MAKING WAVES IN CATTLE HANDLING: A SIMULATION-DRIVEN APPROACH TO SAFER AND MORE PRODUCTIVE FACILITIES

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ABSTRACT

The beef supply chain is important to South Africa's economy, food security, and rural development, with cattle handling facilities playing a critical role in animal welfare, operational efficiency, and meat quality. However, many facilities evolve through trial-and-error designs that neglect cattle behavioural needs, creating stress hotspots and inefficiencies. This study addresses the gap between ethological research and engineering practice by developing behavioural state diagrams that model cattle movement and stress responses across five universal handling phases: movement to sorting pens, passing gates, pen transfers, chute entry, and crush exit. Using an iterative narrative review and UML modelling, observed behaviours and environmental triggers were formalised into discrete states and transitions. The resulting framework links specific design features to behavioural outcomes, enabling more humane, efficient, and evidence-based facility layouts. This approach lays the groundwork for decision-support tools that integrate behavioural science into cost-effective, welfare-driven livestock facility design.

Keywords: Cattle handling facilities, Animal welfare, Facility design, Ethology, Unified Modelling Language

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1 INTRODUCTION

The beef supply chain is critical to South Africa's economy, food security, and rural development, with its growth offering significant opportunities for inclusive progress, provided that persistent challenges such as disease management are addressed [1-3]. Within the beef supply chain, cattle handling facilities serve as critical infrastructure from cow-calf operations to abattoirs, delivering both economic and animal welfare benefits [4].

The beef supply chain is a complex process that involves multiple stages, from raising cattle to delivering beef products to consumers. It all starts at cattle production on a farm of any scale with the cow-calf operation, breeding cows to produce calves. Calves are separated from their mothers at the appropriate time to feed on a diet of grass, hay, or specific feed. Farmers sell their fattened-up cattle through an auction or directly to a feedlot for a finishing phase. Here, cattle are brought to an optimal weight for slaughter through a high-energy diet. Abattoirs process the cattle into primal cuts and package them to distribute to wholesalers for further packaging to meet consumer demand.

Each stage is vital to deliver the correct amount of beef product across South Africa. During the stages, cattle are handled through a facility. Cattle handling facilities are crucial at every stage of the beef supply chain because they ensure animal welfare, operational efficiency, and meat quality. On farms, well-designed "kraals", pens, and chutes allow for safe vaccinations, tagging, and sorting, reducing animal and worker stress [5-8]. Reducing stress in feedlots, weighing scales, feed bunks, and hospital pens helps improve cattle health and growth, ensuring optimal weight gain before slaughter. At abattoirs, lairage pens and humane restraint systems comply with food safety and animal welfare regulations, preventing contamination and ensuring ethical treatment. Even in auctions and transport, proper handling facilities minimise injuries and stress, which can affect meat tenderness and safety [9]. Without these systems, the entire supply chain—from farm to fork—would face higher risks of disease, inefficiency, and poor-quality beef, impacting farmers, processors, and consumers alike.

Despite their importance, many cattle handling facilities have evolved through generational trial and error rather than scientific design. Such legacy layouts often prioritise human convenience at the expense of animal welfare, neglecting key behavioural factors like flight zones and herd dynamics [10-13]. Common design flaws, including narrow chutes, dead ends, and inconsistent lighting, create predictable stress hotspots that trigger adverse responses[4]. Although stress behaviours in livestock are well documented, practical tools to translate these insights into engineering design parameters remain limited [7, 13].

A critical gap exists between ethological research, the scientific study of animal behaviour, and engineering practice. Ethology records behavioural thresholds but rarely expresses them in ways compatible with simulation tools [14, 15]. Meanwhile, engineering models tend to treat cattle as passive units rather than responsive, conscious beings [16, 17].

To address this gap, there is a need for an evidence-based approach that integrates behavioural science with engineering design principles. While the value of behaviourally informed facility design is acknowledged, its implementation depends on two pillars: empirical behavioural modelling and systematic engineering validation.

Currently, no software exists that enables farmers or designers to benchmark their facilities against behaviourally enhanced alternatives quantitatively. This hinders the ability to identify stress-inducing bottlenecks or justify improvements through cost-benefit analysis.

Therefore, this study aims to develop a behavioural state diagram to model cattle movement and stress responses within handling facility designs by translating animal behaviour into actionable, expert-informed design insights.

2 LITERATURE REVIEW

2.1 Cattle movement and behaviour in confinement

Cattle behaviour in handling facilities is shaped by the conflict between their evolutionary instincts and the constraints of artificial environments. In open fields, cattle exhibit fluid, self-directed movement primarily motivated by grazing and social interaction [18]. However, when confined, they encounter stressors such as restricted space, human proximity, and sensory overload. These conditions trigger observable stress behaviours, including baulking, vocalisation, and heavy breathing.

The likelihood of transitioning between behavioural states depends heavily on facility design parameters [13]. For example, cattle maintain defined flight zones, personal space buffers typically ranging from 1.5 to 5 meters, which, when breached, can induce panic responses [10, 12, 19]. Their panoramic vision (approximately 330°) and sensitivity to motion make them highly reactive to visual and auditory stimuli [13]. Cattle often misinterpret shadows or changes in floor texture as obstacles, due in part to limited depth perception caused by minimal binocular overlap [20, 21]. These biological traits create predictable stress hotspots in poorly designed facilities, particularly in areas with narrow chutes, abrupt lighting transitions, or sharp-angled turns.

Understanding these behavioural triggers is essential for developing handling environments that support smooth cattle movement and reduce fear-based reactions.

