CONFERENCE ABSTRACT: WORK IN PROGRESS

From stress to sustainability: Navigating BRD-mediated feedback interactions in integrated beef production systems

Bovine respiratory disease (BRD) is an old but persistent challenge to the sustainability of U.S. beef production systems, with profound implications for economic viability, animal welfare, and environmental health. Over 2 billion USD in economic losses due to BRD are recorded annually. Additionally, as a complex multifactorial disease of cattle, about 30% of total US antimicrobial usage on food animals is attributable to BRD management. This research employed systems thinking to investigate the feedback interactions that drive BRD-induced perturbations within integrated beef production systems. Through a causal loop diagram (CLD), we identified and analyzed the reinforcing and balancing loops that govern the interplay between animal health, economic factors, and management practices. The model was developed with Vensim® PLE version 10.2.0, using diverse data sources from various published articles, including empirical studies, industry reports, and expert inputs, to conceptualize the key variables (and the linkages between them) such as stress-induced BRD susceptibility, antimicrobial usage, vaccination strategies, and the emergence of antimicrobial resistance.

The risk factors associated with BRD (B1) shape herd susceptibility by amplifying stress levels, thereby increasing infection rates and ultimately reducing herd capacity. As BRD prevalence escalates, cattle producers must implement mitigation strategies, including antimicrobial use and vaccination. The cost implications of these interventions form additional balancing loops (B2, B3), where the economic burden of metaphylaxis (preventive antimicrobial administration) and vaccination strategies constraints herd expansion, maintaining equilibrium in production costs and herd sustainability. Beyond direct healthcare costs, BRD disrupts the profitability index (B4). Although profitability drives herd expansion, a larger herd size elevates disease susceptibility, leading to higher morbidity and mortality rates. This feedback mechanism tempers excessive growth by ensuring that increased revenue does not necessarily translate to sustainable long-term profitability. Similarly, herd recovery dynamics (B5) illustrate the cyclical nature of disease burden, antimicrobial intervention, and cattle growth potential. The system's stability hinges on balancing antimicrobial use with recovery rates, where each cycle of treatment and recuperation feeds back into herd size regulation.

A critical factor in herd management is antimicrobial resistance (B6). While metaphylaxis reduces BRD-related losses, its overuse accelerates microbial selection pressure, fostering resistant bacterial strains that undermine treatment efficacy and increase long-term economic risks. This feedback loop underscores the trade-off between short-term disease control and long-term sustainability. Additionally, the potential for cattle maturity (B7) further regulates herd stability, as BRD-induced growth stunting or mortality affects the number of cattle reaching market weight, limiting the overall economic output of the system.

Contrasting these stabilizing mechanisms, the reinforcing feedback loops (R1, R2) highlight the self-reinforcing dynamics within the beef production system. As herd size increases, so does the susceptibility to BRD, necessitating greater antimicrobial intervention. However, effective treatment leads to higher recovery rates, thereby increasing the number of marketable cattle, which boosts revenue and incentivizes further herd expansion (R1). This loop illustrates the economic motivation driving herd growth despite disease risks. Similarly, the Growth-Value Reinforcement Cycle (R2) encapsulates the relationship between feed quality, average daily gain (ADG), carcass value, and profitability. Higher feed quality enhances weight gain, improving carcass value and overall profitability. This increased revenue, in turn, enables investment in better nutrition, reinforcing the cycle of continuous growth and economic return.

For our model, the interplay of balancing and reinforcing loops in the presence of BRD within the system reflects the complex trade-offs faced by beef cattle producers. While economic incentives drive herd expansion, disease susceptibility, healthcare costs, and antimicrobial resistance create natural constraints that regulate system stability. A systems thinking approach to BRD management emphasizes the need for strategic interventions that optimize both economic viability and herd health, ensuring a sustainable beef production system in the long term.

