	N	N	Y	Yes, the races' widths are.
15) Is the fence height 152cm for English breeds, and 167-183 cm for Brahman-type breeds?	Y	N	Y	Y	Y	Y	Y	N	Y	N	Yes, all the fences are adjustable according to cattle breed.

Design principles	A current state analysis of handling facilities										Verification of the concept design layouts.
	A	B	C	D	E	F	G	H	I	J	
16) Is the straight crowd pen funnelling with one side at a 30 angle?	-	N	N	Y	N	N	-	N	-	Y	Yes, all angled fences are at 30-degree angles.
17) Are there no shadows, puddles of water, drain gates and bright sun in the way?	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Yes, the change in design eliminated these stress factors.
18) No light glaring into their eyes.	Y	Y	N	Y	N	Y	N	Y	Y	Y	Yes, the change of equipment placement, removed the glaring light.
19) Is the single file 3-5 m outside the shade if the chute is under the shade?	-	-	N	Y	N	-	-	-	-	-	Yes, longer chutes are added.
20) Are the sides of the single-file race, loading ramp or crowd gates solid?	N	N	N	N	Y	N	N	N	N	N	Yes, solid sides are added, all gates on designs have solid sides.
21) Are rails not at cow's eye height?	N	N	Y	N	N	Y	Y	N	Y	Y	Yes, the lengths are according to no.15.
22) Squeeze side distances: 16 cm for 113-180 kg calves, 21 cm for 272-360 kg cattle, and 30 cm for most cows and fed steers.	N	N	Y	N	N	N	Y	N	Y	N	Yes, designs are adjustable according to cattle type.

5 DESIGN REQUIREMENTS

The design requirements for the new cattle handling facilities were set by integrating both the client's needs and theoretical requirements gathered from the literature. The client requirements reflect the specific needs and preferences of the farmers, considering factors such as herd size, breed, and management practices. The theoretical requirements draw upon established principles and best practices in cattle handling, incorporating insights from experts in the field.

5.1 Client Requirements

1. Safety: The facility should prioritise both the handlers' and the cattle's safety, reducing the possibility of injuries while handling the animals.
2. Efficiency: To reduce handling time and increase productivity, the facility should allow for a constant and smooth flow of cattle.
3. Animal welfare: By providing a humane and low-stress handling environment, the facility should reduce stress and discomfort for the cattle.
4. Flexibility: The facility should be flexible enough to accommodate a range of handling techniques and activities for cattle of various sizes and breeds.

5. Durability: To withstand the wear and tear caused by cattle handling operations, the facility should be built with durable materials.
6. Accessibility: The establishment must be made easy to access for cattle handlers to move and handle cattle efficiently.