2.2 Behaviour variability and herd dynamics

Cattle behaviour is not uniform across individuals or contexts, and this variability presents further design challenges. Herd dynamics typically show that 70–80% of cattle will follow a leader, but breed-specific differences are well documented. For instance, Bos indicus cattle generally exhibit greater reactivity and sensitivity to handling compared to Bos taurus breeds [11, 21, 22]. Reproductive state also influences behaviour. Cows in heat tend to increase locomotion, while maternal aggression in dams with calves requires handlers to adapt their approach [23-25].

GPS tracking studies have shown that, under low-stress conditions, cattle navigate pastures using looping paths over 10–100-meter ranges. These movement patterns are efficient for resource exploitation and typically follow a stop-and-move rhythm [9, 26]. However, when under stress, this behaviour shifts to bunching and rapid flight movements, a pattern exploited by low-stress handling techniques that mimic predator-avoidance responses using 45°–60° approach angles [7, 9].

These behavioural dynamics underscore the need for adaptable facility designs that account for individual differences and herd-based flow tendencies.

2.3 Facility design

Effective cattle handling facilities must integrate three interdependent systems: spatial layout, environmental conditions, and human–animal interaction protocols [4]. Research shows that radial corral layouts reduce stress by minimising the need for 180° turns. Similarly, curved chutes with radii of 12–15 meters outperform angular designs by obscuring the exit and encouraging forward movement [4, 27, 28].

Structural components such as backing gates and solid-sided alleys also contribute to smoother flow [4]. For adult cattle, chute widths of 0.7–0.9 meters prevent reversal behaviours, while solid walls reduce peripheral distractions that may cause hesitation. The sensory environment plays a crucial role as well. Uniform, diffuse lighting eliminates shadow-induced hesitation, and non-slip flooring with a slope of less than 3% supports confident footing.

Human factors are equally significant. Quiet handling has been shown to reduce cortisol levels by up to 20%, while effective positioning of handlers, particularly maintaining the animal's point of balance, can promote voluntary forward movement [9].

Together, these design elements form a behavioural management system in which facility geometry actively influences animal responses, rather than simply containing them.

3 METHODOLOGY

Academic iterative narrative reviews require continuous refinement of search criteria, integration of diverse analytical methods, and robust quality control measures. Iterative narrative reviews in academic research require a cycle of three core components: integrative search and selection, methodological integration, and quality assurance.

This study was initiated by developing behavioural state diagrams based primarily on findings from existing literature. The aim was to formalise cattle behavioural patterns observed in handling facilities into discrete states and transitions that could be used for simulation and design analysis. Key sources included academic publications in ethology, animal handling, and facility design, with particular attention to studies reporting observable stress behaviours, movement tendencies, and environmental triggers. These behavioural insights were extracted, categorised, and mapped into structured state diagrams representing cattle responses across five key facility phases.

Preliminary state diagrams were constructed using Unified Modelling Language (UML)tools (specifically Draw.io) to model behavioural transitions observed during cattle handling. These diagrams were informed by a structured literature review and supported by informal field observations. Key behavioural states such as grazing, calm movement, and resisting were encoded alongside specific environmental triggers, including handler presence, gate movement, and physical confinement. New behavioural states such as hesitation and baulking were added, and transition conditions were refined for improved realism and clarity.

All cattle handling facilities, whether simple "kraals" or advanced modern systems, consist of the same basic phases. The five key phases—moving from the field to a sorting pen, passing through gates, transferring to smaller pens, entering the working area (chute and crush), and finally standing in and exiting the crush—are universal. Even if a facility is high-tech, with automated gates, or a basic setup with wooden fences, these core stages remain consistent. The differences lie in scale, materials, and automation, but the fundamental process ensures that cattle are handled with minimal stress, whether on a small farm, a large feedlot, or an abattoir. This structured approach allows for smooth transitions between different points in the supply chain while maintaining animal welfare and operational efficiency.

The handling process was divided into five functional phases, each corresponding to a distinct physical segment of the facility:

1. Movement from the field to the sorting pen.
2. Passing through a gate.
3. Transfer from a larger pen to a smaller pen.
4. Entry into the working area (chute pen to chute, then crush).
5. Standing in and exiting the crush.

For each phase, a corresponding state diagram was drafted to capture common cattle responses under varying environmental and operational conditions.

3.1 Phase 1: Movement from the field to the sorting pen

The process begins by moving cattle from an open field or pasture into a designated sorting pen. This area is usually larger and allows the animals to gather before being directed further. Workers may use gentle herding techniques, such as walking behind the cattle or using trained dogs, to guide them without causing stress. The sorting pen helps group the animals based on specific needs, such as size, age, or health status, before they proceed to the next stage.

3.2 Phase 2: Passing through a gate

Once sorted, the cattle are guided through a gate that leads them into a more controlled pathway. This gate acts as a funnel, narrowing the space to encourage the animals to move in a single file or small groups. Proper gate design ensures smooth movement while preventing overcrowding or jamming. Workers may stand nearby to assist if an animal hesitates or needs gentle encouragement to move forward. This phase repeats throughout the entire facility each time cattle are moved through a gate.

3.3 Phase 3: Transfers from a larger to a smaller pen

After passing through the gate, the cattle enter a smaller pen, which further restricts their movement. This step helps manage their flow and prepares them for closer handling. The reduced space makes it easier to guide them toward the next stage without causing confusion or stress. Smaller pens are often designed with solid sides to prevent distractions and keep the animals focused on moving forward.

3.4 Phase 4: Entry into the working area

The cattle are then directed into a chute pen, which leads to a narrow chute, a tight walkway that funnels them toward the crush (also called a squeeze chute). The chute restricts sideways movement, ensuring the animal moves straight ahead. Once inside the crush, the animal is gently restrained for procedures like vaccinations, tagging, or health inspections. The crush has adjustable sides to hold the animal securely without causing harm, allowing workers to perform tasks safely and efficiently.