Our CLD effectively informs dynamic modeling and is particularly valuable for producers seeking to optimize herd health while maintaining profitability and for policymakers designing regulations that support sustainable livestock systems. This model forms the groundwork for the next step in our research where we will adapt the CLD to stock and flows diagram with a simulation framework for evaluating and improving decision-making in integrated beef production systems. Ultimately, we aim to integrate the data streams from our system dynamics mathematical model with an artificial intelligence/machine learning (AI/ML) algorithm i.e., a hybrid intelligent mechanistic model (HIMM) currently in design, as a tool for informed decision-making by beef stakeholders.

Keywords: Causal loop diagram, System dynamics, Bovine respiratory disease, Integrated beef production

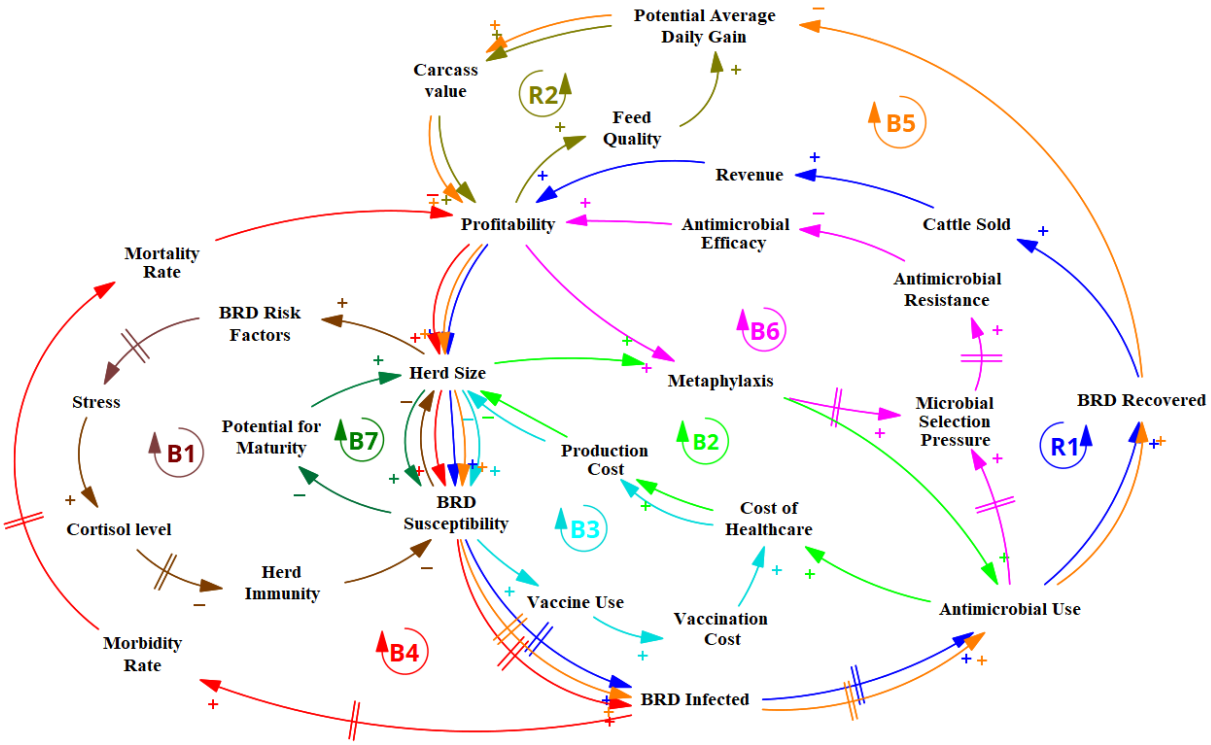

Figure 1: A structural outline of our causal loop diagram, highlighting key components and feedback loops that drive the prevalence and control of BRD in U.S. beef systems.

Loop Naming Conventions		
B1	-	*Risk Factors and Herd Capacity*
B2	-	*Antimicrobial use and cost implications*
B3	-	*Vaccination Cost Management*
B4	-	*Infection - Profitability Index*
B5	-	*Recovery and Growth Potential*
B6	-	*Antimicrobial Resistance and Profitability*
B7	-	*Potential for maturity*
R1	-	*BRD Susceptibility and Revenue*
R2	-	*Growth-Value Reinforcement Cycle*