5.2 Theoretical Requirements (based on literature)

1. Flow and Layout: The facility's layout needs to be well-planned to encourage a steady flow of cattle while avoiding bottlenecks, acute angles, and dead ends. It ought to reduce traffic and offer open paths for the movement of cattle.
2. In all pens, cattle should be able to make 180-degree turns [6].
3. Curved Passages: According to Temple Grandin [10], the facility should have curved passages to improve cattle movement and lessen stress. By taking advantage of the natural tendency of cattle to move in arcs, curves can improve cattle flow.
4. If curved pens or chutes are used their inside radium must be between three and a half (3,5) to six (6) meters [10].
5. High-Solid Sides: The building should have high-solid sides to keep cattle from noticing distractions outside the fence, which will lessen stress and help them keep calm while being handled.
6. The chute, loading ramp and crowed gates should have solid sides [10].
7. Proper equipment placement: The facility should make sure that equipment like pens, chutes, and crushes is placed correctly and is functional. Equipment should be positioned carefully to support effective handling procedures.
8. The junction of the chute pen and the single-file chute must be non-sharp, allowing cattle to move in their natural manner [10].
9. Lighting and environmental considerations: The facility should take lighting and environmental factors into account to reduce shadows, reflections, and other elements that could frighten or confuse cattle. To lessen stress, environmental factors like temperature, ventilation, and noise levels should be optimised.
10. Ergonomics: The facility should take the ergonomics of handlers into account, making sure that tools and handling techniques are made to reduce physical stress and fatigue.
11. The contact surface should be level in the chute with no sudden changes.
12. Indoor facilities should have non-slip flooring with diamond groves [10].
13. All sharp corners must be padded to prevent injury.
14. Remove all stress factors such as the noise of metal banging, glaring sunlight, puddles, or other loud machinery [3].
15. All gates used to crowd or move the cattle must be between 2.44 to 3.66 meters [10].
16. When cattle are at the entrance of the chute, they must be able to see two body in lengths in front of them [10].
17. The chute’s race width must be between sixty-six to seventy-one centimetres [10].
18. The fence height should be placed strategically and not in the cattle’s view. For English breeds, the height is 152 centimetres and for Brahman-type breeds 167 to 183 centimetres [10].
19. A straight crowd pen should funnel leading to the single-file chute, with one side straight and the other at a thirty-degree angle [14].
20. The working area, the squeeze chute should be placed North / South to keep glaring sunlight from dazzling the cattle [9].
21. When a cover is over the working area, a three-to-five-meter chute must be outside before leading the cattle into the shade [3].
22. The squeeze crush’s width is dependent on the cattle type, ensure that for 113 - 180 kg calves the squeeze sides should be 16 cm apart at the chute floor, 21 cm for 272 - 360 kg cattle and 30 cm apart for most cows and fed steers [3].

6 CONCEPT DESIGNS

In Figures 2-11, the current state design is presented on the left and the new design is presented on the right. To distinguish the working area, it is highlighted in purple, while all the gates are represented in pink. The flow of cattle is indicated by arrows, showing the desired movement within the facility. The single lines in the design indicate open sides, allowing visibility and some degree of movement, while the double lines represent solid sides, providing a barrier and preventing the cattle from seeing other animals or handlers. The problem areas are circled with a dashed red circle.