3.5 Phase 5: Standing in and exiting the crush

While in the crush, the animal remains still for the necessary procedures. Workers ensure the process is quick and calm to minimise stress. Once completed, the crush is opened, and the animal exits into a release pen or returns to the pasture. Proper handling during this phase ensures the cattle remain calm and unharmed, making future handling easier.

4 FINDINGS

This section presents the behavioural state diagrams developed to model cattle movement across the five main phases of a handling facility. First, an overview will be given, followed by a detailed description of the phases. Each diagram visualises behavioural transitions in response to environmental stimuli, representing states as rectangles, transitions as arrows, and decision points as diamonds. These state diagrams enable probabilistic simulation of animal movement, where changes in facility design directly influence transition likelihoods and behavioural outcomes.

4.1 Overview

Figure 1 shows the top view of the cattle handling facility used to model movement phases. The layout includes an open field, sorting pen, pens of varying sizes, chute systems, and the crush area. Each zone reflects a typical real-world setup, serving as the spatial foundation for the behavioural diagrams.

The process starts on the left-hand side in the open field. Cattle are gathered in the open field, a large fenced pasture where cattle roam freely and graze on grass. The flow of cattle through the facility is from left to right. A sorting pen is a smaller enclosed area where cattle are gathered and can be separated into groups based on size, age, or purpose (such as medical treatment or sale). The separated groups are moved to a holding pen, a temporary space where cattle wait before being moved further through the facility, ensuring a controlled flow. The crush pen is a confined area that leads animals toward the chute, which is a narrow walkway that guides them single-file into the squeeze crush—a secure stall that gently restrains the animal so workers can safely perform tasks like vaccinations or health checks. Each part of the facility helps move cattle calmly and efficiently while keeping both animals and handlers safe.

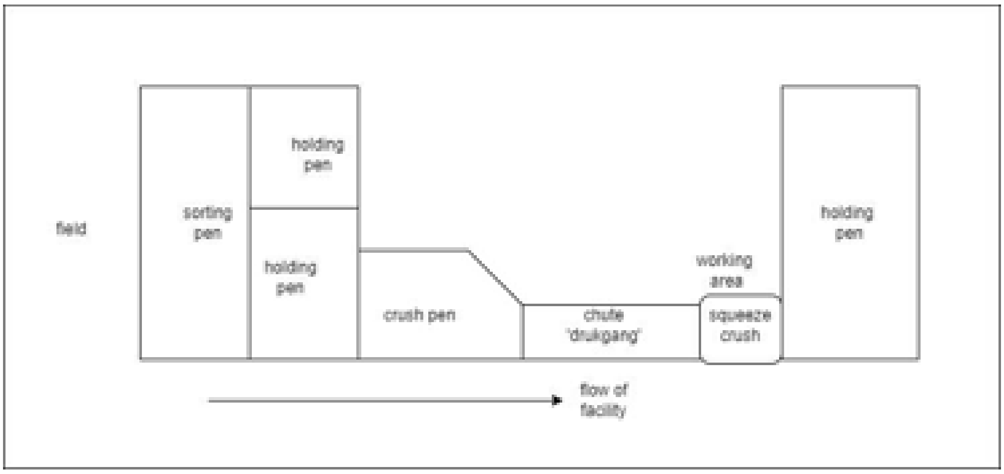

Figure 1: General handling facility top view

Figure 2 presents the high-level behavioural flow diagram, mapping the whole sequence of cattle movement through the facility. The diagram outlines mandatory location-based states and their transitions, providing a macro-level view of the process. The micro-levels will be explained in the sections to follow.

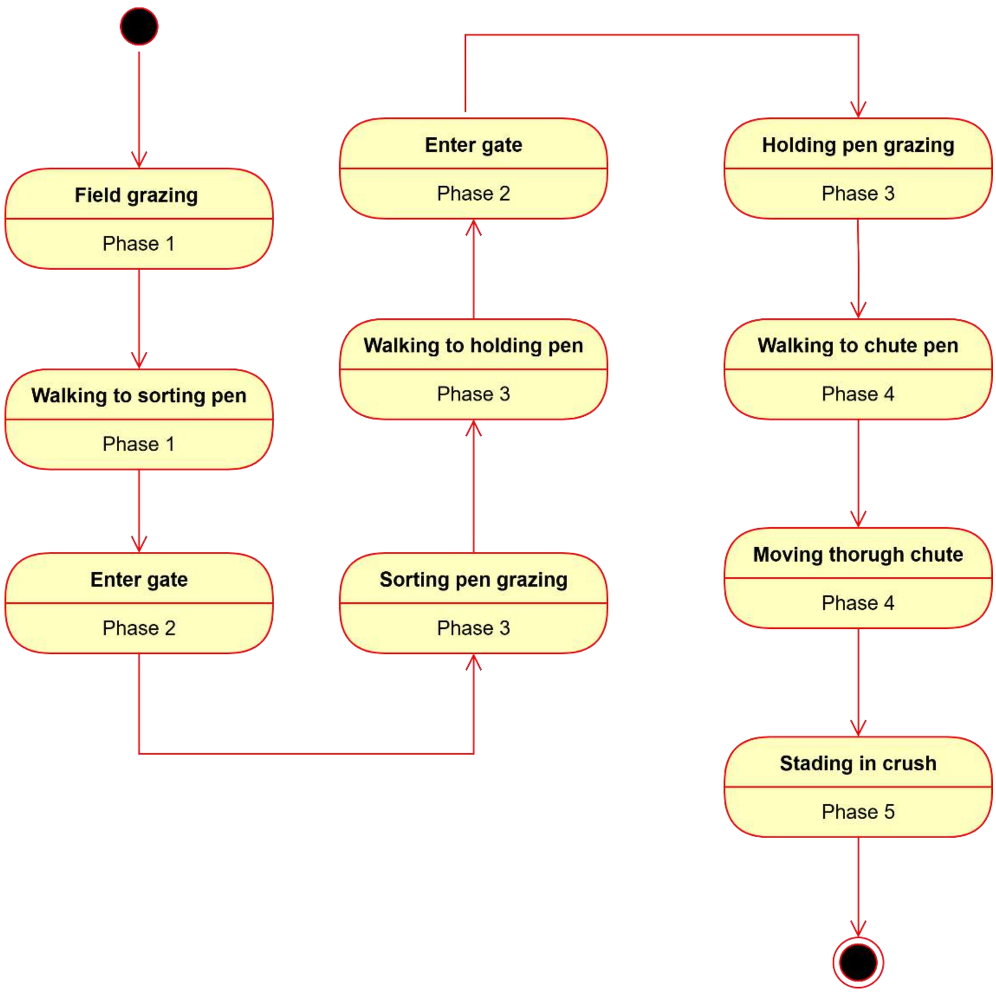

Figure 2: High-level behaviour flow

Two key behavioural bottlenecks are observed: (1) at the sorting pen, where cattle are divided into smaller groups, and (2) at the chute entry, where individual hesitation, baulking, or reversing behaviours often emerge. These points mark significant shifts in group dynamics and are critical for facility design interventions.

4.2 Phase 1 – from the field to the sorting pen

Figure 3 illustrates Phase 1, which captures cattle behaviour as they are moved from open grazing areas into the sorting pen. This phase involves a shift from low-stress states, such as grazing or standing still, to more reactive behaviours triggered by the handler's approach. Movement is often initiated by visual or auditory cues from handlers on foot, horseback, or in vehicles [29].

Common behavioural transitions include:

- From grazing to alert when the handler enters the flight zone.
- Alert to walk away or run, depending on the speed and direction of the handlers' approach.
- Pause or stand still before reaching the pen entrance.

Decision points are most frequent near gates or changes in terrain. Smooth transitions to calm movement are associated with low-pressure handling and clear visibility of the pen entrance [7, 28, 30]

Cattle graze freely in a pasture before they are brought or guided to a handling facility. As handlers approach the herd, cattle move and face a decision point depending on the stress factors. Each cow can face the decision point, or the herd breaks in smaller groups and turns to the handler if they approach too fast, or start running, or stand still if a handler is too close. From each decision point, the probability of more decision points is a possibility; however, in this case, we focus on the overall main probability of cattle returning to a calm movement towards the facility. Handlers will use different techniques and tools to guide cattle towards the final state, such as slowing down their speed, using flags or arm movements, and entering and exiting the cattle's flight zone.

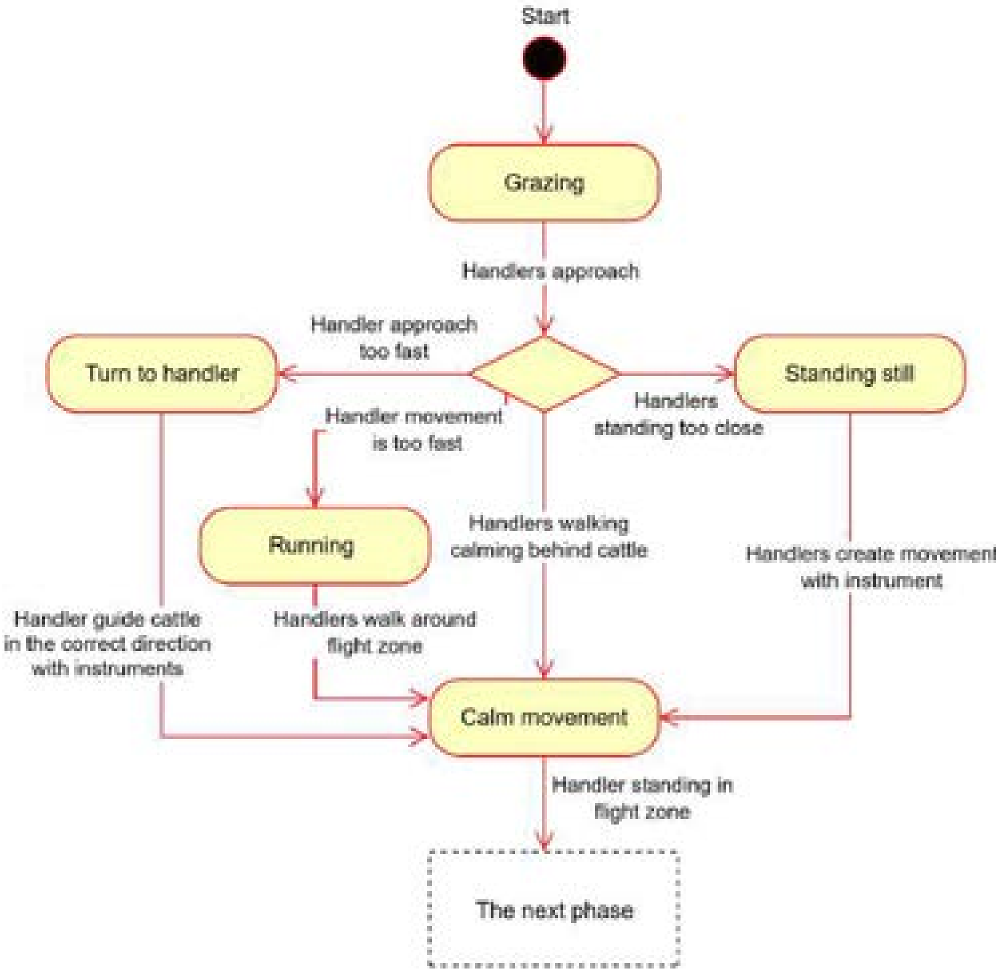

Figure 3: Phase 1 from field to sorting pen

4.3 Phase 2 – cattle passing through a gate

Figure 4 represents Phase 2, which focuses on cattle movement through gates, a frequent but critical transition point in handling systems. The diagram identifies hesitation, redirection, and stress behaviours such as turning back and vocalisation.