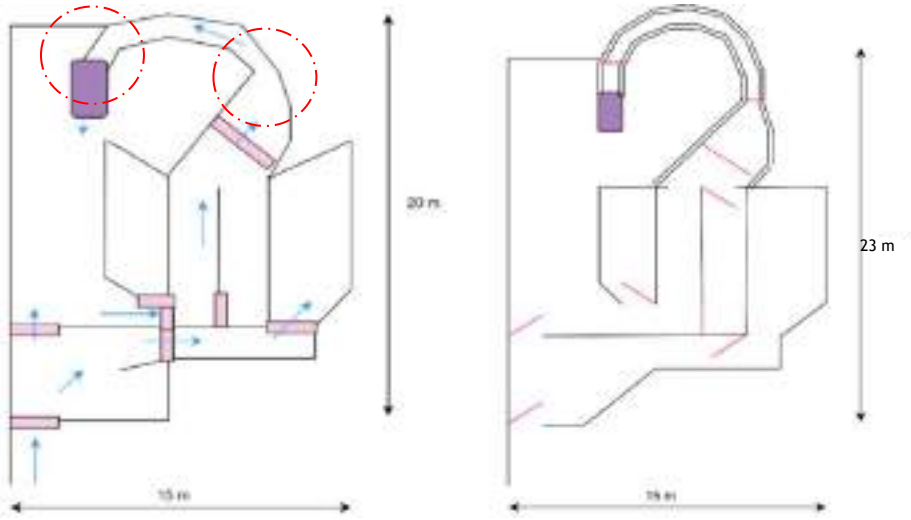

Figure 2: Farm A current vs ideal facility design

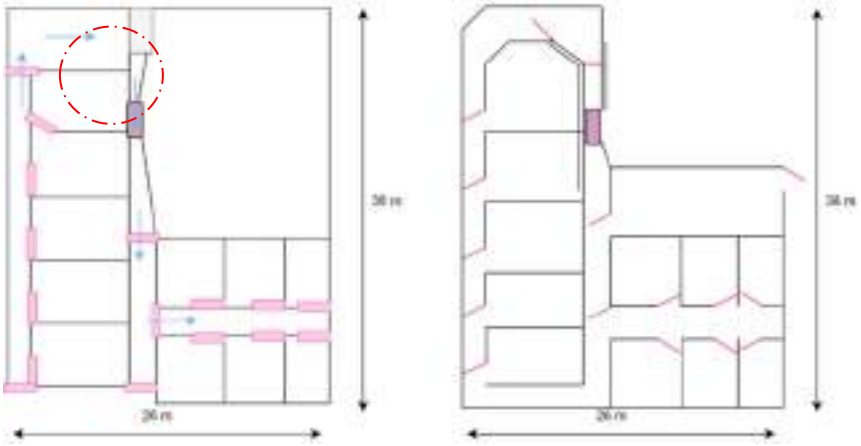

Figure 3: Farm B current vs ideal facility

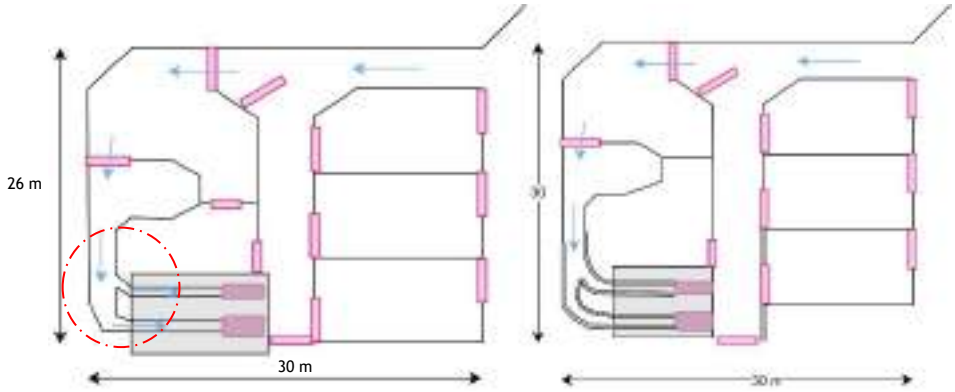

Figure 4: Farm C current vs ideal facility

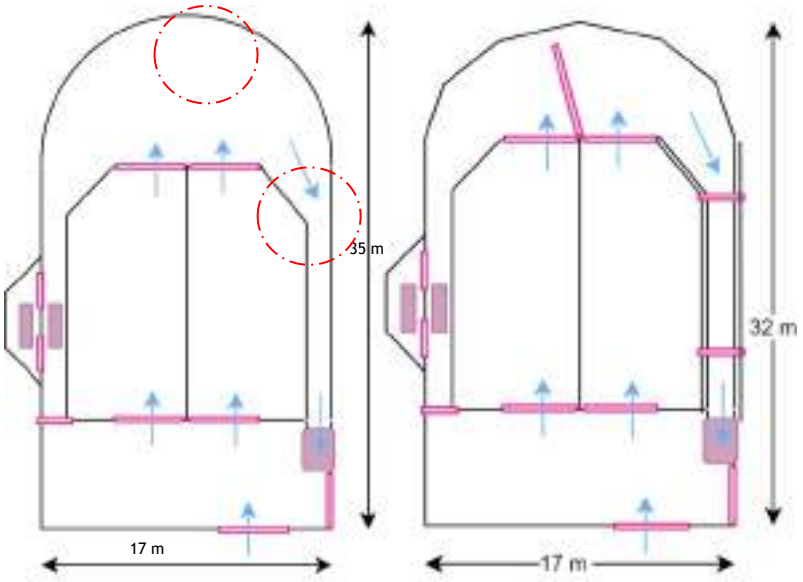

Figure 5: Farm D current vs ideal facility

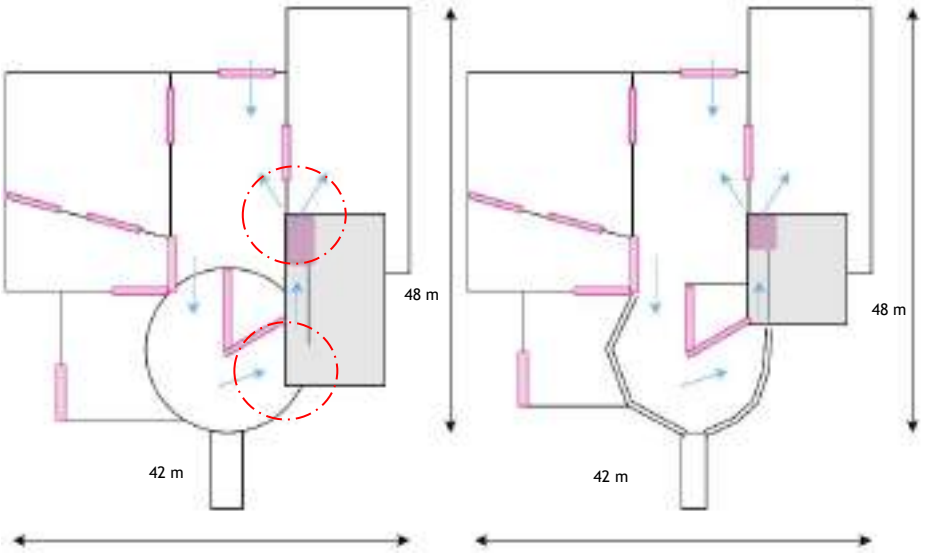

Figure 6: Farm E current vs ideal facility

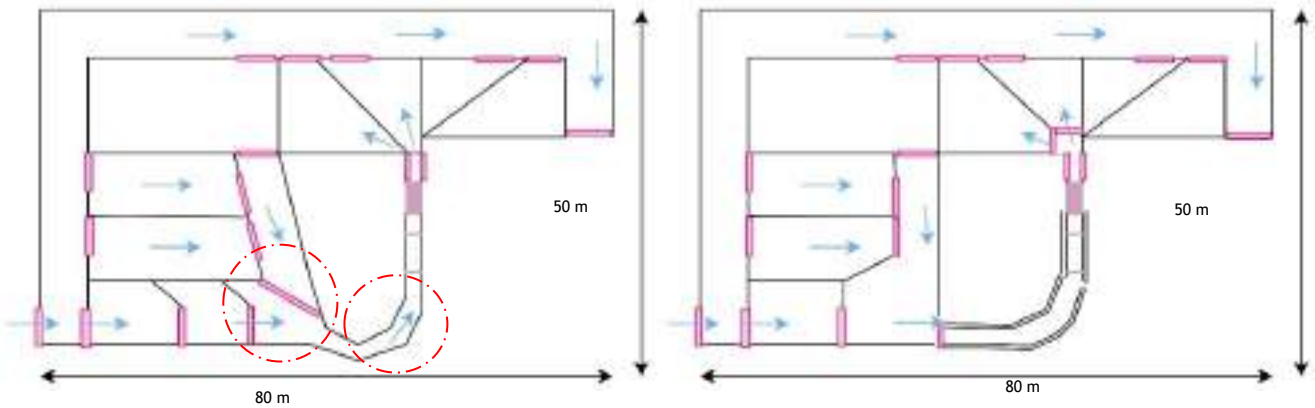

Figure 7: Farm F current vs ideal facility

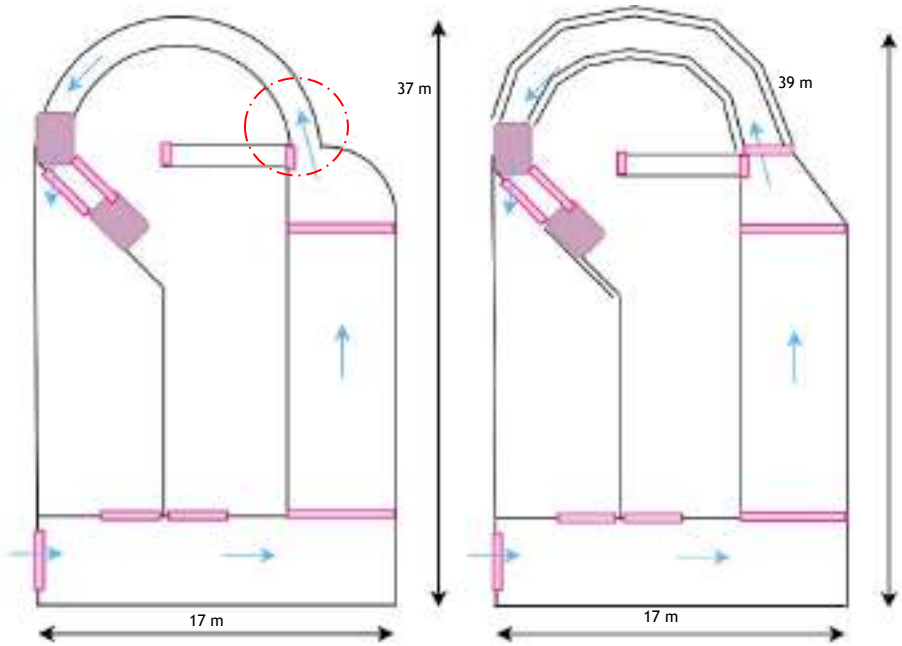

Figure 8: Farm G current vs ideal facility

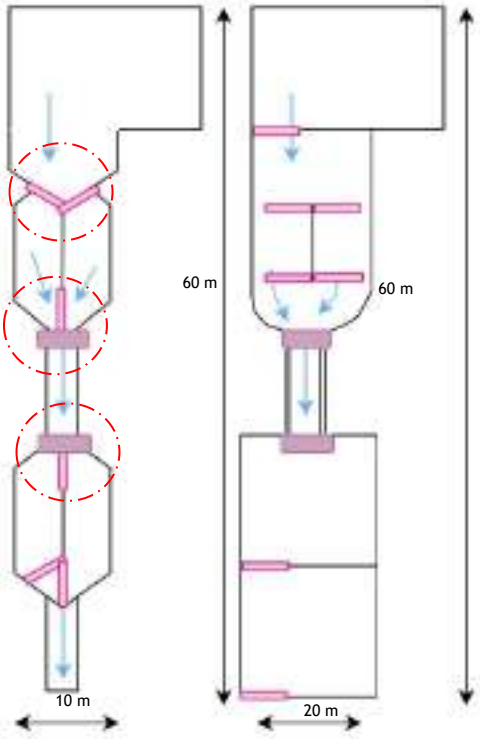

Figure 9: Farm H current vs ideal facility

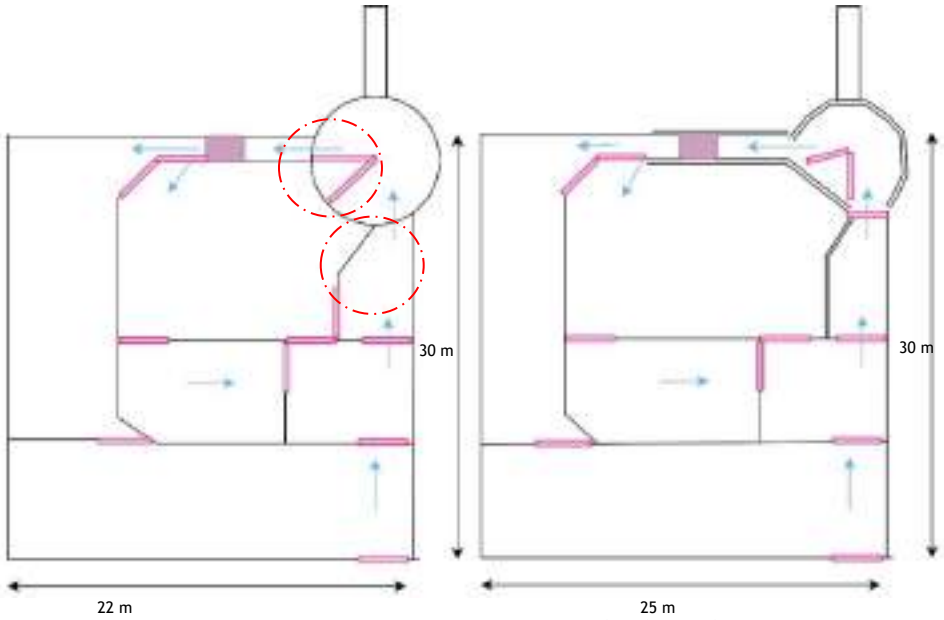

Figure 10: Farm I current vs ideal facility

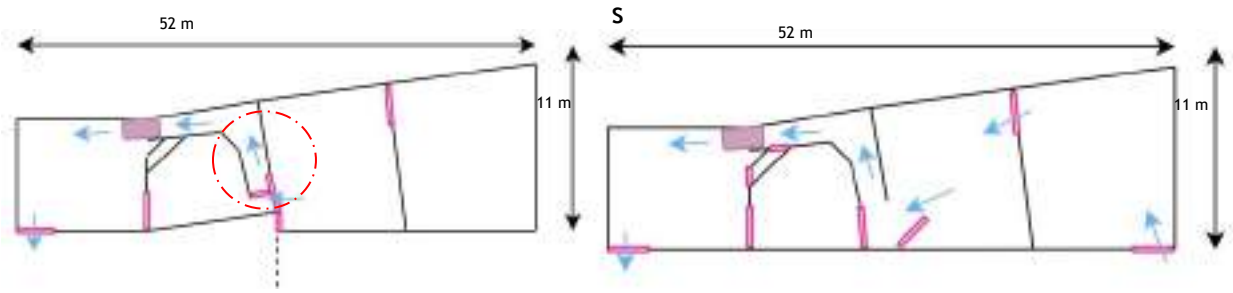

Figure 11: Farm J current vs ideal facility