Video analysis for literature revealed that most of the observed flow disruptions occurred when gates were misaligned by more than 30° from the cattle's natural trajectory [4,31]. Transitions from walking calmly to hesitation or turning around were especially common at poorly positioned or unfamiliar gates.

Cattle will usually be calm before entering the gate as the gate is opened by a handler. A decision point is created, as there is a change in the close environment of the cattle. With an open gate, cattle may walk hesitantly forward and through the gate as a handler is behind them and closing in. They may remain in a calm state and walk calmly, or turn around, as cattle are prone to return in the direction they came from. If they are startled, they will be at a dead stop until a handler puts close pressure in their flight zone. This results in different states. To conclude this phase, the goal is to get cattle from point A to point B, aiming to keep them calm as they enter, which improves over time as cattle get used to entering a handling facility.

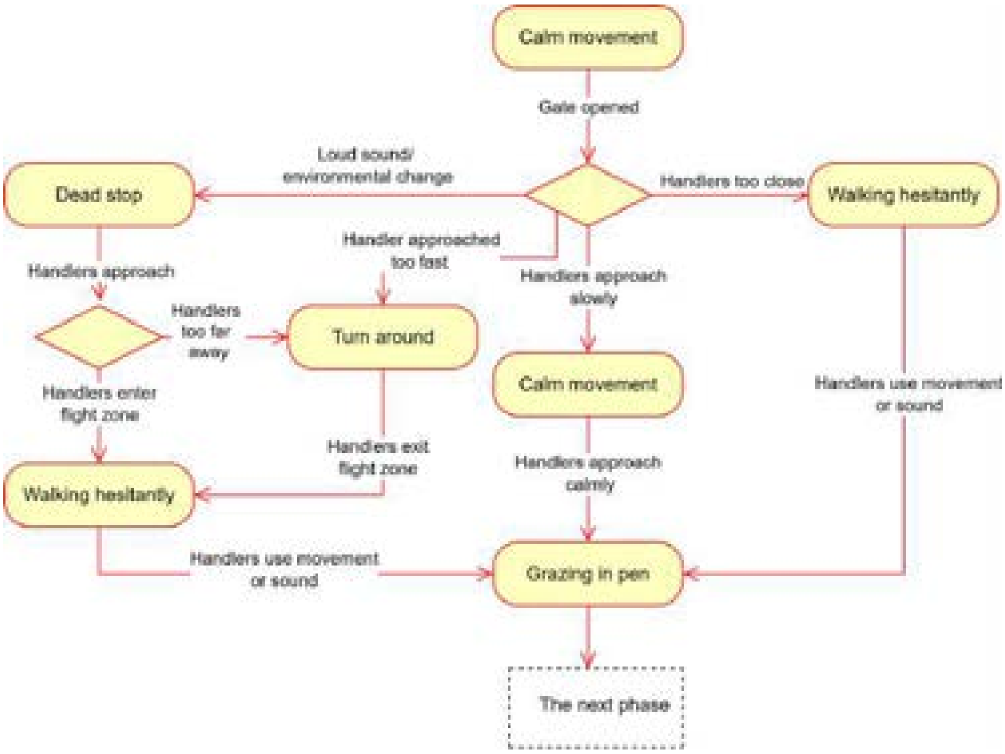

Figure 4: Phase 2 passing through a gate

Figure 4 highlights that gate orientation, visibility, and handler position significantly influence behavioural flow [4]. Well-designed radial gates with curved pathways help reduce indecision and prevent backflow [9].

4.4 Phase 3 – Moving from a larger to a smaller pen

Figure 5 models the transition from larger holding pens into smaller pens, often used to divide herds into manageable subgroups. This phase typically triggers heightened stress due to isolation, increased density, and limited movement options [13, 32].

Behavioural states such as vocalising, bunching, and running to corners were more widespread as group size decreased. Notably:

- Groups with fewer than five animals showed less aimless movement, indicating improved manageability in smaller, cohesive groups [31].
- Decision points increased near entry gates and corners, where cattle assessed crowding and visibility of conspecifics [31].

In Phase 3, cattle are generally observed grazing or standing calmly within the pen prior to any handler interaction. As handlers move closer, a decision point is introduced due to the change in proximity and the associated pressure exerted within the animals' flight zones. At this juncture, cattle may either turn around or move rapidly towards a corner, with the chosen response largely dependent on their perception of the handlers' approach and level of threat.

When turning around, cattle may proceed towards the entrance, walking hesitantly under the influence of the handler's presence, or execute a 180-degree turn if startled, which can also result in hesitant forward movement. Alternatively, when opting to run to a corner, further decision points emerge. Animals may remain stationary (freezing), attempt to jump the fence, or relocate to another corner if the handlers' approach is perceived as excessively fast. From this secondary corner position, movement towards the gate may occur, particularly if handlers continue to apply pressure within the flight zone.

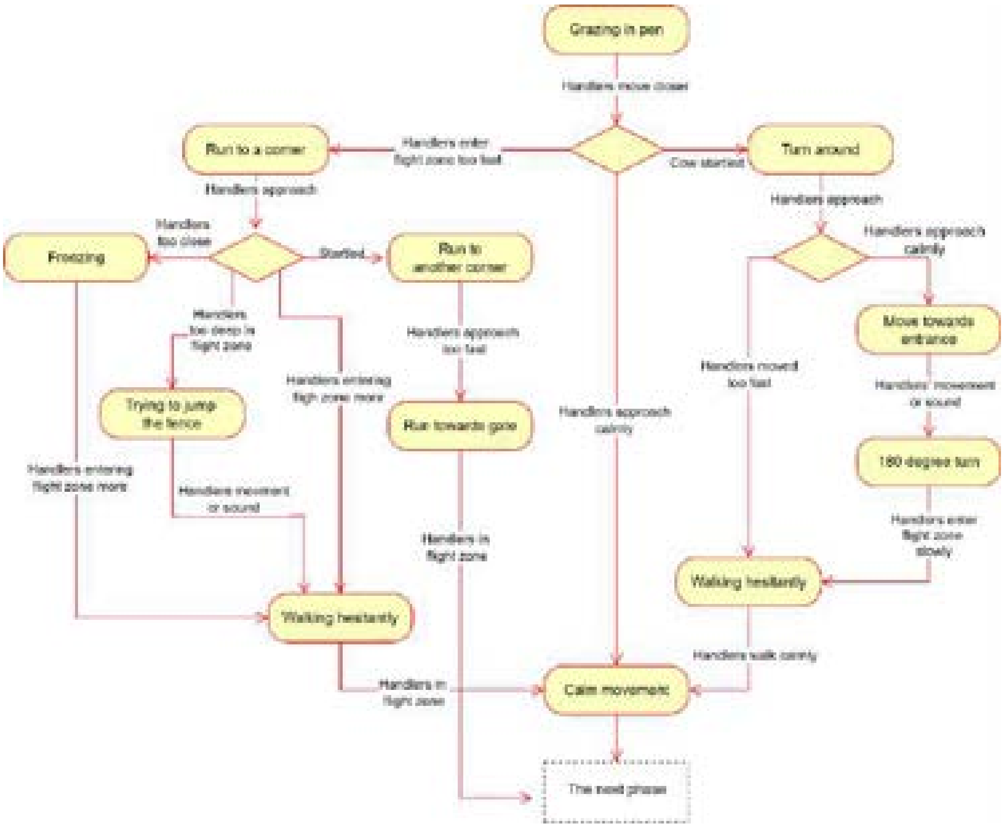

Figure 5: Phase 3, from a large pen to a smaller pen

Throughout these behavioural pathways, the speed, movement, and auditory cues provided by handlers serve as critical stimuli influencing whether cattle transition to calm, directed movement or escalate into avoidance behaviours. The overarching objective in this phase is to facilitate the movement of cattle from their initial position in the pen towards the gate in a controlled and low-stress manner. With repeated exposure to the facility and handling processes, cattle are expected to exhibit reduced reactivity and improved flow, thereby enhancing handling efficiency and animal welfare outcomes.

The diagram suggests that modular pen designs, allowing for rapid herd division and visual continuity, may reduce stress-related behaviours during this phase [13, 26, 32, 33].

4.5 Phase 4 – The working area

Figure 6 represents Phase 4, detailing cattle behaviour as they are guided from a pen into the chute pen, then through the chute and into the crush. This stage involves significant spatial restriction, often resulting in increased behavioural compression [13].

Key findings from observational data include:

- Freezing behaviour was more likely in chutes narrower than 0.8 meters [7, 23].

- More than half of a herd transitioned from hesitant walking to calm movement within seconds when adequate lighting was provided [31].

In Phase 4, cattle typically enter the pen through the gate in a calm and orderly manner. Upon entry, a decision point occurs when environmental or social stimuli—such as vocalisations from other cattle or the division of the herd—affect their behaviour. In some cases, herd division may lead to freezing, followed by hesitant walking as the gate approaches, ultimately resulting in movement towards the chute. Alternatively, cattle may turn around in response to vocal cues or handler movement, moving back towards the gate.

When progressing towards the chute, the closing of the gate behind the animals may help maintain calm movement; however, changes in lighting or the sudden appearance of an opening may cause some to rush forward. Vocalisations from other cattle can induce freezing, after which animals may resume movement hesitantly under the influence of handler movement or sound.

Within this phase, another critical decision point arises when animals are startled or stressed. This may lead to reversing out of position, which can escalate into freezing if handlers apply close pressure. Conversely, cattle in a calm state may continue forward movement, while hesitant walking may occur if the handler's presence is perceived as uncertain or inconsistent.

Throughout this phase, handler actions—particularly movement patterns, speed, and auditory cues—are decisive in influencing behavioural transitions. The goal is to maintain cattle in a calm, forward-moving state towards the chute while minimising stress-induced behaviours such as freezing, rushing, or reversing. With repeated exposure and consistent handling practices, cattle are expected to navigate this stage with improved flow, thereby reducing handling difficulty and enhancing overall animal welfare.