The chutes were redesigned with curved sections to provide smooth and gradual turns for the cattle, following Temple Grandin's recommendations [10]. Solid sides and strategically placed gates were incorporated into the chutes, crush, and chute pen to minimise stress and promote calmness by limiting the cattle's view of other animals, the working area, and handlers. Consideration was given to different cattle breeds, adjusting the positioning of pipes and fence heights to avoid direct eye contact and to accommodate specific breed requirements. The pens were designed to allow comfortable 180-degree turns, while the single-file chute width and gate lengths were standardised for suitable cattle passage. Safety measures were implemented, including smooth surfaces, padded corners to prevent injuries, and gates equipped with tiebacks for ease of operation, ensuring both cattle and handlers' comfort. For a detailed verification against the design principles, please refer to Table 1, which serves as a comprehensive checklist.

7 VERIFICATION

The new concept designs were verified against the design requirements from both the client and the literature, ensuring their potential to improve cattle handling. Proof that the new concept design met these requirements is presented below.

7.1 Verifying Client Requirements

The list of client requirements was provided in Section 5.1. Proof of how these requirements were met in the new concept design is provided in Table 2.

Table 2: Verification of adherence to client requirements

1. Safety	The new layout puts safety first by including elements like rounded edges, non-slip flooring, and securely fastened gates to reduce the possibility of injuries while performing cattle handling procedures.
2. Efficiency	Optimising the layout and flow of the facility, reducing unnecessary movement, and minimising handling time, thereby improving overall productivity, and reducing labour requirements.
3. Animal welfare	The handling process by using gentle handling techniques, lowers stress levels by removing large stress factors and provides comfortable and low-stress environments.
4. Flexibility	It is simple to adjust and modify to accommodate various cattle sizes and breeds, various handling techniques, and potential future changes or facility expansions.
5. Durability	A long-lasting and robust facility is ensured by the new design's use of premium building materials and construction methods specifically to withstand the demanding conditions of cattle handling operations.
6. Accessibility	By incorporating wide walkways, strategically placed gates, and appropriately sized entrances to make it easier for people and equipment to move around the facility.