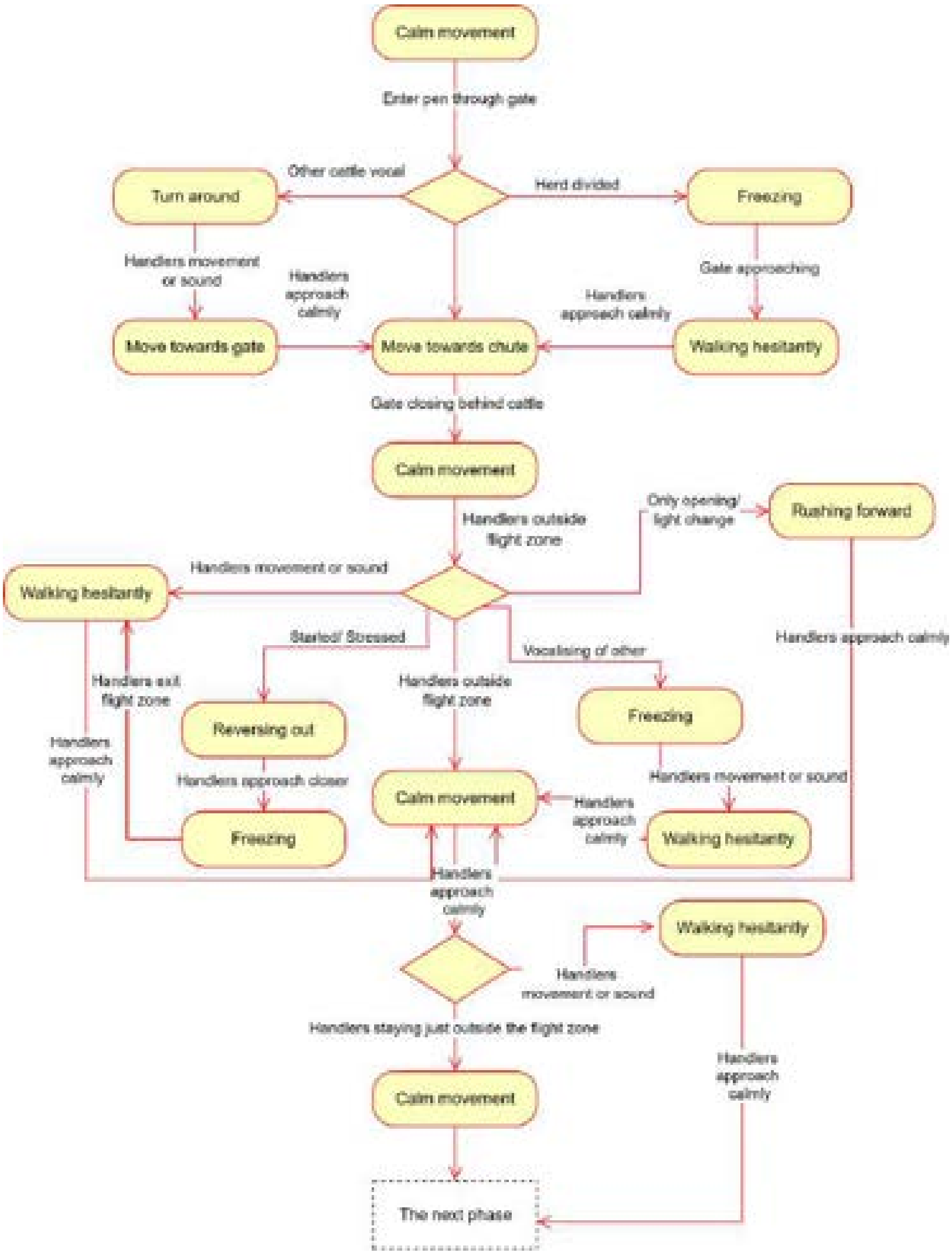

Figure 6: Phase 4, the working area

The state diagram demonstrates how proper chute geometry, lighting, and handler positioning can reduce flow resistance and encourage voluntary movement. Decision nodes in this phase were common at the chute entrance and within the crush approach corridor.

4.6 Phase 5 – Exiting the working area

Figure 7 models the final stage, where cattle stand still in the crush for handling procedures and are then released. This phase is critical, as it concentrates stress, and recovery is heavily influenced by the exit pathway design [4].

Behavioural transitions observed include:

- From standing still to trotting upon release, especially if the standing duration exceeded 30 seconds.

- Most cattle exhibited signs of stress (e.g., rapid movement, vocalisation) after prolonged restraint, especially if they were young and if it was the first time in the handling facility [31].
- Cattle exiting to open pastures resumed grazing a lot faster than those placed in unfamiliar or confined post-procedure pens [23, 31].

In Phase 5, cattle generally begin in a state of calm movement as they approach the crush, with handlers positioned within their flight zone to maintain forward progression. At this point, the opening of the crush introduces a decision point, where environmental factors such as loud sounds or sudden visual changes may cause reversing behaviour. This reversal can be managed through appropriate hands-on handling techniques, returning the animal to forward movement.

If the crush is opened without startling stimuli, cattle may stand still momentarily before resuming calm movement in response to the handler's presence, movement, or sound. Once positioned inside the crush, the gate is closed, and animals remain stationary while required handling or inspection procedures occur.

Upon completion, the crush is opened again, initiating another decision point. The presence of a loud noise at this stage may induce a startle response, resulting in a rapid walking or trotting exit. In the absence of startling stimuli, animals typically exit in a controlled manner, maintaining calm movement as they leave the facility.

The phase concludes with cattle entering the field, ideally in a relaxed state. Throughout this stage, the primary objective is to facilitate smooth and low-stress movement through and out of the crush, minimising hesitation, reversing, or startle responses. Effective handler positioning, quiet movement, and consistent pressure are critical in achieving efficient flow while safeguarding animal welfare.