7.2 Verifying literature design requirements

To ensure that the new concept design adhered to the literature design requirement, the Temple Grandin checklist was used again for evaluating the new designs against each of the principles in the checklist. Refer to the right-hand column of Table 1.

8 CONCLUSIONS

In conclusion, this study has built upon previous research in the field of cattle handling facilities, specifically focusing on the application of industrial engineering and animal psychology principles to improve design concepts. Previous research has frequently overlooked methodological flaws like a lack of thorough analysis and integration of important design principles.

To address these shortcomings, this study employed a rigorous methodology that involved evaluating numerous design principles and best practice, taking into account the interaction between industrial engineering and agriculture. The aim was to provide improved concept facility designs that prioritise safety, efficiency, animal welfare, flexibility, durability, and accessibility. The results of this study demonstrated the significant impact that well-designed cattle-handling facilities can have on animal welfare, worker safety, and overall productivity. By implementing targeted design principles, such as low-stress handling, efficient movement, and effective worker positioning, notable improvements in cattle flow, can be achieved.

This work contributes to the research map in the field by emphasising the importance of integrating industrial engineering and animal psychology principles into the design process for cattle handling facilities. By addressing the weaknesses in current handling facilities and providing comprehensive evaluations and design concepts, this research enhances our understanding of how the engineering principle of facility design can positively impact the well-being of both animals and handlers.

An achievement of this study is the development of concept facility designs that align with the natural behaviours and instincts of cattle. By incorporating features such as curved chutes and solid sides, stress levels can be minimised, leading to smoother and calmer movement. The achievements of this work hold significant meaning and implications for the industry.

Well-designed cattle handling facilities can create safer and more productive environments, ultimately benefiting both animals and handlers.

Incorporating industrial engineering principles and Temple Grandin's insights into cattle handling has been crucial in opening up new opportunities for efficiency and improved procedures within cattle handling facilities. This study emphasises how different handling process optimisation can be when facility design concepts from industrial engineering are combined with the unique requirements of livestock management. By combining these disciplines, the study explains how specialised facility layouts, thoughtful equipment placement, and workflow optimisation all work together to improve the flow of cattle, lower stress levels, and increase operational productivity. This research has indicated that industrial engineering principles are the missing puzzle piece needed to elevate agricultural practices to increased production, improved flow, and facility optimisation.

The implications of the results extend to various applications within the agricultural sector. The findings provide valuable insights for farmers, facility designers, and industry professionals, highlighting the importance of considering design principles that optimise animal welfare and operational efficiency. These insights can guide the development and modification of existing facilities to promote better handling practices as most of the current handling facilities' flaws are due to inheriting facilities with old design layouts.

9 FUTURE RESEARCH

It is important to acknowledge the limitations of this study, which should direct future research efforts. The concept facility designs presented in this study serve as a starting point and require further evaluation and validation in real-world settings. Additionally, the study focused on specific design principles and may not encompass the entirety of factors influencing cattle handling facility design. Future research should explore additional design considerations and conduct comprehensive studies to assess the feasibility and impact of implementing these design concepts.

Furthermore, while this study investigated current designs and proposed improved ideal designs based on research-based requirements, the actual implementation and assessment of these designs in real-world settings remain pending. Future studies should focus on the practical implementation of the concept designs proposed in this paper, evaluating their feasibility, effectiveness, and impact on existing cattle-handling facilities. This could involve conducting pilot studies, monitoring performance, and gathering stakeholder feedback. By bridging the gap between conceptualisation and implementation, valuable insights can be gained into the practicality and benefits of these design improvements, paving the way for wider adoption and further refinement of cattle handling facilities. Additionally, it is important for future research to expand beyond the 10 case-study farms in the central Free State and include a broader investigation of farms in other parts of South Africa to gain a more comprehensive understanding of the current state of cattle-handling facilities.

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