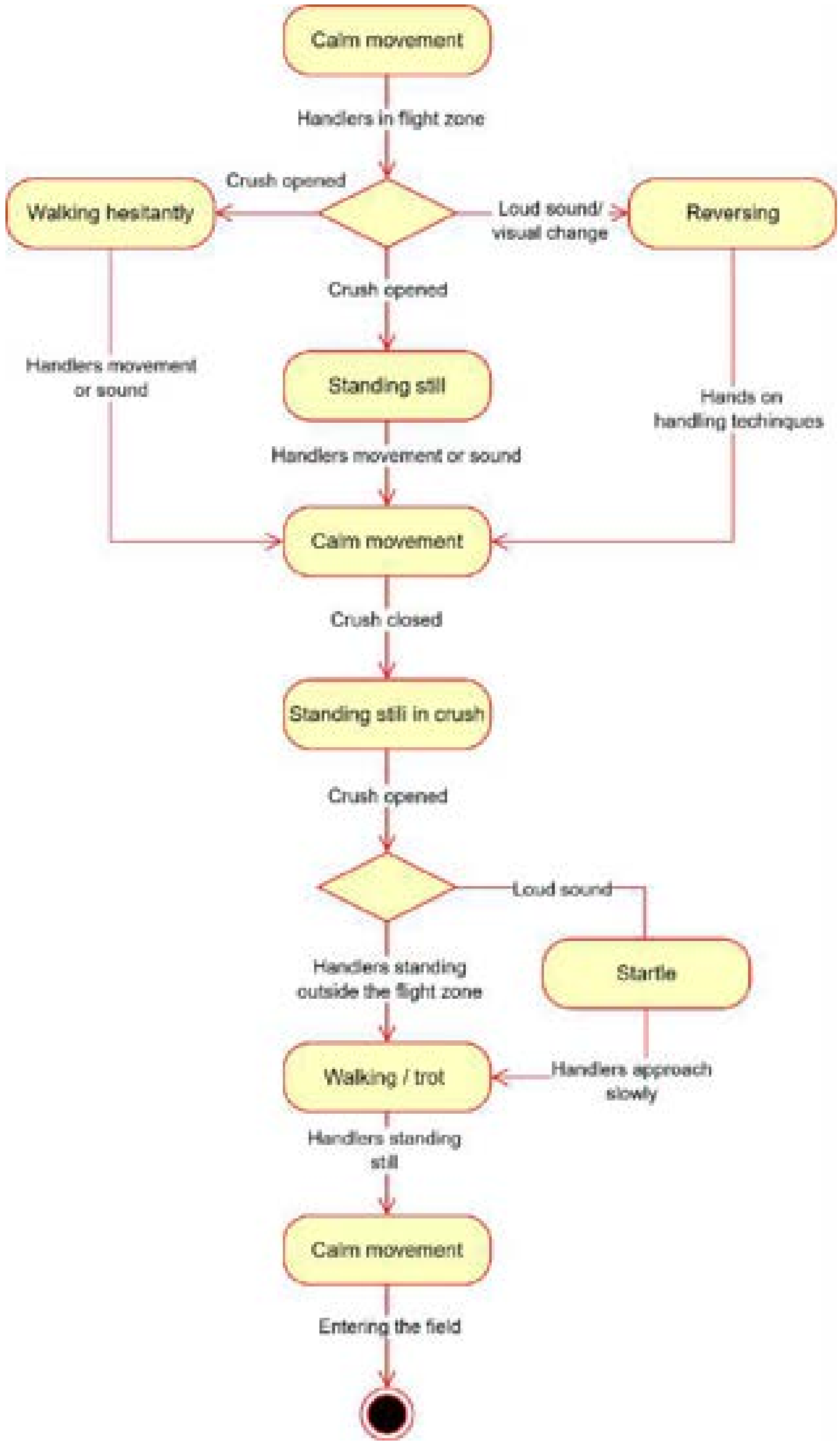

Figure 7: Phase 5 exiting the working area

The diagram highlights the importance of designing clear, calming exits from the crush to support behavioural recovery and maintain welfare.

5 DISCUSSION

The behavioural state diagrams developed in this study provide a structured framework for understanding how cattle respond to specific handling conditions within facility environments.

Rather than simply documenting movement, the diagrams formalise cattle decision-making processes in terms of spatial constraints and external stimuli.

The state diagrams presented in Figures 2 to 7 systematically guesstimate cattle behaviour across all facility phases. They establish clear links between design features (such as chute width, gate angle, and lighting) and behavioural responses (such as freezing, vocalisation, and baulking).

The observed transitions across all five facility phases demonstrate that cattle behaviour is not random but highly contingent on design features, such as gate alignment, pen dimensions, and lighting conditions. Stress hotspots consistently appeared at herd division points (Phase 3) and chute entries (Phase 4), underscoring the need for careful planning in these areas. This reinforces the need to design systems that anticipate and accommodate behavioural variability.

Importantly, the state-based models capture the distinction between voluntary flow behaviours and stress-induced reactions, offering a more nuanced perspective than traditional layout analyses. By translating qualitative behavioural insights into discrete, modelled states, the diagrams bridge an important gap between ethological observation and engineering application.

The inclusion of behavioural responses during the exit phase is particularly noteworthy. This is an area often overlooked in facility modelling, yet the findings suggest that how animals exit confinement has a measurable effect on their recovery. By encoding these post-release behaviours into the state model, the study extends the application of behaviour-based design beyond containment and restraint.

Overall, the diagrams bridge an important gap between ethological observation and engineering application by translating qualitative behavioural insights into discrete, modelled states.

6 CONCLUSION

This study has presented a behavioural modelling framework for cattle handling systems, using phase-specific state diagrams to formalise how cattle respond to environmental and human-induced stimuli across different facility zones. By integrating behavioural science with engineering principles, the research has identified key stress points, such as gate transitions, herd separations, and chute entries, that consistently influence animal welfare and flow efficiency. Through these continued efforts, the research aims to contribute to the development of humane, data-driven, and cost-effective cattle handling systems that align with long-term goals for animal welfare and sustainable agricultural practices.

6.1 Future research

While the current framework provides a foundational step toward a practical decision-support tool for livestock facility design, further validation through expert consultation and real-world testing remains essential to refine its predictive accuracy and operational reliability. Future work should prioritise expanding the behavioural state database to encompass a broader range of facility conditions, integrating economic modelling to assess cost-benefit trade-offs, and validating the framework through simulation tools in operational settings. A Delphi-style expert review process could further enhance the model's precision by systematically incorporating stakeholder feedback. Once refined, this tool will enable data-driven facility improvements by explicitly linking behavioural outcomes to measurable design parameters, ultimately serving as the behavioural foundation for scientifically grounded, yet practically applicable, predictive design tools.

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